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Impacts of variability in coefficient of thermal expansion on predicted concrete pavement performance

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HIGHLIGHTS

- Concrete samples from four different field projects were laboratory-tested for CTE and other Level 1 material properties.
- Rigid pavements analyzed in AASHTO Pavement ME Design® with range of CTE inputs.
- Changes in predicted pavement distress compared with variability in CTE values.
- Quantified the effects of CTE variability on pavement thickness and service life.
- Precision required for measuring the concrete CTE for use in the AASHTO Pavement ME Design is identified.

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ABSTRACT

Research published recently has emphasized the importance of the coefficient of thermal expansion (CTE) for characterizing concrete behavior in the field. This study defined the sensitivity of CTE, based on pavement design analyses using material and data samples from the field projects. The CTE's level of precision was examined along with its impacts on the predicted distresses, service life, and pavement thickness for the desired design life. A precision of ±0.5 με/°C was found to have minimal impact (±1.3 cm) on the optimized pavement thicknesses predicted. Also, observed differences in predicted service life further demonstrate the sensitivity of the CTE.

1. Introduction

The implementation of new pavement performance prediction tools such as the Mechanistic Empirical Pavement Design Guide (MEPDG) has provided the opportunity for analyzing the service characteristics of rigid pavement designs prior to the final design phase [1]. In a recent study of the sensitivity of various input factors on rigid pavement performance in the MEPDG software by Schwartz et al. [2], the modulus of rupture (MOR), the modulus of elasticity (MOE), and the coefficient of thermal expansion (CTE) were all identified as being input factors that had measurable impact on the concrete pavement's performance over time.

The test method to determine the CTE of concrete is relatively new and was first accepted as an American Association of State Highway and Transportation Officials (AASHTO) provisional test method (TP 60) in 2000 and became a full test method (T336) in 2009 [3]. Based on past field experience and analytical work, the CTE was believed to be an important input for pavement design but prior to the MEPDG was not considered [4].

The Federal Highway Administration (FHWA) Mobile Concrete Laboratory (MCL) and Turner-Fairbank Highway Research Center have performed significant work over the past six years in improving and refining the CTE test method. In 2014, the FHWA completed a precision and bias study for the CTE test method (AASHTO T336) with 19 laboratories (twenty CTE units) representing a wide range of entities (FHWA, state Department of Transportation (DOTs), universities, commercial testing laboratories and industry) across the country [5]. Based on the results from this study, the acceptable difference between two CTE tests from the same laboratory is 0.3 με/°C and between two laboratories is 0.8 με/°C. Since the CTE is not yet a routine test that agencies currently use for concrete mixture design, it is important to determine

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the level of precision that is required for the CTE test method and its acceptability based on its impact on the required pavement thickness. This paper provides information on whether the precision of the current test method (AASHTO T336) is adequate, further research is required to improve the test method or whether a more precise test method should be developed.

1.1. Objectives

The main objective of this study was to define and quantify the effects of the precision of CTE inputs on the predicted concrete pavement performance. The impact of CTE on predicted rigid pavement design life and on the optimized pavement thickness from the AASHTO Pavement ME Design® [6] was also investigated, based upon the field data collected from four new concrete pavement highway projects.

1.2. Research approach

Most of the past sensitivity studies investigated the impact of the CTE on predicted damage in the MEPDG and were performed on assumed pavement sections using simulated data. These studies generally used larger increments (minimum of 0.9 με/°C) in CTE over the full range of CTE values, as listed in [7]. In this study, the sensitivity of CTE on the MEPDG was determined on pavement sections from four actual field projects built between 2009 and 2011 that represent a range of geographical and climatic conditions and used Level 1 input data for all of the concrete material inputs including CTE. Additionally, previous research focused only on the change in predicted damage with a given change in CTE but did not focus on quantifying the sensitivity of CTE in terms of optimized pavement design thickness, pavement design life, or its impact on the monetary value of the project. State transportation agencies (DOTs) can use this information to better decide which level of concrete materials input (Levels 1, 2, or 3) should be required for a given pavement design.

This study focused on adjusting the CTE values to evaluate their impact on predicted distresses, predicted design life, and the required pavement thickness needed to achieve the desired design life. Investigation of the tolerance limits in CTE may then provide some insight into the level of precision required for measuring CTE of concrete for use in the MEPDG.

The AASHTO Pavement ME Design® Version 1.3, Build 1.3.28 [8] software was used to perform mechanistic-empirical analysis of the rigid pavement structures from four jointed plain concrete pavements (JPCP) projects. The FHWA MCL was used on these four projects to collect Level 1 concrete material inputs and any other inputs were obtained from the participating DOTs.

It is acknowledged that in evaluating the impact of CTE on the predicted amount of rigid pavement distresses, this study focused exclusively on optimizing the pavement thickness based on an expected error in the CTE Level 1 input value, along with the impact on the predicted design life. Other design parameters that could minimize the effect of a higher CTE, such as shorter joint spacing, slab width greater than 3.7 m, different base layer designs, etc., were not included in this study.

2. Literature review

Recent research has been published that investigated the relationship between various concrete mixture properties and their use and influence in rigid pavement design. Pavement analyses conducted in the past few years have shown that the CTE influences the mechanical response of a rigid pavement. A brief description of recent research efforts is presented in the following sections.

2.1. Concrete coefficient of thermal expansion

The concrete CTE is a parameter that quantifies the extent with which a material changes its length in response to changes in temperature. The CTE is defined as unit length change per unit change in temperature (in units of με/°C) of a material. The most widely-used test method to measure CTE of concrete is AASHTO T336-11, "Standard Test Method for the Coefficient of Thermal Expansion of Hydraulic Cement Concrete" [3].

Concrete CTE can also be predicted using empirical models [4,5,7]. These current concrete CTE prediction models are mainly based on empirical relationships where the mechanics of the concrete thermal expansion and aggregate gradation are not investigated [8]. However, a micromechanical model was recently developed to predict concrete CTE based on thermal mechanical analysis which considers concrete as a composite material [8,9]. Based on this predictive model, the aggregate type is a major factor affecting concrete CTE [8,9].

The CTE has a large impact on the performance and serviceability of concrete pavements because temperature changes will affect the opening and closing of joints [10]. A temperature gradient through the thickness of the slab, in combination with the restraint offered by the base layer and slab weight, will produce curling and axial stresses in the slab. The CTE also impacts the pavement performance with respect to early age cracking, curling, faulting and joint spalling JPCP [11]. In continuously reinforced concrete pavements (CRCP), the CTE of concrete affects the crack spacing and the crack width, which in turn impacts the crack load transfer efficiency and number of punchouts that develop [11].

2.2. Impact of CTE on field performance

Kohler et al. [13] investigated the influence of CTE on cracking of jointed concrete pavements based on crack survey data and laboratory evaluation of samples from approximately 100 sections of in-service highway pavements throughout the state of California. It was reported that the CTE affects crack development on jointed concrete pavements and that pavements with a CTE higher than 11.2 με/°C exhibited more cracking than those with a CTE lower than this value. McCullough et al. [14] reported that the analysis of visual pavement condition survey data over a 20-year period on CRCP pavements across the state of Texas showed significant differences in performance between pavements constructed with siliceous aggregates as opposed to limestone coarse aggregates. For similar designs, pavements constructed with siliceous aggregates showed closer and more random crack spacing patterns primarily due to the greater thermal expansion of the siliceous aggregates compared to pavements with limestone aggregates, leading to accelerated punchout development. It was reported that concrete paving mixtures with siliceous aggregates tended to spall more than mixtures made with limestone aggregates.

2.3. Concrete CTE and pavement design

The CTE has been established as an important parameter; however, it was not considered as a direct input in the pavement design process until it was included in the AASHTO MEPDG [11]. In the MEPDG approach, the CTE is used to estimate the slab movement and stress development due to temperature changes. Numerous studies were performed since the original release of the initial MEPDG software in 2004 which focused on identifying the sensitivity of various rigid pavement inputs [2,15–25]. The most recent and comprehensive sensitivity study on this topic was the National