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RESEARCH ARTICLE

New Definition of Neutral Temperature in Continuous Welded Railway Track Curves

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Abstract

Changes in axial force for control and prevent track buckling are vital to know the natural temperature. Thermal neutral temperature actually refers to the railway tracks where there is no pressure and no traction, or in other words the axial force is zero in rails. In this paper, the new definition for variations in neutral and float temperatures in Continuous welded Rail (CWR) is proposed as a function of media temperature, lateral track stiffness (or lateral displacement of the track). The neutral temperature is selected with respect to minimum and maximum temperatures in the region where the railway installed.

In this research, a case study with field tests has been used and computer modeling to prove this purport(idea) for a curve of radius 250 m with a length of about 145 m. In field test explained the relation between rail and media temperature and this item helps to modeling track to comprehend when lateral track resistance to be change, variation in neutral temperature how to change.

Keywords

neutral temperature, buckling rail tracks, axial rail forces

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1 Introduction

Because of the existence of gap junctions in traditional ballast tracks, they could be longitudinally displaced without any axial forces [1]. In contrast to these tracks, due to the removal of gaps in welded tracks, axial force occurs, which is a function of railway cross-section of rails, modulus of elasticity, thermal expansion coefficient, and temperature variations relative to welding temperature.

Railway neutral temperature during railway construction as well as repair and maintenance operations should be selected and controlled so that the minimum compressive force is applied to the track in summer to prevent track buckling and the tensile force in the tracks in winter does not cause any failure nor breaking in tracks [2].

When railway gaps are welded (converted into CWR), the welding temperature of tracks is considered neutral temperature, at which there is no axial force. Knowing the railway neutral temperature in railway tracks could not only make it possible to calculate the axial force in the rails, but also help estimate the critical temperature and appropriate temperature for repair and maintenance operations.

Selecting appropriate time for welding and thus neutral temperature is of high importance and depends on the maximum and minimum regional temperature. Since compressive axial force occurs in the rails at temperatures higher than neutral temperature, in addition to the railway cross-section resistance criterion, lateral stability criterion of track structure should be also considered to prevent track buckling. Thus, in the technical literature, most of the experts believe in considering neutral temperature as follows [4], [3]:

$$T_{neutral} = (T_{max}+T_{min})/2 + T_{st}$$

where Tst is often positive and selected about 5°C. Previous studies [5],[6] have shown that, in straight tracks, neutral temperature is almost constant and only slightly increases in summer and decreases in winter. Further, the traffic crossing the track can change neutral temperature. Department of Transportation Federal Railroad Administration (FRA) collected the railway temperature and axial force variations during 9 months on FAST track by installing strain gauges and thermometers.

The results showed that, in the first 3 months of the measurement (end of summer), when no traffic was crossing the track, neutral temperature remained relatively constant. In the next 6 months (fall and winter), after traffic crossing, neutral temperature decreased by about 20°F [7]. In fact, no reason was proposed for this reduction and also ratios of traffic share and temperature variations from the reduced neutral temperature were not specified. Also, for the curved tracks, only the railway axial force variation due to the track lateral displacement was discussed and the reason for neutral temperature variations in the curves was not presented. It was evident that neutral temperature remained constant in CWR tracks. In this article, the reason of neutral temperature variations is defined and the results of the field tests on a 250 m CWR curve with the length of about 145 m are presented. Then, the results of the numerical modeling of this curve are proposed.

First, the relationship between railway temperature and environmental temperature is discussed.

2 Parameters that important in variations of neutral temperature

The relationship between air temperature and railway temperature depends on various parameters such as track position, sunny weather, wind blowing, air humidity, rainy and cloudy weather, etc.

The experimental relation proposed by Hunt (1994), which is

$$T_{rail} = 1.5 \times T_{air} \tag{1}$$

$$T_{rail} = T_{air} + 17 \tag{2}$$

used merely for high temperature of rails, is as follows Eq.(1, 2).

In 2001, Esveld compared the railway temperature in sunny and cloudy weather and then compared it with Hunt's experimental relation [3] (Fig 1).

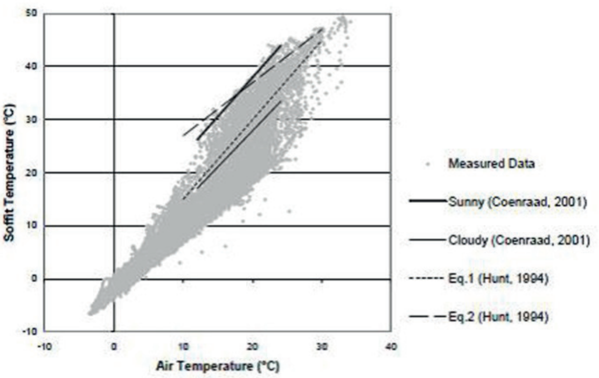

Fig. 1 The relation between air and rails temperature on sunny and cloudy weather

Researchers have also performed many studies to compare the accuracy of measurement instruments between air and railway temperatures.

Mr. Chapman predicted the air and rail temperatures using a high-quality thermal camera. At first, it was done to predict the icing of roads and also thermal distribution at railway cross-section [13], [14].

Currently empirical relations have been utilized for determining the rail temperature from the ambient temperature. F. Birmann and F. Raab [9] concluded that there was an accumulation of permanent lateral track deformations due to reversal of temperature over a period of time, which increases buckle potential. Rail Neutral Temperature (RNT) tends to shift downward over time due to the effects of traffic, rail movement and track maintenance. Longitudinal stiffness plays an important role in controlling neutral temperature variation. In curves, lateral stiffness is very important. Pandit [9] described the theoretical formula of neutral temperature using longitudinal strain in rail. (Equation 3)

$$TN = TL + \frac{1}{\pm}\left\{\left(\frac{\partial u}{\partial x}\right) + \frac{1}{2}\left(\frac{\partial v}{\partial x}\right)^2 + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2\right\} \tag{3}$$

On a curve of radius R, if the track is shifted by an amount equal to C, the above formula can be changed to: (Equation 4)

$$TN = TL + \frac{1}{\alpha}\left\{\left(\frac{\partial u}{\partial x}\right) + \frac{1}{2}\left(\frac{\partial v}{\partial x}\right)^2 + \frac{C}{R} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2\right\} \tag{4}$$

$$\frac{\partial u}{\partial x}, \frac{\partial v}{\partial x}, \frac{\partial w}{\partial x} : \text{Tensile strains in x direction}$$

TN – Neutral rail temperature

TL – rail laying temperature

α – Coefficient of elasticity

From equation (4), it is clear that if the displacement u,v and w cause compressive strains neutral temperature (TN) will be lower than the laying temperature (TL). Rail longitudinal movement can be caused by train action (acceleration and braking) or wheel rolling action. Track lateral shift may occur due to hunting motion of bogie or curving. Non-uniform vertical settlement of ballast caused by vertical wheel load can generate longitudinal strain in the track, which further changes the rail neutral temperature.

3 measurement rail and ambient temperature in real railway

Tests are done in Boneh-Koh station in city of Garmsar in Iran (The curve track with 250 meter in radius and 145 meters in length) (Fig.2).

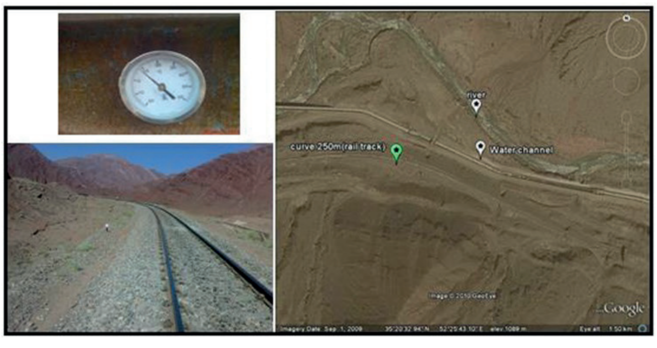

Fig. 2 location of the Field test

A mercury thermometer has been used for measuring the air temperature. Figure 3 indicates the relation between rail temperature and air temperature measured at 7 months of the year.

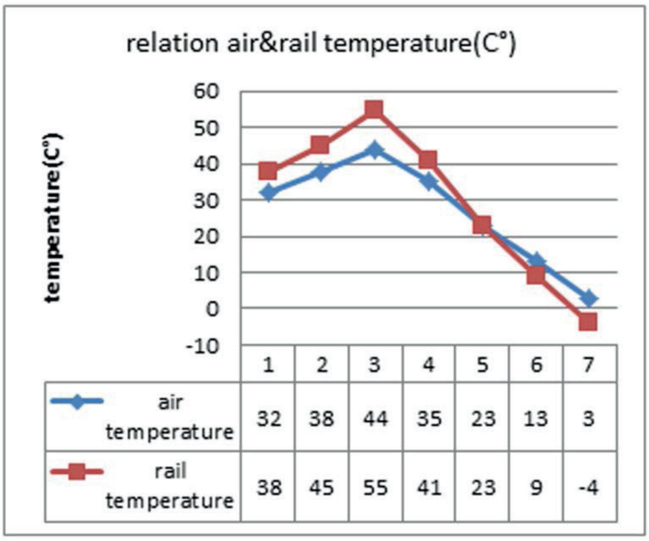

Fig. 3 The relation between rail temperature and air temperature measured at the year

4 Variable or floating neutral temperature

In the curves, lateral displacement of railway track is a function of lateral stiffness. Since the track lateral supports are not solid, the length of railway track is practically increased and move toward the outside with temperature increase. This displacement decreases the rail axial force and, in other words, increases the neutral temperature.

Neutral temperature is variable in the rails, especially in the curves where neutral temperature variation is more obvious. In order to prove this claim, first, a more accurate definition of neutral temperature is provided. Neutral temperature is the temperature at which axial force is zero in the rails and the rails are installed and welded. So, when railways are being installed and welded, no longitudinal force is established in the rails. Now, assume that the track lateral stiffness is so high that inhibits its lateral displacement; as a result, when the temperature is increased or decreased, an extreme axial force occurs, since the track cannot displace and the neutral temperature becomes the same as railway installation temperature, but if the track lateral stiffness is so low (close to zero), then by increasing or decreasing the temperature, the track moves freely and no axial force occurs. It is important to note that, since the axial force is zero in the rails, in fact, the new temperature is introduced as the neutral temperature. Therefore, in the curves, the neutral temperature is variable due to lateral displacement, which is known as neutral temperature caused by track lateral displacement (variable neutral temperature).

The relationship between rail temperature and neutral temperature can be observed in Figure 4, which is obtained from the field results. For example, when the rail temperature is 55°C, the neutral temperature is about 30.1°C, which is 3.5°C higher than the installation temperature (initial neutral temperature of 26.5°C). It should be noted that, for measuring the neutral temperature in the curve, a new method is used [11].

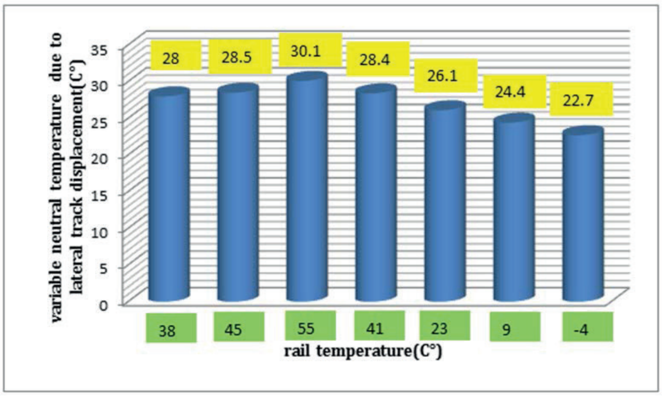

Fig. 4 Neutral temperature changes

Variable neutral temperature is a function of the lateral track stiffness. With decreasing lateral track stiffness there will be more change in neutral temperature. That process of change in neutral temperature can be seen in Fig.6. This diagram is extracted by a numerical modelling of one curve with a radius of 250 m, 145 m in length and variable lateral stiffness (Figure 5) [11]. For normal concrete sleepers (lateral resistance 67 kN/m) by changing in rail temperature ΔT = +45°, the natural temperature rises about 10 degrees Celsius.

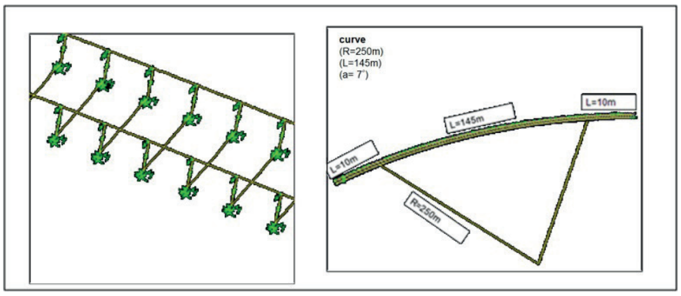

Fig. 5 Numerical model of curve with various lateral stiffness and rail temperature

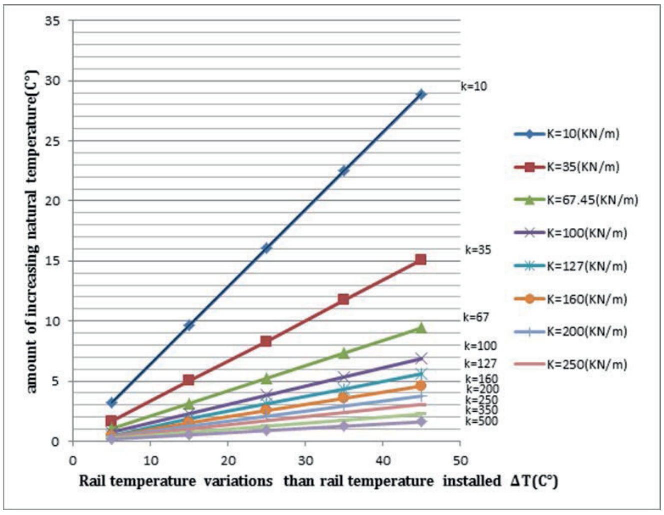

Fig. 6 The amount of increasing the neutral temperature in different lateral track Stiffness

For the expression of variations in neutral temperature, the definitions of temperatures and their changes should be presented as follows:

$$\Delta T_i = T_i - T_{weld} \quad (5)$$

$$\Delta T_{dis} = T_{weld} - T_{var} \quad (6)$$

$$\Delta T_{var} = \Delta_{Ti} - T_{var} \quad (7)$$

T_{weld} – rail temperature during welding

T_i – the moment rail temperature

T_{var} – variable or floating neutral temperature of rail in curves

Δ_{Ti} – the difference in rail temperature during welding

ΔT_{dis} – the real variations rails neutral temperature (temperature difference is calculated based on the change in rail axial force)

ΔT_{var} – value increases or decreases neutral temperature of the selected Δ_{Ti}

In this study, the lateral track stiffness considered from the amount 10, 35, 67 kN/m (in track with normal sleepers [12]), 100, 127 (track with friction sleeper, [12]), 160, 200, 250, 350, 500 and infinite (imaginary track) and the moment of rail temperature has been changed with the steps 5° than rail temperature during welding up to the 45° (plus temperature during welding). The purpose of such an analysis was calculating the axial force in case model with considering lateral track displacement and hence obtained change neutral temperature than Δ_{Ti}. Thus amount of increase or decrease neutral temperature can be calculated than Δ_{Ti}.

In the table (1), the mentioned stiffness values in the previous paragraph are presented, the temperature variations are calculated in two case, first the rail temperature is +5° more than (Δ_{Ti}) the rail temperature in installation time, and the second case, the rail temperature is +45° more than (Δ_{Ti}). The result of calculations are presented in this table such as: the displacement of the centre of curve, axial force generated in rail, the amount of neutral temperature of variations (ΔT_{var}), the real rail temperature variations (ΔT_{dis}), presented rate of the initial variations rail temperature and variations real rail temperature (ΔT_i) /(ΔT_{dis}).

In table (1), it can be seen that by increasing the rail temperature to +45° C more than (ΔT_i) the rail temperature in installation time, the variation of neutral temperature is zero for the track with infinitely stiffness. This value can be increased by reducing the lateral stiffness. For normal sleeper, neutral temperature increase 9.43° C.

The result of calculations shows that the ratio (ΔT_i) / (ΔT_{dis}) is the constant in the different temperature variations (with different ΔT_i). In Fig.(7) this ratio is presented versus the lateral stiffness. [11]

Table 1 Neutral temperature of variations caused by the lateral displacement of railway track

K (lateral stiffness)kN/m	T_i(C°)	Displacement middle of curve (mm)	Axial force KN	$T_{dis} = T_{weld} - T_{var}$	$T_{var} = T_i - T_{var}$	(Ti) /(Tdis)
10	5	10.5	-35.32	1.793	3.2	0.357
35	5	5	-65.67	3.33	1.67	0.665
Normal(67.39) sleeper	5	3.3	-77.91	3.95	1.05	0.79
100	5	2.4	-83.57	4.24	0.76	0.847
Friction sleeper (127.11)	5	2	-90	4.57	0.43	0.875
160	5	1.6	-90.2	4.58	0.42	0.898
200	5	1.3	-90.4	4.59	0.41	0.916
250	5	1	-91.92	4.66	0.34	0.932
350	5	0.8	-93.7	4.75	0.25	0.95
500	5	0.5	-95.1	4.83	0.17	0.96
8	5	0	-98.52	5	0	1
10	45	94.7	-317.099	16.09	28.91	0.357
35	45	48	-589.5	29.91	15.09	0.665
Normal(67.39) sleeper	45	29.6	-700.85	35.57	9.43	0.79
100	45	21.4	-751.3	38.13	6.87	0.847
Friction sleeper (127.11)	45	17.4	-776.184	39.39	5.61	0.875
160	45	14.2	-796.24	40.41	4.59	0.898
200	45	11.6	-812.61	41.24	3.76	0.916
250	45	9.4	-826.25	41.93	3.07	0.932
350	45	6.9	-842.49	42.75	2.25	0.95
500	45	4.9	-855.11	43.39	1.61	0.96
8	45	0	-886.73	45	0	1

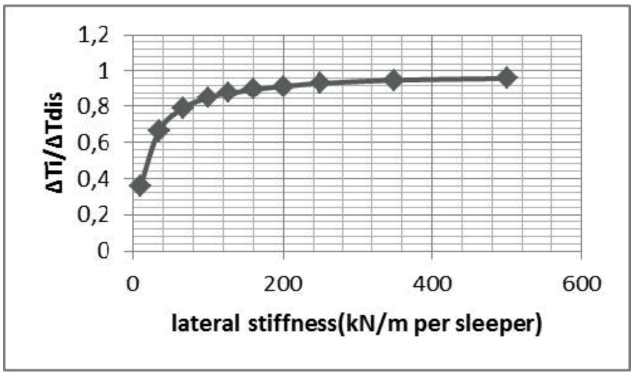

Fig. 7 The variation of the ratio (ΔT_i)/ (ΔT_{dis}) versus the lateral track stiffness

Equation (8) demonstrate relation between neutral temperature and rail temperature with changing the lateral stiffness.

$$TN = T_{rail} - TL \times \left(\frac{\Delta T_i}{\Delta T_{dis}}\right) \quad (8)$$

TN: Neutral rail temperature

TL: rail laying temperature

If the lateral stiffness was infinity (rigid track), amount of $\left(\frac{\Delta T_i}{\Delta T_{dis}}\right)$ equal near one and TN = T_{rail} – TL, but if the lateral track stiffness near zero (imaginary track), amount of $\left(\frac{\Delta T_i}{\Delta T_{dis}}\right)$ equal near zero and TN = T_{rail}

5 Conclusions

- In curves, the lateral displacement of railway tracks is a function of lateral stiffness. Since the track lateral supports are not solid, with increasing temperature, the length of railway track is practically increased and moves toward the outside. The displacement decreases the railway axial force and, in other words, increases neutral temperature.

- Any factor that changes axial force on the track at a certain temperature can change the neutral temperature, such as traffic crossing the track, repair and maintenance operations, lateral and vertical track displacement, etc.
- Calculations show that, for UIC60 rail with maximum tempreature variation of $\Delta T = 45°C$, the neutral temperature on the track with friction sleeper is increased by almost 5.5°C and, for the track with the conventional concrete sleeper, it is increased by almost 9.5°C.
- Results of the selected model analysis show that $(\Delta T_1)/(\Delta T_2)$ ratio is unique per lateral stiffness. Different temperature variations relative to the track installation state is shown by (ΔT_1) and real temperature variations due to variations at the rail neutral temperature is demonstrated by (ΔT_2).

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