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Technical Paper

Characterizing strength and thermal properties of concrete for implementation of pavement mechanistic-empirical design in New Mexico

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ABSTRACT

The format of the design and performance prediction of rigid pavements was reformed with the advent of Pavement mechanistic-empirical (ME) design procedure, which now serves as the state-of-the-art tool in pavement design. Various state agencies have either completed or in the process of calibration of distress prediction models and characterization of concrete materials to provide accurate inputs required by Pavement ME design software. There are numerous concrete properties for which input data is required in ME design software, but with previous research, it was found that the concrete strength and thermal properties including elastic modulus, modulus of rupture and coefficient of thermal expansion (CTE) are the most important ones that affect the design and performance of rigid pavements. Accurate rigid pavement design is heavily dependent on accuracy of these material inputs. This study is part of a New Mexico Department of Transportation (NMDOT) research project that focuses on the development of guidelines for characterizing Portland cement concrete (PCC) materials for paving mixes being used in New Mexico. Concrete mixes with 5 different coarse aggregates were tested for these pivotal concrete properties at the curing age of 7, 14, 28 and 90 days, and for CTE at 28 days. The laboratory test results represent level 1 PCC material inputs. The data collected offered an excellent opportunity to validate and refine the ME default level 2 models for estimating flexural strength and elastic modulus based on compressive strength data. The data demonstrated a slight deviation from the nationally calibrated models. CTE values of concrete based on aggregate type were established for these paving mixes. Further analysis verified the benefit of using the level 1 inputs over the default level 3 inputs for accurate pavement design and performance prediction. It was also highlighted that transverse cracking is the most significantly affected performance parameter between the pavement designed with level 1 and level 3 material inputs.

Introduction

A concrete pavement is a structure comprising of a layer of Portland cement concrete usually supported by underlying layers on the subgrade. Concrete pavements may be either unreinforced or reinforced depending on the preference to control the cracking. The high strength and rigidity of concrete provides a concrete pavement with a reasonable degree of flexural strength which leads to distribution of externally applied wheel loads to a wider area. This results in minimizing the pressure applied to the sublayers. The load capacity of a rigid pavement is solely dependent on the concrete layer. This study found that jointed plain concrete pavement (JPCP) is the most widely used rigid pavement across the United States (U.S.) and there are about 18 different material properties of concrete, which are required as input for design of JPCP according to mechanistic-empirical (ME) design procedure. After studying the sensitivity of various input factors on rigid pavement performance, Schwartz et al. [1] identified the modulus of rupture (MOR), the modulus of elasticity, and the coefficient of thermal expansion (CTE) as input factors that had significant impact on the concrete pavement's performance with regards to transverse cracking, joint faulting and pavement roughness. Tanesi et al. [2] worked to determine the effect of the variability of the CTE on the predicted pavement performance. They performed a sensitivity analysis by varying the CTE values on a single jointed plain concrete pavement design and found that with the increase in CTE value of concrete, the percentage of slabs with transverse cracking also increases. Hein [3] conducted his research and described that thermal expansion and contraction of a concrete pavement can have a significant effect on its performance. Thermal contraction

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can result in transverse cracking of slabs depending on the joint spacing. Thermal effects also impact slab bending and curling and when joints/edges are curled upwards, they do not have full contact with the base and are subject to cracking under traffic loading. This could be particularly significant for long, thin slabs under heavy, frequent loading. Sabih and Tarefder [4–6] investigated the effects of variability of mechanical and thermal properties of concrete on performance predictions of concrete pavements and found that concrete properties such as elastic modulus, flexural strength and coefficient of thermal expansion significantly affect the performance of concrete pavement over the pavement design life including transverse cracking, joint faulting and pavement roughness.

The process of design and performance prediction of concrete pavements was mostly empirical until the advent of Pavement ME design procedure which was originally developed under the NCHRP Project 1-37A. This procedure was eventually adopted by AASHTO as the standard for pavement design and AASHTO made standard guidelines for agencies to implement the procedure and perform local calibration [7]. According to the survey conducted in 2014 by NCHRP to determine the implementation status of Pavement ME design, it was found that most of the states are using the default input values as they are in the process of local calibration and implementation [8]. Pavement analysis and design can currently be performed using the software program commonly referred to as Pavement ME design. It is based on mechanistic-empirical design concepts, which means that the design procedure calculates pavement responses such as stresses, strains, and deflections under axle loads and climatic conditions and then accumulates the damage over the design analysis period. The procedure then empirically relates calculated damage over time to pavement distresses and smoothness based on performance of actual projects throughout the U.S. Pavement ME design performs a wide range of analysis and calculations in a rapid, easy-to-use format [9].

According to the previous research, accurate determination of concrete material properties enhances the accuracy of the designed pavement. The variability of CTE, MOR and elastic modulus impacts the performance indicators of JPCP such as faulting, roughness and cracking. These key parameters can be determined for each paving mix through laboratory tests. They are used by the structural response models and performance prediction models for damage calculations and performance predictions. One of the features of the Pavement ME Design is its ability to use default, regional, or site-specific values for materials data inputs which are regarded as level 3, 2, and 1 respectively. These levels of inputs define the accuracy of the output in the form of designed pavement. Level 1 inputs comprise of the laboratory tested data of the specific paving mix while level 2 inputs are the values based on the default interconversion models and the values obtained from the average of the constituents of concrete. Level 3 has lowest accuracy in design as it comprises of the software default values. This study encompasses the testing of New Mexico paving mixes to generate level 1 input data of these parameters and refine the level 2 models correlating compressive strength, elastic modulus, and MOR. Simulations will be conducted in Pavement ME design version 2.3 to evaluate the impact of level 1 and level 3 material inputs on JPCP performance predictions.

Objectives

- Testing and evaluation of concrete for CTE, MOR and elastic modulus to develop a database to be used with pavement ME design for design of rigid pavements in New Mexico. Moreover, to develop level 2 interconversion correlations between compressive strength, MOR and elastic modulus.
- To conduct the sensitivity analysis of these material input levels on rigid pavement performance.

Casting of concrete specimens (cylinders and beams)

This study consisted of laboratory testing of 5 concrete paving mixes from different districts of New Mexico prepared with different coarse aggregates. Concrete cylinder and beam specimens were casted from these mixes to determine compressive strength, elastic modulus, MOR and CTE. The test results provided pavement engineers with level 1 inputs to be used in rigid pavement design with Pavement ME design software for these specific mixes and level 2 correlations were produced for interconversion of compressive strength into elastic modulus and MOR for New Mexico paving mixes. Forty cylindrical specimens and twelve beam specimens were prepared from each of the five mixes. These mixes are indicated as CA-ID-1 to CA-ID-5 for data composition and analysis purposes. The detail of coarse aggregate mineralogy of these mixes is listed in Table 1.

Details of mix design

The concrete mixes consisted of different coarse aggregates with different mix proportions and mix properties. The details of all the tested mixes are tabulated in Table 2. The concrete specimens were prepared in the field and transported to the pavement laboratory at UNM, after an initial setting, and placed in temperature controlled curing tanks at 75 °F for final curing. All of the paving mixes considered in this study contains fly ash as a supplementary cementitious material, which contributes to the properties of fresh and hardened concrete. Fly ash improves the workability, reduces the water demand and reduces the heat of hydration of plastic concrete. It also increases the ultimate strength and durability and reduces the permeability of hardened concrete.

Compressive strength and elastic modulus testing

Compressive strength testing and results

The compressive strength of concrete cylinders (4 × 8 in.) was determined per ASTM C39-16 [10] and AASHTO T-22-14 [11] at the age of 7, 14, 28 and 90 days. This test method covers determination of compressive strength of cylindrical concrete specimens

Table 1
Summary of concrete mixes with coarse aggregate mineralogy.

Mix ID	Coarse aggregate source	Coarse aggregate mineralogy	Fine aggregate	Location
CA-ID-1	Dark Canyon	Un known	Grand Falls	Hobbs
CA-ID-2	Steele pit	Granite	Steele pit	Clovis
CA-ID-3	Tinaja	Limestone	Tinaja	Grants
CA-ID-4	Placitas	Quartzite	Placitas	Santa Fe
CA-ID-5	Avispa	Limestone	Dryer	Vado