GALAXY INTERNATIONAL INTERDISCIPLINARY RESEARCH JOURNAL (GIIRJ)
ISSN (E): 2347-6915
Vol. 9, Issue 6, June (2021)

CALCULATION TECHNIQUE FOR TYPICAL CIRCULAR TUNNEL LININGS WITH TAKING INTO ACCOUNT THE INTERACTION OF THE STRUCTURE WITH THE GROUND

Miralimov Mirzahid Khamitovich
Associate Professor of the Department of Bridges and Tunnels, Doctor of Technical Sciences,
Tashkent State Transport University, Tashkent, Uzbekistan,
e-mail: mirzakhid_miralimov@yahoo.com

Normurodov Shahboz Ulugbekovich
Assistant of the Department of Bridges and Tunnels,
Tashkent State Transport University, Tashkent, Uzbekistan,
e-mail: normurodovsh25 @ mail.ru

Tayirov Shopulat Shomansur o'g'li
student, Tashkent State Transport University, Tashkent, Uzbekistan,
e-mail:shoputayirov255@gmail.com

ABSTRACT

The general method for calculating tunnel lining, as a multilayer one, developed by N.S. Bulychev and N.N. Fotieva [1, 2, 3], is based on the use of equivalent loads and effects (Fig. 1).

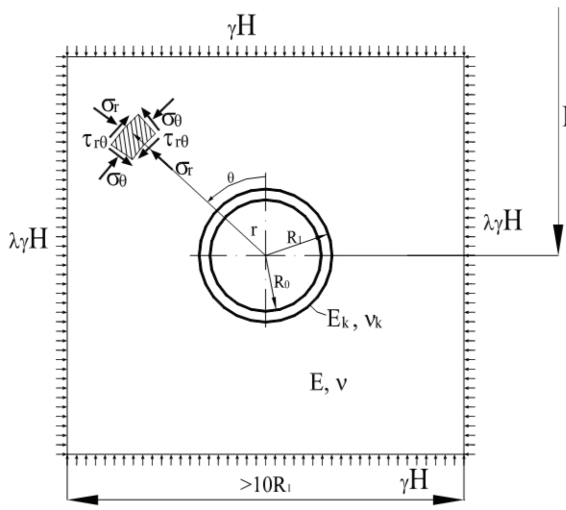


Fig. 1. Design scheme for determining the equivalent loads on the tunnel

Here, under the action of the initial gravitational and tectonic stresses, it will be in the form:

$$P_{eg} = P_{0eg} + P_{2eg} \cos 2\theta$$

$$P_{0eg} = \frac{\alpha^*(\sigma_1^{(0)} + \sigma_2^{(0)})}{2} \cdot \frac{2}{\chi_0 + 1} \tag{1}$$

$$P_{2eg} = \frac{\alpha^*(\sigma_1^{(0)} - \sigma_2^{(0)})}{2} \cdot \frac{\chi_0}{\chi_0 + 1}$$

Equivalent quasi-static stresses from the action of a longitudinal seismic wave are calculated in the form [1, 2]:

$$P_{0eg} = \pm\frac{1}{2\pi}AK_1\gamma V_p T_0 \frac{1+\lambda}{2}$$
$$P_{2eg} = \pm\frac{1}{2\pi}AK_1\gamma V_s T_0 \frac{1-\lambda}{2} \tag{2}$$

from shear wave action

$$P_{0eg} = 0, \quad P_{2eg} = \pm\frac{1}{2\pi}AK_1\gamma V_s T_0 \tag{3}$$

Where χ_0 - coefficient taking into account the flat deformed state. Consider the stress distribution (Fig. 2), in an elastic ring with external stresses:

$$P(j) = P_0(j) + P_2(j)\cos 2\theta, \quad q(j) = q_2(j)\sin 2\theta \tag{4}$$

Where $j = 0$ on the L_0 and $j = 1$ on the L_1, α^* - dimensionless coefficient, taking into account the lag of production from the face [1, 2], $\sigma_1^{(0)}, \sigma_2^{(0)}$ - the main initial stresses in the soil. The normal stress on the outer and inner contours of the ring from the standpoint of the classical theory of elasticity is [1, 2]:

$$\sigma_{\theta ex} = p_0(1)m_1^1 - p_0(0)m_2^1 + (p_2(1)n_1^1 - q_2(1)n_2^1 - p_2(0)n_3^1 + q_2(0)n_4^1)\cos 2\theta$$
$$\sigma_{\theta in} = p_0(1)m_1 - p_0(0)m_2 + (p_2(1)n_1 - q_2(1)n_2 - p_2(0)n_3 + q_2(0)n_4)\cos 2\theta \tag{4'}$$

$$m_1 = \frac{2c^2}{c^2-1}, m_2 = m_1 - 1, m_1^1 = m_2, m_2^1 = m_1 - 2, n_1 = 2m_1 m_2, n_2 = m_1 m_1, n_3 = 2m_2 m_2^1$$

$$n_4 = 2\frac{c^4 + 2c^2 - 1}{(c^2-1)^2}, n_1^1 = n_3, n_3 = 2\frac{c^4+6c^2+1}{(c^2-1)^2}, n_2^1 = 2\frac{-c^4+2c^2+1}{(c^2-1)^2}, n_4^1 = n_1, c = r_1/r_0$$

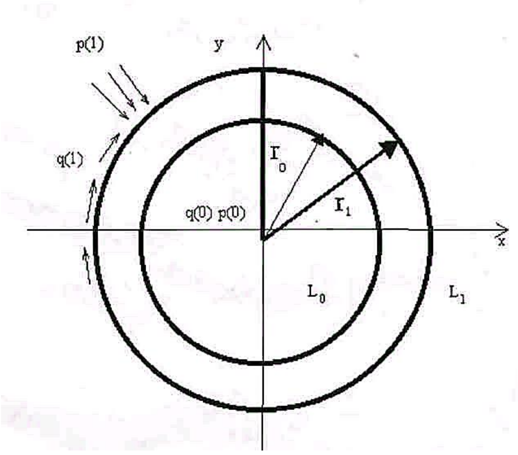


Fig. 2. Ring in an elastic medium

Under the action of stresses, the ring is deformed, while the points of the outer and inner contours experience displacements according to [1, 2]:

$$u(j)=u_0(j)+u_2(j)\cos 2\theta,\ \ v(j)=v_2(j)\sin 2\theta \qquad (5)$$

$u(j),\ v(j)$ - radial and tangential movements.

From (5) displacements are determined in the form: displacement on the inner contour and displacement on the outer contour:

$$u_{\theta in}=\frac{r_0}{4G(c^2-1)}(p_0(1)d_1-p_0(0)d_2),\ \ u_{\theta ex}=\frac{r_0}{4G(c^2-1)}(p_0(1)d_1^1-p_0(0)d_2^1)$$

$$(u_2+v_2)_{in}=\frac{r_0}{6GD}(p_2(1)a_1-q_2(1)a_2-p_2(0)a_3-q_2(0)a_4)$$

$$(u_2-v_2)_{in}=\frac{r_0}{2GD}(p_2(1)a_1^1-q_2(1)a_2^1-p_2(0)a_3^1-q_2(0)a_4^1) \qquad (6)$$

$$(u_2+v_2)_{ex}=\frac{r_1}{6GD}(p_2(1)b_1-q_2(1)b_2-p_2(0)b_3-q_2(0)b_4)$$

$$(u_2+v_2)_{ex}=\frac{r_1}{6Gd}(p_2(1)b_1^1-q_2(1)b_2^1-p_2(0)b_3^1-q_2(0)b_4^1)$$

$u_{\theta in},\ u_{\theta ex}, G$ - radial displacements of the inner layer, radial displacements of the outer layer and shear modulus. Here

$$\chi=3-4\nu, a_1=c^2(3-c^2), a_3=3c^2+1+D, a_4=3c^2-1-D, a_1^1=c^2(2c^4+c^2+1)$$

$$a_2^1=c^2(c^2+1), a_3^1=c^4(c^2+1)+2c^2-D, a_4^1=c^2(c^2+1)-D, b_1=c^4(3+c^2)-D$$

$$b_2=c^4(3-c^2)+D, b_3=c^4(3c^2+1), b_4=c^2(3c^2-1), b_1^1=2c^4+c^2+D$$

$$b_2^1=c^2+1+D, b_3^1=c^2(c^2+1)+2, b_4^1=c^2(c^2+1), D=\frac{(c^2-1)^2}{\chi+1}$$

$$d_1=c^2(\chi+1), d_2=2c^2+\chi-1), d_1^1=c^2(\chi-1)+2, d_2^1=\chi+1$$

Where χ - coefficient for lining material.

The design scheme of a two-layer lining with a working array is shown in fig. 3.

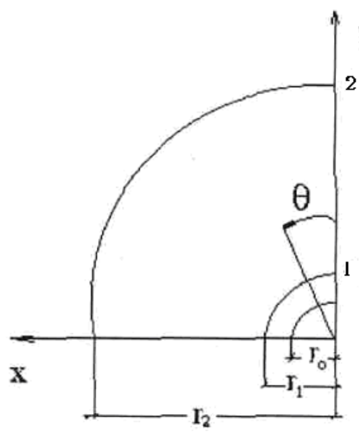


Fig. 3. Diagram of a ring in an elastic medium

Now, let's determine the transfer coefficients of external loads in the ring. We assume that a uniform deformed state occurs, i.e., the stresses at the contact between the structure and the ground are equal to $\sigma_r(1) = p_0(1)$... Then we consider that the stresses on the outer and inner contours of the layers are related by the ratio:

$$p_0(1) = p_2(1)K_0(2) \tag{7}$$

Under the action of external stresses applied to the two-layer ring, the layers under consideration are deformed, and we assume that there is a relative displacement on the contact line of the two layers equal to Δu_0...

Then according to one can write $(u_{\theta in,2} + \Delta u_0) = u_{\theta ex,1}$ and it is the total displacement of the inner contour of the 2nd layer with a certain relative displacement exactly equal to the displacement of the outer contour of the 1st layer. The problem is elastic and linear, and based on the above condition, we will compose the following equation:

$$\begin{aligned} &\frac{r_1}{4G_2(c_2^2-1)}\left(p_0(2)d_1(2) - p_0(1)d_2(2) + \frac{p_0(1)}{k_r}\right) = \\ &= \frac{r_1}{4G_1(c_1^2-1)}\left(p_0(1)d_1^1(1) - p_0(0)d_2^1(1)\right) \end{aligned} \tag{8}$$

Here k_r - the coefficient of the radial (transverse) interaction of the structure with the ground. According to [4, 5], one can write

Substituting equation (8) into equation (7) and after cancellation we obtain

$$d_1(2) - K_0(2)d_2(2) = \frac{G_2(c_2^2-1)}{G_1(c_1^2-1)}K_0(2)(d_1^1(1) - K_0(1)d_2^1(1)) - \frac{4G_2(c_2^2-1)}{r_1 k_N p_0(2)1{,}63(1+\lambda)}$$

Here, the stress transfer coefficient through the 1st inner lining layer is equal to zero $K_0(1) = 0$... Further, we finally obtain the following expression for the transfer coefficient of uniform external stresses through the 2nd layer:

$$K_0(2) = \frac{d_1(2) + \dfrac{4G_2(c_2^2-1)}{r_1 k_N p_0(2)1{,}63(1+\lambda)}}{d_2(2) + \dfrac{G_2(c_2^2-1)}{G_1(c_1^2-1)}d_1^1(1)} \tag{9}$$

Divide the numerator and denominator by $c_2^2 \to \infty$ since the voltage is transmitted through an infinite layer. Then we get

$$K_0(2) = \frac{\chi + 1 + \dfrac{4G_2}{r_1 k_N p_0(2)1{,}63(1+\lambda)}}{2 + \dfrac{G_2(c_2^2-1)+2}{G_1(c_1^2-1)}} \tag{10}$$

Now consider the case where external forces are transmitted unevenly through an infinite soil layer. Irregular components of radial contact stresses $p_2(1)$, $p_2(2)$ and shear stresses $q_2(1)$

and $q_2(2)$ on the inner and outer contours of the layers are connected with each other by the following relationships, which also contain the transfer coefficients of external stresses [1]:

$$\begin{aligned} p_2(1) &= p_2(2)K_{11}(2) + q_2(2)K_{12}(2) \\ q_2(1) &= p_2(2)K_{21}(2) + q_2(2)K_{22}(2) \end{aligned} \tag{11}$$

or in matrix form

$$\vec{P}_1 = K_2\vec{P}_2 \tag{12}$$

Where K_2 - matrix of transfer coefficients of external voltages

$$K_2 = \begin{bmatrix} K_0(2) & 0 & 0 \\ 0 & K_{11}(2) & K_{12}(2) \\ 0 & K_{21}(2) & K_{22}(2) \end{bmatrix} \tag{13}$$

Let us represent the expressions for displacements in matrix form

$$\vec{U}_{in} = r_1[A_2\vec{P}_2 + A_2^1\vec{P}_1]$$

$$\vec{U}_{ex} = r_1[B_1\vec{P}_2 + B_1^1\vec{P}_0]$$

$$\text{Here } \vec{U}_{in} = \begin{Bmatrix} u_{\theta in}(2) \\ (u_2 + v_2)_{in} \\ (u_2 - v_2)_{in} \end{Bmatrix}, \vec{U}_{ex} = \begin{Bmatrix} u_{\theta ex}(1) \\ (u_2 + v_2)_{ex} \\ (u_2 - v_2)_{ex} \end{Bmatrix} \tag{14}$$

A_2, A_1^1, B_1, B_1^1 - matrix of coefficients of influence. To shorten the arithmetic calculations, we do not present them here, since they coincide with the coefficients given in [33]. If we assume that the interaction coefficients are known in advance and determined experimentally [4, 5], then under the condition of contact between the two layers, it can be written as:

$$\vec{U}_{2,in} + \Delta\vec{U} = \vec{U}_{1,ex}$$

$$\vec{U}_{in} = \begin{Bmatrix} \Delta u_0 \\ \Delta(u_2 + v_2) \\ \Delta(u_2 - v_2) \end{Bmatrix} = \begin{bmatrix} \frac{1}{k_r} & 0 & 0 \\ 0 & \frac{1}{k_r} & \frac{1}{k_\theta} \\ 0 & \frac{1}{k_r} & -\frac{1}{k_\theta} \end{bmatrix} \begin{Bmatrix} p_0(1) \\ p_2(1) \\ q_2(1) \end{Bmatrix} \tag{15}$$

The stresses are related in the form

$$\vec{P}_0 = K_1\vec{P}_1 = K_1K_2\vec{P}_2 \tag{16}$$

Substituting expression (16) taking into account (14) into condition (16), we obtain

$$r_1[A_2 + A_2^1 K_2]\vec{P}_2 + K_1 K^{*-1}\vec{P}_2 = r_1[B_1 + B_1^1 K_1]K_2\vec{P}_2 \qquad (17)$$

From this it is easy to obtain a matrix formula for determining the transfer coefficients of external stresses

$$K_2 = A_2[B_1 + B_1^1 K_1 - A_2^1 - K^{*-1}]^{-1} \qquad (18)$$

Here K^{*-1} - diagonal matrix of interaction coefficients

$$K^{*-1} = \begin{bmatrix} \frac{1}{k_r} & 0 & 0 \\ 0 & \frac{1}{k_r} & \frac{1}{k_\theta} \\ 0 & \frac{1}{k_r} & -\frac{1}{k_\theta} \end{bmatrix}$$

The matrix of stress transfer coefficients through the outer infinite layer, modeling the rock mass, has the following form

$$K_2 = \begin{bmatrix} K_0(2) & 0 & 0 \\ 0 & K_{11}(2) & 0 \\ 0 & K_{21}(2) & 0 \end{bmatrix} \qquad (19)$$

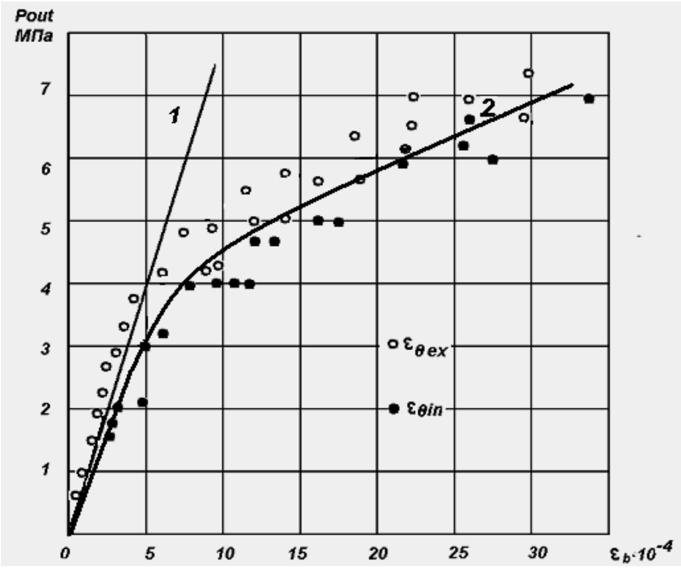
as $q_2(1) = 0$, so $K_{12}(2) = 0$ and $K_{22}(2) = 0$...

Stress transfer coefficients through the 1st layer are equal to zero $K_1 = 0$, as a consequence of which the load transfer coefficients through the 2nd layer are determined by the formula (19). Here you can take

$$p_0(1) = p_{0eg}K_0(2), p_2(1) = p_{2eg}K_{11}(2), q_2(1) = p_{2eg}K_{21}(2)$$

According to the obtained values at the contact of the lining with the soil massif, the stresses on the inner and outer contours of the cross-section are determined by the formulas (4). The developed calculation method differs from the existing method [1, 2, 3], taking into account the influence of the layer of interaction of the structure with the soil. For its implementation, a calculation program was drawn up.

Let us consider an example where M. Kwasniewski carried out model tests of a concrete structure for uniform external loads created by a jack installation [3]. The characteristics of the model are as follows: R =32.5 cm - lining diameter, t = 8 cm - lining thickness, E = 45185 MPa, σ_c= 34.1 MPa - ultimate strength of the lining material.



1- deformation on the inner contour obtained by the developed method, 2- deformation on the inner contour, obtained according to [3]

Fig. 4. Dependence between deformations on the inner ($\varepsilon_{\theta in}$) and external ($\varepsilon_{\theta ex}$) the contour of the section of the concrete lining

In fig. 4 shows the results of measurements of tangential deformations on the inner and outer contour of the lining cross-section as the uniform external loads on the lining grow. To carry out a comparative analysis according to the developed method, the lining was calculated for uniform external pressure. Here you can see a satisfactory convergence of the obtained deformations with the measured ones, by almost 80-85% in the linear stage of the material operation.

REFERENCES

1) Bulychev N.S., Amusin B.Z. Olovyannyy A.G. Raschet krepi kapital'nykh gornykh workings. M .: Nedra, 1974, p. 320
2) Bulychev N.S., Fotieva N.N. Assessment of the stability of the rock surrounding the mine workings. Mine construction, 1977, No. 3, p.15-21
3) Bulychev N.S. Mechanics of underground structures, Moscow: Nedra, 1994, p. 268
4) Rashidov T.R. Dynamic theory of seismic stability of complex systems of underground structures, Fan, Tashkent, 1973, p. 138
5) Sultanov K.S. About models of interaction of underground structures with soil under dynamic influences. Uzbek j-l "Problems of mechanics", Tashkent, No. 2, 1992.