COMPDYN 2015
5th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Crete Island, Greece, 25–27 May 2015

TEMPERATURE WARPING AND TRAIN-TRACK DYNAMIC ANALYSIS OF CRTS II SLAB BALLASTLESS TRACK

Jingjing Yang[1] and Nan Zhang[1]

[1]School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, China
E-mail: 12115292@bjtu.edu.cn, nzhang@ bjtu.edu.cn

Keywords: CRTS II slab ballastless track, track slab, temperature warping, additional rail irregularity, dynamic performance of train-track system.

Abstract. *CRTS II ballastless slab track is widely adopted in high-speed railways in China. The influence of temperature induced deformation of CRTS II slab track on the running safety of high-speed trains is an important issue to be considered. With the temperature field of track slab simulated by applying temperature load on the track slab nodes, the warping of CRTS II track slab under overall temperature change and temperature gradient is analyzed. By applying the vertical rail displacements caused by the slab warping as the additional rail irregularities, the dynamic analysis model for the train-track system is established, to analyze the dynamic performance of the train. With the additional rail irregularities caused by slab warping under the most positive temperature difference as excitations, the dynamic responses of the track and the train vehicles, such as the wheel-rail interaction forces, wheel offload factor, reaction forces of fastener, as well as the accelerations of rail and track slab, are calculated, when the train passes on the track at the speed of 250km/h. The results show that the dynamic responses are larger, especially the accelerations of rail and track slab when considering the additional rail irregularities caused by temperature warping of track slab.*

1 INTRODUCTION

The CRTSII slab ballastless track widely adopted in high-speed railways in China is composed of rail, fasteners, track slab, CA (cement asphalt) mortar layer, concrete supporting layer and anti-frozen layer. A standard track slab is 6.45×2.55×0.2m, as shown in Figure 1. The CA mortar layer is 0.03m thick and 2.55m wide. The concrete supporting layer is 0.3m thick and 2.95m wide.

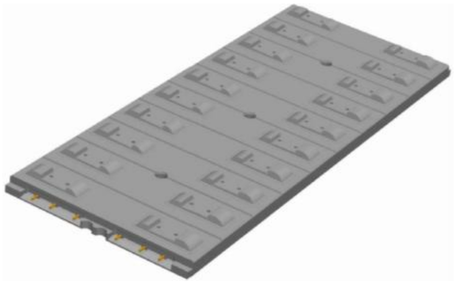

Figure 1: The standard track slab

There are mainly two types of temperature loads to be considered when analyzing the track slab, namely the overall temperature change and the temperature gradient. The temperature gradient of track slab has already been studied thoroughly [1-7], However, the overall temperature change and the temperature gradient happen at the same time, and the concretes at different heights of track slab have different temperature changes to form the temperature gradient in height. The temperature warping of track slab should be caused by the overall temperature change and the temperature gradient.

The warping of track slab under overall temperature change and temperature gradient is analyzed with the temperature field of track slab simulated by applying temperature load on the track slab nodes. By applying the vertical rail displacements caused by the slab warping as the additional rail irregularities, the dynamic analysis model is established, to analyze the dynamic performance of the train-track system.

2 TEMPERATURE WARPING OF CRTS II SLAB BALLASTLESS TRACK

The temperature field of track slab is simulated by applying temperature load on the track slab nodes. The initial temperature is the construction target temperature when track slab has neither temperature difference nor deformation. The final temperature is the measured temperature.

The calculation is simulated with the software Midas. The track slab, the CA mortar and the concrete supporting layer are simulated by solid elements. The track slab and the CA mortar are connected by nonlinear springs which are only compressed. The CA mortar and the concrete supporting layer are concurrent in contact surface. The rail is simulated by beam elements, and the fastener is simulated by the common springs.

The model of a track slab is shown in Figure 2.

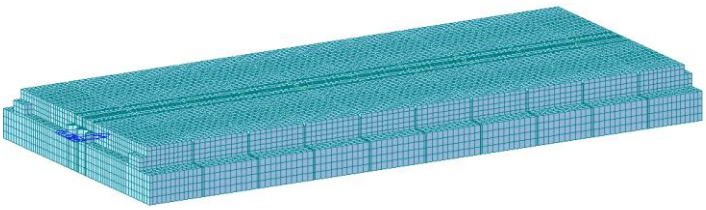

Figure 2: Model of a track slab

The temperature is cited from literature [6] to analyze the warping of track slab during a whole day. The surface temperature, the bottom temperature and the temperature difference of track slab during the whole day are shown in Figure 3. The temperature warping of track slab within 24 hours is shown in Figure 4.

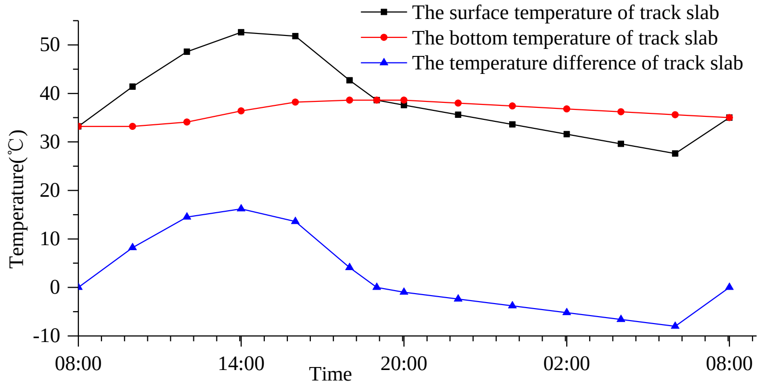

Figure 3: The surface temperature, the bottom temperature and the temperature difference of track slab during the whole day

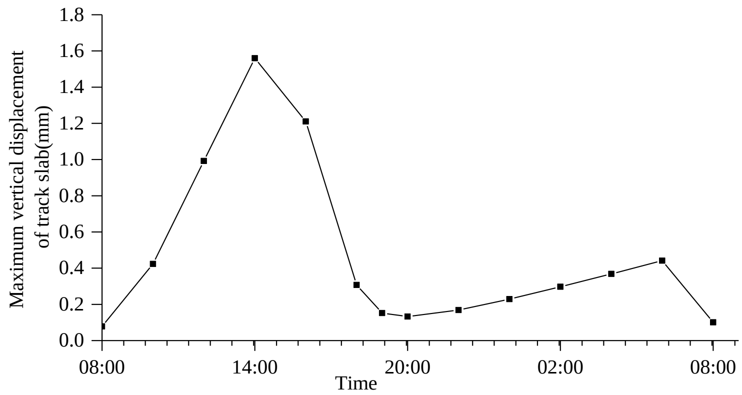

Figure 4: Temperature warping of track slab within 24 hours

The temperature warping of the track slab at the time of the most positive temperature difference and the most negative temperature difference are respectively shown in Figure 5 and Figure 6. The temperature warping is upward in the central area of the track slab at the time of the most positive temperature difference and the temperature warping is upward in the four corners of the track slab at the time of the most negative temperature difference.

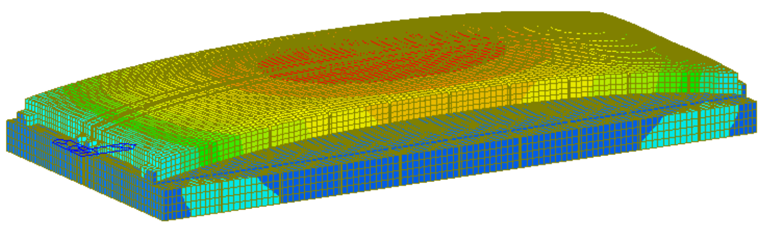

Figure 5: Temperature warping of the track slab at the time of the most positive temperature difference

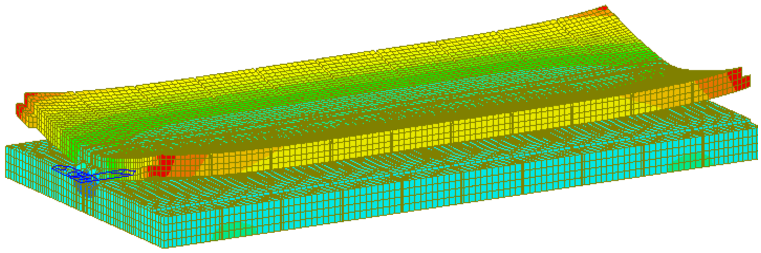

Figure 6: Temperature warping of the track slab at the time of the most negative temperature difference

3 DYNAMIC ANALYSIS OF TRAIN-TRACK SYSTEM UNDER TEMPERATURE LOAD

By applying the vertical rail displacements caused by the slab warping as the additional rail irregularities, the dynamic analysis model for the train-track system is established, to analyze the dynamic performance of the train. With the additional rail irregularities caused by slab warping under the most positive temperature difference as excitations, the dynamic responses of the track and the train vehicles, such as the wheel-rail interaction forces, wheel unloading rates, reaction forces of fastener, as well as the accelerations of rail and track slab, are calculated based on inter-system iteration[8-11], when eight vehicles pass on the track at the speed of 250 km/h.

3.1 The influence of fastener stiffness on the additional rail irregularities

The deformations of the rail and the track slab are calculated under the most positive and negative temperature difference when the stiffness of the fastener is respectively 22.5 kN/m, 60 kN/m and 60000 kN/m. The results are shown in Table 1.

The vertical stiffness of fastener	The maximum vertical displacements of rail		The maximum vertical displacements of track slab	
	The most positive temperature difference	The most negative temperature difference	The most positive temperature difference	The most negative temperature difference
22.5 kN/m	1.34mm	0.09 mm	1.56 mm	0.44 mm
60 kN/m	1.27 mm	0.11 mm	1.50 mm	0.43 mm
60000 kN/m	1.07 mm	0.11 mm	1.32 mm	0.34 mm

Table 1 The maximum vertical displacements of rail and track slab with different fastener stiffness

Table 1 shows that as the vertical stiffness of fastener reduces, the maximum vertical displacements of rail and track slab under the most positive temperature difference decrease. Besides, the maximum vertical displacement of rail under the most negative temperature difference can be ignored compared to the most positive temperature difference. So the additional rail irregularities caused by slab warping under the most positive temperature difference when the stiffness of the fastener is 22.5 kN/m are taken as excitations in this analysis.

3.2 The dynamic index for safety evaluation

The safety indexes of vehicles are composed of the derailment factor, offload factor of the wheel, and the lateral wheel-rail interaction force[12]. However, the lateral wheel-rail interaction force and the derailment factor are zero in this paper, because the lateral rail irregularities are neglected. So only the wheel offload factor is considered in this paper and it should satisfy: $\Delta P/P \le 0.6$, according to the <<Code For Design Of High Speed Railway>> in China.

3.3 Dynamic responses under temperature load

With the additional rail irregularities caused by slab warping under the most positive temperature difference when the stiffness of the fastener is 22.5 kN/m as excitations, the dynamic responses of the track and the train vehicles, such as the wheel offload factors, reaction forces of fastener, as well as the accelerations of rail and track slab, are calculated when eight vehicles pass on the track at the speed of 250 km/h. The results are shown in Table 2.

Dynamic indexes	Normal road section	Road section under temperature load	The increase percent
Wheel offload factor	0.300	0.318	6.0%
The maximum vertical reaction force of fastener	24.39/kN	25.25/kN	3.5%
The maximum vertical acceleration of rail	79.49/(m/s^2)	95.93/(m/s^2)	20.7%
The maximum vertical acceleration of track slab	1.72/(m/s^2)	2.08/(m/s^2)	20.7%

Table 2 The dynamic responses under temperature load

Table 2 shows that the dynamic responses are larger when considering the additional rail irregularities caused by temperature warping of track slab. The wheel offload factor increases by 6.0%, the maximum vertical reaction force of fastener increases by 3.5%, and the maximum vertical accelerations of rail and track slab increase obviously by 20.7%.

The wheel offload factor under temperature load is 0.318 and it satisfies: $\Delta P/P \le 0.6$, so it is safe for the train vehicles.

The vertical wheel-rail interaction forces, the vertical reaction forces of fastener, and the vertical accelerations of rail and track slab are shown respectively in Figures 7 to 10.

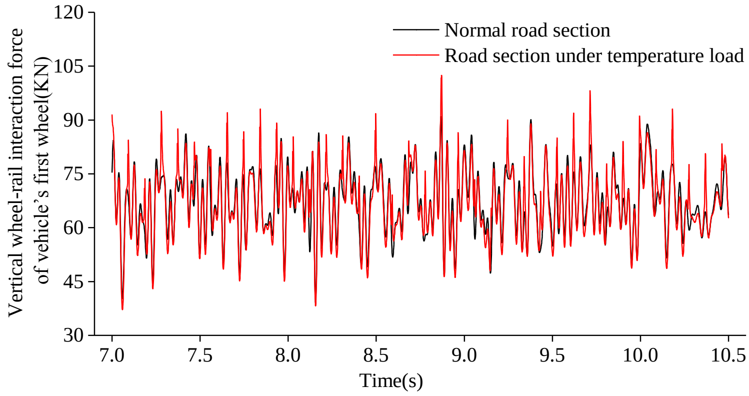

Figure 7: Vertical wheel-rail interaction force histories of vehicle's first wheel

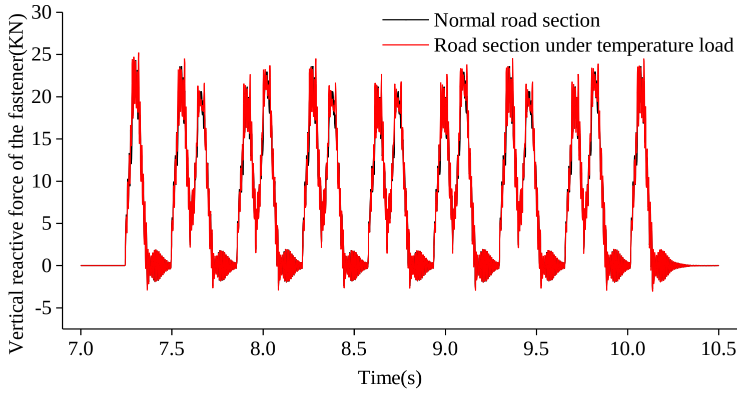

Figure 8: Vertical reaction force histories of fastener

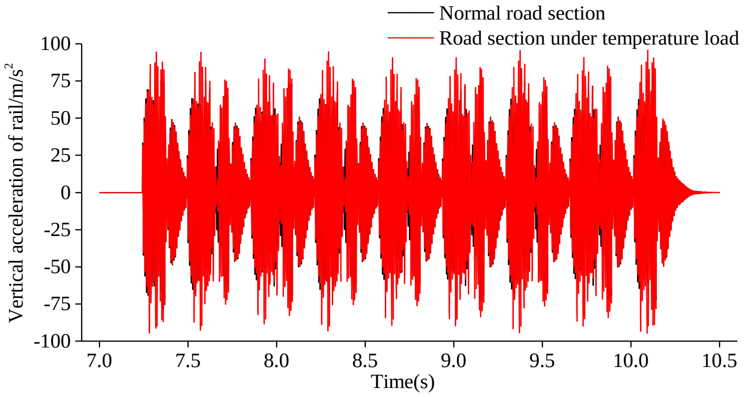

Figure 9: Vertical acceleration histories of rail

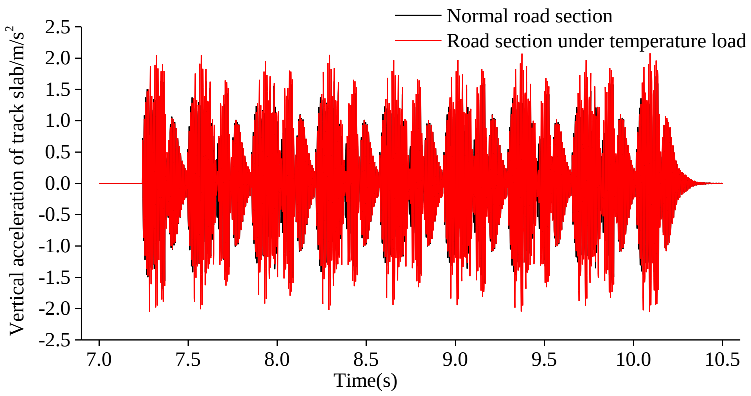

Figure 10: Vertical acceleration histories of track slab

4 COCLUSIONS

In this paper, the warping of track slab under overall temperature change and temperature gradient is analyzed with the temperature field of track slab simulated by applying temperature load on the track slab nodes. By applying the vertical rail displacements caused by the slab warping as the additional rail irregularities, the dynamic analysis model is established, to analyze the dynamic performance of the train-track system. According to the analysis results, some conclusions can be obtained:

(1) The temperature warping is upward in the central area of track slab at the time of the most positive temperature difference and the temperature warping is upward in the four corners of track slab at the time of the most negative temperature difference.
(2) The maximum vertical displacements of rail and track slab under the most positive temperature difference decrease as the vertical stiffness of fastener reduces. Besides, the maximum vertical displacement of rail under the most negative temperature difference can be ignored compared to the most positive temperature difference.
(3) The dynamic responses become larger when considering the additional rail irregularities caused by temperature warping of track slab. The wheel offload factor increases by 6.0%, the maximum vertical reaction force of fastener increases by 3.5% and the maximum vertical accelerations of rail and track slab increase obviously by 20.7%.

ACKNOWLEDGEMENTS

The research is sponsored by the Major State Basic Research Development Program of China (973 Program: 2013CB036203), the 111 Project (Grant No. B13002) and the Doctoral Fund of Ministry of Education of China (Grant No. 20130009110036).

REFERENCES

[1] Ando, K., S. Miura, K. Wataname, Twenty years' experience on slab track. *Proc., Sixth World Conference on Transport Research*, Vol. IV, Lyon, France, July 1992.

[2] Ando, K., S. Mura, J. Okazaki, M. Sunaga, H. Aoki, O. Maruyama, Development and practical use of concrete roadbed for slab track on earthworks. *Proc., Eighth World Conference on Transport Research*, Antwerp, Belgium, July 1998.

[3] Morcher, J, Development of ballastless track in Germany. *Proc., International Conference on Innovations in the Design & Assessment of Railway Track*, Delft University of Technology, Delft, Netherlands, Dec 1999.

[4] Shiraz D. Tayabji, David Bilow, Concrete slab track state of the practice. Transportation Research Record: Journal of the Transportation Research Board, **1742**, 87-96, 2007.

[5] Y Liu, GT Zhao, Analysis of early gap between layers of CRTSII slab ballastless track structure. China Railway Science, **34(4)**, 1-7, 2013. (in Chinese)

[6] Y Liu, P Chen, GT Zhao, Study on the characteristics of early temperature field of CRTSII slab ballastless track structure. China Railway Science, **35(1)**, 1-6, 2014. (in Chinese)

[7] JJ Wang, RL You, M Wang, C Jiang, Research on the slab temperature warping of the unit slab track system. China Railway Science, **31(3)**, 9-14, 2010. (in Chinese)

[8] N Zhang, H Xia, Dynamic analysis of coupled vehicle–bridge system based on inter-system iteration method. Computers and Structures, 114-115, 26-34, 2013.

[9] N Zhang, S Zhou, H Xia, L Su, Evaluation of vehicle-track-bridge interacted system for the continuous CRTS-II non-ballast track slab. Science China, **57(10)**, 1895-1901, 2014.

[10] WM Zhai, H Xia, CB Cai, High-speed train–track–bridge dynamic interactions-Part I: Theoretical model and numerical simulation. International. J Rail Transp, **1**, 3-24, 2013.

[11] WM Zhai, SL Wang, N Zhang, *et al.*, High-speed train–track–bridge dynamic interactions-Part II: Experimental validation and engineering application. J Rail Transp, **1**, 25-41, 2013.

[12] H. Xia, G. De Roeck, J. M. Goicolea. *Bridge Vibration and Controls: New Research*, New York: Nova Science Publishers Inc., 2012.