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Simulation of performance of subway wooden sleepers and determination of their tense state using Lira software complex

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Abstract. The article uses the software complex Lira for the calculation of wooden sleepers, in which the finite element method in the form of displacements is used. FEM provides for making a system of equations that is solved by considering each individual finite element, which is very easy to implement and thus is an important advantage of the method. The purpose of its use is to calculate the wooden sleepers for strength and to determine its bearing capacity. The following types of finite elements were chosen to simulate the upper track structure in the subway tunnel: universal rod-type spatial finite element (type 10) and universal finite element of spatial problem of the elasticity theory (type 31). To design a spatial model, a section of the rail with seven sleepers in the subway tunnel was simulated and loaded with one axle of the car, since the influence of the adjoining sleepers on the estimated sleeper is negligible. They were divided into eight-node tetragonal parallelepiped-shaped finite elements. In order to simulate a sleeper encased in track concrete, a movement restriction was introduced at its points of contact with track concrete. The loads are applied to the rail above the middle sleeper symmetrically relative to its middle and are assumed as concentrated forces on each track line. The part of the sleeper above the culvert is not supported by track concrete and can move freely in all directions. To obtain the values of stresses, the maximum-stress theory of strength is used.

1. Introduction

In all software systems of the Lira family [1], the finite element method (FEM) in the form of displacements is used. FEM is considered for cases when the desired function being solved is a displacement. The reason for this is that the choice of computational scheme for FEM in displacements is easy to algorithmize, as practical use of FEM is impossible without modern computers.

The basic concept of FEM is direct discretization of the computational system, which is divided into finite elements with the computational grid. For the obtained discrete model, a system of piecewise continuous functions $\{\varphi_i(x)\}$ defined on a finite number of subdomains – stars of finite elements – is introduced.

FEM provides for making a system of equations that is solved by considering each individual finite element, which is very easy to implement and is an important advantage of the method.

2. The analysis of studies and publications

A sleeper in the subway tunnel is a parallelepiped-shape wooden beam with a cross-section of 160×250 mm and a length of 2750 mm; it is encased in track concrete for 2/3 of its length [2-8].

To simulate the upper track structure in the subway tunnel, Lira 9.6 software complex was used and the following types of finite elements were selected:

1) Universal rod-type spatial finite element (CE 10) (figure 1) which has a local coordinate system *X1*, *Y1*, *Z1*, relative to which the local load is specified and the forces are determined. This element takes the following forces: axial, torque, bending moments and lateral forces in the vertical and horizontal planes.

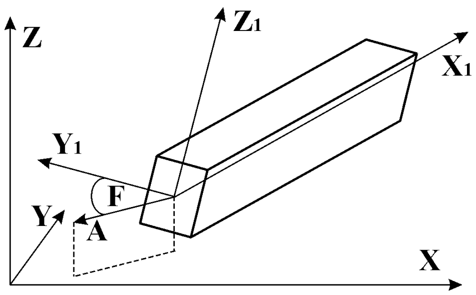

Figure 1. Universal rod-type spatial finite element (CE 10).

2) Universal finite elements of the spatial problem of the elasticity theory (CE 31 – parallelepiped) (figure 2) are intended to determine the stress-strain state of continuous objects and massive spatial structures from a homogeneous isotropic linear-elastic material in the statement of a three-dimensional problem. This element takes normal and tangential stresses in all planes.

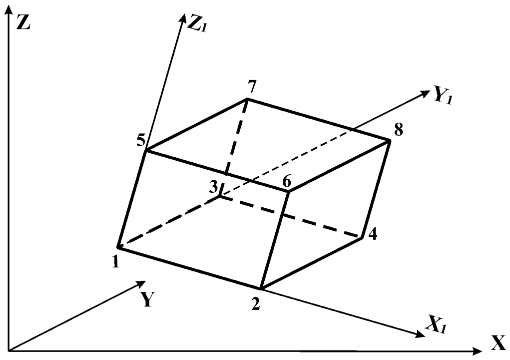

Figure 2. Parallelepiped (CE 31).

3. The basic part

Finite elements of different types were used to simulate the upper structure of the subway track: type 10 with a given cross-section corresponding to the cross-section of R50 rail was used for the rail, and type 31 was used for the baseplate and wooden sleepers. For the rail and the baseplate, physical and stiffness characteristics are set with reference to steel, while for wooden sleepers – with reference to pine wood.

To design a spatial model, a section of the rail and seven sleepers in the subway tunnel was simulated and loaded with one axle of the car, since the influence of the adjoining sleepers on the estimated sleeper is negligible. They were divided into eight-node tetragonal parallelepiped-shaped finite elements. In order to simulate a sleeper encased in track concrete, a movement restriction was introduced at its points of contact with track concrete. They are directed along axes which are perpendicular to the planes of the concrete base, as well as vertically along them. It is the loads are applied to the rail above the middle sleeper symmetrically relative to its middle that are taken as the concentrated forces on each track line. The part of the sleeper above the culvert is not supported by track concrete and can move freely in all directions. The general appearance of the model of the upper track structure in the subway tunnel for determining the stresses in the estimated wooden sleeper is shown in figure 3.

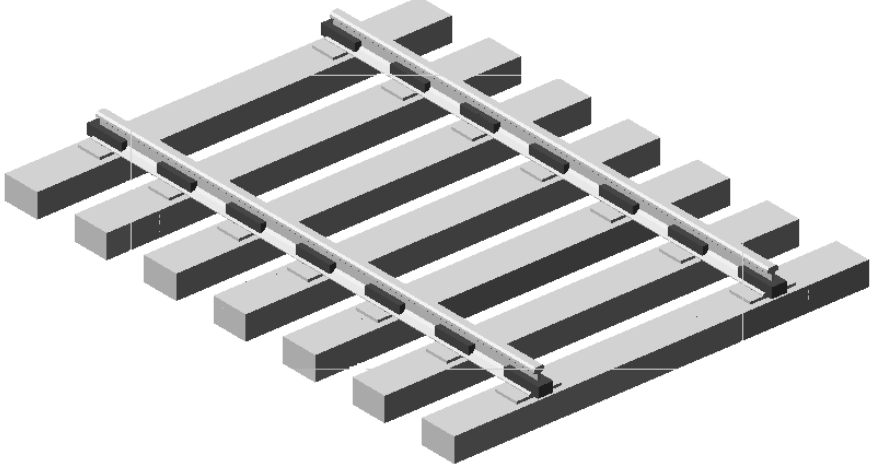

Figure 3. Model of the upper track structure in the subway tunnel.

After assembling the elements of the upper track structure, a finite element model was obtained to design a wooden sleeper in the subway tunnel which is shown in figure 4. As a result of division into finite elements, 42306 equations, 9644 elements, 14212 nodes were obtained.

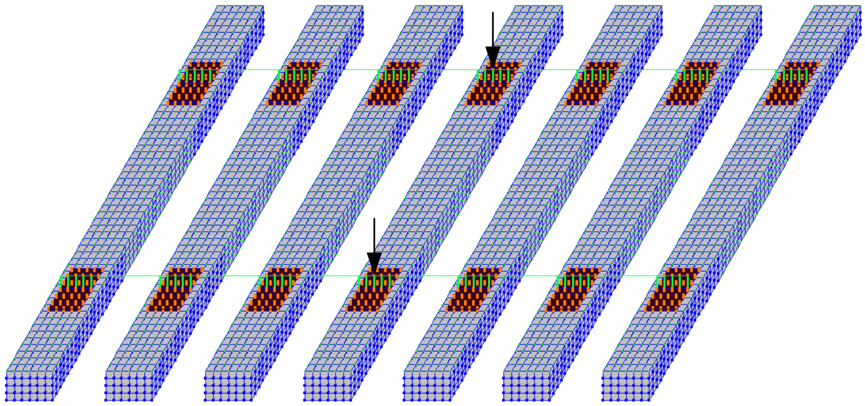

Figure 4. Finite element model a wooden sleeper in the subway tunnel.

The cross-sectional and longitudinal sections for the estimated sleeper are shown in figure 5 and figure 6. The sleeper in the middle is assumed as the estimated one.

The design was performed under action of concentrated force on the estimated sleeper, as shown in figure 4. Since the load was applied symmetrically relative to the longitudinal axis of the track, the results of the design will be given only for one railway track line of the subway.

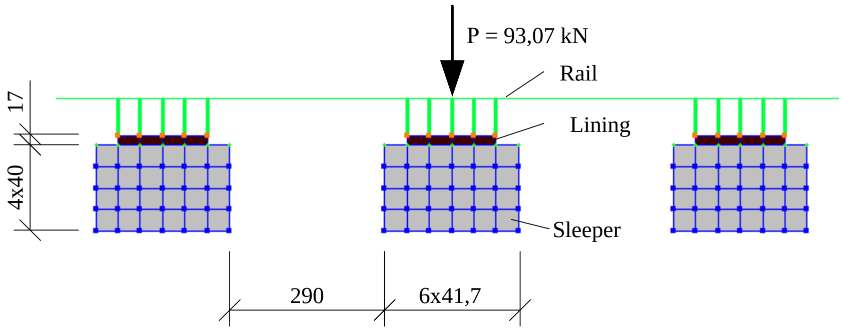

Figure 5. Cross-sectional sections for the estimated sleeper.

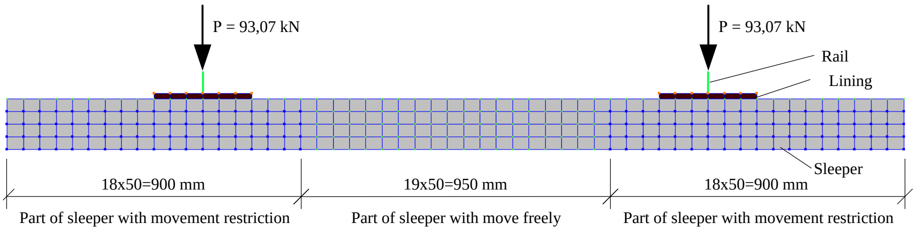

Figure 6. Longitudinal sections for the estimated sleeper.

To obtain the values of stresses, the maximum-stress theory of strength is used. As a result, the values of the minimum, average, and maximum principal stresses in the form of isopoles are obtained, which are shown in figure 7-9, respectively. To evaluate the strength, the highest values corresponding to the isopoles of the maximum principal stresses are chosen.

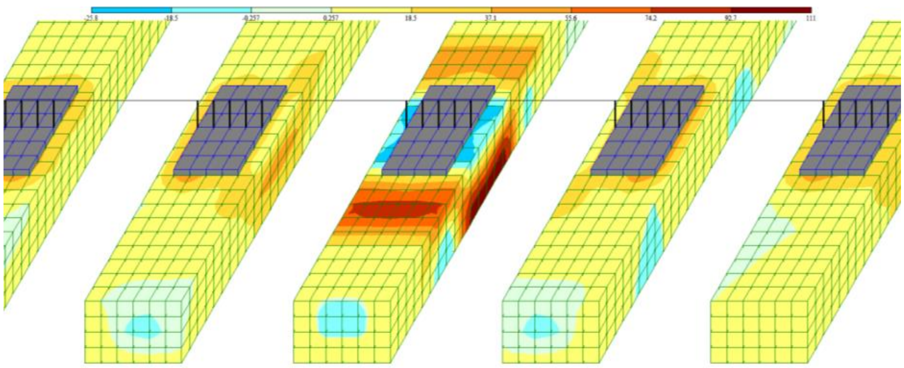

Figure 7. Isopoles of the minimum principal stresses.

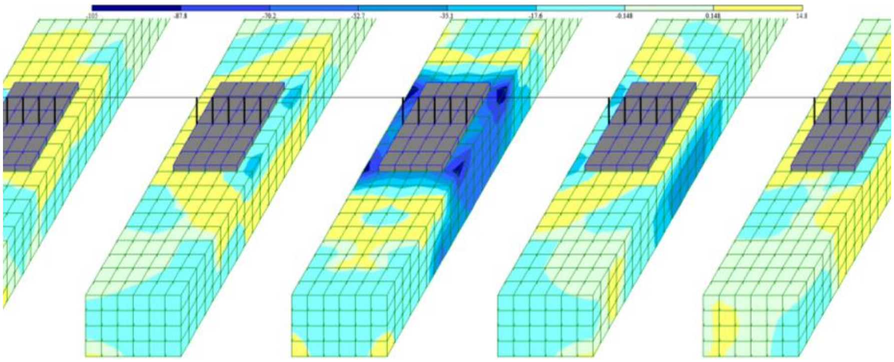

Figure 8. Isopoles of the average principal stresses.

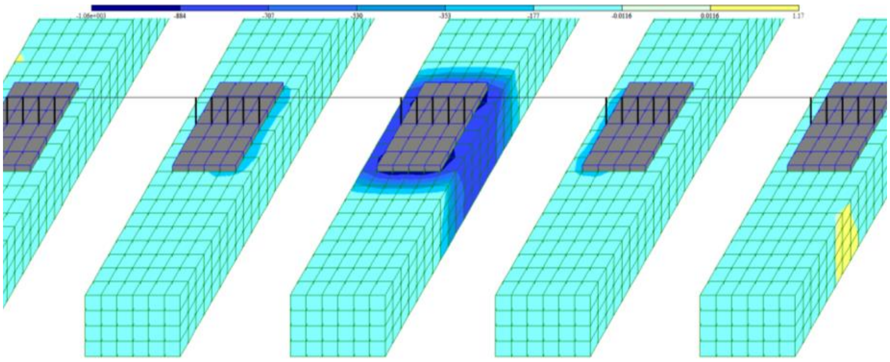

Figure 9. Isopoles of the maximum principal stresses.

4. Conclusions

According to the results of computation using Lira 9.6 software complex, the stresses in the estimated sleeper are

$$\sigma_s = 884 \text{ kN/m}^2 < [\sigma_s] = 2200 \text{ kN/m}^2.$$

Comparing the obtained results with the results of the strength design of the subway track according to the "Rules of strength and durability design of the railway track" [9, 10], where $\sigma_s = 867$ kN/m^2, it can be concluded that the error is not more than 2 %. Given this, the use of the of the railway track design method, in accordance with the above rules, is legitimate for the upper track structure in the subway tunnel on wooden sleepers.

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