**Study of the Influence of Subgrade Condition on the Formation of Rigidity of a Jointless Track**

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**Abstract.** The article considers improved methods of calculating the stiffness of the track depending on the deformation characteristics of its elements and new designs of under-rail supports with improved stiffness characteristics in modern conditions, making a significant contribution to the acceleration of scientific and technological progress in railway transportation. And also considered the issues of the determined influence of the speed of rolling stock on the deformations of the trackless track, high-speed sections of the railroad track and made an analysis of different temperatures. Determination of the spheres of distribution of the main types of the foundation of the trackless track on the degree of deformability, based on the study of the characteristics of soils of the railroad subgrade.

**Keywords:**earth bed, ballast prism, sleepers, main area of the earth bed, embankment, track stiffness, modulus of elasticity

**INTRODUCTION**

The design of the earth bed shall be carried out on the basis of the results of engineering surveys. The results of engineering surveys should be reliable and sufficient to establish the design values of parameters and other design characteristics of the building or structure, as well as projected measures to ensure its safety. The calculated data as part of the results of engineering surveys should contain a forecast of changes in their values during construction and operation of the earthwork [1, 2].

When reconstructing existing railroads, designing and constructing new railroads for high-speed traffic, it is necessary to solve a whole set of technical and economic problems. These are, first of all [3, 4, 5, 6, 7, 8], the issues of train traffic safety associated with the increasing forces of interaction between the track and rolling stock, increasing vibration, more intensive accumulation of residual deformations, decreasing service life of the main elements of the track structure, increasing the amount of work on the current maintenance and repair of the track.

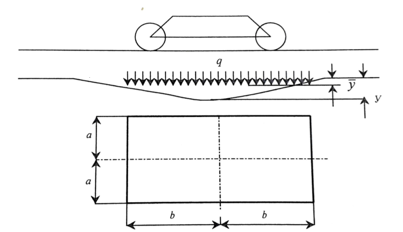
The first full-scale studies of elastic deformations of embankment sections from the impact of rolling stock were performed by A.N. Vasyutinsky [9, 10, 11]. In his opinion, the deformations are explained by additional dynamic forces that appear during the movement of trains and increase the acting load on the track. Later, S.K. Volobuev came to the conclusion that the main causes of deformations leading to track destabilization are over-wetting of the earth bed and ground vibrations under the influence of moving train load [12].

**RESULTS AND SURVEY**

Many years of experience in the operation of railroads have shown that the methodology used to determine the parameters of railroad track stiffness does not take into account the influence of the subgrade in the formation of the overall stiffness [14].

On the roads of Uzbekistan on the overwhelming length of the main track the top structure with P65 rails is laid at the epure of 1840÷2000 sleepers per 1 km and the thickness of ballast layer under the sleepers is not less than 45÷60 cm. In this case, the train load from the sand cushion on the subgrade is distributed along the length of sleepers and along the track length (within the bogie) much more evenly than in the past with a smaller thickness of the ballast layer, a sparser sleeper cushion and lighter rails [13].

We consider that the train load from the sand cushion on the subgrade is uniformly distributed within the rectangular area 2b× 2a (Figure 1), where a and b are half of the larger and smaller side of the rectangle, respectively.



**FIGURE 1.** Load diagram of the main site of the earth bed

In the transverse direction relative to the track, the size of the side of the rectangle can be assumed to be equal to the length of the sleeper.

With this design scheme, the formula for determining the vertical deformation of the main area of the subgrade under the influence of train load is as follows:

(1)

where, *y* - vertical deformation of the surface of the main area of the subgrade, sm; *q* - distributed train load (stress on the main site) averaged within the load site, MPa; *a* - half of the smaller side of the rectangle, sm; *E* - modulus of elasticity in compression of earth bed soil, MPa; *μ* - is the Poisson's ratio; *K0* - dimensionless coefficient depending on the location of elastic settlement determination, shape and dimensions of the loading site.

In the late 50's and early 60's, as a result of research by many scientists, a solution to the spatial problem of elasticity theory was found for calculating stresses and displacements under the action of a distributed load on the surface of an isotropic layer underlain by an absolutely rigid base. For such a case, as applied to the calculation of elastic settlement of the main area of the earth bed:

(2)

where *К* - is a dimensionless coefficient that takes into account the influence of the rigid underlying layer (bedrock).

The *К* value is the ratio of the elastic deformation (settlement) of the ground mass surface under a distributed load at the top layer thickness h < ∞ to its value at h = ∞. For the calculation of deformations of the main site of the earth bed under train load, the values of *К*. They are obtained as a result of some transformations (with respect to the earth bed) of the data of K. E. Egorov with consideration of friction between layers [15].

However, this methodology does not take into account:

- nonlinear properties of soils;

- multilayered earth bed and foundations;

- nonlinearity of geometric dimensions of the earth bed.

The paper presents a methodology that takes into account the above parameters: determination of the stress-strain state of a multilayer railroad embankment lying on an elastic deformable half-space. Also here is considered the case of the construction of the earth bed on the ground with nonlinear parameters. Taking into account these factors allows us to clarify the stress-strain state and develop measures to improve the serviceability of the earth bed.

The initial stress-strain state of the embankment material under the action of its own weight is assumed to be zero and the stress field caused by the additional train load and the weight of the track structure is investigated.

The embankment has a typical profile and is composed of three layers of elastic material. The first layer has a thickness of H=6 m and has the shape of trapezoids with the slope of the sides k3 = 1:1.5. The second layer has a slope- k2 = 1:1.75, the height of the layer - H=6 m. The bottom layer has a slope k, = 1:2, the height of the layer is H-3 m.

The main site has a width of b1 = 7.6 m. The size of the lower base of the embankment at the adopted heights and slopes of the sides is b2 = 58 m.

The railroad embankment is erected on a horizontal pad. A load of Р = 0,08 MPa, equal to the weight of the track structure and train load, is transmitted to the main platform through the sand cushion.

Due to the axial symmetry with respect to the vertical passing through the path axis, half of the region is considered.

The variants of the performed calculations for the horizontal embankment base are summarized in Table 1.

**TABLE 1.** Calculation parameters and calculation options

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| № | Moduli of elasticity (MPa) and Poisson's ratio | | | |
| Basis | Layers | | |
| 1 | 2 | 3 |
| 1 | Hard, E=∞ | E=60, ν=0,3 | E=60, ν=0,3 | E=60, ν=0,3 |
| 2 | Hard, E=∞ | Ground by nonlinear parameters:  α1=180; α2=8200; β1=420 β2=18000 | | |
| 3 | E=80, ν=0,3 | E=60, ν=0,3 | E=60, ν=0,3 | E=60, ν=0,3 |
| 4 | E=80, ν=0,3 | Ground by nonlinear parameters:  α1=180; α2=8200; β1=420; β2=18000 | | |
| 5 | Soil with nonlinear parameters | Ground by nonlinear parameters:  α1=180; α2=8200; β1=420; β2=18000 | | |

The first two variants refer to the case when the earth bed is on a rocky base, i.e., the stiffness of the base is so great that its deformation can be neglected compared to the deformation of the embankment itself. The parameters *α, β*, define the equations of state of the soil, taken as parabolic dependencies identical under loading and unloading:

и (3)

The calculation procedure is the same. The calculations are carried out in dimensionless values. The height of the embankment is chosen as the typical linear dimension.

L0 = h1 + h2 + h3 = 15 м. Linear dimensions are converted to dimensionless form by formulas of the form . Then:

, и (4)

Dimensionless values of the lower and upper bases of trapezoids

и (5)

The mark = 0 is the upper boundary of the half-plane on which the railroad embankment rests. In order to study the influence of the base deformation on the stress-strain state of the earth bed, the half-plane is extended to the right from the embankment edge to the mark =45 м or = 3.

Values with pressure dimension are converted to dimensionless form by the formula , where - is a characteristic value with pressure dimension. As such, the maximum finite value of the elastic modulus is chosen. For example, for the third variant, the moduli of elasticity of the layers =1, i=1,2,3 and the modulus of elasticity of the base half-plane = 0,33. In the following, unless otherwise specified, the dashes above the dimensionless variables are omitted.

|  |  |
| --- | --- |
| *а)* | *b)* |
|  |  |

**FIGURE 2.** Finite element grid of the embankment breakdown  
*a) on a rigid base; b) on a deformable base*

Figure 3, shows the strain grid for different calculation options.

The area is discretized by a grid of quadrilateral elements. For each layer the following number of vertical elements is set:

1 layer - 10 elements, 2 layer - 10 elements, 3 layer - 5 elements, half plane - 20 elements, total 45 elements. On a horizontal up to a mark.

X = 1,93 the quantity of elements is accepted equal to m = 40, on an interval 1,93 ≤ X ≤3.0 - m2 =10 elements. Numbering of elements is carried out from the point with coordinates (0-1,0).

Variant 1: A linear-elastic embankment on a rigid base is considered. It is assumed that a homogeneous three-layer railway embankment rests on a non-deformable base Ybas - 0. The material of the layers obeys the generalized Hooke's law. The moduli of elasticity are given in Table 1.

The boundary conditions are set as follows: at the base of the embankment, the displacement vector is zero  
ux= uy= 0 when 0≤ х ≤ 1,93, y = 0; at the symmetry axis, the conditions ux = 0, σxy = 0 when x= 0 and 0≤ y≤1 are satisfied; at the upper base, a constant in magnitude normal to the side load σxy = 0, σyy = Рy, = - 0,08 when 0≤x≤0,23, y=1 is applied; the sloping side of the embankment is free from the forces σn = στ = 0.

Figure 2, shows the finite element partitioning mesh of an embankment on a rigid and deformable base.

In variant 2, the material of the layers obeys the nonlinear-elastic law of deformation. Without changing the boundary conditions and element mesh, the determination of nodal displacement components in this case is reduced to solving a system of nonlinear algebraic equations. The results of calculations related to variant 2 are presented in Figure 3 b.

In the first two options, the base of the embankment was considered fixed.

However, under realistic embankment conditions, the base will deform under the action of loads. In order to evaluate the influence of the pliability of the embankment base on the total stress field, the equilibrium problems of the same embankment resting on an elastic deformable half-space are further considered in variants 3-5 of Table 1. The material of the half-space is linear-elastic in cases 3,4 and nonlinear-elastic in case 5.

Figure 3 b shows the results for the case where the embankment is backfilled with the same linear-elastic material as the half-plane material.

|  |  |
| --- | --- |
| *а)* | *b)* |
|  |  |

**FIGURE 3.** Deformation grid under different calculation variants:   
*a) linearly deformable soils; b) nonlinearly deformable soils*

Comparison of the meshes shows the deformation trend when normal load is applied at the main site. The maximum deformation of the main site is under the sleepers, i.e., under the load.

The grid analysis after deformation of the embankment made of soils with nonlinear parameters shows (see Figure 3 b) that the deformation increases by a factor of 1.14 when the train load is applied to the main area of the earth bed. Comparison with the previous calculation (see Figure 3 a) shows a qualitative agreement between the results of the two different models.

Qualitative coincidence of the calculation results is also observed when comparing with a linearly deformed base. Comparison of qualitative indicators with the first variant shows that the same train load leads to an increase in deformation by a factor of 1,34. If we consider the base as a nonlinear-elastic base, the deformation increases up to 1,4 times.

The above calculations show that the base of the subgrade plays an important role in the formation of the rigidity of a rigid track.

The most important deformation characteristic that integrally determines the role of the subgrade in the formation of rail deflections under the wheels of trains is the modulus of elasticity of the soils composing the subgrade.

**CONCLUSIONS**

1.The currently used methodology for determining the parameters of railroad track stiffness does not take into account the influence of the subgrade in the formation of the overall stiffness. The values of elastic modulus obtained experimentally (based on measured deflections of rails relative to short piles (0,70 – 0,90 m) driven into the ballast between the ends of sleepers) do not take into account the deformations of the subgrade, so they are highly overestimated, especially for the track with reinforced concrete sleepers. As a result, such calculations give highly overestimated values of forces acting on wheels and may cause illusion about rigidity of the track as the main reason of intensive damage of locomotives and cars.

2. Calculations show that for the same train load, taking into account the deformation of the subgrade and its foundation leads to an increase in deformation by a factor of 1,34. If we consider the base as a nonlinear-elastic base, the deformation increases up to 1,4 times.

These calculations show that an important role in the formation of the rigidity of a track without joints is played by the base of the subgrade. The most important deformation characteristic, which integrally determines the role of the subgrade in the formation of rail deflections under the wheels of trains, is the modulus of elasticity of the soils composing the subgrade.

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