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OPTIMIZING RAIL INTEGRITY – DEFINING NEW STRESS-FREE TEMPERATURE INTERVALS FOR CONTINUOUSLY WELDED RAIL (CWR)

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Abstract

For continuously welded rail (CWR), according to the Romanian technical prescription in force (Railway Instruction no.341), the final stress-free temperature interval is set between 17 ºC and 27 ºC. Admitted temperatures in a rail that is part of a CWR are between -30 ºC and +60 ºC. There is only one situation when the Romanian Railway Company deviated from the prescribed CWR stress-free temperature interval prescribed by the Railway Instruction No.341. Thus, for a project on a European Corridor located in a "hot" plain in the east of the country, where the prescribed stress-free temperature interval was defined between 20 ºC and 30 ºC. However, there is an increasing concern of the Regional Railway Maintenance Departments from all over the country that this interval should be adapted to their regions and their climate. The aim of the work is to define prescribed stress-free temperature intervals according to the climatic regime, i.e. according to the maximum temperatures, but also the maximum temperature differences. The work also considers the influence of seasonal warm and cold winds, as well as other parameters that can influence the behavior of the CWR.

Keywords: continuously welded rail (CWR), rail temperature, stress-free temperature

1 Introduction

Romania is the 12th country in terms of area in Europe with a high ratio of the variation of relief forms to surface area. But not only the relief is varied, but also the climate.
Romania's geographical relief is characterized by four elements: variety, proportionality, complementarity, and symmetrical layout. The Romanian Carpathians extend like a ring, closing a large depression in the center of the country, that of Transylvania. Outside the Carpathian Mountains is a ring of hills, which in turn is surrounded by plains. The Danube Delta is the lowest region of the country. All these forms of relief present their particularities, both in terms of maximum and minimum air temperatures as well as temperature variations in all four seasons.
It was a necessity that the railway network traverses all these landforms. The distribution of railway lines in Romania is circular with radial links. There are two rings (one inner and one outer) and 7 radial lines as can be observed in Fig. 1. Most of the tracks are installed as continuously welded rails (CWR).

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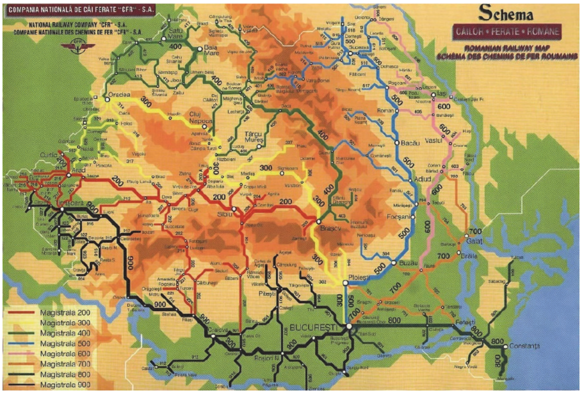

Figure 1 Main railway lines in Romania

For Romanian railways, the definitive fixing temperature (t_{fd}) of continuously welded rail (CWR) is set between 17 °C and 27 °C inclusive, for all rail types, in alignment and curves, on wooden or concrete sleepers, with direct or indirect fastening [1].

Under normal conditions of construction and maintenance, the CWR permanently fixed within t_{fd} limits is insured against buckling, breaking of rails and fish-bolts, whatever the subsequent temperature may be. The temperature t_{fd} is also called a "neutral temperature" (t_n).

The fixing temperature of CWR, located outside the limits established for t_{fd}, is considered provisional fixing temperature (t_{fp}). Before the temperature increases by more than Δ›t = 43 °C or decreases by more than Δ›'t = 57 °C from the provisional fixing temperature, destressing of the CWR shall be performed.

In Romania, the rail temperature interval is established between $t_{s\ min}$ = -30 °C and $t_{s\ max}$ = +60 °C. The prescribed interval of fixation is shown in eqn (1) and Fig. 2:

$$t_{s\ max} - \Delta' t \le t_n \le t_{s\ min} + \Delta'' t \tag{1}$$

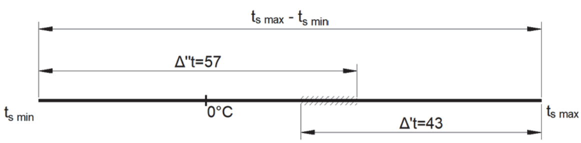

Figure 2 Defining the prescribed CWR fixing temperature interval

To determine the correspondence between air and rail temperatures, in the past (the 1960s), systematic measurements were carried out day by day, in stations located throughout the country, over several annual cycles. From the statistical processing of measurements, the following conclusions were drawn:

1) The relationship between air temperature (t_a) and rail temperature (t_s) is:

$$t_s = t_a \tag{2}$$

for negative air temperatures, and:

$$t_s = 1.0615 \cdot t_a + 0.00874 \cdot t_a^2 \tag{3}$$

for positive air temperatures.

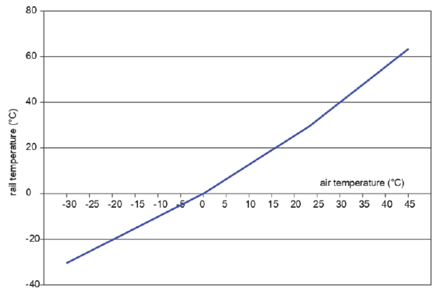

Figure 3 The graphic representation of these relationships is shown in Fig. 3.Rail temperature and air temperature relation according to old data

2) The frequency curves of the recorded values are asymmetric, for both air temperature and rail temperature. The recorded maxima are below the average value, which indicates a low spread of recordings for lower temperatures and a rather pronounced dispersion of records corresponding to maximum temperatures.
3) Extreme values, for both maximum and minimum temperatures, were obtained for relatively small areas of the country.

Although in practice the instructional provisions are respected and the final fixing temperature is between 17 °C and 27 °C, rail breaks occur in the winter on the lines in the submontane areas, and speed restrictions are introduced on the lines in the southern plain area in the summer, due to the risk of loss of track stability.
In the paper [2] it is mentioned that it is necessary to increase the limits of the temperature range in the rail for the definitive fixation of the CWR by 5 °C (compared to the prescriptions in force). This modification reduces the risk of loss of stability and ensures better conditions for working with heavy-track machinery.
Knowledge of the existence of temperature differentiations by region would allow problems related to CWR to be treated differently. In harsher areas, the final fixing of the track can be done at the lower end of the regulated range for such temperatures, and in high temperature areas the final fixing can be done at the upper end of the range.
Research to determine the ratio between air and rail temperatures has also been done at other railway administrations [3]. The rail temperature is ideally determined from direct measurements and extrapolation of annual records. The method of determining the maximum rail temperature based on the maximum ambient temperature data is also in use:

$$t_{s,max} = t_{a,max} + \Delta_1 \tag{4}$$

where:
$t_{s\,max}$ – maximum rail temperature [°C]
$t_{a\,max}$ – maximum air temperature [°C]
Δ_1 – corrective factor relating to maximum rail temperature [°C].

The corrective factor is generally in the range of 15 - 20 °C.
The exact relationship between rail temperature and air temperature is complex and depends on a certain number of parameters: wind speed, orientation of the rail relative to the sun, geographical location of the line, relief, etc. [5]. During a hot summer day, the air temperature in Europe can reach values in the range from 35 to 45 °C. Due to this fact, the maximum rail temperature can be in the range from 50 to 60 °C. Esveld [4], considers Δ_1 to be about 17 °C.

Field data on minimum rail temperatures is limited. Due to ground freezing, wind, etc., the minimum rail temperature may be lower than the minimum air temperature. The following equation is proposed for the minimum rail temperature:

$$t_{s,min} = t_{a,min} - \Delta_2 \quad (5)$$

where:

$t_{s\ min}$ – minimum rail temperature [°C]
$t_{a\ min}$ – minimum air temperature [°C]
Δ_2 – corrective factor related to minimum rail temperature [°C].

The corrective factor is in the range from 0 °C to 5 °C. Esveld [4], provides two connecting relationships between rail temperature and air temperature, depending on the weather, sunny or cloudy, but only for positive temperature values (Fig. 4).

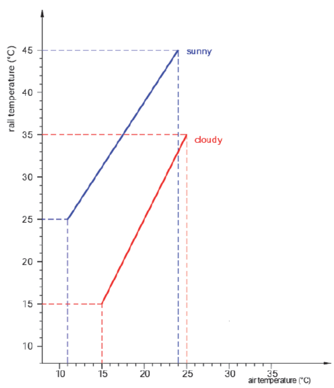

Figure 4 The relationship between rail and air temperature according to Esveld

There are differences between the two relationships. Esveld's bond relationship between the two temperatures treats only the case of positive temperatures and is linear. It is interesting that a differentiation is made between sunny and cloudy weather. Similar results are obtained only in the upper zone of positive temperatures, considering in the case of Esveld a mean curve of the two cases.
In reality, the temperature varies irregularly, but still some periodicity is observed. Such are daily variations, within narrower limits, and seasonal variations, within wider limits. The maximum temperature difference is recorded between the highest temperature in summer and the lowest in winter. During this time, there are daily variations between certain limits.
If temperatures are recorded daily, at the same time, maximum at midday and minimum in the morning, it will result in the appearance of temperature variation during the 12 months of the year. This temperature variation could fall between two curves: the maximum daily temperatures curve and the minimum daily temperatures curve (Fig. 5). There are oscillations between these two curves every hour, with greater differences between morning and midday hours.

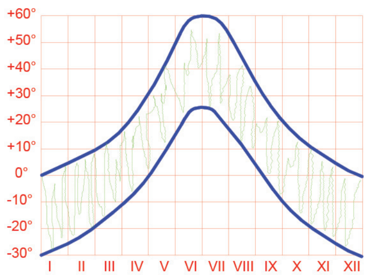

Figure 5 Maximum and minimum daily temperatures curves

2 Analysis based on new temperature measurements

The National Institute of Meteorology, Hydrology and Water Management conducted a study to analyze the influence of certain meteorological parameters on the railway network and especially on the contact line [6]. Meteorological parameters whose characteristics have been analyzed and whose territorial distribution has been achieved, refer to wind characteristics, frost deposits on air conductors and extreme values of air temperature on the territory of Romania. Data from 106 meteorological stations were processed. For each meteorological parameter, 12 maps were made, corresponding to the main lines and railway lines. For the present work, the distributions on railway sections of the maximum and absolute minimum air temperatures were of interest. Below are the processing for two mains lines:

- Main Line 200: Brașov - Podu Olt - Sibiu - Vințu de Jos - Simeria - Arad - Curtici (470 km). This railway track starts from a depression area, passes through a submontane area, then a hill area and afterwards enters the Romanian Western Plain (Table 1).
- Main Line 800: Bucharest - Ciulnița - Fetești - Medgidia - Constanța - Mangalia (268 km). This railway track located in the southeast of Romania crosses only plain areas, passes over the Danube and reaches the Black Sea (Table 2).

The processing of measurements made for one year, in 10 points evenly distributed throughout the country, were statistically processed (Fig. 6), and led to the following conclusions regarding the relationship between rail temperature and air temperature:

- for air temperatures below 20 °C, the temperature in the rail is practically equal to the air temperature.

$$t_s = t_a \tag{6}$$

- for air temperatures above 20 °C, the relationship between the two temperatures is:

$$t_s = 0.05 \cdot t_a^2 - t_a + 20^\circ \tag{7}$$

The relation between the two temperatures, based on equation (6) and (7), can be observed in Fig. 7.
Based on the extreme air temperatures, the rail extreme temperatures will be determined with eqn (6) and (7), and then the limits of the prescribed fixing interval will be established. In Table 1 can be observed that the prescribed fixing temperature intervals resulting on most railway sections have the upper limit approximately 5 °C lower than the upper limit of the prescribed fixing temperature interval by Instruction 341 in force.

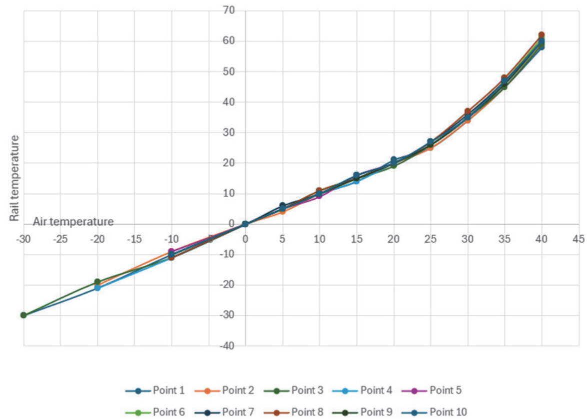

Figure 6 The concentrated results of the measurements

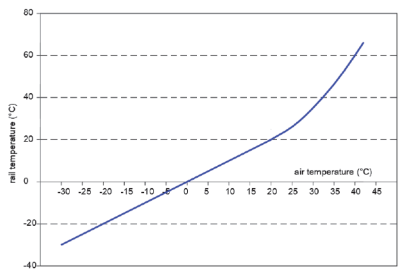

Figure 7 Rail temperature and air temperature relation according to new data

Table 1 Data processing for Main Line 200

Section	Length [km]	$t_{a\,max}$ [°C]	$t_{a\,min}$ [°C]	$t_{a\,max} - t_{a\,min}$ [°C]	$t_{s\,max}$-43° [°C]	$t_{s\,min}$+57° [°C]
Brașov - Ghimbav	9.4	37.0	-32.5	69.5	8	24.5
Ghimbav - Valea Homorod	24.8	36.5	-28.0	64.5	7	29
Valea Homorod - Perșani	11.2	38.0	-28.0	66	11	29
Perșani - Podu Olt	82.0	39.0	-34.0	73	14	23
Podu Olt - Veștem	11.8	38.0	-32.0	70	11	25
Veștem - Turnișor	13.6	40.0	-32.0	72	17	25
Turnișor - Tilișca	31.6	38.0	-29.0	67	11	28
Tilișca - Miercurea Sibiului	17.4	39.0	-29.0	68	14	28
Miercurea Sibiului - Cunța	8.5	40.0	-34.0	74	17	23
Cunța - Răhău	7.2	41.0	-34.0	75	20	23
Răhău - Vințu de Jos	15.0	42.0	-34.0	76	23	23
Vințu de Jos - Șibot	14.6	41.0	-34.0	75	20	23
Șibot - Mintia	44.4	40.0	-32.0	72	17	25
Mintia - Pietriș pe Mureș	43.5	39.0	-32.0	71	14	25
Pietriș pe Mureș - Bârzava	38.1	40.0	-32.5	72.5	17	24.5
Bârzava - Păuliș	32.6	40.5	-32.5	73	19	24.5
Păuliș - Sofronea	37.3	40.5	-30.0	70.5	19	27
Sofronea - Curtici	7.3	40.5	-28.0	68.5	19	29

For Main Line 200, on submontane areas (the shaded cells in Table 1) it is recommended that the final fixing temperature should be between 17 °C and 23 °C.
In Table 2 can be observed that the prescribed fixing intervals resulting on most railway sections have an upper limit approximately 5 °C higher than the upper limit of the prescribed fixing interval by Instruction 341 in force.
For Main Line 800, in plain areas with intense solar radiation (the shaded cells in Table 2) it is recommended that the definitive fixing temperature should be between 25 °C and 30 °C.
A prescribed fixing range of more than 15 °C makes it difficult to choose a permanent fixing temperature. To eliminate the risks of loss of stability in summer, or risks of rail breakage in winter, two fixing temperatures may be imposed:

- an autumn setting temperature between 17 °C and 25 °C
- a spring setting temperature between 25 °C and 30 °C.

Table 2 Data processing for Main Line 800

Section	Length [km]	$t_{a\,max}$ [°C]	$t_{a\,min}$ [°C]	$t_{a\,max}$-$t_{a\,min}$ [°C]	$t_{s\,max}$-43° [°C]	$t_{s\,min}$+57° [°C]
București Nord – Pantelimon	16.3	41.0	-32.0	73	20	25
Pantelimon - Dâlga	69.0	41.0	-32.0	73	20	25
Dâlga - Jegălia	43.0	41.5	-32.0	73,5	22	25
Jegălia - Fetești	18.0	41.0	-28.0	69	20	29
Fetești - Ovidiu	8.0	40.0	-25.0	65	17	32
Ovidiu - Dunărea	8.0	41.0	-25.0	66	20	32
Dunărea - Cernavodă	4.0	42.0	-25.0	67	23	32
Cernavodă - Mircea Vodă	14.0	41.0	-23.0	64	20	34
Mircea Vodă - Medgidia	10.0	40.0	-23.0	63	17	34
Medgidia - Valu lui Traian	25.0	40.0	-25.0	65	17	32
Valu lui Traian - Constanța	10.0	39.0	-25.0	64	14	32
Constanța - Mangalia	43.0	39.0	-24.0	63	14	33

3 Conclusion

In conclusion, it is necessary to define new prescribed ranges of CWR fixation, based on recently measured extreme air temperatures and establish their applicability to different regions of the country. A correctly defined prescribed fixation interval is important to ensure track stability and allows safe intervention on CWR.
Redefining the prescribed fixing intervals is also necessary in other European countries with a uniform climate, in the current context of rapid climate change.
Considering the results of the entire research, the autors intend to propose to the National Railway Society of Romania, the modification of the fixing temperatures for CWR on the railway sections where there are problems with the continuously welded track due to temperature variations.

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