Investigation of the period of natural oscillations of the embankment on approaches to bridges

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Abstract. The article analyzes the designs of existing transition sections on the approaches to bridges and shows a decrease in the natural oscillation period of the subgrade as a result of strengthening the transition sections with the developed design solutions.

1 Introduction

In the world, special attention is paid to ensuring the safety of railways passing in seismically active areas, reducing the impact of high-frequency vibrations from train traffic on the roadbed and increasing the dynamic stiffness of the soil at the approaches to bridges, determining the amplitude-frequency characteristics arising in the ground and developing ways to reduce them. Currently, in developed countries, more attention is paid to the design, construction and operation of railways in difficult and seismic conditions. And also, special attention is paid to ensuring the safety of train traffic by increasing the speed of railways passing in difficult and seismically active areas.

When an earthquake occurs and the speed of traffic increases, longitudinal, transverse, and vertical vibrations are created on the roadbed [1]. 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 [2].

The main prerequisites for the development of high–speed lines are safety, reliability and comfort, which are ensured by the high quality and reliability of all elements of the railway system. Operational experience and the results of numerous studies show that a sharp change in the rigidity of the sub-rail base at the junction of the roadbed and an artificial structure leads to uneven precipitation of the structure, which in turn leads to damage to the structure. This is especially true in high-speed traffic conditions.

Currently, on approaches to bridges and tunnels with ballast-free track structures, the typical design is the usual structure of the upper structure of the track. Due to the different characteristics of rigidity and deformability of these structures, there is an increased accumulation of disorders of the geometry of the rail track in this zone, which leads to an increase in the volume of work on the current maintenance of the track and a reduction in service life for the elements of the upper structure of the track. These sections become

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"barrier" places with increasing speeds and loads on the axis of the rolling stock, when the dynamics of the impact of the rolling stock is particularly significant. On standard track designs of approaches to such artificial structures, due to frequent corrections of the track, speed limits of trains are possible under the condition of ensuring safety [3].

Analysis of domestic and foreign experience shows that the use of special transitional track structures on approaches to artificial structures - bridges with a ballast-free bridge bed (BMP) and tunnels with a smooth change in stiffness reduces the dynamic effects of rolling stock on the track, disorders of the elements of the upper structure of the track and bridge or tunnel structures, reduces the cost of maintaining the track.

The length of the transition path section with variable stiffness on the approach to the $L_{v.s}$ artificial structure is determined for each specific object by the length of the actual zone of increased path disorders. To identify these zones, the data of track measuring cars, the results of tests by load trains are used.

The minimum length of the section of stiffness change on the approach ($L_{v.s}$) at the same time, depending on the speed of trains, is taken according to Table 1.

Table 1. Minimum lengths of the stiffness change section on the approach

Maximum train speed, km/h	more 120	80 - 120	less than 80
Minimum length of the $L_{v.s}$ section, m	25	20	15

The coupling of embankments with a bridge is an important element of railways, designed to ensure a smooth transition from a relatively pliable roadbed to a rigid superstructure. At the same time, it is in the places where the roadbed interacts with artificial structures that deformations are very often observed, which lead to the destruction of the roadbed.

One of the main problems is the maintenance of the railway track at the same level during the movement of high-speed trains due to the presence of structures with different rigidity in the transition zone. 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 stability of the bridge is destroyed [4].

The interface of the roadbed and the AS there are characteristic irregularities in the form of so-called bridge pits. A general view of the path with a bridge pit is shown in Figure 1.

Fig. 1. Deformations of the embankment at the interface with the bridge [5]

Dynamic loads of high-speed trains have a great influence on the disorder of the way. The process of deterioration of the quality of the rail track of the transition zone is pronounced with different track designs (on ballast on the approach and without ballast on the bridge) and is shown in Figure 2 [5].

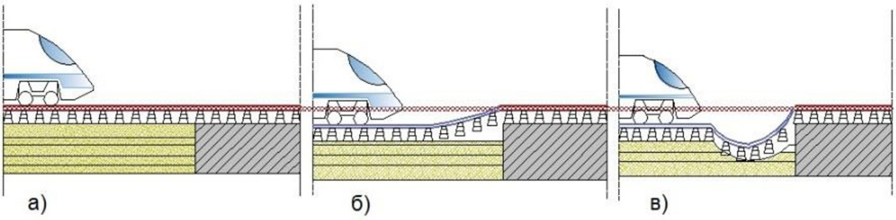


Fig. 2. The process of deterioration of the quality of the transition zone [5]

Figure 2a shows a rail track with an ideal geometry. After the accumulation of residual deformations, voids appear - backlashes under the sleepers next to the bridge, shown in Fig.2b. Later, a bridge pit is formed, shown in Fig.2b, caused by vibrations of the rail and sleepers due to vibrations of the span structure of considerable amplitude. Figure 3 shows the result of vibrations of the rail-sleeper grid due to vibrations of the superstructure - crushing of ballast into dust and the formation of a "pit".

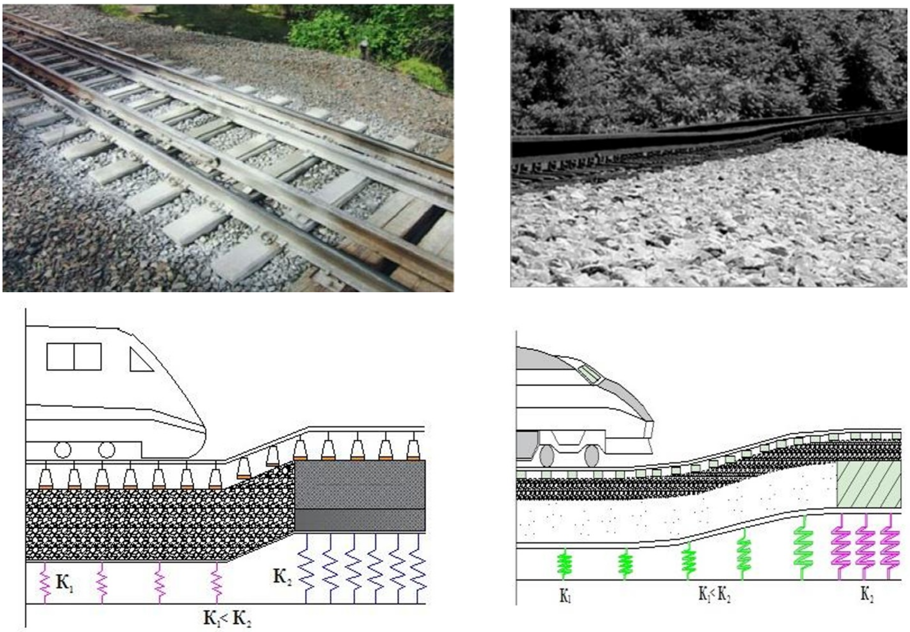


Fig. 3. Formation of a bridge pit due to ballast crushing [5]

2 Main part

Currently, the following constructions are widely used in the transition sections [6]. Designs of the transition path used in Russia:

1. Construction of a section of the transition path using reinforced concrete boxes. The smoothness of the change in the stiffness of the path is achieved by gradually changing the height of the boxes from the maximum at the abutment of the bridge to the minimum at the junction with the usual path. Since the boxes of different heights are filled with ballast, the different power of the ballast layer obtained in this way creates a smooth change in the elastic modulus of the sub-rail base on the transition section of the track. The developer of this design is the Research Institute of Bridges Russia [6] (Fig.4).

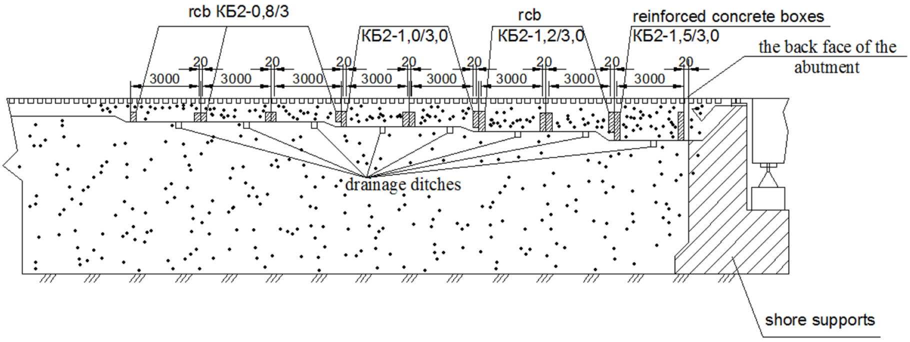


Fig. 4. The transition path from the bottomless boxes

2. Construction of a section of the transition path with substallastic reinforced concrete slabs. For a smooth increase in the rigidity of the path, flat reinforced concrete slabs of variable width are used (in the direction transverse to the axis of the path). A set of plates, starting from the back face of the abutment, consists of a set of plates of a three-stage transition section of a variable stiffness path. The first stage (closest to the abutment) consists of three slabs (individual) measuring 3.2x3.75 m, the second – of three slabs 2.75x3.5 m and the third – of six slabs 1.75x3.0 m. The structure with sub-ballast plates was developed by Far Eastern State University of Railway Engineering [6] (Fig.5).

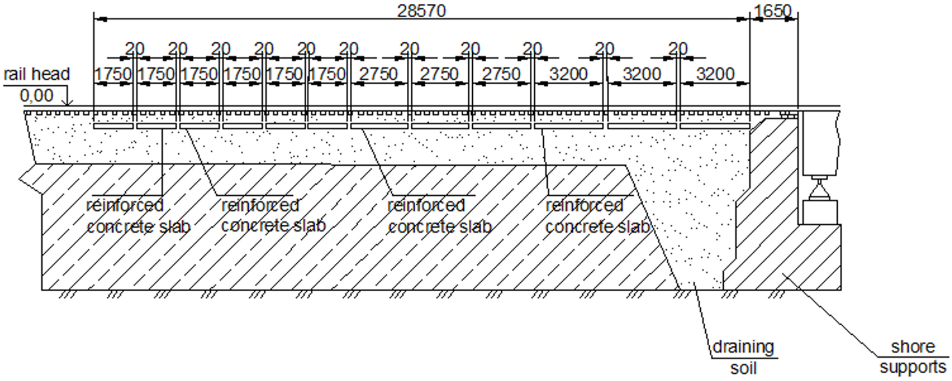


Fig. 5. Transition with sub-ballast reinforced concrete slabs

3. Construction of a section of the transition path with the use of gabions. A transitional section with the use of gabions is arranged by replacing the soil of the embankment with crushed stone, laid with a layer-by-layer seal between the walls of gabions filled with stone.

Gabion structures are manufactured in accordance with C. The design of the transition path section using gabions was developed in Russian University of Transport [6] (Fig.6).

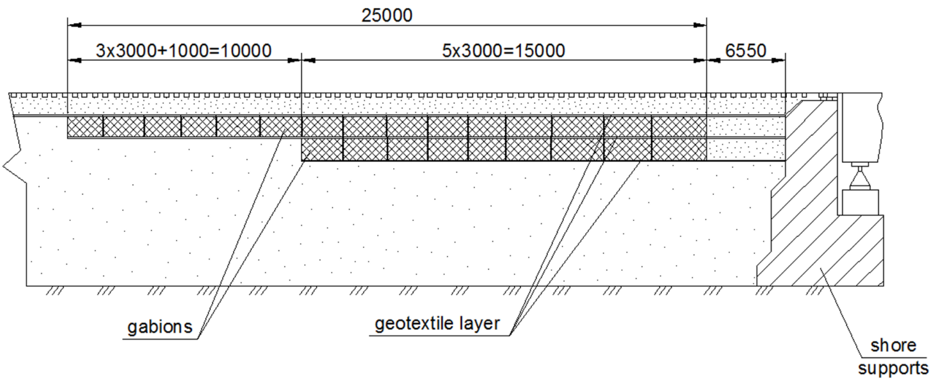


Fig. 6. The transition path with the replacement of the soils of the upper part of the embankment with crushed stone laid between the walls of gabions

4. Construction of a section of the transition path with the use of geogrids. In addition to the above structures, a variant of the transition section of the path from geo-interstices has been developed in Russian University of Transport, based on replacing the soils of the upper part of the embankment with crushed stone, in which, to exclude lateral deformations of the ballast, the layers of crushed stone are reinforced with polymer grids Figure 7.

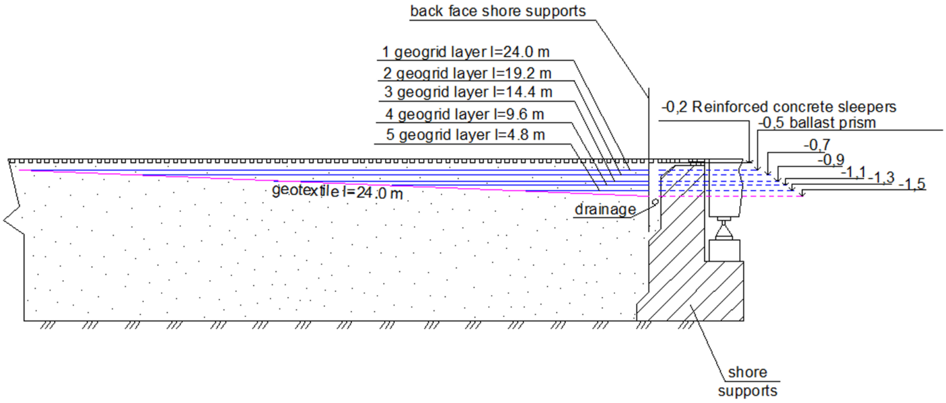


Fig. 7. The transition path with the replacement of the soils of the upper part of the embankment, laid between layers of geogrids

5. The construction of the section of the transition path with the consolidation of the sub-ballast layer by cementation. The section of the transition path with the consolidation of the sub-ballast layer by cementation has the following parameters [6]:

- the length of the plot is 30 m;
- the thickness of the fixed sub-ballast layer changes after 5 m by 0.05 m: from a maximum of 0.4 m at the abutment to 0.15 m at the boundary of the site;
- the depth of the layer under the sole of the sleeper is 0.35 m (Fig.8).

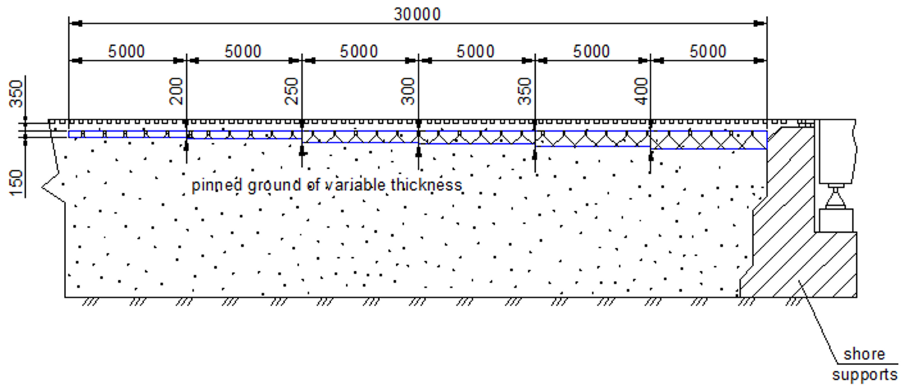


Fig. 8. The transition path with the device of the fixed soil by cementation.

The works of scientists: E.S. Ashpiz, A.I. Gasanov, G.G. Konshin, A, V. Zamukhovsky, K.V. Merenchenko, S.I. Klinov, Yu.G. Kozmin, G.M. Stoyanovich, V.Yu. Polyakov, I.V. Prokudin, D.V. Serebryakov, C. Gallage, R. Sañudo, J. Bronsert, W. Li, M. Shahraki, G. Michas, D. Read, etc. were devoted to the problem of coupling of the earthwork and artificial structures [7-20].

3 Results and Discussion

The movement of high-speed trains, as well as seismic effects on the roadway, lead to amplitude-frequency oscillations, which increase when the embankments are connected to the bridge. This is due to a decrease in the dynamic stiffness of the embankment, since it is interrupted and receives an additional degree of vaulting, which leads to a decrease in the period of natural oscillations [21].

The period of natural oscillations of the embankment at the approaches to the bridges is determined by the following formula.

$$\mathrm{T} = \frac{\sqrt{H}}{\sqrt[3]{B_0}} \cdot \alpha \cdot n. \qquad (1)$$

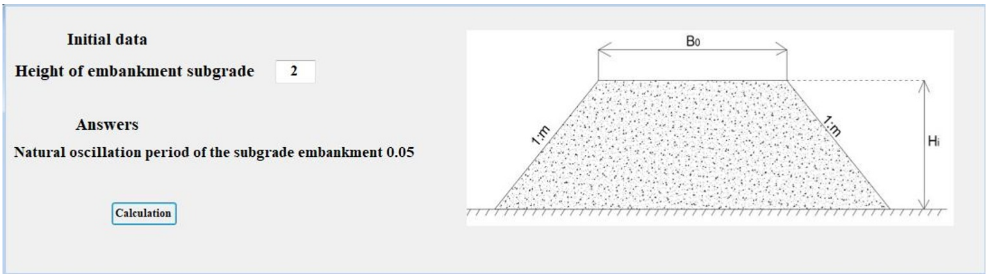
where H, B_0 – height and width of the embankment of the roadbed (m); n – coefficient taking into account the working conditions of the embankment of the roadbed, for embankments remote from the bridge, n=1.0; for mating embankments with suspension and cable-stayed bridges - n=1.5; with reinforced concrete girder bridges - n=1.3, with metal bridges - n=1.4; α – coefficient taking into account the connectivity of the embankment soils: for sandy and gravelly α=0.08.

As a result of the introduction into the first expression of the coefficient determined by experiment, the basic formula for determining the period of natural oscillations of the embankment on approaches to bridges has the following form:

$$\mathrm{T} = \frac{\sqrt{H}}{\sqrt[3]{B_0}} \cdot \alpha \cdot n \cdot \text{к}. \qquad (2)$$

where K – the design coefficient determined by the experiment taking into account the rigidity of the shore support: for an arched support – k=0.9; for arched support with buttresses – k=0.8; when piling strengthening of the embankment – k=0.7.

The period of natural vibrations of the roadbed at the height of the embankment of 2 m, 4 m and 6 m on the approaches to the bridges was determined as a result of the introduction of a constructive coefficient into the formula determined by experiment using the computer program "Visual Studio 2019, C#" (Fig.9-11).



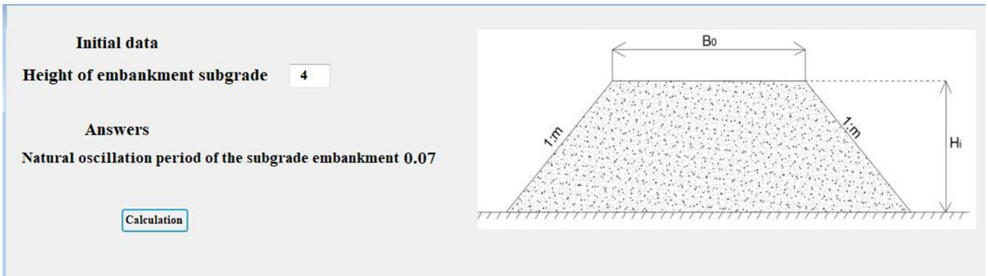
Initial data

Height of embankment subgrade 2

Answers

Natural oscillation period of the subgrade embankment 0.05

Fig. 9. The period of natural oscillations is 50 ms, when the height of the embankment of the roadbed is 2 m.



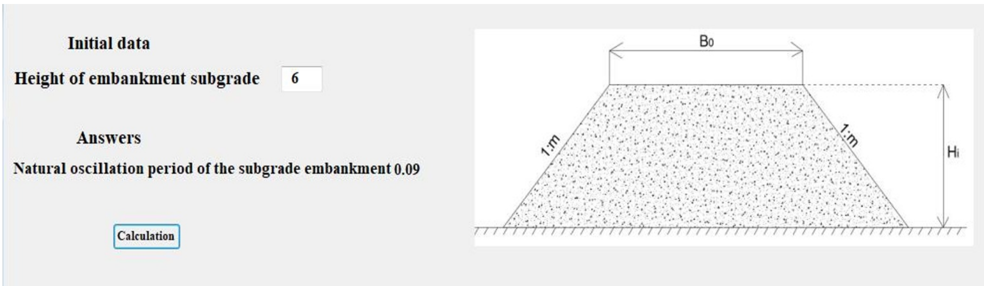
Initial data

Height of embankment subgrade 4

Answers

Natural oscillation period of the subgrade embankment 0.07

Fig. 10. The period of natural oscillations is equal to 70 ms, when the height of the embankment of the roadbed is 4 m.



Initial data

Height of embankment subgrade 6

Answers

Natural oscillation period of the subgrade embankment 0.09

Fig. 11. The period of natural oscillations is 90 ms, when the height of the embankment of the roadbed is 6 m.

A decrease in the period of natural oscillations of the embankment after driving piles at the approaches to the bridges is determined. Let's consider the dependence of the height of the embankment on the period of natural oscillations on the approaches to the bridges based on the results obtained using the computer program "Visual Studio 2019, C#" (Fig.12).

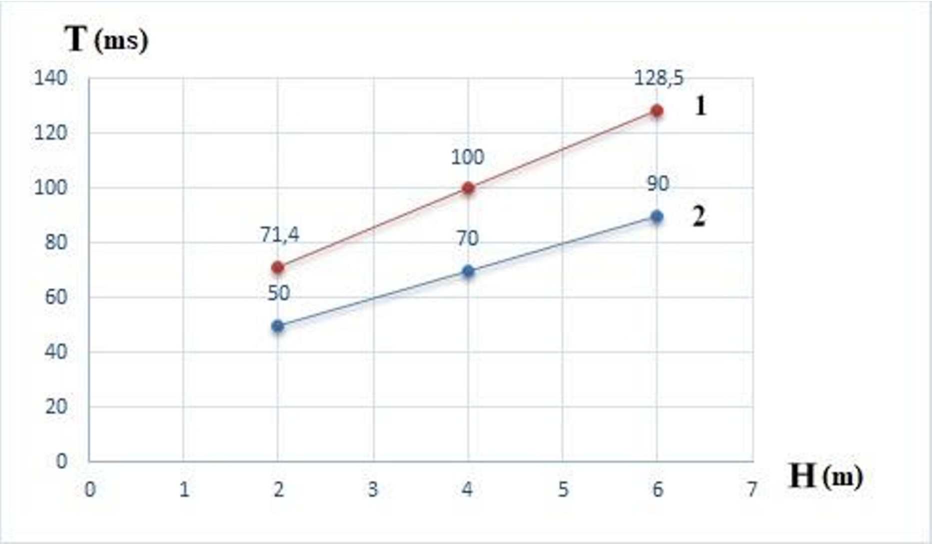


Fig. 12. Graph of the dependence of the height of the embankment on the period of natural vibrations of the roadbed. 1 – in an embankment not reinforced with reinforced concrete piles. 2 - in an embankment reinforced with reinforced concrete piles.

Reinforcement with reinforced concrete piles on the approaches to the bridges leads to a decrease in the period of natural oscillations of the embankment. This serves to ensure elastic deformation of the embankment soils.

4 Conclusions

1. The causes of vertical irregularities of the railway track on the approaches to the bridges are analyzed.
2. The existing designs of transitional sections on approaches to bridges are considered and analyzed.
3. On the basis of theoretical calculations, it was found that when fortifying reinforced concrete piles in the transitional sections of approaches to bridges, the natural oscillation period of an embankment 6 m high decreases to 30%.

References

1. Abdujabarov A.Kh., and Mekhmonov M.Kh. Structures options for the coastal bridge support, taking into account the seismicity of the district. In AIP Conference Proceedings Vol. 2432, p. 030045 (2022).
2. Abdujabarov A.H., Begmatov P.A., Eshonov F.F., Mekhmonov M.H., Khamidov M.K. Influence of the train load on the stability of the subgrade at the speed of movement. In E3S Web of Conferences, Vol. 264 (2021).
3. Technical conditions for track structures on approaches to artificial structures. JSC "Russian Railways", Moscow (2004).
4. Abdujabarov A.Kh., Mekhmonov M.Kh., Eshonov F.F. Design for reducing seismic and vibrodynamic forces on the shore support. In AIP Conference Proceedings Vol.2432, 030003 (2022).

5. Dang Ngoc Thanh. Operability of the bridge bed of girder superstructures in high-speed traffic. (2019).
6. Serebryakov D.V. Strength on embankments under the vibrodynamic effect of trains in the area of the interface of the roadbed with bridges. St. Petersburg State University of Railways of Emperor Alexander I. p.158. (2005).
7. Ashpiz E.S. Substantiation of the standards of deformability of the under-rail and under-sleeper base. The world of transport. No.5. pp. 112-119. (2012).
8. Gasanov A.I. Path on approaches to metal bridges. Path and track management. No. 7. pp. 29-30. (2012).
9. G.G. Konshin M.B. Volkovitsky E.V. Yakovleva. More attention to the roadbed on the approaches to bridges. Path and track economy. No. 11. pp. 16-17. (1993).
10. A.V. Zamukhovsky and K.V. Marinchenko Experimental examination of sites of variable stiffness. The world of transport. No. 3. pp. 74-82. (2013).
11. Merenchenko K.V. The genesis of residual deformations arising from the coupling of an earth bed and an artificial structure. Modern problems of railway track design, construction and operation. Proceedings of the XIII Scientific and Technical conference with international participation, Moscow: readings dedicated to the 112th anniversary of Professor G.M. Shakhunyants. M.: RUT. pp. 200-204. (2016).
12. Konshin G.G. The working zone in the embankment. Path and track economy. No. 2. pp. 32-36. (2001).
13. Gallage C. State-of-the-art: track degradation at bridge transitions. In Pathirana, K.P.P. (Ed.) Proceedings of the 4th International Conference on Structural Engineering and Construction Management. pp. 40 - 52. (2013).
14. Sañudo R., Dell'Olio L., Casado J. A., Carrascal I. A., and Diego S. Track transitions in railways: A review. Construction and Building Materials, Vol.112, pp.140-157. (2016).
15. J. Bronsert M. Baeßler P. Cuellar W. Rucker Numerical modeling of train-track-interaction at bridge transition zones considering the long-term behavior. 11th International Conference on Vibration Problems. Lisbon, Portugal, (2013).
16. W. Li, W. Bian. Dynamic Performance of Pile-Supported Bridge Embankment Transition Zones under High-Speed Train Moving Loads. Procedia Engineering. Vol.143. pp.1059 – 1067. (2016).
17. Shahraki M., Warnakulasooriya C., Witt K.J. Numerical study of transition zone between ballasted and ballastless railway track. Transportation Geotechnics. Vol. 3. pp.58 – 67. (2015).
18. Ashpiz E.S. Strengthening of the main platform of the roadbed. Path and track economy. No. 4. pp. 19-33. (2004).
19. Michas G. Slab Track Systems for High-Speed Railways. Division of Highway and Railway Engineering. Master Degree Project. Stockholm. Sweden. p. 107 (2012).
20. D. Read, Dingqing Li. Research Results Digest 79. Transit Cooperative Research Program, Sponsored by the Federal Transit Administration. Washington (2006).
21. Transport facilities in seismic areas. Design rules. Codes of Rules SP 268.1325800.2016, Moscow Standard inform (2017).