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Effect of daily changing temperature on the curling behavior and interface stress of slab track in construction stage

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HIGHLIGHTS

- Daily changing temperature of slab was measured on a full-scale testing platform.
- The temperature behavior of slab track in construction stage was investigated.
- Initial temperature had significant influence on the track temperature behavior.
- It is suggested that CA mortar injection should be finished before midnight.

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ABSTRACT

Interface damage, which even happens in construction phase, has become a major problem for China Railway Track System (CRTS-II) slab track. The slab track in construction stage is a block structure and sensitive to daily changing temperature. In order to reveal the temperature behavior of the slab track and provide meaningful information to the control of early interface damage, a three-dimensional finite element model of slab track was developed to study the deformation and interface stress of the slab track under daily changing temperature in this paper. The daily changing temperature was measured on a testing platform constructed in open field, and imported to the model using user-defined subroutines UTEMP. Based on the developed model, the effect of initial temperature and construction seasons were then investigated. The analysis indicates that the slab deformation and stress change with time obviously and the positions of maximum interface stresses are near the slab corner, which is consistent with the location of interface disease. Initial temperature has significant influence on the slab temperature behavior. The initial temperature at 14:00 induces the largest interface tensile stress exceeding the interface bonding strength, while the interface stresses are relatively small from 19:00 to 24:00. Therefore, it is suggested that CA mortar injection should be finished before midnight. Additionally, as the overall temperature variation and temperature gradient are very obvious in summer, spring and autumn, the grouting operation of CA mortar in these three seasons is required to pay equal attention.

1. Introduction

Slab track, using concrete or asphalt as track bed instead of ballast, has been widely used around the word for high-speed railway systems. For example, among the 22,000 km (double track) long high-speed railway in China, slab track railway is about 14,000 km. It is believed that the slab track is widely used just for its significant advantages such as high comfort, good stability, long service life and low maintenance cost [1,2].

In particular, China Railway Track System (CRTS-II) slab track, which is technically improved from German Bögl slab track, is one of the most widely utilized ballastless tracks in China. More than 10 high-speed passenger railway lines and intercity railways with a total length of 4852 km (double track) are constructed with this kind of slab track, such as Beijing-Tianjin (120 km, 2008), Beijing–Shanghai (1318 km, 2011), Beijing–Wuhan (1224 km, 2012), Nanjing-Hangzhou (256 km, 2013), Hangzhou–Ningbo (150 km, 2013), Tianjin-Qinhuangdao (287 km, 2013), Shanghai–Kunming (2252 km, 2016) and so on. The slab track system mainly consists of the rails, fastener, prefabricated slab, cement emulsified asphalt mortar (CA mortar) layer and concrete base, as shown in Fig. 1. The prefabricated slabs are bonded to continuous concrete base firmly by CA mortar layer.

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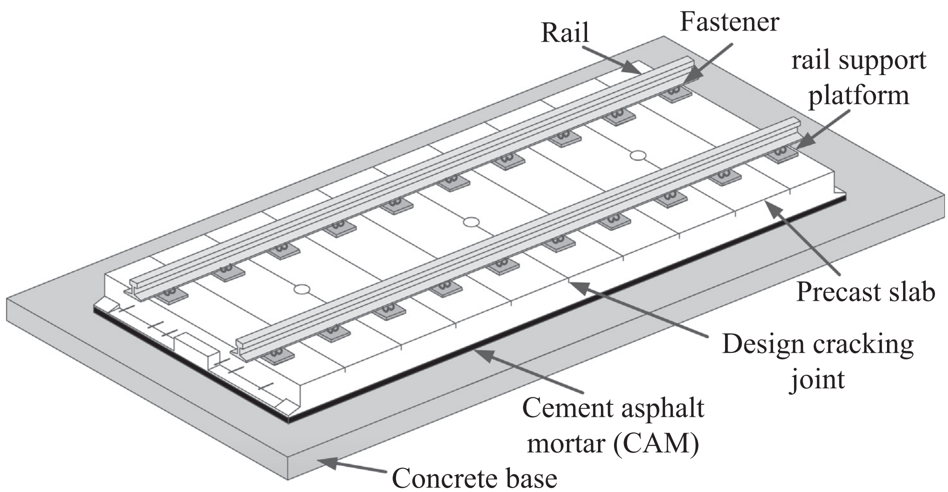

Fig. 1. CRTS-II slab track system components.

Temperature is one of the most critical parameters related to the behavior and response of track slab [3–5]. Slab deformation and interface damage induced by temperature have attracted much attention. Young Kyo Cho et al. [6] analyzed the displacement and stress of ballastless track under the negative linear vertical temperature gradient resulting in the curling up of the slab edges. Song Xiaolin et al. [7] investigated the temperature induced deformation considering the deteriorated CA mortar layer with some possible interfacial separation and slip. Numerical results showed that interfacial delamination may occur between track slab and CA mortar layer, which had a significant effect on track dynamical properties. Ren Juanjuan et al. [8,9] pointed out that the track slab was likely to delaminate from CA mortar and suffer from upwarping when temperature raised obviously. Zhu Shengyang [10] adopted a cohesive zone model to describe the damage, cracking and delamination at the interface between prefabricated slab and CA mortar layer to reveal the interface damage evolution mechanism under temperature and vehicle dynamic loads. In addition, the influence of interface damage on dynamic behavior of slab track had also been further investigated [11–16].

It is noteworthy that almost all the researches only focus on the temperature behavior of slab track in operation phase rather than construction stage. In the construction stage, the CRTS-II track slabs are finally connected longitudinally by post-tensioned steel rods [17]. A fact that should be highlighted is that normal time from the completion of CA mortar injection to the longitudinal connection of slabs is about 14 days [18]. That is say, the track slabs are still separate during this period.

Temperature deformation and interface stress of unit slab are obvious [9], especially under the great temperature gradient. If there is a sharp change of temperature during this period, the interface crack may occur, which is harmful to the service performance of slab track. Actually the delamination at the corners of track slab was found in some high-speed lines during construction phase [19]. It was also observed that almost all the delamination occurred at the interface between slab and CA mortar layer, and the maximum gap width exceeded 2 mm [20]. Previous studies showed that the interface crack was closely associated with temperature. Therefore, it is very necessary to analyze the temperature behavior of CRTS-II track slab in construction phase. However, little attention has been paid to it. Liu [19] reported the early gap between layers of CRTS-II slab track, but there was a lack of detailed analysis on the curling behavior and interface stress of slab track in construction stage, and the effect of initial temperature was not considered.

This paper focuses on the curling behavior and interface stress of CRTS-II track slab undergoing daily changing temperature in construction phase, and estimates critical conditions by comparing the interface stresses with the interface bonding strength. Through this research, it is expected to provide meaningful information on avoiding the de-bonding of slab in construction stage. It should be emphasized that the formation and propagation of cracks between interfaces were not discussed in this paper. Therefore, the firm bonding interfaces between the slab and CA mortar layer as well as the CA mortar layer and concrete base are considered here, which will not be separated in spite of undergoing temperature loading. In order to consider the actual temperature conditions, the monitoring temperature of slab track should been set as input data.

This paper is organized as follows. First of all, daily changing temperature was measured on a track model which was constructed with a full-scale prefabricated standard slab. Then, taking the measured temperature data as input, a three-dimensional finite element analysis model of slab track was developed to calculate the temperature deformation and interface stress. Finally, the effect of initial temperature and construction seasons on the interface stress distribution were investigated.

2. Temperature measurement

2.1. Description of the testing platform and method

In order to obtain daily changing temperature of slab track, a full-scale track model shown in Fig. 2 has been constructed in the outdoor open field. The orientation of the track model is basically from east to west. The test site is located in Beijing, China (116.35°E, 39.96°N), which has a monsoon-influenced humid continental climate.

Just like the practical track structure, the track model consists of rails, fasteners, prefabricated slab, CA mortar layer and concrete base. The rails and fasteners, set up primarily for other experiments, are not absolutely necessary in the test, as they have few effect on the slab temperature. Track slab with the dimensions of 6.45 m × 2.55 m × 0.2 m was prefabricated in the factory, of which the concrete grade was C55. The concrete base is made of C15 concrete and is 30 cm thick, 6.80 m long, and 3.30 m wide. A cavity with the height of 30 mm is set between track slab and the concrete base, which is filled with CA mortar. The CA mortar material parameters and construction process of the slab track can be found in Ref. [17].