Earthquake resistance of culverts of railways of Uzbekistan

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Abstract. Based on full-scale and model experiments using a seismic platform and vibration disturbances from rolling stock during high-speed movement, additional functions affecting the dynamic stability of the railway roadbed have been identified. The calculation formulas for ensuring the seismic resistance of railway culverts with the determination of the influence of the slope of the terrain of the road and the speed of trains have been clarified. If the core is reinforced with geotextile after 0.5 m, the soil layer above the pipe can be reduced to h = 1.5 m, which significantly reduces the excavation volume and the rail-sleeper grid's slopes. In addition, the magnitude of long irregularities that occur in the pipe area decreases, increasing the repair time of roads and the resistance to seismic forces. When conducting experimental studies on models, when focusing on this coefficient, there is no need to bring the model of the structure to destruction, which saves time and building materials.

1 Introduction

Uzbekistan's climatic and relief conditions are characterized by a sharp change in relief, ground, and climatic changes along the length of railways, which affects the stability of the roadbed during an earthquake.

When an earthquake occurs, and the speed of traffic increases, longitudinal, transverse, and vertical vibrations are created on the roadbed [1].

As a result of changes in the physical and mechanical properties of the soil and an increase in the vibration frequencies under the influence of vibrodynamic forces, various deformations, and destructions occur in structures [2].

Measurements of ground vibrations of the subgrade carried out by G. G. Konshin, G. N. Zhinkin, and T. G. Yakovleva showed that the characteristics of the ground decrease with distance from the bottom of the ballast prism, depending on the speed of movement and axial load [3].

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2 Materials and Methods

The most accurate and reliable values reflecting the level of vibrations occurring in the roadbed can be obtained from field studies.

To determine the propagation of vibrations in a triaxial coordinate system (x, y, z), vibration displacement, logarithmic decrement of vibrations, vibration velocity, and vibration acceleration of vibrations of the embankment soils, oscilloscope sensors (SM-3) were used (Fig.1).

- sensors for determining vibration displacement and vibration velocity in the three main coordinate systems (x, y, z) - 3 pcs;

Fig. 1. Sensors for determining main oscillation parameters in three main coordinate systems x, y, z.

Before starting the experiment, all devices and equipment are checked for readiness for working conditions. An electric current is supplied to connect a computer, an oscilloscope (SM-3), and a VI-9-8A vibrator to a power source. The supplied electric current is connected during the measurement process.

Figure 2 shows a block diagram of a two-channel mobile engineering seismometric station (MESS).
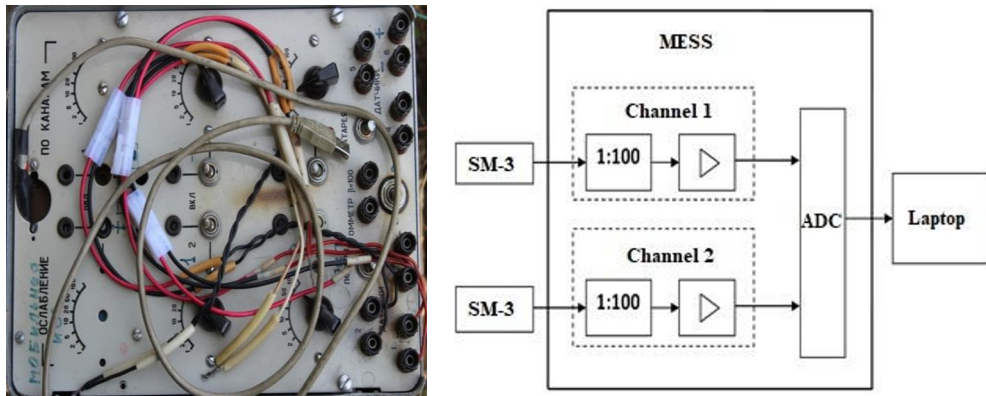
Fig. 2. Block diagram of mobile engineering seismometric station (MESS).

Each measuring channel includes the following: an input divider, an amplifier, an analog-to-digital converter for all channels (ADC), and a laptop with software. During the measurements, data was received on 4 channels. Measuring work is carried out at 4 points. Two upper and two lower points of the roadbed on the slopes. The measuring methods are based on the scheme shown in Figure 3.

Fig. 3. Schematic view of measuring points. MP is measuring point

The calculation of the movement of the upper and lower points of the roadbed on the sloping sections during fluctuations is carried out according to the formula:

$$A_{td} = \frac{\beta \cdot V_s}{f_s} \qquad (1)$$

where A_{td} is true displacement, mm; β is attenuation coefficient set on the channel of the mobile station (dimensionless); V_s is signal amplitude from maximum to minimum (double amplitude of the average signal value calculated by the program), V; f_s is channel sensitivity coefficient, V/mm.
Table 1 shows the channel gain coefficients obtained during calibration MESS.

Table 1. Channel gain factors

Gain factor	Channel 1	Channel 2
f_c, V/mm	f_{c1}= 630	f_{c2}= 654

The value of amplitudes on seismograms is determined using the following expression.

$$A = A_{max} - A_{min} \qquad (2)$$

where: A_{min} is minimum amplitude value (mm), A_{max} is maximum amplitude value (mm).

3 Results and Discussion

The influence of the slope of the foundation of the roadbed, the groundwater level, and the physical and mechanical properties of soils are given in [4] in graphic form. The dynamic rigidity of the roadbed, which depends on the period of natural oscillations – T and logarithmic decrement – δ, the values of which can be calculated using known formulas, do not make it possible to determine analytically the influence of the slope of the base and soil properties.

The period of free oscillations of the embankment of the roadbed, taking into account the slope of the base is proposed according to the formula, which is obtained based on full-scale and model measurements using a seismic platform:

$$T_1 = \frac{\sqrt{H}}{\sqrt[3]{B_0}} \alpha m tg\beta \qquad (3)$$

where H, B_0 are height and width of the roadbed, m;

β is the angle of the slope – fig-4.

α is a coefficient that takes into account the properties of soils,

a) sandy, crushed stone soils: α=0.1;

b) clay and sandy loam soils: α=0.08.

m is the coefficient of working conditions of the embankment:

a) near bridges: m=1.4;

b) near the pipes: m=1.2;

v) if there are no artificial structures: m=1.0.

It can be seen from formula (3) that to reduce the period of free oscillations of the embankment of the roadbed, it is sufficient to increase the slope of the slopes, which leads to a significant increase in soil consumption, which is not economically justified.

To assess the dynamic stability of the roadbed of the embankment and excavation, the coefficient of dynamic stability is determined - β_0.

In the course of experiments, its value should not exceed $\beta_0 \leq 1.35$; if exceeded, the collapse of the embankment or the slopes of the excavation occurs.

$$\beta_0 = \frac{W_{max}}{W_{min}} tg\beta \qquad (4)$$

where: W_{max} is acceleration of the upper points of the roadbed; W_{min} is acceleration of the lower points of the roadbed –fig-4; β is slope angle, deg.

From here, it can be seen that the location of the culvert at an angle gives a sharp increase in the value of dynamic stability, which can lead to the destruction of the culvert.

Using formula (4) makes it possible to adopt an optimal design of the roadbed capable of resisting seismic influences, taking into account the slope of the railway passage.

Determination of dynamic stability makes it possible to determine the condition of the roadbed after a possible earthquake, as well as to assess its condition after construction without damaging it; it is necessary to install only vibration sensors, as indicated in Fig. 4.
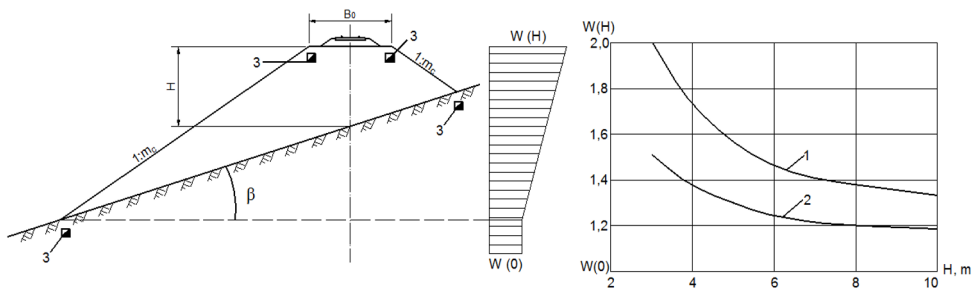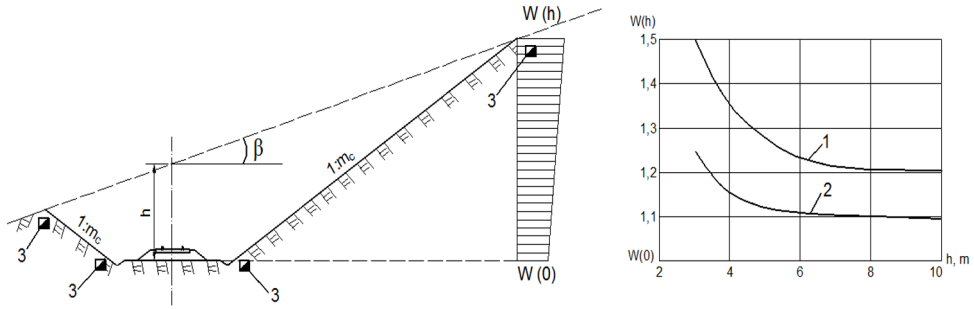
Fig. 4. Graph of changes in the calculated seismicity in height (depth) of the roadbed on sloping areas with different soils: 1 is loam, sandy loam, 2 is crushed stone, gravel, coarse sands, 3 is vibration sensors.

To determine the voltage in the base plate of the culvert, the formula has been clarified [5]:

$$\sigma = \frac{WT\sqrt{E_n + E_r \alpha \gamma_{av}}}{2\pi\sqrt{(1+\alpha)g}} Ktg\alpha \qquad (5)$$

where E_n, E_r are modulus of elasticity of the base plate and soil;

W is calculated seismic acceleration during an earthquake;

T is the period of ground vibrations during an earthquake;

γ_{av} is the average volumetric weight of the slab and the base soil;

K is the constructive coefficient, for the convexity of the plate $K = 0.7$, for a flat plate $K = 0.9$;

α is the angle of inclination of the plate along the axis of the watercourse, deg.

It is known from the consequences of many earthquakes that the embankments of the railway roadbed are more prone to deformation and destruction in the culvert area. These sections have a length of 5-30 m [6] and are called the active zone, which requires stronger strengthening and depends on the intensity of the earthquake, and the speed of movement of the rolling stock. It is proposed to determine its length by a refined empirical formula:

$$L_{laz} = K(50dAK_1 + 2Hctg\alpha)v \qquad (6)$$

where: L_{laz} is length of the active zone, m – Fig. 5;

K is constructive coefficient, for rectangular structures K=1.1, for round structures K=1.0;

d is pipe diameter or width, m;

A is seismicity coefficient, SNiP II-7-81;

K_1 is coefficient for transport facilities K$_1$=0.25 (Table 3, SNiP II-7-81);

α is fig. 5. for sandy soils $\alpha=45^0$, for connected soils $\alpha=60^0$;

H is height of the embankment, m;

v is the coefficient, the value of which depends on the speed of movement of the rolling stock,

up to 70 km/h v=1,0;

70-120 km/h v=1,2;

>120 km/h v=1,35.

The increase in the active zone, i.e., the mass of the roadbed and the structure of the culvert, which experiences joint oscillations equal in frequency and amplitude, is explained by an increase in the frequency of oscillations with an increase in the speed of movement of the rolling stock [7-23].
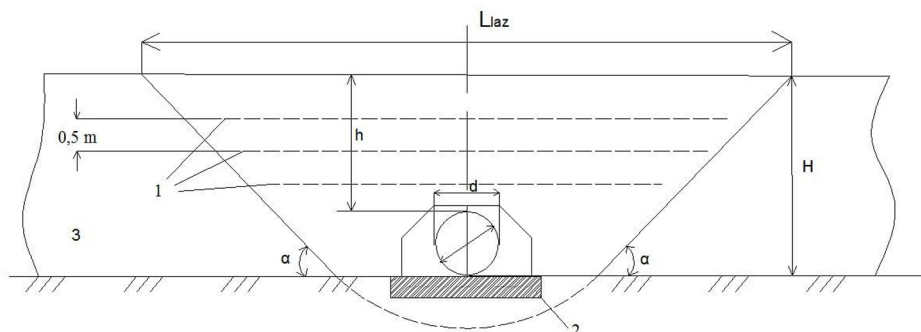
Fig. 5. Geotextile reinforcement scheme of core: 1 is geotextile, 2 is pipe foundation, 3 is embankment of the roadbed.

Technical conditions of operation of the Uzbekistan railways provide a layer of soil above the culvert at least h ≥2 m, reducing the effort from the rolling stock.

4 Conclusions

1. Theoretical calculations, model, and full-scale experiments clarified the calculation system of the "embankment-culvert" structure.

2. The influence of the terrain's slope on the roadbed's seismic resistance is determined.

3. The design of the active zone of the roadbed near the culvert has been clarified.

4. To ensure the seismic resistance of the entire structure, a constructive reinforcement of the core with geotextile is proposed, which is much cheaper than increasing the flatness of the slopes of the roadbed.

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