Removing Obstacles for Pavement Cost Reduction by Examining Early Age Opening Requirements: Material Properties

Introduction

The risk of cracking in a concrete pavement that is opened to traffic at early ages is related to the maximum tensile stress, σ_l, that develops in the pavement and its relationship to the measured, age-dependent, flexural strength of a beam, f_r. The pavement stress that develops is due to several factors, including traffic loading and restrained volume change caused by thermal or hygral variations, and also depends on time-dependent mechanical properties, pavement thickness, and subgrade stiffness. There is a strong incentive to open pavements to traffic as early as possible for both construction traffic and the traveling public. However, if pavement is opened to traffic too early, cracking may occur that may compromise the service life of the pavement. The purpose of this report is twofold: (1) to examine the current opening strength requirements for concrete pavements (typically a flexural strength from beams, f_r) and (2) to propose a criterion based on the time-dependent changes of σ_l/f_r which accounts for pavement thickness and subgrade stiffness without adding unnecessary risk for premature cracking. An accelerated pavement testing (APT) facility was used to test concrete pavements that are opened to traffic at an early age to provide data that can be compared with an analytical model to determine the effective σ_l/f_r based on the relevant features of the concrete pavement, the subgrade, and the traffic load. It is anticipated that this type of opening criteria can help decision makers in two ways: (1) it can open pavement sections earlier, thereby reducing construction time, and (2) it may help to minimize the use of materials with overly accelerated strength gain that are suspected to be more susceptible

to developing damage at early ages than materials that gain strength more slowly.

Findings

This work examined the criteria that should be used to determine when a concrete pavement can be opened to traffic. The risk of cracking is estimated based on the ratio between the maximum tensile stress developed beneath the wheel and the flexural strength of the concrete (σ_l/f_r). The importance of pavement thickness (h), subgrade reaction modulus (k), time-dependent elastic modulus ($E(t)$), and time-dependent flexural strength (f_r) of the concrete pavement are discussed in relation to the risk of cracking. The theoretical estimation of the maximum stress that develops in the pavement, σ_l, is compared with experimental results obtained from full-scale concrete pavement sections tested at the APT.

The experimental results indicate that when the typical INDOT opening to traffic criterion is used for 10-inch concrete pavement (flexural strength of f_r = 550 psi), the stresses that develop in the pavement are at most 20% of the flexural strength. A similar observation was made for the 10-inch-thick pavement opened to traffic when the flexural strength was 350 psi with the stress-to-strength ratio reaching only 30% of the flexural strength. For thinner concrete pavements (5 inches thick), opening at flexural strength values of 275 psi, 350 psi, and 550 psi resulted in stress-to-strength ratios of 1.09, 0.86, and 0.54, respectively. While a single flexural strength may be the simplest to specify, the results of this study indicate that allowing thicker pavements to be opened at a lower strength may not add substantial risk of cracking due to traffic loading.

Simulations were performed to consider pavements with thickness between 8- and 16-inch depths and different subgrade stiffness between 50 and 400 lb/in^3, and it was determined that traffic loading resulted in stress that was less than 20% of the flexural strength ($\sigma_l/f_r < 0.2$) for any pavement that was more than 10 inches thick (i.e., $h \geq 10$ in). It was observed that the rate of elastic modulus development ($E(t)$) is inversely related to the stress development caused by traffic loading. This implies that stiffer concrete pavement will develop a higher stress. The subgrade stiffness also influences the stress that develops in the concrete pavement, with a greater impact on thinner pavements. It was also observed that the shape of the footprint of the wheel has a minor impact on the estimated stress and strain. On the other hand, considering a perfect bonding condition underestimates the strain development while the frictionless condition has good agreement with experimental measurements of strain due to traffic loading.

Recommended Citation for Report

Setup of the two 10-inch-thick concrete pavements constructed in the APT facility (Lanes #1 and #2).