Reducing impact of embankment soils on shore support of bridge on the approaches to bridges

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Abstract. The article defines the reduction of active ground pressure and amplitude-frequency characteristics by theoretical and practical studies on approaches to bridges by driving reinforced concrete piles into the embankment. Reinforced concrete piles were driven into the model of the roadbed, and vibrations were created using a vibrator mounted on piles. The frequency of these oscillations was 50 Hz, and the values of the oscillations were recorded at different points of the roadbed. Processing the obtained results made it possible to determine the distance between piles for different soils on the transition section reinforced with reinforced concrete piles. As a result, some of the vibrations in the roadbed are transmitted to the base using reinforced concrete piles. The amplitude-frequency characteristics (frequency response) of the vibrations of the embankment soils are decreasing.

1 Introduction

Construction is one of the most complex and labor-intensive branches of the national economy, characterized by high dynamism, i.e., constant changes in time of both production conditions and the construction objects themselves [1]. With the further development of transport, loads on the axis of locomotives can increase up to 300 kN, and loads on the axis of wagons - up to 250 kN [2].

The active pressure of the ground acting on the shore support of the bridge increases significantly under the influence of the seismic force. As a result, the bridge's stability is destroyed [3].

When an earthquake occurs, and the speed of traffic increases, longitudinal, transverse, and vertical vibrations are created on the roadbed [4]. 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 [5]. Fluctuations in the soil of the roadbed increase significantly at the approaches to the bridges. These fluctuations affect the shore support of the bridge, which will lead to an increase in active ground pressure. This problem is very relevant for all railways globally [6].

At the same time, the coastal support should perceive the active ground pressure (E_a) arising from the oscillatory force of the rolling stock and transmit it to the base, as well as ensure the safe operation of the structure [7-23].

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2 Objects and methods of research

To clarify the results of the model and full-scale experiments on the soil environment's influence on the soil's seismic insulating effects on the engineering structure, full-scale experiments were conducted on the effect of vibration loads on the pile.

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 carefully connected during the measurement process. 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 were used.

Each measuring channel includes the following: an input divider, an amplifier, an analog-to-digital converter for all channels, and a laptop with software. During the measurements, data was received on 4 channels. The measuring methods are based on the scheme shown in Figure 1.

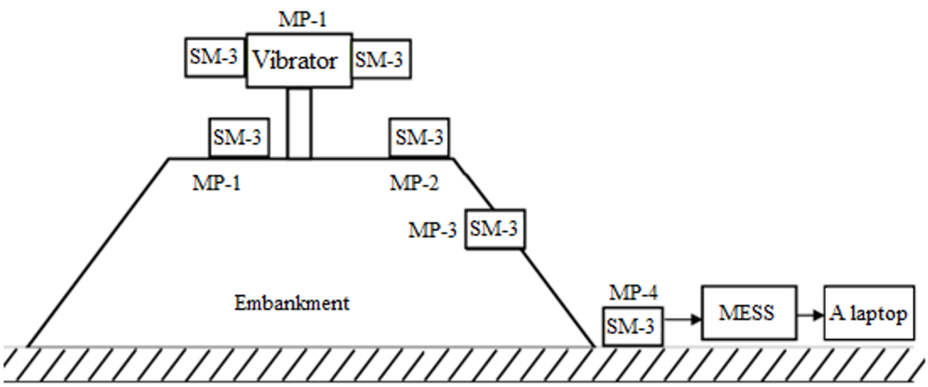


Fig. 1. Schematic view of measuring points.

The results in a three-axis coordinate system obtained from the above test are recorded on a computer with the placement of sensors on the slopes of the roadbed and at a distance of 1.5 m from the edge of the embankment base and with a load of 11.3 kN on a reinforced concrete pile.

Measuring work was performed in 5 cases. In the 1st case, it is assumed that $\beta_1=\beta_2=\beta_3=\beta_4=100$. In case 2, $\beta_1=\beta_2=\beta_3=100$, $\beta_4=5\rightarrow10$ is assumed. In the 3rd case, the microseismic value of the place where the roadbed is located is determined. In this case, the 1st and 2nd channels are disconnected. The 3-channel is accepted as $\beta_3=100$, and the 4-channel $\beta_4=10$. In the 4th case, the 1st and 2nd sensors were not used, and the sensitivity of the 3rd and 4th sensors was reduced. And in the 5th case, the SM-3 sensor in the 3rd channel is installed on the slopes of the roadbed. The sensor's location received by the oscillation in the 4-channel remained unchanged. In all cases, to reduce the sensitivity of the SM-3 sensors, an additional shunt is connected; as a result, the measurement accuracy will still be higher.

3 Results and discussion

The amplitude of the oscillations resulting from the movement of high-speed trains on the approaches to the bridges is equal to the value of the amplitude of the oscillations obtained from the 4-5 point seismic force. This leads to a significant increase in the value of the seismic horizontal pressure from the effects of vibrations.

The resultant of the calculated seismic horizontal ground pressure is determined by the formula:

$$\mathrm{E} = \frac{1}{2} \cdot \gamma \cdot \mathrm{B} \cdot \mathrm{H}^2 \cdot \mu_\mathrm{c} \qquad (1)$$

where γ is specific gravity of the embankment soil, $\left(\frac{kN}{m^3}\right)$;

B is the calculated width of the abutment in the plane of the rear faces, on which the seismic pressure of the soil is distributed (m);

H is the height of the embankment, counting from the sole of the foundation plate to the sole of railway bridge sleepers (m);

μ_c is the coefficient of lateral pressure of the embankment soil in conditions of seismic impact.

The lateral pressure coefficient of the sandy soil of the embankment μc can be determined in Fig.2. depending on the normative angle of internal friction φ and the strength of the calculated earthquake (Fig.2a) [24].

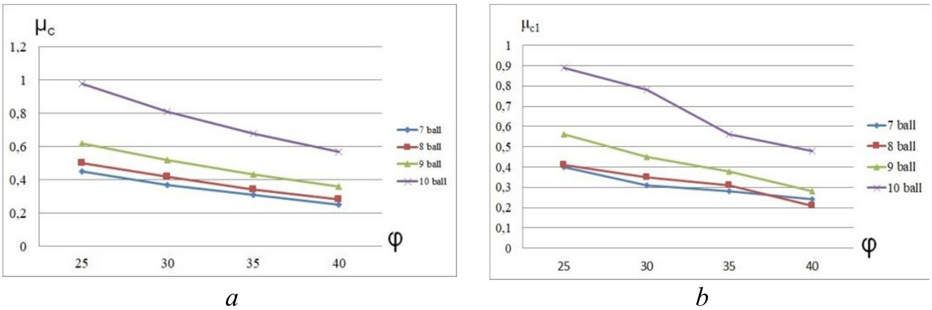


Fig. 2. The values of the lateral pressure coefficient on the properties of soils at different earthquake intensity: a) before driving piles, b) after strengthening reinforced concrete piles.

Reducing the active pressure of the soil acting on the shore support of the bridge is achieved by driving piles, which significantly reduces the seismic force (Fig. 2b).

$$\mathrm{E_c} = \frac{1}{2} \cdot \gamma_1 \cdot \mathrm{B} \cdot \mathrm{H}^2 \cdot \mu_{c1} \qquad (2)$$

where γ_1 is the specific gravity of the soil after driving piles into the embankment, $\left(\frac{kN}{m^3}\right)$; B is the calculated width of the abutment in the plane of the rear faces, on which the seismic pressure of the soil is distributed, (m); H is the height of the embankment, counting from the sole of the foundation plate to the sole of railway bridge sleepers, (m); μ_{c1} is the coefficient of lateral pressure of the soil after driving piles in the embankment with a possible seismic impact.

Under the influence of seismic force, the soil's active pressure increases, resulting in the oscillation period and the logarithmic decrement of the structure exceeds. As a result of changes in the amplitude-frequency characteristics of the soil, the oscillation energy decreases.

Reducing the active pressure of the soil acting on the shore support of the bridge under the action of seismic and vibrodynamic forces from the rolling stock is achieved by driving piles into the embankment in front of the shore support. The dynamic rigidity of the soil increases from driving piles; as a result, the logarithmic decrement of vibrations decreases, and the coefficient of repayment of the structure's energy during the oscillation is significantly reduced. This makes it possible to increase the structure's service life due to a more uniform distribution of forces since part of the horizontal loads is transferred to the base. Seismograms of the results of vibrations fixed in all cases are shown in Fig. 3-5.

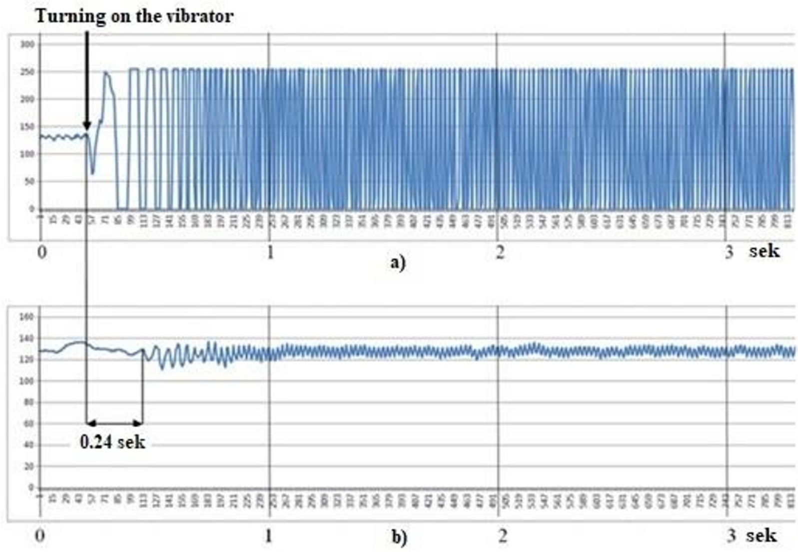


Fig. 3. Seismograms on SM-3 sensors located on reinforced concrete piles (a) and in soils (b) at a distance of 10 cm from the piles when starting the vibrator.

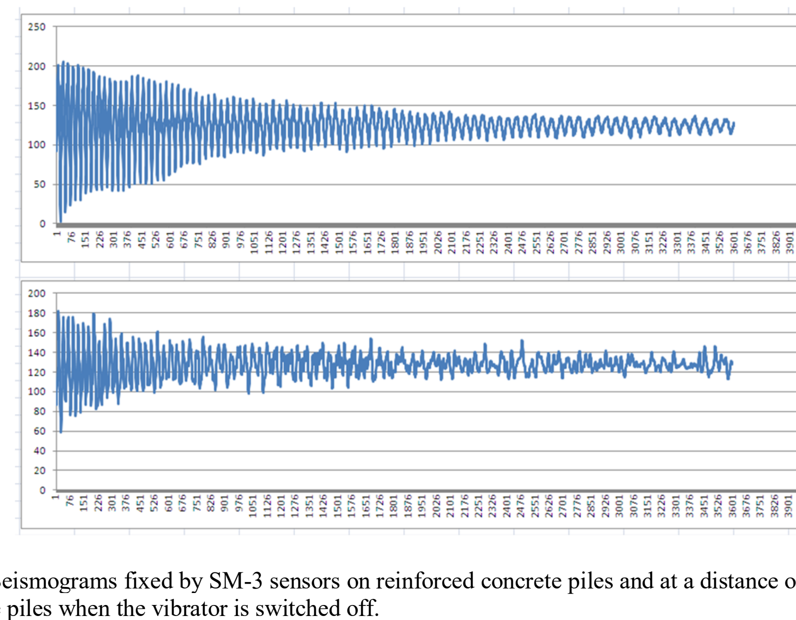
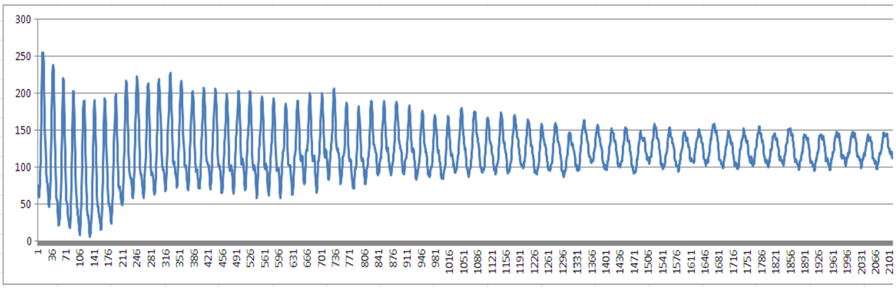
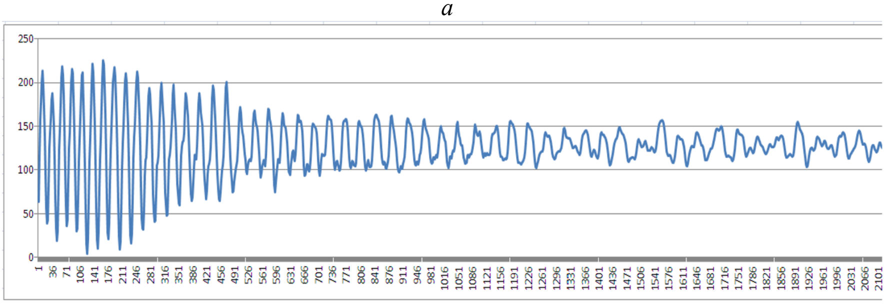


Fig. 4. Seismograms fixed by SM-3 sensors on reinforced concrete piles and at a distance of 10 cm from the piles when the vibrator is switched off.



a



b

Fig. 5. Seismograms fixed by CM-3 sensors on the edges (a) and slopes (b) of the roadbed when the vibrator is switched off.

The value of amplitudes on seismograms is determined using the following expression [25].

$$A = A_{max} - A_{min}, \quad (3)$$

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

During the oscillation, the displacement near the reinforced concrete piles and at the end of the roadbed is determined by the following formula [24].

$$A_{td} = \frac{\beta \cdot V_c}{f_c} \quad (4)$$

where A_{td} is true displacement (mm), β is attenuation coefficient set on the channel of the mobile station (dimensionless), V_c is signal amplitude from maximum to minimum (double amplitude of the average signal value calculated by the program), (mm), f_c is channel sensitivity coefficient, fc gain coefficients of the first and second channels obtained during calibration mobile engineering seismometric station: f_{c1} = 630 V/mm, f_{c2} = 654 V/mm.

As a result of the experiment, it was determined that the vibrations arising from the vibrator pass to the base through reinforced concrete piles. At the same time, the oscillatory process in reinforced concrete piles is theoretically justified because the oscillation process in reinforced concrete piles begins 0.24 seconds before the oscillation at a distance of 10 cm from the reinforced concrete pile. The late onset of vibrations at a distance of 10 cm from the reinforced concrete pile, soil with a seismic-insulating quenching coefficient, was determined- λ_a.

The experiment allowed adding an additional coefficient to the expression of finding the distance between the piles. Taking into account the results of studies of the stress–strain state of the railway track under the seismic influence on the intermediate support of the bridge, an analysis of the condition of this structure was carried out at high embankments of the roadbed reinforced with piles. As a result, the degree of influence of the soil of the roadbed is determined as a function of damping the vibrations of the roadbed on the railway track, which makes it possible to reasonably increase the distance between the piles of reinforcement, and the formula will take the form:

$$L = \frac{b^2 \cdot K}{H \cdot tg\varphi} \cdot \lambda_a \text{, m} \qquad (5)$$

where b is width of the roadbed, m; H is height of the embankment, m; φ is dynamic coefficient that takes into account the properties of soils; K is coefficient that takes into account the speed of trains:

K=1.0 at speeds up to 40 km/h, K=0.95 at speeds up to 60 km/h, K=0.90 at speeds up to 80 km/h, K=0.85 at speeds up to 120 km/h, K=0.80 at speeds up to 160 km/h, K=0.78 at speeds up to 200 km/h.

λ_a is seismic isolation quenching coefficient, the value of which is equal to:

λ_a =1,2 with strong ground bases, λ_a =1,1 with weak soil bases.

When applying formula (5), it should be noted that it is advisable to strengthen high embankments at a distance between piles L≤15 m – with loose soils and L≤20 m – with connected soils, and if these limits are exceeded, there are no real fortifications of the embankment.

We calculate the distance between reinforced concrete piles driven into the ground to increase the dynamic rigidity of soils on approaches to bridges at an embankment height of 6 m on solid ground foundations: the width of the main platform of the roadbed on the I track sections is 7.6 m, the width of the main platform on the II track sections is 11.7 m (SHNK 2.05.01-19. Railways of 1520 mm gauge. Design standards).

I wayside sections:

$$L = \frac{7{,}6^2 \cdot 1{,}0}{6 \cdot tg40} \cdot 1{,}2 = \frac{57{,}76 \cdot 1{,}0}{6 \cdot 0{,}8391} \cdot 1.2 = 13.76 \text{ m.}$$

II road sections:

$$L = \frac{11.7^2 \cdot 1.0}{6 \cdot tg40} \cdot 1.2 = \frac{136.89 \cdot 1.0}{6 \cdot 0.8391} \cdot 1.2 = 32.63 \text{ m.}$$

where, L is distance between reinforced concrete piles, m; b is width of the main platform, b=7.6 m; H is height of the embankment, H=6 m; φ is dynamic coefficient that takes into account the properties of soils. φ is for sand dunes, φ=40.

K is coefficient that takes into account the speed of trains:

K=1.0 at speeds up to 40 km/h, K=0.95 at speeds up to 60 km/h, K=0.90 at speeds up to 80 km/h, K=0.85 at speeds up to 120 km/h, K=0.80 at speeds up to 160 km/h, K=0.78 at speeds up to 200 km/h.

λ_a is seismic isolation quenching coefficient, the value of which is equal to:

λ_a =1.2 with strong ground bases.

We calculate the distance between reinforced concrete piles driven into the ground to increase the dynamic rigidity of soils on approaches to bridges at an embankment height of 6 m on weak soil bases: the width of the main platform of the roadbed on the I track sections is 7.6 m, the width of the main platform on the II track sections is 11.7 m (SHNK 2.05.01-19. Railways of 1520 mm gauge. Design standards).

I wayside sections:

$$L = \frac{7.6^2 \cdot 1.0}{6 \cdot tg40} \cdot 1.1 = \frac{57.76 \cdot 1{,}0}{6 \cdot 0.8391} \cdot 1.1 = 12.62\, m.$$

II road sections:

$$L = \frac{11.7^2 \cdot 1.0}{6 \cdot tg40} \cdot 1.1 = \frac{136.89 \cdot 1,0}{6 \cdot 0.8391} \cdot 1.1 = 29.91\, m.$$

where, L is distance between reinforced concrete piles, m; b is width of the main platform, b=7.6 m; H is height of the embankment, H=6 m; φ is dynamic coefficient that takes into account the properties of soils. φ is for sand dunes, φ=40.

K is coefficient that takes into account the speed of trains:

K=1.0 at speeds up to 40 km/h, *K*=0.95 at speeds up to 60 km/h, *K*=0.90 at speeds up to 80 km/h, *K*=0.85 at speeds up to 120 km/h, *K*=0.80 at speeds up to 160 km/h, *K*=0.78 at speeds up to 200 km/h.

λ_a is seismic isolation quenching coefficient, the value of which is equal to:

λ_a =1.1 with weak soil bases.

Due to a significant increase in the active pressure of the soil under the action of seismic and hydrodynamic forces at the approaches to the bridges, the compressed soil zone increases, resulting in residual deformations. Because the dynamic rigidity of the roadbed is less than the dynamic rigidity of the shore support, vertical irregularities of the railway track are observed at the approaches to the bridges. It is recommended to drive reinforced concrete piles into the embankment to prevent these irregularities.

4 Conclusion

Due to the processing of the experiment results, the amplitude of vibrations of the embankment soils on the bridge transition sections decreased, the period of natural vibrations of the roadbed decreased by 15%, vibration velocity, and vibration acceleration by 10%, and 15%, respectively. As a result, it is determined that the logarithmic decrement of oscillations decreases to 20%. Depending on the steepness of the slopes of the riverbed and the properties of the soil of the base and the roadbed, the sediment of the roadbed and ballast prism occurs on average up to $S = 15$ cm for three months when reinforced with piles $S = 5 - 7$ cm, which reduces the cost of repairing the railway track by 2 times and contributes to an increase in the degree of accident–free path contents.

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