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CTCP temperature fields and stresses

Minjiang Zhang [a], Chao Guo [b,*], Baoyang Yu [c], Yanhai Yang [a], Zhengran Lu [d]

[a] *School of Transportation Engineering, Shenyang Jianzhu Univ., No. 9, Hunnan Road, Hunnan District, Shenyang City, Liaoning, PR China*
[b] *School of Civil Engineering, Shenyang Jianzhu Univ., No. 9, Hunnan Road, Hunnan District, Shenyang City, Liaoning 110168, PR China*
[c] *Transportation Equipment and Ocean Engineering College, Dalian Maritime Univ., No. 1, Linghai Road, Dalian City 116026, Liaoning, PR China*
[d] *School of Management, Shenyang Jianzhu Univ., No. 9, Hunnan Road, Hunnan District, Shenyang City, Liaoning 110168, PR China*

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Abstract

Cross-tensioned concrete pavements (CTCPs) are used in the construction of continuous Portland cement concrete pavements. They eliminate the need for transverse joints and also restrict cracking of the pavement. A CTCP consists of three components, namely, the CTCP slab, the sand sliding layer (SSL), and the cement-stabilized macadam base, from top to down. The retard-bonded tendons (RBTs) of the CTCP slab are arranged diagonally. In the present study, a detailed 3D finite element model was developed and used to examine the temperature fields and stresses of a CTCP by thermal-mechanical coupling analysis, and the results were compared with field measurements. The model investigations revealed that, under typical cloudless summer conditions, the temperature field of the CTCP varied nonlinearly with both time and depth. The resultant step-type temperature gradient of the CTCP represents a significant deviation from that of a conventional pavement and impacts the thermal contact resistance of the SSL. It was found that the SSL could effectively reduce the temperature stresses in the CTCP, and that the residual temperature stresses were effectively resisted by the staged cross-tensioned RBTs. The potential problem areas in the vicinity of the temperature stresses were also investigated by the finite element method and field tests.

Keywords: Portland cement concrete pavement; Prestressed concrete pavement; Temperature stress; Temperature field; Finite element method; Retard-bonded tendon

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1. Introduction

Joints are the weakest parts of Portland cement concrete pavements (PCCPs). The deterioration of a PCCP is mostly caused by the intrusion of water into the pavement system and the inferior performance of the joints. Part of the water runoff usually infiltrates the pavement through joints and cracks. During construction and routine maintenance, the transverse joints and cracks are typically sealed with a flexible joint sealant, which keeps most of the water out. However, some water still manages to penetrate the pavement, resulting in deterioration by pumping and eventual faulting. The elimination of the transverse joints and cracks is one of the solutions to this common PCCP problem, and has been demonstrated in continuously reinforced concrete pavements (CRCPs). Prestressing of a PCCP can be used to eliminate the joints and cracks. This can be done by tensioning through the application of an external force. Theoretically, all the transverse joints and cracks in a pavement can be eliminated by this means. The high stresses induced by the tensioning hold the cracks very tightly, making them impervious to water. The prestressing of a PCCP is also

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* Corresponding author.
E-mail addresses: zhangminjiang1@163.com (M. Zhang), guochaoglovel@126.com (C. Guo), yubaoyang12380@126.com (B. Yu), Yangyanhai168@126.com (Y. Yang), luzhengranglovel@126.com (Z. Lu).

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expected to extend the service life, as well as produce better ride quality owing to the absence of transverse joints. Prestressing also increases the load capacity of the pavement, thereby decreasing the maintenance costs. Further, the design technique allows the use of thinner slabs compared to conventional PCCP under equivalent loading [1].

In addition, the original cross-tensioned concrete pavement (CTCP) concept, which was based on a PCP, was proposed by Hossainin [1], who outlined the fundamental design. Finite element analysis has been used to demonstrate the feasibility of the crossing of the strands near the pavement edge with regard to stress. This is because the high tensile stress between opposing bearing plates can be reasonably accommodated using mild steel plates or a newly designed bearing assembly. CTCP has the potential of being used to achieve longer lasting pavements in the 21st century.

The stress distribution in an indoor CTCP skewed by unbonded tendons determined by an indoor full-scale model test was found to be consistent with that obtained by finite element analysis [2]. This confirmed the feasibility of a cross-tensioned prestressed concrete pavement.

A domestic experiment was performed on an RBT-skewed CTCP section on the Xiu-Shui line in Yinkou City, China. The axial load under varying RBT conditions at the temperature of a typical unclouded summer day was measured using an axial load gauge. The deformation of the CTCP was also investigated using a vernier caliper.

It is generally assumed that transverse slab cracking in a concrete pavement (CP) is initiated at the bottom of the slab near the mid-panel. Evidence has, however, been obtained that fatigue cracks can, and are typically initiated at the top of the slab and propagate downward [3,4]. This is attributable to the combined effects of temperature stress and axle loading. CPs are usually subjected to a wide range of temperature conditions throughout their service lives, resulting in a correspondingly broad range of deformed slab shapes. Considering that the shape of the slab at the time of traffic loading significantly affects the development of the slab stresses, the Mechanistic-Empirical Pavement Design Guide (MEPDG) recommends the consideration of environmental effects in the computation of the critical stresses for top-down and bottom-up cracking, and separate determination of the accumulated damage for each possible failure mode [3]. Consequently, the shape of the slab must be accurately characterized for input to the MEPDG to obtain the most accurate predictions regarding cracking and the CP service life.

The slab curvature, which varies with the transient slab temperature conditions, is also affected by several other factors such as (1) extreme temperature conditions during the service life; (2) the material properties of the concrete, such as the coefficient of thermal expansion, creep, and elastic modulus; and (3) restraints to the slab deformation, such as the slab self-weight, friction at the slab-sub-base interface, and restraints to joint movement [3]. The foregoing first and third factors were the primary focus of the present study.

The temperature gradients during service also significantly affect curling and warping of the slab. The effective temperature gradient is defined as the resultant of all the different temperature gradients in the slab. The actual value of the effective temperature gradient is dependent on factors such as the coefficient of thermal expansion/contraction of the Portland cement concrete (PCC) mix, the temperature conditions at the time of paving, and the curing practices and conditions. Before the setting of the concrete, the slab remains flat because the concrete is in a plastic state. After setting, the response of the slab is affected by the magnitude and direction of the effective built-in temperature gradient. For example, when the temperature is uniform, the slab may curl rather than lie flat; it can only be flat if the transient temperature gradient equals the built-in value. The slab curls upward if the built-in gradient is positive, and downward if negative. The built-in gradient has been found to be an important factor in estimating the stress in a concrete pavement, especially when using the MEPDG [5–7].

In the present study, three different methods for determining the in-service slab curvature of a CTCP panel with respect to the temperature were examined. The methods are (i) measurement of the slab temperature, (ii) measurement of the slab deformation, and (iii) the finite element method. Based on data collected from an instrumented CTCP, the three methods were used to evaluate the effects of the built-in gradients on the slab curvature.

2. Project description

The present study focused on characterizing the temperature conditions of an in-service pavement and determining the resultant slab behavior. A section of the Xiushui line near Dashiqiao, Yinkou (approximately 240 km east of Shenyang) was instrumented during construction in September 2014, as shown in Fig. 1. The instrumented sec-

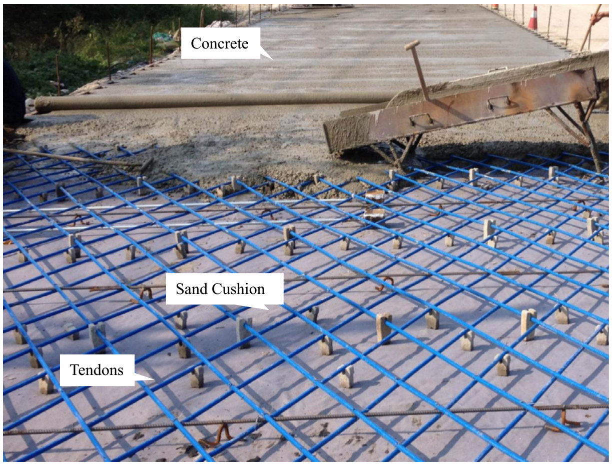

Fig. 1. Construction of CTCP.

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