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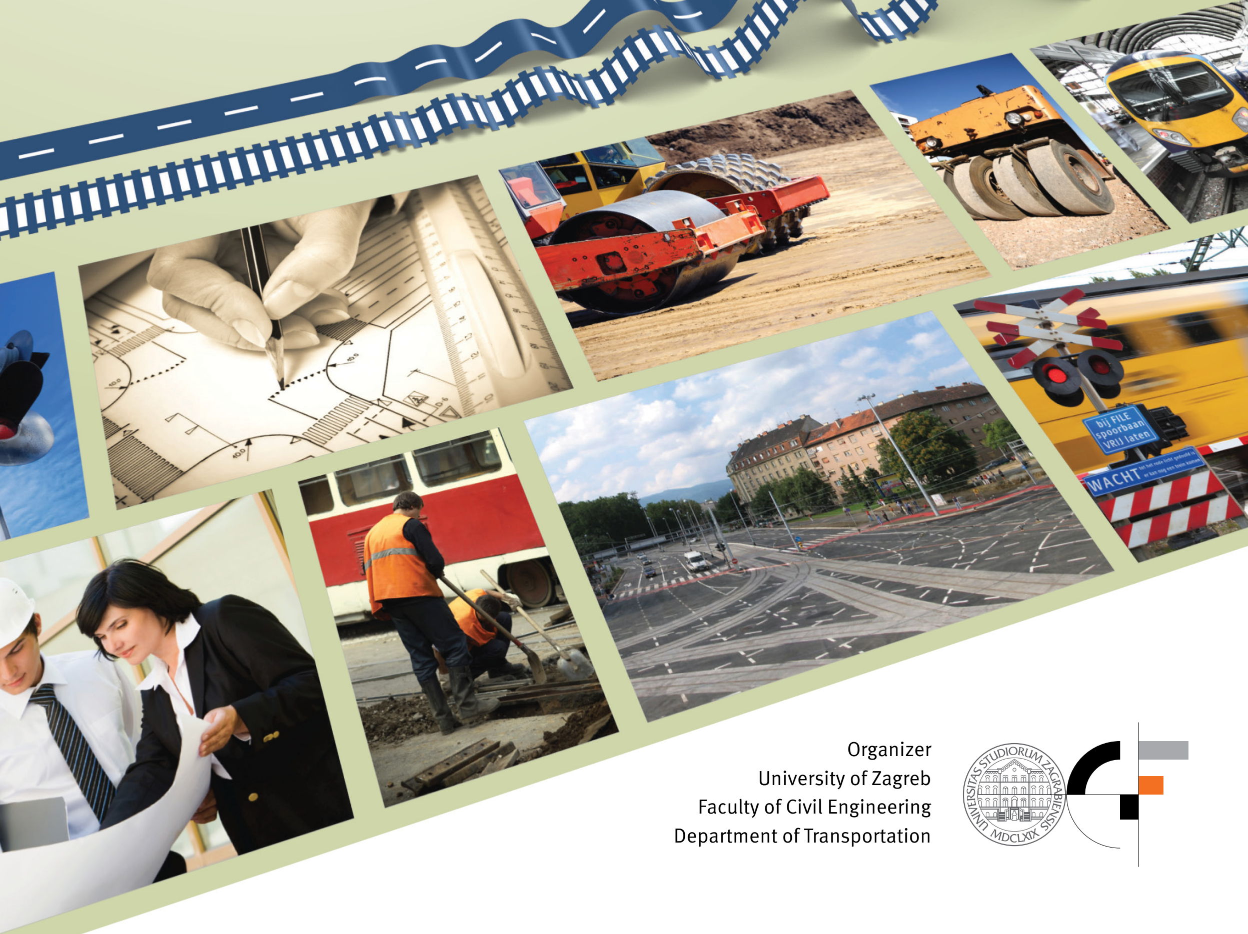
Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure II

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CONTINUOUSLY WELDED RAIL (CWR) TRACK BUCKLING AND SAFETY CONCEPTS

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Abstract

The continuous welded rail is now in widespread use on most railways. The main reasons for their mass deployment is in the numerous advantages over the jointed track (in technical, environmental and economic terms), as well as being one of the basic preconditions for the introduction of high speed services.
The main disadvantage of continuously welded tracks is reflected in the limited freedom of expansion and contraction of the rails due to temperature changes. As a consequence, large longitudinal forces induced in the rails lead to rail deformation and lateral and longitudinal displacements of the track. This paper will present a methodology for ensuring stability in the CWR track (leaflet UIC 720), and will make its comparison with the calculation method of the CWR track defined in the applicable regulations, on the lines in operation in Bosnia and Herzegovina.

Keywords: continuous welded rail, track stability, UIC 720

1 Introduction

Because of its many advantages, especially in terms of the working expenses and maintenance costs reduction, continuous welded rails are now widely used on most of the world's railways. However, their use requires certain precautions in the way of laying and track maintenance and dimensioning structures (elements), in order to ensure stability of the track and maintenance of rail deformations in the allowable limits.
Due to limited freedom of expansion and contraction of the rails and temperature changes, the rails can induce large longitudinal forces which can, in the middle of the fixed part, in extreme temperatures be up to 1000kN.
At extremely high summer temperatures large longitudinal pressure forces appear, which may cause lateral displacement or track buckling.
These phenomena are very adverse because they cause traffic suspensions and if not detected in time, can lead to derailment of railway vehicles, tracks and road traffic accidents with disastrous consequences.
A large number of parameters influences the stability of continuous welded rails, such as climatic characteristics of the area (minimum and maximum air temperature), characteristics of the superstructure (rails, fastening systems, thresholds and ballast) and substructure elements (subgrade, ballast bed, bridges), geometric elements with imperfections (misalignment) and vehicle characteristics and movement speed. In addition, proper installation and maintenance elements of the track superstructure and substructure play a large role.
Therefore, the construction knowledge is of great importance, knowledge to the extent to which one can go in service and construction. Not all the sameAlso, there is a difference

whether the buckling of continuous welded rails comes at a temperature of 30°C or 40°C, whether continuous welded rails and curves are of smaller radius (sharper than 300 m, etc). According to the Bosnia and Herzegovina regulations on track stability calculations implemented by the method of prof. K.N.Mishchenko (from 1952.g) and German Railways (DB), that are based on theoretical considerations and experimental track testing, the quality of the current track structure noticeably differs . This paper aims to compare these methods and guidelines on the criteria of safety and stability of a CWR track (UIC -720).

2 Calculation of the CWR tracks stability

2.1 Calculation of CWR tracks stability according to the current regulations in BiH

The concept of safety, security and stability of a CWR track, according to the current regulations in BiH, ensures the application of 'Uputstvo 330 (Guidelines 330)' and 'Uputstvo 347 (Guidelines 347)', which were accepted by the former railway administration 'Zajednica Jugoslovenskih Željeznica (Community of Yugoslav Railways)'. According to the Guidelines 347 certain calculations were required before the installation of the CWR on bridges. Among other, track stability on the bridge and on the sections before and after the bridge needed to be checked, as well as the overall stress in the long rail track.
Also mentioned are the calculating methods for some influential values (in accordance with previously adopted regulations), as are the characteristics of the track structure elements (superstructure) and calculations of their allowed values.
Influential values calculation is based on a model, that should bring a solution for the CWR incorporation on bridges where all the conditions relating to the stability of the of track, the maximum size opening in the rail cracks in winter conditions, stress and rails bridge pillars must be met.
Calculations of the CWR track stability under these instructions are based on the equation of prof. K.N.Mishchenko, where stability control should be implemented for sections in front of and behind the bridge, and on the bridge itself.
The buckling process occurs mainly on a horizontal plane, and the buckling of track grid opposes its stiffness (I_{HK}) and the lateral resistance (q), as well as the longitudinal resistance of the track p.
The influence of the rail track longitudinal resistance on the safety factor of the track grid buckling is determined by the relationship:

$$n = 1 + \frac{P_{cr}}{4 \cdot p \cdot L_{cr}} \tag{1}$$

where p is the longitudinal resistance of the sleeper in the ballast prism of a single rail.
The initial value of critical force $P_{cr}(0)$ is determined by the formula:

$$P_{cr}^{(0)} = 1.2 \cdot 2 \cdot N \tag{2}$$

where N is the axial force (axial pressure force) that occurs as a consequence of temperature change in a single rail. The critical force which leads to track buckling is calculated by the formula:

$$P_{cr}^{(n)} = \frac{2.416}{\sqrt[4]{n}} \cdot \sqrt[4]{I_E \cdot 2 \cdot A \cdot E^2 \cdot q^2} \tag{3}$$

where 2A is double the size of a cross–section rail, and E is the modulus of elasticity of rail steel. The equivalent moment of track grid inertia is calculated by the equation:

$$I_{HK} = \beta \cdot 2 \cdot I_H \tag{4}$$

where I_H is the moment of inertia of tje the rail around y- axis, and β coefficient depends on the sleeper type (for wooden β is 2.0, and for concrete sleepers is 2.5).
The process is iterative and is carried out until it obtains the deviation Δ values:

$$\Delta = \frac{P_{cr}^{(n)} - P_{cr}^{(n-1)}}{P_{cr}^{(n)}} \leq 2\% \tag{5}$$

in this case the safety factor k must be:

$$k = \frac{P_{cr}^{(n)}}{2 \cdot N} > 1.2 \tag{6}$$

Characteristics of buckling waves are represented by (given) the wave length of the track buckling 'L_{cr}' and his arrow, 'f_{cr}', and are calculated according to equations:

$$L_{cr} = 19.18 \cdot \sqrt{\frac{E \cdot I_{HK}}{P_{cr}}} \tag{7}$$

$$f_{cr} = 2.88 \cdot \sqrt{\frac{n \cdot I_{HK}}{2 \cdot A}} \tag{8}$$

In the case of stability checking of the curved track, it is necessary to determine the minimum value of lateral resistance (minimum distributed load), which prevents the track buckling and provides the track stability.
The minimum required values for track lateral resistance are determined by the equation:

$$q = \frac{P_{cr}^{\ 2} \cdot \sqrt{n}}{7.18 \cdot E \cdot \sqrt{I_{HK} \cdot 2 \cdot A}} + \frac{P_{cr}}{R} \tag{9}$$

where R is the radius of curvature. Wave length of the track buckling 'L_{cr}' and his arrow, 'f_{cr}' are calculated according to equations:

$$L_{cr} = 13.92 \cdot \sqrt{\frac{E \cdot I_{HK}}{P_{cr}}} \tag{10}$$

$$f_{cr} = 4.18 \cdot \sqrt{\frac{p \cdot I_{HK}}{2 \cdot A}} \tag{11}$$

In this way with the obtained values of the lateral resistance qkr, compared with the values of resistance (Table 1 – Guide 347), we can conclude if the track has provided stability and whether it is necessary to install the devices against lateral displacement of tracks.

2.2 Calculation of track stability with the German Railways method

This method for calculating track grid stability is applied quite often in practice and is based on formulas of Dr. Meier (1937). It is based on calculation of critical temperature values, i.e. the difference between the neutral (required) temperature and the buckling temperature. Critical temperature track increment is calculated by the equation:

$$\Delta t_{crit} = \sqrt{\frac{8.7 \cdot I_{HK} \cdot q}{\alpha^2 \cdot (2 \cdot A)^2 \cdot E \cdot f_x}} \tag{12}$$

For the curved track, the equation is:

$$\Delta t_{crit} = -\frac{8 \cdot I_{HK}}{\alpha \cdot 2A \cdot R \cdot f_x} + \sqrt{\left(\frac{8 \cdot I_{HK}}{\alpha \cdot 2A \cdot R \cdot f_x}\right)^2 + \frac{16 \cdot I_{HK} \cdot q}{\alpha^2 \cdot (2A)^2 \cdot R \cdot f_x}} \tag{13}$$

The value of force (in both rails) which results in track buckling is calculated by the equation:

$$P_0 = \alpha \cdot \Delta t_{crit} \cdot E \cdot 2A \tag{14}$$

Length of the rail buckling is calculated by the equation:

$$L = 3 \cdot \pi \cdot \sqrt{\frac{2 \cdot E \cdot I_{HK}}{P_0}} \tag{15}$$

Critical lateral displacement of rails is calculated with the formula:

$$f = 8.7 \cdot q \cdot \frac{E \cdot I_{HK}}{P_0^2} \tag{16}$$

The calculus is carried out when we enter basic information about the material (modulus of elasticity E and coefficient of thermal extension of steel rail α) and the selected type of rail (the cross–section rails A, etc) in the expressions above. The size of the initial deformation of f_X, depends on railway management rules, and is usually 2.0 or 2.5 cm. Based on an assumed lateral resistance track (q), calculation is getting the value of the critical temperature at which the track buckling and the value of the force required for track bukling.

2.3 Assessment of track grid stability (safety) according to UIC 720

In March 2005 a UIC 720 leaflet UIC 720, which contains guidelines for use, installation and control of ballasted track with continuous welded rail (CWR), as well as the new safety criteria for their stability, was issued. It replaced the older leaflet on the same subject, and contains the new improved knowledge about the forces in the continuous welded rail, that have been acquired on basis of numerous tests, theoretical research, and many years of practical experience on railway management, as well as the results of work on this subject carried out by the Committee ERRI D 202.

Structure type and number	Curve radius (mm)	Sleepers (tan φ)	Lateral ballast resistance (kN/m')	Torsional resistance of fastening (kNm/rad/m')	Misalignment (mm)
Secondary-line track (4)	600	Concrete friction 0,86	10/10, 15/12, 20/16	75, 150	14/18/22
Secondary-line track (5)	600	Wooden friction 1,2	7/7, 10/10, 15/12	150, 250	14/18/22
Freight-line track (6)	300	Corrective friction 0,86	10/10, 15/12, 20/16	75, 150	14/22/30
Freight-line track (7)	300	Wooden friction 1,2	7/7, 10/10, 15/12	150, 250	14/22/30

Figure 1 Different track properties

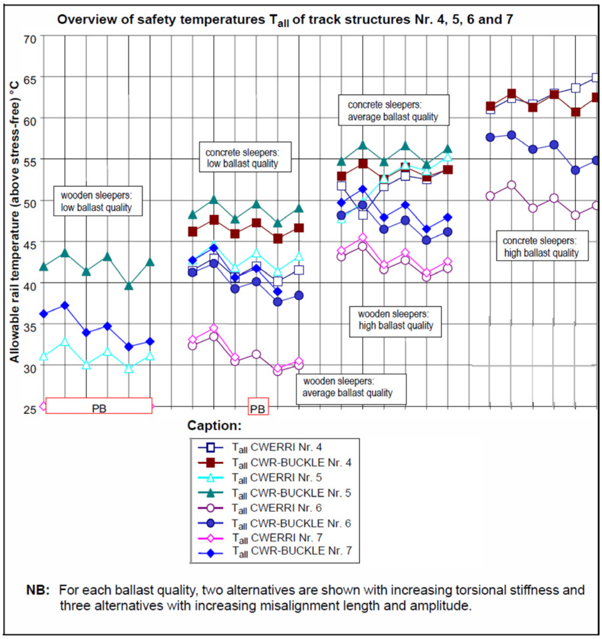

Figure 2 CWERRI and CWR–BUCKLE results for safety temperatures for secondary–line and freight–line tracks.

Safety aspects of the methodology and the introduction of the safety concept based on the buckling, as well as risk assessment represent an improvement to the previous leaflet on the same subject. The safety concept methodology is based on conducted case studies. New safety criterion is formulated based on the minimum and maximum buckling temperature (T_{bmax} and T_{bmin}.), i.e. estimating the possibility of occurrence of buckling.

As part of the case studies, numerical models were made (using CWERRI and CWR–BUCKLE programmes) for various examples of line types (high speed, major, minor, freight), concrete and wooden sleepers, and the parameters were chosen to reflect the maximum temperature for 50 % of the buckling energy levels. A variety of different scenarios (parameter values and the construction track – Figure 1) shows the allowable temperature of rails (Figure 2).

3 Example of the CWR stability calculations

For example, in calculation methods, for track stability, in accordance to the above mentioned regulations applicable in BiH, the same track structure (rails UIC 60, elastic fastenings, concrete sleepers) will be chosen as the one for the UIC 70 regulations example. Main railway lines in BiH, according to their characteristics (radius of curvature, speed) are in accordance with the UIC 720 class track for freight traffic (Freight line track 6 – table 1), and for speed of $v \geq 80km/h$ and $R_{min} = 300m$.

Resistance values (lateral, longitudinal), track structure or its individual elements, as well as values of maximum, minimum and neutral (required) temperatures will be adopted in accordance with applicable Guidelines 330. Input data and calculation results of stability track according to the Mischenko and DB methods, for the curved track (R=300m), are shown in Table 1.

Table 1 Input data and calculation results.

Input data		**Mishchenko**	**DB**
T_{min}=-30°C	$E=2.1x10^7N/cm$	F_{max}^{sum}=789kN	ΔT_{crit}=78,6°C
T_{max}=65°C	$\alpha=1,15\ x10^{-6}N/cm$	P_{cr}=1893kN	P_{cr}=2917kN
T_r=22,5°C	$I_y=513cm^4$	q=117 N/cm	
ΔT_s=42,5°C	$I_{HK}=2565cm^4$	$L_{cr.}$=2348cm	L_{cr}=1207cm

Based on the maximum and minimum temperature values (T_{max} and T_{min}), that are characteristic for the BiH territory, the value of the required temperature ($T_r = T_{average}$+5°C) is determined. Based on the temperature difference between the required and the maximum summer temperature (ΔT_s), according to the equation of prof. Mishchenko, certain values of maximum force in a single rail (F_{max}), the value of critical buckling force in both rails (P_{CR}), the length of the critical buckling wave (L_{CR}) and the minimum value of the lateral resistance track (q) are calculated.

The obtained (by Mishchenko) minimum value of the lateral resistance track (q) and the size of the lateral displacement rails (f_x = 2.0 cm), according to the German Railways method (DB), is determined by the critical temperature at which the track buckles (ΔT_{crit}).

It should be noted that in these calculation methods the load of the vehicle was not taken into account. In practice, using the calculation method DB any additional stress (caused by vehicle acceleration, braking) is taken into account by using the so–called 'safety temperature'(and amounts to 20°C), value of which reduces the value of the critical temperature. That is, when taking into account the stress, the value of safe temperatures, according to the DB method is about 59°C.

4 Conclusion

Based on the results of the calculations it can be concluded that there are some differences in the results obtained by different methods. The differences recommended by the UIC-720 are a little lower (up to 15%) compared to the method according to the applicable regulations in Bosnia (Mishchenko – DB) that are significant and mount to up to 50%. If we compare the results of each calculation, using all methods, we can conclude the following:

- the results of calculation done by DB method (T_{all}=59°C) are approximately similar to calculation results derived by the method of CWR–BUCKLE (T_{all}=54–58°C),
- in comparison to the calculation results gotten by CWWERi model (T_{all}=48–52°C), the Mischenko method gives somewhat lower values of safe temperature (T_{all}=42.5°C, and are still a lot lower than the CWR–Buckle model results.

These calculation results, in accordance with the Mischenko method, to ensure the stability of the track against buckling, require large values of lateral resistance track, which can in most cases provide, for the curved tracks (R‹500m), only the installation of additional devices against lateral displacement of sleepers. Also, there are considerable differences in the values of certain parameters, such as the values of the lateral resistance of the track buckling amounts that are up to 20 kN/m' (according to UIC), while according to the 'Guidelines 347' maximum allowed value is 16 kN/m' for the track with wooden sleepers (with devices on every sleeper). For concrete sleepers, the maximum recommended value isf 8.8 to 10.6 kN/m', while for concrete sleepers with devices there is no recommended value.
Although, obviously, the calculation of track stability by the Mischenko method in combination with the recommended parameter values for safety, questions the justification of installing devices for resistance increment of track movement, as well as dilatation devices. From all the above, it can be concluded that it is necessary to make a detailed analysis of the existing regulations for the calculation of the stability track, or make a calculation model based on the results of a recent research (parametric analysis) carried out by the UIC and current practices for specific conditions present on the BiH railroad network.

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