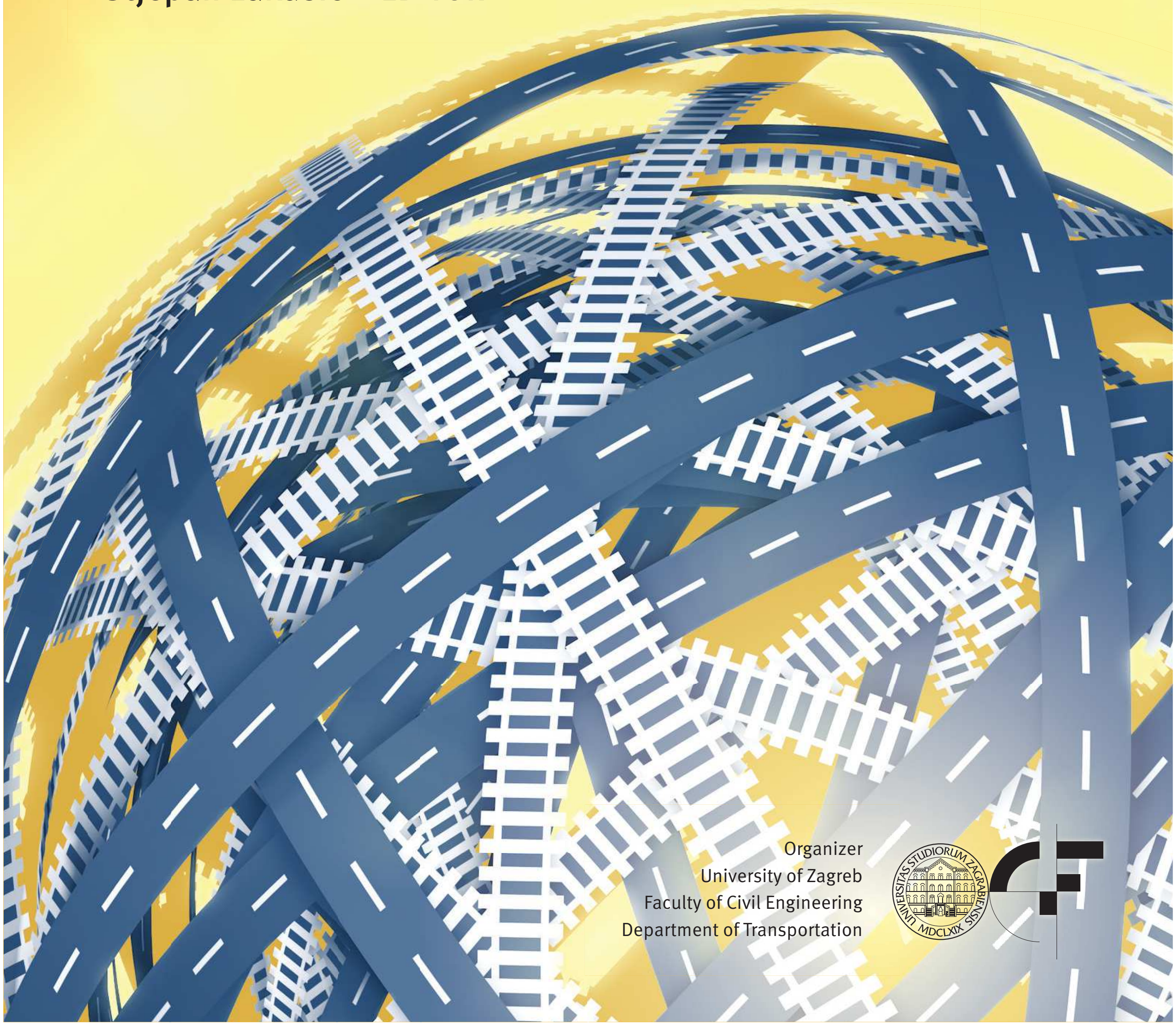
CETRA 2016

4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA^{2016}
4th International Conference on Road and Rail Infrastructure
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FOREWORD

The 4th International Conference on Road and Rail Infrastructure – CETRA 2016 was organized by the University of Zagreb – Faculty of Civil Engineering, Department of Transportation. The Conference is held in Šibenik, Croatia. Šibenik is the first town in the world to benefit from electric lighting. In fact, on 28 August 1895, the alternating current electric lighting was acti¬vated for the first time in the streets of Šibenik. The merit for this certainly goes to the inventor, vi¬sionary genius and researcher of Croatian descent, Nikola Tesla, whose alternating current discovery lighted up streets and squares of Šibenik. The Šibenik power plant was the first alternating current power system in Croatia, the first commer¬cial hydro power plant in Europe, and the second one in the world. It was put in operation on 28 August 1895 at 20:00, two days after the Adams Power Plant on the Niagara Falls.
The 1st International Conference on Road and Rail Infrastructure – CETRA 2010 is held 17-18 May 2010 in Opatija. The 2nd International Conference on Road and Rail Infrastructure – CETRA 2012 is held on 7-9 May 2012 in Dubrovnik. The 3rd International Conference on Road and Rail Infrastructure – CETRA 2014 is held on 28-30 April 2014 in Split. Great interest of participants in topics from the field of road and rail infrastructure during the previous conferences CETRA, confirmed the soundness of Department for Transportation Engineering's decision on organizing such international event. Positive comments of the participants after the past Conferences motivated the Department for Transportation Engineering, Faculty of Civil Engineering at University of Zagreb to continue the organization of such an international event.
The CETRA conference has established itself as a venue where scientific and professional information from the field of road and rail infrastructure is exchanged. The idea on linking research organisations and economic sector has been the guiding concept for the realisation of this conference. Conferences of this kind are undoubtedly a proper place for bringing closer together the economy and university operators, and for facilitating communication and establishing greater confidence that might result in cooperation on new projects, especially those that contribute to greater competition. Lectures organized in the scope of the conference are based on interesting technical solutions and on new knowledge from the field of transport infrastructure as gained on already realised projects, projects currently at the planning stage, and those now under construction, in all parts of the world. In addition to authors from the academic community, lectures were also presented by practical authors, the idea being to ensure the best possible synergy between the theory and practice. Because of a great interest for the themes from the field of road and rail infrastructure, as shown during the past two conferences (CETRA 2010, CETRA 2012 and CETRA 2014), the Department for Transportation Engineering of the Faculty of Civil Engineering – Zagreb assumed the responsibility to organise the CETRA conference in this year as well.
Our goal for the International Conference on Road and Rail Infrastructure – CETRA is to have all published papers indexed in scientific databases in order to achieve greater recognition for the conference itself, for published papers, and for their authors. As the serial publication entitled Road and Rail Infrastructure has been achieved with last conference (CETRA 2014), the precondition has been fulfilled to obtain the International Standard Serial Number (ISSN), which was the condition for starting procedure for registering this publication in scientific databases. A great novelty is that the CETRA 2016 conference will be indexed in the TRID base, which is an inte¬grated database that combines the records from TRB's Transportation Research Information Ser¬vices (TRIS) Database, and the OECD's Joint Trans¬port Research Centre's International Transport Research Documentation (ITRD) Database. TRID provides access to

more than one million records of transportation research worldwide. In addition, the TRID base has accepted all papers that were published at previous CETRA conferences.
In the year 2016, 4th International Conference on Road and Rail Infrastructure – CETRA 2016 has been organized, with the intention of bringing together scientists and experts in the fields of road and railway engineering, giving them another opportunity to present the results of their researches, findings and innovations as well as to analyze problems encountered in everyday engineering practice and to offer possible solutions for a more efficient planning, design, construction and maintenance of transport infrastructure.
Conference CETRA 2016 covers many areas: Traffic planning and modelling, Infrastructure projects, Infrastructure management, Road pavement, Rail track superstructure, Construction and maintenance, Transport geotechnics, Tunnels and bridges, Structural monitoring and maintenance, Computer techniques and simulations, Noise and vibration, Innovation and new technology, Urban transport, Integrated timetables on railways, Vehicles dynamics, Traffic safety and for the first time Traction Vehicles and Power Supply of Transport Systems.
This Conference CETRA 2016 attracted a large number of papers and presentations from 37 countries and 54 Universities. More than 140 papers were presented at the Conference and are contained in these proceedings **Road and Rail Infrastructure IV**.
The organizers of the Conference express their thanks to all Businesses and Institutions which support this Conference. Special thanks are extended to the European Railway Agency (ERA), for their assistance and support in organizing very important conference sessions regarding **Interoperability of the European rail system** especially regarding 4th Railway Packages issues and Technical Specifications for Interoperability (TSI). The objective of ERA is to contribute, on technical matters, to the implementation of the European Union legislation aimed at improving the competitive position of the railway sector by enhancing the level of interoperability of railway systems, developing a common approach to safety on the European railway system and contributing to creating a Single European Railway Area without frontiers, guaranteeing a high level of safety.
The Editor commends all authors for excellent papers contributed to these proceedings, and wishes to thank members of the International Academic Scientific Committee, and numerous experts who participated in the review process. The gratitude is also extended to all participants for deciding to come to Šibenik and take part in CETRA 2016. We believe that these CETRA 2016 proceedings entitled Road and Rail Infrastructure IV will be, just like the preceding three proceedings from the CETRA cycle, highly interesting and useful to all experts exhibiting a scientific and professional interest in road and rail infrastructure.

THE EDITOR
Prof. Stjepan Lakušić
May, 2016.

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CETRA 2016 23–25 May 2016, Šibenik, Croatia
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ANALYSIS OF NEW SUPERSTRUCTURE COMPONENTS OF RAILWAY TRACK IN TUNNEL SOZINA IN MONTENEGRO

Zoran Krakutovski[1], Darko Moslavac[1], Zlatko Zafirovski[1], Aleksandar Glavinov[2]
[1] *University "Ss. Cyril and Methodius" – Faculty of Civil Engineering Skopje, Republic of Macedonia*
[2] *University "Goce Delcev" – Stip, Military academy "General Mihailo Apostolski" Skopje, Republic of Macedonia*

Abstract

The actual superstructure components of railway track in tunnel Sozina in Montenegro is with following materials: wooden sleepers, rail type 49, rigid fastening K system and crushed stone for ballast. The envisaged new railway superstructure should be completed with mono-block prestressed concrete sleepers, rail type 49E1, elastic fastening and crushed stone for ballast. The replacement of wooden sleepers with concrete sleepers and rigid with elastic fastening is the principal replace of superstructure components. This requirement is completed by the railway infrastructure company in Montenegro because the maintenance works of track are very important in the tunnel and the cross section of the tunnel allows usage of slippers with a length of 2.4 m. The influence of vertical track loads and of temperature changes on continuous welded track (CWT) is calculated for a new conception of track. The theoretical analysis under the influence of vertical loads on the track is carried out according to the Zimmerman and Eisenmann theoretical approach. The effect of axial forces from temperature changes are also calculated and added to the dynamic stresses in order to obtain the total stress in the rails, which were compared with a maximum allowable stresses. The effects of temperature changes, as well as crack of rails, are also considered. The stability of Continuous Welded Rails (CWR) on bulging under the impact of vertical or lateral forces is also verified.

Keywords: railway superstructure, rails, sleepers, calculation of railway superstructure

1 Introduction

The analyses of a new railway superstructure components concern the segment in tunnel Sozina on railway section Virpazar- Sutomore in Montenegro. The required modifications of superstructure design project refer to the replacement of wooden sleepers with concrete prestressed sleepers with length of 2.40 m and application of elastic fastening for fixing the rails to the sleepers, compatible with concrete sleepers. The calculations of superstructure elements are studied under influence of the vertical loads and also from the temperature changes on continuous welded track (CWT). The total length of tunnel is 6.170 km, and the total length of track where the new superstructure would be laid is 6.500 km. The layout on the exit of the tunnel is designed in curve with radius of 350 m.

2 Characteristics of materials in superstructure and subsoil used in analysis

According to the requirements of the Railway Infrastructure Company, the new conception of the superstructure includes the following components:

- Rail 49E1, Quality 260
- Mono block pre-stressed concrete sleeper, length L = 240cm
- Fastening type Vossloh – SKL 14
- Crushed stone for ballast and minimum thickness of 35cm below the lower surface of the sleepers.

Geometrical and physical characteristics of rails 49E1 are follows:

- Cross section of the rail 49E1, As=62,92 cm^2
- Weight of the rail 49E1, g=49,39 kg/m
- Moment of inertia of the rail 49E1, Ix=1816 cm^4
- Section modulus of the rail 49E1, W=247,5 cm^3

Geometrical and physical characteristics of mono block pre-stressed concrete sleeper are following:

- Weight (without fastening) 260 kg
- Length 2400 mm
- Width 300 mm
- Height of sleeper 234 mm (214 mm)
- Support surface 6237 cm^2
- Maximum speed 160 km/h
- Permissible axle load 25 t

The usage of crushed stone of silicate and eruptive rocks is envisaged concerning the quality of crushed stone ballast. The rocks which are particularly suitable for making crushed stone for ballast are following: diabase, granite, gabbro, syenite and quartz. The thickness of the ballast taken in the calculations is h = 35 cm below the sleepers. The allowable stresses at the contact surface of the sleeper-ballast are 0.30 MPa (or 0.30 N/mm^2).
The geotechnical investigation works along the section of the railway tunnel indicate that the quality of materials in the subsoil below ballast is good. According to these results, the track reaction modulus relates to the material classified as “good” (Table 1).

Table 1 Admissible stresses in the subsoil

Classification of materials	Elasticity modulus of subsoil	Track reaction modulus	Admissible stress in subsoil after n number of loading cycles
	$E\nu_2$ [N/mm^2]	C [N/mm^3]	σ_{adm} [N/mm^2] $n = 2 \cdot 10^6$
Poor	10	0.03	0.011
	20	0.04	0.022
Fair	50	0.07	0.055
Good	80	0.09	0.089
	100	0.11	0.111

Source: [1] Esveld C., 1989

The calculations of the superstructure under the impact of vertical loads are carried out for good quality material with track reaction modulus of C = 93333 kN/m^3 (0.093 N/mm^3).

3 Analysis of the superstructure laded with vertical loads

3.1 Theoretical context

The axle load for the calculation of the superstructure is adopted for railway lines category D4, with a maximum axle load of P = 250 kN.

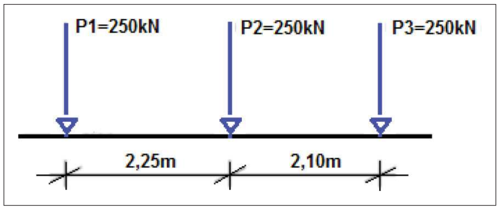

Figure 1 Vertical loads of track considered in analysis

The analysis of track is done according to the theory of Zimmerman. One rail with infinite length is analysed like elastic beam laid on continuous elastic supports. Another assumption in the analysis is that the track reaction modulus C is constant and the wheel load is simulated by a concentrated load P.

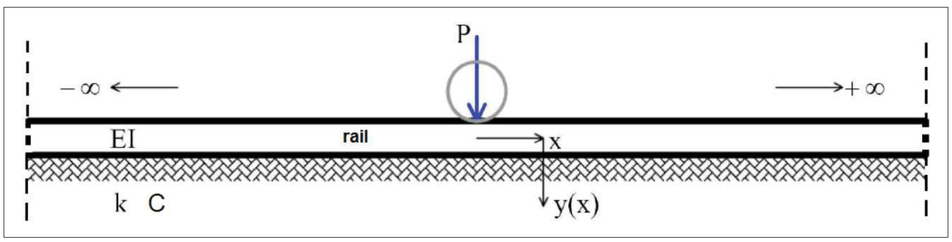

Figure 2 Analysis of rail according to the theory of Zimmerman

The Winkler hypothesis says that the normal stresses σ is proportional with the local deformation w, or more exactly:

$$\sigma = C \cdot w \tag{1}$$

C – track reaction modulus [kN/m^3]
w – beam settlement [mm]

If we mark spacing between sleepers with a, the sleeper seating surface A (for half sleeper), then stiffness coefficient of the base k [kN/m^2] will be:

$$k = \frac{C \cdot A}{a} \tag{2}$$

The assumption is that the beam has infinite length, with same cross section and with coefficient of bending stiffness EI. After elastic theory this problem could be solved with the differential equation of fourth degree:

$$E \cdot I \cdot w^{IV} + k \cdot w = 0 \tag{3}$$

The solution is:

$$w(x) = \frac{P \cdot L^3}{8 \cdot E \cdot I} \cdot \eta(x) = \frac{P}{2 \cdot k \cdot L} \cdot \eta(x) \tag{4}$$

In upper equation L is rail characteristic length defined with:

$$L = \sqrt[4]{\frac{4 \cdot E \cdot I}{k}} \tag{5}$$

In Eq.(4) the function η(x) appears which determine the deformation elastic line. It's form is:

$$\eta(x) = e^{-|x|/L} \cdot \left[\cos\frac{x}{L} + \sin\frac{|x|}{L}\right] \tag{6}$$

The bending moments elastic line is defined by the function μ(x) as follow:

$$\mu(x) = e^{-|x|/L} \cdot \left[\cos\frac{x}{L} - \sin\frac{|x|}{L}\right] \tag{7}$$

The equation for calculation of bending moments for a beam on elastic support is:

$$M(x) = \frac{P \cdot L}{4} \cdot \mu(x) \tag{8}$$

The compressive stress on the foundation, according to Winkler is:

$$\sigma(x) = C \cdot w(x) = \frac{P \cdot a}{2 \cdot A \cdot L} \cdot \eta(x) \tag{9}$$

In reality several vertical concentrated forces act on the rail on the distances between them l_i, so it should make superposition of influences of all wheels:

$$w(0) = \frac{1}{2 \cdot k \cdot L} \cdot \sum_i P_i \cdot \eta_i(l_i) \tag{10}$$

$$\sigma(0) = C \cdot w(0) \tag{11}$$

$$M(0) = \frac{L}{4} \cdot \sum_i P_i \cdot \mu_i(l_i) \tag{12}$$

3.2 Stresses in the rail, sleepers, ballast bed and in the subgrade

The effect of additional dynamic loads of train for calculation of stresses corresponds with a model in Germany developed by Eisenmann for calculation of stresses in the rail including dynamic loads. The model is based on statistical observations and it takes into account train speed, material fatigue and track conditions. The biggest expected dynamic bending stress in the rail leg is:

$$\sigma_{max} = \sigma_{st} \cdot (1 + t \cdot s) \tag{13}$$

$$\sigma_{st} = \frac{M}{W} = \frac{P \cdot L}{4 \cdot W} \quad (14)$$

Where W is section modulus of the rail (m^3) M is bending moment, P is vertical force, and L is characteristic length. t is increasing factor which depends from the confidence interval in the statistical analysis. It is recommended to adopted t = 3, and s is coefficient of variation.

$$s = 0{,}1 \cdot \phi \ \text{ – for new rails} \quad (15)$$

$$s = 0{,}3 \cdot \phi \ \text{ – for rails with fair quality} \quad (16)$$

$$\phi \ \text{ – speed factor,} \quad \phi = 1 \ \text{ for } V < 60 \text{ km/h} \quad (17)$$

$$\phi = 1 + \frac{V - 60}{140} \ \text{ for } V > 60\text{km/h} \quad (18)$$

In accordance with the existing Main Design for the rehabilitation of the railway line in the tunnel Sozina the speed limit is 70 km/h, which is taken into the calculations. The rails are under stresses with different nature: residual stresses as a result from rail manufacture, normal stresses due to temperature changes, bending stresses from wheel loads etc. The admissible bending stress must take into account all impacts on rails, and for a new rail 49E1, welded in CWT the admissible bending stress is 282 MPa. The sleepers are laid in the ballast bed and the maximum force which influences the sleeper could be calculated after Eisenmann as:

$$K_{max} = \frac{P \cdot a}{2 \cdot L} \cdot (1 + t \cdot s) \quad (19)$$

The compression stresses in the sleeper under rail pad are calculated as:

$$\sigma = 1 + \frac{K_{max} + F_0}{b \cdot B} \quad (20)$$

Where F_0 is fastening force, b is rail leg (rail pad) width and B is sleeper width. The compressive stresses which sleepers transfer to the ballast are highest immediate under the sleeper. The maximum stresses in the ballast under the sleepers after Eisenmann are:

$$\sigma_{max} = \sigma_{sr.} \cdot (1 + t \cdot s) \quad (21)$$

$$\sigma_{sr.} = \frac{P \cdot a}{2 \cdot L \cdot A} = \sqrt[4]{\frac{C \cdot a^3}{4 \cdot E \cdot I \cdot A^3}} \quad (22)$$

Where P is wheel load, a is spacing between sleepers, L is characteristic length, A is sleeper resting area (for half sleeper), and C is track reaction modulus. When the load is acting on one sleeper, the stresses under the adjacent sleepers is:

$$\sigma_i = \sigma_{max} \cdot \eta(x_i) \quad (23)$$

The methods of Odemark and Brauming are used for calculation the maximum stresses from the ballast to the subsoil.

4 Analysis of the superstructure under influence of temperature changes on CWR

The maximum and minimum temperature changes in the rails are T_{max} = 65 °C and T_{min} = –30 °C. The neutral or laying temperature of rails is T_n = 22.5 °C, and the maximum and minimum temperature changes are:

$$\Delta t_{max} = \Delta t_{summer} = t_{max} - t_n = 65 - 22.5 = 42.5°C \quad (24)$$

$$\Delta t_{min} = \Delta t_{winter} = t_{min} - t_n = -30 - 22.5 = -52.5°C \quad (25)$$

Longitudinal resistance of the ballast bed against track movement is non-linear function from the intensity of displacements and could be defined as:

In summer: $$\tau_s = 75 \cdot U^{0.25} \ [N/cm] \quad (26)$$

In winter: $$\tau_w = 150 \cdot U^{0.125} \ [N/cm] \quad (27)$$

For adopted maximum displacement of the track U_{max} = 0.5 cm, linearization of the longitudinal resistance is calculated from the condition that area under the parabola is equal to the area of the triangle (Figure 3):

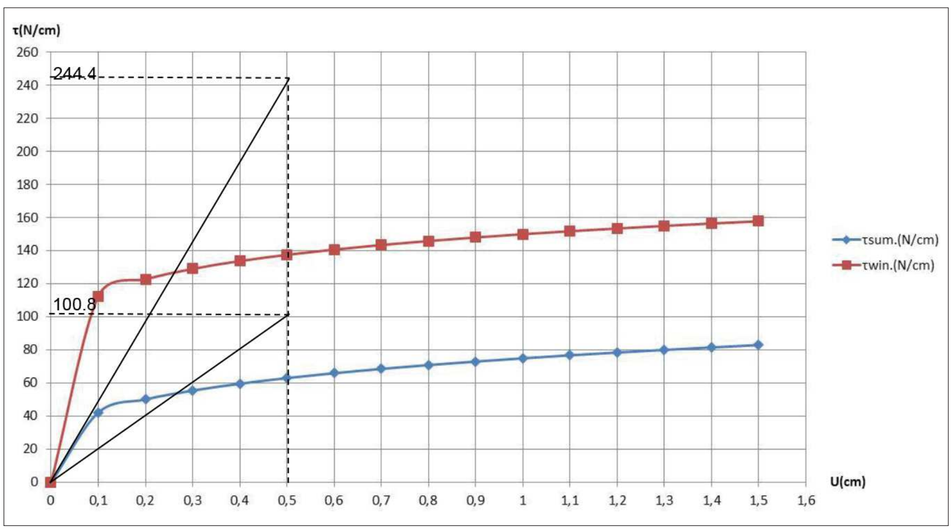

Figure 3 Longitudinal resistance of the ballast bed against track movement in summer and in winter

In summer: $$P = \int_0^{0.5} 75 \cdot U^{0.25} dU = 75 \int_0^{0.5} U^{0.25} dU = 25.2 \quad (28)$$

$$\frac{\tau_s \cdot U}{2} = P \quad \rightarrow \quad \tau_s = \frac{2P}{U} = \frac{2 \cdot 25.2}{0.5} = 100.8 \ N/cm \quad (29)$$

In winter: $$P = \int_0^{0.5} 150 \cdot U^{0.125} dU = 150 \int_0^{0.5} U^{0.125} dU = 61.1 \quad (30)$$

$$\frac{\tau_w \cdot U}{2} = P \quad \rightarrow \quad \tau_w = \frac{2P}{U} = \frac{2 \cdot 61.1}{0.5} = 244.4 \text{ N/cm} \tag{31}$$

The rail stresses due to temperature changes, the stability of track from track buckling in horizontal and vertical direction are also analysed and considered.

5 Results from analysis of the superstructure

Calculation of superstructure begins with calculation of stress of a beam on elastic supports on which the track is loaded with axle load of P_{max} = 25 t. The dynamic additional loads are taken into account by increasing the static stress with dynamic coefficient, which is a function of the speed of trains. The rails are treated as a beam on elastic supports for which is calculated the stress from the static and dynamic effects (Zimermmann's theory).
The effect of axial forces from temperature changes are also calculated and added to the dynamic stresses in order to obtain the total stress in the rails, which were compared with a maximum admissible stresses. The effects of temperature changes, as well as the crack of rails, are also verified. The stability of Continuous Welded Rails (CWR) under the impact of vertical or lateral forces is also tested. The safety coefficient from track buckling in vertical direction is k = 1.54. This value is higher than the requested safety coefficient k = 1.2 which means that the track is stable in the vertical plane. The summarized results of analaysis are the following:

- Bending moment of the rail M_{max} = 22.8 kNm
- Total bending stresses in the rail 321 MPa › 282 MPa which are 14% higher than the admissible total stress. These stresses are calculated with a maximum axle load of 250 kN and extreme temperature differences on the open line. The control of stresses summarizes all stresses obtained with the maximum temperature changes. The temperature variations of the temperature of laying the rail are following: in summer 42.5 °C and in winter – 52.5 °C. These temperature differences are extreme temperatures on the open line. If the assumed minimum temperature in rail in the tunnel during winter is -15 °C and the maximum temperature in rail in the tunnel during summer is + 30 °C, then the additional stresses in winter are 66.4 MPa. With these overall stresses the bending rails stress is 255 MPa ‹ 282 MPa.
- The maximum vertical force on the sleeper is K_{max} = 63.8 kN
- Pressure from the sleeper to the ballast is $\sigma_{max.pr-z}$ = 0.236 N/mm^2 ‹ 0.300 N/mm^2
- Pressure from the ballast to the subsoil:
  Method Odemark $\sigma_{max.z-pl.}$ = 0.110 N/mm^2 ‹ $\sigma_{adm.}$ = 0.111 N/mm^2
  Method Brauming $\sigma_{max.z-pl.}$ = 0.119 N/mm^2 ≈ $\sigma_{adm.}$ = 0.111 N/mm^2

The calculation results for stability of tracks with concrete sleepers against displacement of track in a curve with a radius of 350 m indicate that it should incorporate "caps" to increase the lateral resistance track and it should be installed these devices on each third sleeper throughout the entire length of the curve. The critical lateral resistance of track without "caps" is 9.25 kN/m, which is higher than the critical lateral resistance of 8.6 kN/m. The track with "caps" devices has a lateral resistance of 10.6 kN/m; it is superior to the critical lateral resistance.

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