Application of ballastless construction of the railroad track in the Arctic zone

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Abstract: the article provides a calculation justification of the proposed railway structure on a reinforced concrete sleeper-free base, for which an analysis of the existing methodology for calculating the railway track for strength is carried out, according to which for a railway track on a sleeper-free base, dynamic loads acting from the rolling stock on the track are determined. The analysis of the applied sleeper-less structures of the railway track and the results of measurements of emerging stresses in the substructure, the measured depth of the core are carried out. Using the previously obtained results of studies of the depth of the core, the justification of the required height of the embankment and the calculation of the parameters of the subplate base is carried out. Next, the finite element method calculates the bending stresses arising in the bearing plate, where the maximum is 1.82 MPa and is compared with the permissible value, which is much greater for a reinforced concrete slab. Also, the result is the obtained elastic vertical movements, which indicate a more uniform distribution of the load from the rolling stock on the roadbed. Keywords: ballastless, construction of the railroad track, the Arctic zone, concrete

1 Introduction

A ballastless railroad track design is the one in which a monolithic or slab foundation is used instead of a typical sleeper. A ballastless track design provides several advantages over the standard sleeper design: greater stability in the profile and plan, lower vertical settlement and maintenance costs, etc., which can have a positive effect when such a design is used in the permafrost zone. Nonetheless, it is necessary to determine the feasibility of such a design and, first of all, its strength characteristics, i.e., to perform a track strength calculation.

In order to perform the aforesaid calculation, it is necessary to substantiate the calculation scheme and calculation methodology. To this end, we analyzed the existing methodology provided in [1,2,3] and the parameters that need to be adjusted to account for the operation of the ballastless structure in the permafrost zone.

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The path calculation methodology given in TSP 52-14 [1] assumes:

- The structure of the track structure and the crew part are in good condition and complies with the requirements of the "Regulations of Technical Operation of Railways of the Russian Federation" and the current technical standards.
- All forces impacting the track are reduced to horizontal and vertical.
- All forces impacting on the path are independent of each other.
- Horizontal transverse forces, as well as torsional moments due to the eccentricity of the application of vertical forces, for the purposes of the calculations should be taken into account by the factor calculated from the test outcomes.

The procedure for calculating the strength of the track structure should be effected as follows:

- Identification of the dynamic load from the wheel on the rail.
- Determination of the equivalent load on the track.
- Determination of the stress and strain state of elements of the track structure.

Criteria for assessing the strength of the track are allowable stresses are taken as follows:

- Stretching in the edge of the bottom of the rail, due to its bending and torsion due to vertical and transverse horizontal impact of the wheels of rolling stock [bk]
- On buckling on wooden sleepers (spacers on reinforced concrete) under pads, averaged over the area of the pad [bsh]
- Compressions in the ballast under the sleeper in the sub-rail zone [bb]
- Compressions on the main site of the earth bed in the sub-rail zone [bz]

The above-mentioned four criteria for the strength of the track are determined from the condition of ensuring its reliability, depending on the class of track, normalized following the "Regulations on the system of track facilities on the railroads of the Russian Federation:

- [bk]-from the condition of not exceeding the allowable number of rail failures for the normative operating time;
- [bsh]-from the condition of not exceeding the allowable wear of sleepers and shims under the pads for the period of standard operating time;
- [bb] and [bz]-from the condition not to exceed the allowable intensity of the accumulation of residual deformation, respectively, in the ballast and on the main site of the subgrade.

As per [4,5,6,7,8], soils should be divided by compressive strength and by the degree of deformability. There exist two options of compressive strength. The first option is low-temperature permafrost clay soils, which also include coarse-clastic and sandy soils, which have a temperature of minus two degrees Celsius and below at a depth of 10-15 m when calculated from the ground surface. The second option is high-temperature clay soils, which have a temperature above minus two degrees Celsius, and also include those lying on the island regardless of the temperature.

There exist also two types of deformability. Stable soils are the rocks, sandy and coarse-clastic soils containing not more than 50% of the clayey aggregate, consistency index up to 0,75, which includes particles less than 0,01 mm in quantity up to 20 or 30% when the level of the groundwater table is above or below the slope of the designed excavation. Stable soils are those soils that change their consistency from soft plastic to the fluid when thawing. This includes timber and crushed stone soils with more than 30% of clay aggregate of plastic and fluid consistency after thawing as well as non-rocky soils if there is underground ice under them.

Natural foundations of the earth bed are subdivided according to the degree of deformation into strong, subsidence, and weak.

As a rule, coarse-clastic soils belong to strong soils, which is also no exception for permafrost soils, because the value of the relative settlement is less or equal to 0.03, in this case, is provided by sandy, coarse-clastic and rocky soils without ice inclusions. If we
consider the second group, which includes weak soils, then the value of relative deformation will be in the range of 0.03 to 0.1. Clayey soils of tight plastic, soft plastic, and fluid plastic consistency, and sandy and coarse-clastic soils with clay aggregate can provide the such value of the settlement, provided that layer-by-layer presence of ice in them does not exceed 10%, considering on each meter in general. The third group of soils includes those that provide relative settlement values from 0.1 to 0.4. Such soils include peaty and clayey soils of fluid plastic consistency, as well as sandy and coarse-clastic soils with layer-by-layer ice of no more than 40% for each meter of the permafrost under study. And, accordingly, the fourth group, is characterized by values of relative sedimentation of more than 0.4. This group includes peat deposits and clay soils in flowing consistency, as well as all other soils, in which the presence of stratified ice is more than 40% for each meter of the studied thickness.

Grounding upon the above, applying the methodology for calculating the strength of the railroad track, given in TSP 52-14, there were were calculated dynamic loads from the cargo gondola at a design speed of 70 km / h (Table 1).

Table 1. Outcomes of calculation of dynamic load from the wheel on the rail.

<table>
<thead>
<tr>
<th>Name of the indicator</th>
<th>Freight gondola</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of movement. km/h</td>
<td>70</td>
</tr>
<tr>
<td>Static axial load. kH</td>
<td>245.2</td>
</tr>
<tr>
<td>Static wheel load on the rail. Pst. kH</td>
<td>122.6</td>
</tr>
<tr>
<td>Weight of unsprang parts. q. kH</td>
<td>9.4</td>
</tr>
<tr>
<td>Coefficient of vertical dynamics. kd</td>
<td>0.39</td>
</tr>
<tr>
<td>Maximum dynamic wheel load on the rail from vertical vibrations of the superstructure. kH</td>
<td>44.0</td>
</tr>
<tr>
<td>Average dynamic wheel load on the rail from vertical vibrations of the superstructure. kH</td>
<td>33.0</td>
</tr>
<tr>
<td>Average vertical dynamic wheel load on the rail. kH</td>
<td>155.6</td>
</tr>
<tr>
<td>Mean square deviation of the dynamic wheel load on the rail from the vertical vibrations of the superstructure. kH</td>
<td>3.5</td>
</tr>
<tr>
<td>Calculated dynamic load from the wheel on the rail. kH</td>
<td>164.8</td>
</tr>
</tbody>
</table>

The railroad track calculation method specified in TSSP 52-14 is true for the classical sleeper structure, which, when built in the Arctic zone, must have a ballast layer under the sleeper of at least 300 mm, a sand base thickness of at least 1200 mm, and measures to increase thermal insulation. Such a design is shown in Fig. 1.

![Fig. 1. Calculation scheme of the construction of railroad track on permafrost soils with a ballast layer of 300 mm under the sleeper and a sand embankment with a layer of 1200 mm with the use of polystyrene foam with a thickness of 40 mm.](image-url)
In case a ballastless structure is used in the permafrost zone when calculating the arising stresses in the track superstructure elements and the body of the earth bed, the track should be considered as a reinforced concrete slab on an elastic base. Modern CAD systems are used to calculate such structures, which allow the calculation of stresses arising in the structure by the finite element method. The main normative documents, in this case, will be SP "Concrete and reinforced concrete structures" and SP "Foundations of buildings and structures". [10]. To perform the calculations, it is necessary to determine the variant of the railroad track structure and justify the possible methods of calculating the parameters of the subgrade base.

World experience demonstrates that different variants of constructions are possible, where the common feature is the construction of a double-layer reinforced concrete base. For example, the construction operated on roads in Germany (Fig.2).

Fig. 2. Structure on a ballastless base of the RHEDA type-RHEDA Classic.

Nowadays, at the test site in Shcherbinka, Moscow, tests are being carried out on the design of the railroad track for high-speed lines with several layers of plates (Figure 3). The following calculation was performed for this design.

![Fig. 3. Construction of a railroad track on a ballastless base.](image)

Calculation of forces arising in load-bearing reinforced concrete slabs by the finite element method using CAD involves the breakdown of the structure into elements and their classification following the functional purpose of the layer:
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Calculation of forces arising in load-bearing reinforced concrete slabs by the finite element method using CAD involves the breakdown of the structure into elements and their classification following the functional purpose of the layer:

- The rail slab (top slab) absorbs loads from the rail, distributes them over a large area, and transmits them to the self-compacting concrete layer. This slab has a longitudinal reinforcement, so it also absorbs bending loads.
- Self-compacting concrete takes the vertical loads from the rail slab and transfers them to the foundation slab. This layer has no reinforcement, so only direct load transfer from the top slab to the bottom slab can be considered, without taking any bending moments.
- The foundation slab absorbs loads from the self-compacting concrete, distributes them, and transmits them to the asphalt concrete layer. The foundation slab has a longitudinal bearing reinforcement, so it accepts both vertical forces and bending forces (longitudinal and transverse).
- Layers of the crushed stone-sand-gravel mixture-a protective layer.
- The sand layer acts as a load transfer and drainage function.
- A layer of foam plastic serves as thermal insulation.

Density of foamlex 31C, 31, 35, 45C, 45 varies from 28 to 45 kg/m³, compressive strength - from 66 to 167 kPa, the modulus of elasticity-from 14 to 18 MPa. The average values of the considered intervals were taken as the calculated ones.

When calculated by the finite element method, it is also necessary to take into account the distinguishing features of interaction between the rolling stock and the railroad track when applying SP "Concrete and reinforced concrete structures and SP "Foundations of buildings and structures". [9,10]. While the application of SP "Concrete and Reinforced Concrete Structures" has stipulated all the possible cases (transverse loads on the slab, bending moments, longitudinal forces, etc.), the application of SP "Foundations of Buildings and Structures" is to take into account that it is designed for static loading. The question is fundamental because it is necessary to determine the depth of the active zone from the dynamic load, i.e., to find out at what depth the stresses from the dynamic component of the vertical load become insignificant, which makes it possible to justify the minimum height of the sub-base of high-quality soils.

As per SP "Foundations of buildings and structures" [10], the working area is defined by the formula:

\[ \sigma_{zp} = 0.5 \sigma_{zg} \]

Where \( \sigma_{zp} \) - active pressure on the ground
\( \sigma_{zg} \) - domestic ground pressure.

This formula is used in determining settlements from foundations under static loading and is used to design buildings and structures of various complexity. As for vertical stresses from dynamic loading, Shakhunyants G.M. noted in his works that the effect of dynamic vertical loads from the train is fundamentally different from the static ones [11]. This is demonstrated in Fig. 4.
Analysis of the outcomes of these studies shows that at a depth of 1 m from the surface of the earth bed there is a significant difference in stresses from dynamic and static loading (twice), with increasing depth up to three meters—almost three times. The works of Kolos A.F. and Sidorenko A.A. [12,13,14] show that with increasing depth the influence of dynamic load from train significantly decreases, and after a depth of more than 1 m, it becomes close to the permanent load. At the considered depth of 3.0 m, in particular, dynamic stresses are 10% of the constant load (figure 5) [12,13,14].

Meanwhile, Konshin G.G. [15,16] proved that deformations in the soil from the train load are also fixed at a depth of 6 m. But in case it is considered that the value of stresses from the train at this depth is less than 5% of the passive pressure of the ground, the additional deformation becomes insignificant and evenly distributed along the entire length of the rolling stock.

The outcomes of these studies should be taken into account in further work since the calculation methodology which is described in SP "Foundations and Foundations" takes into account the dynamic nature of the disturbing force only at the expense of coefficients. Therefore, it is important to determine the boundary of the working zone for the ballastless structure, as this will allow justifying the minimum embankment that will determine the structure of the earth bed.
Thus, the calculation of strength and settlements of the ballastless structure of the railroad track is reduced to the calculation of the slab on an elastic basis, taking into account the following provisions:

- Reinforced concrete slabs separated by a layer of self-compacting concrete in the calculation scheme have vertical ties to ensure joint operation.
- The depth of the active zone under the asphalt layer will spread from the dynamic load and is determined based on field measurements for similar ballastless structures. For the considered structure, the depth of the active zone from dynamic loads is 3 m.
- Calculation of the strength of the load-bearing slabs should be conducted according to SP 63.13330.2018 "Concrete reinforced concrete structures" for the two limiting states.
- When calculating, computer-aided design systems should be used that perform calculations by the finite element method, taking into account the work of the under-plate space, compaction of the soil, and consolidation over time under its weight.

According to the proposed calculation scheme, calculations were performed and the outcomes obtained on the vertical deflection of the slab and the arising stresses are shown in Figure 6.

![Figure 6](image)

**Fig. 6.** Settlement of the structure (mm) and the backing reaction of the sub-plate soil (MPa) of the ballastless structure from a cargo puluvagon for a speed of 70 km/h.

The considered design of the railroad track on a ballastless base allows the load from the train to be distributed over a larger area and more evenly, providing less elastic deformation from the train, and greater stability of the rail track, which increases the potential for increasing traffic speeds. However, in order to implement this design, it is necessary to further develop measures to ensure favorable temperature conditions of the slab, sub-plate space, and slopes, since changes in the temperature of soils fundamentally change their deformative properties.

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