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**TEXNIKA FANLARI DOKTORI, PROFESSOR  
MIRAXMEDOV MAXAMADJON MIRAXMEDOVICH  
TAVALLUDINING 80 YILLIGIGA BAG'ISHLANGAN  
“SAMARALI QURILISH MATERIALLARI, KONSTRUKSIYALARI VA  
TEKNOLOGIYALARI”  
MAVZUSIDAGI XALQARO ILMIY-AMALIY KONFERENSIYASI  
ILMIY ISHLARI TO'PLAMI**

Toshkent davlat transport universiteti RAASN akademigi, O'zbekistonda xizmat ko'rsatgan yoshlar murabbiyi, texnika fanlari doktori, professor Miraxmedov Maxamadjon Miraxmedovich tavalludining 80 yilligiga bag'ishlangan, ilmiy ishlar to'plami nashr etilishi ko'zda tutilgan «Samarali qurilish materiallari, konstruksiyalari va texnologiyalari» mavzusidagi Xalqaro ilmiy-amaliy konferensiyani o'tkazishni rejalashtirmoqda.

M.M. Miraxmedov kompozitsion qurilish materiallarining polistruktura nazariyasini rivojlantirishga salmoqli hissa qo'shgan. Uning qurilish materialshunosligi sohasidagi ilmiy hissi e'tirofi sifatida 1995-yilda Rossiya arxitektura va qurilish fanlari akademiyasining (RAASN) xorijiy a'zosi etib saylangan. M.M. Miraxmedov 6 ta monografiya, 200 dan ortiq ilmiy maqolalar va 25 ta ixtiroga mualliflik guvohnomalari muallifidir.

Ushbu konferensiyaning asosiy maqsadi - qurilish materialshunosligi, bino va inshootlarni loyihalash va qurilish sohasidagi ilmiy tadqiqotlar natijalarini, shuningdek, muhandislik ta'limini takomillashtirish yo'llarini muhokama qilishdan iborat.

Konferensiya ishida ishtirok etish uchun oliy o'quv yurtlari va ilmiy tadqiqot institutlari olimlari, O'zbekiston Respublikasi va xorijiy davlatlarning ishlab chiqarish vakillari, ilmiy tadqiqotlarda salmoqli natijalarga ega bo'lgan mutaxassislar taklif etiladi.

**“Samarali qurilish materiallari, konstruksiyalari va texnologiyalari”** mavzusidagi xalqaro ilmiy-amaliy konferensiyaning asosiy yo'nalishlari quyidagilardan iborat:

1. Resurs va energiya tejovchi qurilish materiallari va texnologiyalari.
2. Atrof-muhitning transport infratuzilmasiga ta'siri va uni himoya qilish usullari.
3. Bino va inshootlarning qurilish konstruksiyalari: hisoblash va loyihalashning zamonaviy usullari.
4. Arxitektura, shaharsozlik va shahar muhitini rivojlantirish.
5. Qurilishni tashkil etishning innovatsion usullari va qurilish jarayonlari texnologiyalari.
6. Transport obyektlarini loyihalash va qurishda raqamli texnologiyalar hamda sun'iy intellekt.
7. Temir yo'l transporti infratuzilmasi obyektlarini loyihalash, qurish va ekspluatatsiya qilish.
8. Zamonaviy muhandislik ta'limi tizimini takomillashtirish.

Mazkur konferensiya ilmiy hamjamiyatning turli vakillarini bir joyga jamlab, qurilish materialshunosligi sohasidagi zamonaviy muammolar va istiqbollarni muhokama qilish uchun qulay platforma vazifasini bajardi.

# Hydraulic Calculation of Culverts in Railway Earthwork Embankments

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**Abstract:** The article examines the issues of designing culverts in railway embankments located in seismic regions, taking into account the operational characteristics of the foundations of these structures and the terrain conditions. Based on the obtained and briefly described experimental methodologies, recommendations are provided for selecting structural designs suitable for seismic areas. In addition, new structural solutions combining reliability under seismic loading with reduced consumption of construction materials have been developed. The proposed theoretical solutions are supported and refined through experimental investigations.

**Keywords:** Earth embankment, railway track superstructure, seismic forces, embankments, cuttings, seismic resistance

## 1. INTRODUCTION

The results of experimental and theoretical studies have shown that the seismic resistance of culverts within railway embankments largely depends on the dynamic parameters of the roadbed, which in turn significantly reduces their seismic stability. This explains the extensive damage commonly observed in the areas of culverts and embankments during earthquakes.

Analysis of the consequences of numerous earthquakes indicates that reinforced concrete culverts installed in earth embankments represent one of the weakest components of railway roadbed structures, often resulting in partial or even complete failure. However, up to the present time, seismic protection measures have not been adequately incorporated into the design of these structures, and calculations of stresses and displacements during the design process of culverts in embankments are generally not performed.

This particularly applies to reinforced concrete culvert structures designed for the Baikal–Amur Mainline, as well as for railways in the republics of Central Asia and Uzbekistan, a considerable portion of which passes through regions characterized by high seismic activity [1, 2, 3, 4].

It is well known that damage to culverts within embankments occurs due to the following factors:

- the effect of seismic inertial forces acting on the structure;
- deformation of the embankment, which leads to a loss of foundation stability manifested in the form of non-uniform settlement of the culvert along its length.

Accordingly, the effect of seismic inertial forces on culverts located within railway embankments is considered first.

## 2. METHODOLOGY


Analysis of earthquake consequences indicates that the most hazardous direction of seismic impact is the transverse direction relative to the culvert axis within the embankment. Therefore, when selecting an appropriate dynamic design model for culverts in railway earth embankments, this factor of the critical direction of seismic wave propagation for the given engineering structure must be taken into account.

In the analysis of seismic inertial forces, the soil conditions of the culvert foundation are assumed to be sufficiently stable and strong, which is frequently the case in practice, since reinforced concrete culverts in railway embankments are generally constructed on dense soils with relatively low compressibility coefficients or on preliminarily compacted foundations.

It should be noted that culverts within embankments, which are widely used in railway and highway construction, possess a number of specific structural and operational characteristics, as well as distinct dynamic parameters. These features make it impossible to identify them analytically with pipelines laid in trenches, which are generally located below the ground surface and often have considerable longitudinal extension in plan.

One of the major problems in the theory of seismic resistance is that seismic forces determined by different methods are often inconsistent with one another. As a result, the reliability of calculations performed in the design of structures and in the study of their behavior under seismic conditions remains insufficiently accurate, showing mainly qualitative

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agreement with actual behavior. This fact indicates the necessity of experimental verification and refinement in the calculation of engineering structures subjected to seismic forces.

Both domestic and foreign scientific literature [5, 6] contain numerous examples of structural analysis under seismic loading based on accelerogram (seismogram) laws. Analysis of seismograms has shown that, as a simplified mathematical interpretation, soil displacement during an earthquake may be represented by the superposition of a series of harmonic functions of the following form:

$$W_p = \sum_{i=1}^n a_{0i} L^{-\varepsilon_{0i} t} \sin(\omega_i t + \gamma_i) \quad (1)$$

where:

$W_p$  – soil displacement;

$a_{0i}$  – initial amplitude of the corresponding harmonic component;

$\varepsilon_{0i}$  – soil damping coefficient;

$\omega_i$  – vibration frequency of the corresponding harmonic component;

$\gamma_i$  – phase angle determining the initiation moment of the corresponding harmonic component;

$t$  – time.

As is well known, the combined action of such harmonic functions with different parameters (i.e., different initial amplitudes  $a_{0i}$ , frequencies  $\omega_i$ , damping coefficients  $\varepsilon_{0i}$ , and activation times  $t$ ) may produce highly diverse patterns of soil displacement, thereby practically describing any law of motion.

If it is assumed that all components of expression (1) possess equal initial acceleration amplitudes and identical damping characteristics, but different frequencies, then it is evident that the greatest effect on a single-degree-of-freedom system will be produced by the harmonic component whose frequency  $\omega_i$  is equal or close to the natural vibration frequency of the system, denoted by  $p$ .

Taking this into account, it may be concluded that, as a further approximation of the simplified computational model of a seismic phenomenon, it is most appropriate to consider the effect on the structure of only one component from expression (1), namely the component producing the maximum dynamic effect.

Consequently, the simplified practical seismic analysis may be reduced to the determination of forces and deformations arising in the structure under the action of a single damped sinusoidal function, the frequency of which may vary within certain limits, i.e.

$$W_p = A_0 L^{-\varepsilon_{0i} t} \sin \omega t \quad (2)$$

For extended structures, such as culverts within embankments, the relationship between the length of the structure and the wavelength of longitudinal

seismic waves propagating through the soil is of considerable importance. In this regard, the principal analytical approach is to represent soil motion during earthquakes in the form of a traveling wave with variable intensity:

$$W_p(x, t) = A_0 L^{-\varepsilon_{0i} (t - \frac{x}{c_p})} \sin \omega (t - \frac{x}{c_p}) \quad (3)$$

where:

$A_0$  – amplitude of forced vibrations;

$\varepsilon_{0i}$  – damping coefficient of soil vibrations;

$x$  – coordinate of the point under consideration;

$\omega$  – frequency of forced vibrations;

$c_p$  – propagation velocity of longitudinal seismic waves.

The above-described methodology may now be applied to the analysis of seismic vibrations of culverts within embankments.

As is well known, the requirements imposed on a dynamic computational model are such that, on the one hand, it must adequately account for the parameters characterizing structural deformation in the direction of seismic force action and accurately represent mass distribution, while on the other hand, it must remain sufficiently simple for practical calculations. The adopted computational model should make it possible to formulate the deformation conditions of the structure in the form of corresponding mathematical expressions. Such an approach is characteristic of both static and dynamic analyses.

In practice, in order to satisfy these requirements and enable the derivation of mathematical relationships, the actual structure of a culvert within an embankment must be considerably simplified. Assumptions are widely employed in engineering calculations because they substantially reduce computational complexity, while the errors associated with such idealizations are generally insignificant. Moreover, simplifications not only facilitate calculations by reducing computational effort, but also decrease the likelihood of errors and unavoidable inaccuracies in numerical analysis, thereby contributing to more reliable results. However, this should not lead to the conclusion that any simplification is always rational and justified. Simplifications are appropriate only when they do not distort the essential aspects of the analysis while significantly facilitating computations.

The primary task in ensuring the seismic stability of culverts within embankments is to guarantee uniform settlement of the culvert along its entire length. Only after this condition is addressed does it become appropriate to consider the analysis of culverts under the action of inertial seismic forces. In the presence of sufficiently dense and weakly compressible foundation soils, the principal issue becomes the calculation of culverts subjected to inertial seismic forces caused both by the self-weight



of the culvert and by the attached mass of surrounding soil.

As previously noted, the selection of a rational computational model is of great practical importance. Let us now proceed to the specific choice of a dynamic computational model for a culvert within an embankment subjected to a seismic wave described by expression (3). Under such seismic excitation, the primary interest lies in the relative displacements of various points along the culvert length.

A dynamic computational model is proposed (Fig. 3.2), based on the assumption that the soil displacements for points located within the same segment are approximately identical. Therefore, the displacements of these points are assumed equal to the displacement of the segment's center of gravity. As a result, a computational dynamic model with unknown parameters in the form of transverse forces is obtained. This simplification does not introduce significant inaccuracies into the analytical system. The proposed dynamic model under the given seismic excitation is characterized by unknown parameters, namely the relative displacements of the segments,  $W_i(x,t)$ , which must be determined.

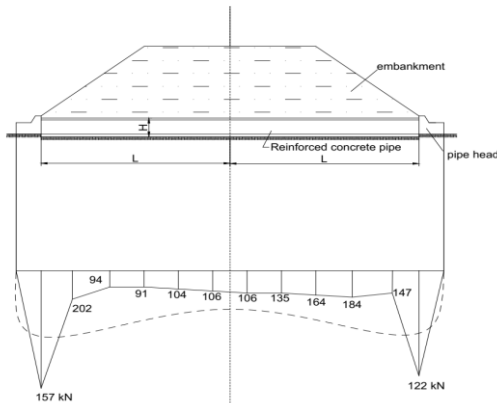


Fig. 3.2

If the force method is applied to the stated problem, the system of canonical equations may be written in the following form:

$$\begin{cases} \delta_{11}x_1 + \delta_{12}x_2 + \Delta_1p = 0 \\ \delta_{21}x_1 + \delta_{22}x_2 + \delta_{23}x_3 + \Delta_2p = 0 \\ \delta_{32}x_2 + \delta_{33}x_3 + \delta_{34} + \Delta_3p = 0 \\ \delta_{i(i-1)}x_{(i-1)} + \delta_{ii}x_i + \delta_{i(i+1)}x_{(i+1)} + \Delta_i p = 0 \\ \delta_{(n-1)n}x_{(n-1)} + \delta_{nn}x_n + \delta_{n(n+1)}x_{(n+1)} + \Delta_n p = 0 \\ \delta_{(n+1)n}x_n + \delta_{(n+1)(n+1)}x_{(n+1)} + \Delta_{(n+1)}p = 0 \end{cases} \quad (4)$$

The unit displacements  $\delta_{ij}$  are determined using the Gorbunov-Posadov solution for rigid plates [7]. In order for the plate to be considered rigid, the following condition must be satisfied:

$$n_{min} = \frac{L}{H_{sech}} \sqrt{3\pi \frac{E_r}{E_\tau} \frac{1-v_\tau^2}{1-v_r^2}} \quad (5)$$

where:  $L, H_{sech}, n$  – (parameters shown in Fig. 3.1)  $E_r, E_\tau$  – deformation moduli of the soil and culvert material, respectively;  $v_r, v_\tau$  – Poisson's ratios of the soil and culvert material, respectively.

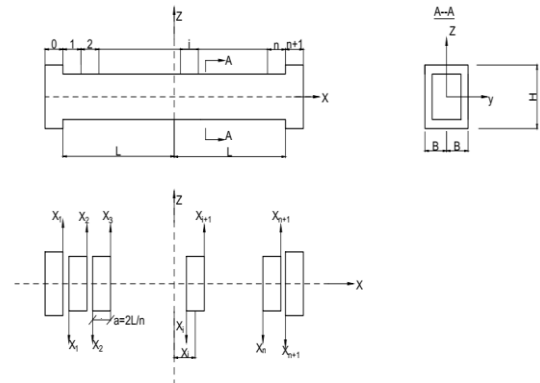


Fig. 3.1. Dynamic computational model of a culvert within an embankment with unknown parameters in the form of transverse forces

### Determination of Unit Displacements

In studies [7, 8], the problem of the displacement of a rigid plate with dimensions  $2a \times 2b$  subjected to a bending moment  $M$  and a concentrated force  $P_0$  was solved.

The settlement of the plate caused by the action of a centrally applied concentrated force  $P_0$  is determined by the expression:

$$W = \frac{1-v_\tau^2}{E_r} K_0 \frac{P_0}{\sqrt{F}} = \frac{1-v_\tau^2}{E_r} K_0 \frac{P_0}{\sqrt{ab}} \quad (6)$$

The coefficient  $K_0$  is determined depending on the aspect ratio of the rectangular plate,  $\alpha = a/b$  according to Table 1.

Table 1

| $\alpha$ | 1   | 1,5  | 2    | 3   | 5    | 7    | 10  |
|----------|-----|------|------|-----|------|------|-----|
| $K_0$    | 0,8 | 0,86 | 0,85 | 0,8 | 0,76 | 0,72 | 0,6 |
|          | 8   | 5    | 5    | 3   | 5    | 5    | 7   |

The angle of rotation caused by moments  $M_x$  (acting in the vertical plane parallel to the larger side  $2a$ ) and  $M_y$  (acting in the vertical plane parallel to the smaller side  $2b$ ) is determined, respectively, by the following expressions:

$$\begin{cases} tg\varphi_x \approx \varphi_x \frac{1-v_\tau^2}{E_r} K_1 \frac{M_x}{a^3} \\ tg\varphi_y \approx \varphi_y \frac{1-v_\tau^2}{E_r} K_2 \frac{M_x}{b^3} \end{cases} \quad (7)$$

The coefficients  $K_1$  and  $K_2$  in these formulas are determined according to Table 2.

Table 2

| $\alpha$ | 1 | 1,5 | 2 | 3 | 5 | 7 | 10 |
|----------|---|-----|---|---|---|---|----|
|----------|---|-----|---|---|---|---|----|



|       |     |     |     |     |     |     |     |
|-------|-----|-----|-----|-----|-----|-----|-----|
| $K_1$ | 0,5 | 0,6 | 0,8 | 1,1 | 1,4 | 1,7 | 2,0 |
|       | 5   | 7   | 5   |     | 5   |     |     |
| $K_2$ | 0,6 | 0,4 | 0,3 | 0,2 | 0,1 | 0,1 | 0,0 |
|       | 3   | 3   | 39  | 36  | 45  | 05  | 74  |

Using the above formulas, the values of unit displacements  $\delta_{ij}$  can be obtained from the following relationships:

$$\begin{cases} \delta_{ij} = \frac{1-\nu_r^2}{E_r} K_{ij} \frac{n}{L} - \frac{1-\nu_r^2}{2E_r} K_{0i} \frac{\sqrt{n}}{\sqrt{bL}} \\ \delta_{ij} = 2 \left( \frac{1-\nu_r^2}{2E_r} K_{0j} \frac{\sqrt{n}}{\sqrt{bL}} - \frac{1-\nu_r^2}{2E_r} K_{li} \frac{n}{L} \right) \end{cases} \quad (8)$$

The initial data used for comparison of results were adopted from Example 1. The calculation results are presented in Fig. 3.5, which shows the dependence graph of  $\bar{x}_1^{max} = mx_1^{max}$  the value of  $K_{Q1}$ . It should be noted that  $m \leq 1$

The graph demonstrates that, in order to reduce  $x_1^{max}$  by a factor of 10, it is necessary to ensure a joint flexibility coefficient of  $36 \cdot 10^{-4}$  M/kH. Based on this value, the material and dimensions of the flexible joint may be selected using the following expression:

$$K_{Q1} = \frac{\delta_{CT}}{b \delta_{CT} E_{CT}} \quad (9)$$

where  $E_{CT}$  is the deformation modulus of the joint material. Other designations are shown in Fig. 3.3(b).

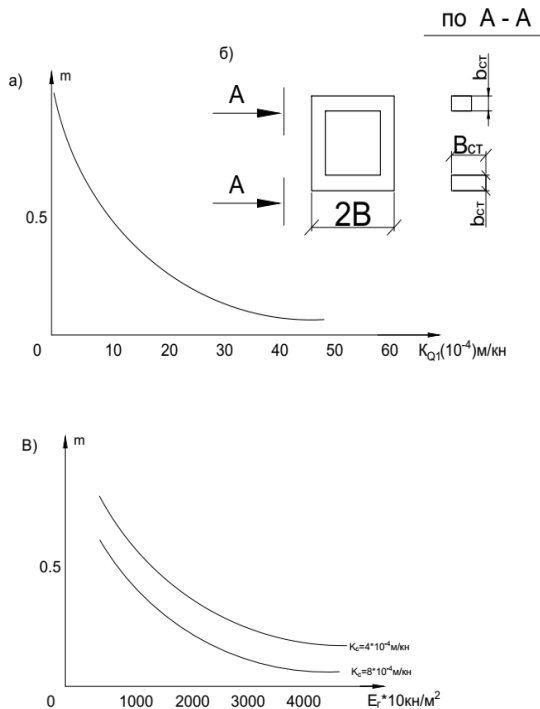


Fig. 3.3

The graph showing the dependence of the flexibility coefficient  $K_{Q1}$  on the soil deformation modulus  $E_r$ , indicates that, as  $E_r$  increases, the required flexibility

coefficient decreases (under otherwise identical conditions) in order to reduce the forces acting within the given section (Fig. 3.6).

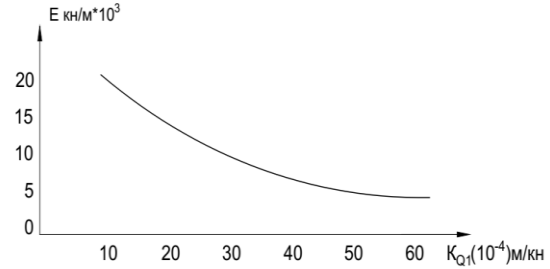


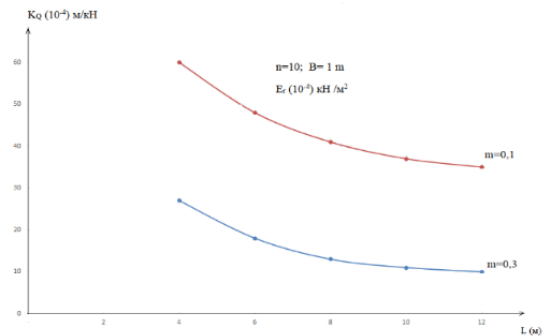
Fig.3.6

Let us establish the dependence of the flexibility coefficient  $K_{Q1}$  on the value of  $b$ , i.e., on the dimensions of the culvert cross-section. First, based on Tables 3.1 and 3.2, the following relationships are obtained:

$$K_{Q1} = 0,855 - 0,025 \left( \frac{L}{b_n} \right); \quad K_{11} = 0,3 \left( \frac{L}{b_n} \right) + 0,25 \quad (10)$$

Then, the expression for determining  $K_{Q1}$  may be written as:

$$K_{Q1} = \frac{4(1-\nu_r^2)}{E_r} \left[ 0,427 \sqrt{\frac{n}{bL}} - 0,0125 \left( \sqrt{\frac{L}{nb^3}} + \frac{0,3}{b} + 0,25 \frac{n}{L} \right) \frac{1-m}{m} \right] \quad (11)$$



Using this expression, the graph of the dependence  $K_{Q1} = \phi(b)$  (Fig. 3.5) and the graph of the dependence  $K_{Q1} = \phi(L)$  (Fig. 3.4) were obtained.

### 3. CONCLUSIONS

1. In order to ensure the seismic resistance of culverts within embankments, it is necessary to select seismically stable foundation soils during the site investigation stage. If such soils are absent, soil strengthening measures for the culvert foundation must be designed.



2. The soil surrounding culverts within embankments should possess high density and strength characteristics, which reduce stresses in the culvert sections under seismic loading.
3. Flexible joints installed in critical sections of culverts are capable of significantly reducing and redistributing stresses within the structure.

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CONTEXT / MUINDARILJA

