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Investigation on seasonal variation of thermal-induced strain in flexible pavements based on field and laboratory measurements

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Abstract

Pavement temperature variation has a large influence on the structural response of flexible pavements. Daily and seasonal temperature fluctuation causes expansion and contraction of pavement material, which then leads to the generation of thermal strain. In this study, field observation and laboratory tests were conducted to investigate seasonal variation of thermal-induced strain in flexible pavement. Field observations were conducted at the Integrated Road Research Facility (IRRF)'s test road in Edmonton, Alberta, Canada, which is fully equipped with structural and environmental monitoring instruments. The main objective of the field study was to compare the variation of thermal-induced strain in warm and cold seasons. Field results indicated that thermal-induced strain is 1.4–2.0 times greater in cold seasons than in warm seasons following the same pavement temperature variations; however, strain generation rate was greater in warm seasons. Laboratory testing of asphalt slab and cylindrical samples produced comparable ratios. Moreover, field observation and laboratory testing showed a similar trend of temperature and thermal strain variations.

Keywords: Thermal-induced strain; Asphalt strain gauge; Field observation; Flexible pavement; Laboratory testing; Seasonal variation

1. Introduction

1.1. Background and previous studies

Thermal-induced stress is built up on asphalt concrete due to extreme temperatures during hot summer and cold winter days. As thermal stresses occur in the asphalt layer, they cause the pavement to undergo thermal cracking. The asphalt mix is viscoelastic, meaning that this stress is a function of time which is then governed by two factors: variation of temperature and relaxation modulus of the asphalt mix. These factors are in turn a function of temperature [10]. Thermal cracking is one of the major concerns in flexible pavement, especially in regions where daily and seasonal temperature change is significant and rapid. Water infiltration through thermal cracking can accelerate the formation of other distresses, including stripping in the HMA layer and weakening of the base and subgrade layers. Temperature change affects flexible pavements in two different ways: daily temperature variation and seasonal temperature variation. Change in structural response is the result of seasonal variation of temperature, and thermal expansion and contraction are the results of daily thermal cycles [14]. Thermal cracking consists of two major distresses: (a) thermal fatigue cracking and (b) low-temperature cracking. Thermal fatigue cracking is caused by a repetition of thermal cycles that creates the HMA

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stress lower than material strength. The generation of irrecoverable deformation and fluctuation of material stress and strain also result in thermal fatigue cracking [1,10]. On the other hand, a high rate of cooling in extremely cold weather causes low-temperature cracking when the tensile thermal stresses exceed the tensile strength of the HMA. Thermal distresses are defined by thermal properties, such as coefficient of thermal contraction (CTC) and coefficient of thermal expansion (CTE). CTC and CTE are the fractional dimension changes due to the unit change of temperature [7]. Thermal expansion and contraction cause thermal stress and strain generation within the asphalt layer [3]. Throughout the time that thermal strain transpires, temperature has a double impact and thus alters the material's relaxation modulus. As a result of stress relaxation, thermal stresses in a viscoelastic material will vary even if the temperature and, consequentially, strain remain stable. It is imperative to take note of this fact in the hot mix asphalt (HMA)'s low-temperature crack spacing [9] and [11]. Therefore, quantifying and comparing the asphalt strain amplitude associated with thermal loading on flexible pavements in different seasons, as well as high and low temperature ranges, are vital.

Several studies have been conducted through field experiments to evaluate the variation in thermal-induced strain of asphalt pavement. Longitudinal strain at the bottom of the HMA was recorded as high as 350 μm/m from a one-year field experiment using asphalt strain gauges (ASGs) at the Virginia Smart Road located in Southwest Virginia [1]. The Centre for Pavement and Transportation Technology (CPATT) performed another field study at their test track in Waterloo, Ontario, Canada, and the result showed that high amplitude thermal-induced strain can occur in flexible pavements on a daily and seasonal basis. The daily thermal-induced strain was as high as 600–650 μm/m during warm weather months, whereas it was lower during cold months [3]. This study also demonstrated that, on average, the monthly thermal-induced strains were significant at 1.6–1.8 times higher than the 49 kN wheel load with the speed of 25 km/h. However, none of the studies estimated the effect certain daily temperature changes have on asphalt strain in different seasons. Another field observation performed at a test road on the I-40 interstate highway in New Mexico, United States, revealed that the structural response of flexible pavement depends on the temperature variation of the day [4]. Furthermore, a recent study on the thermal properties of asphalt concrete found that the change in thermal strain differs with temperature. Thus, a nonlinear relationship of thermal coefficients has been found with respect to temperature [6]. Moreover, some laboratory testing programmes were conducted to determine the thermal properties of asphalt concrete under different conditions using ASGs and linear variable differential transformers (LVDTs) [8,7,5]. However, it is certain that the previous research investigated the mechanism of thermal fatigue cracking; measured asphalt thermal strain at the bottom of the HMA on a daily, seasonal and yearly basis; and determined thermal properties of asphalt concrete using laboratory testing. But the past studies have not evaluated the effect of seasonal temperature change on asphalt thermal strain generation, and they did not attempt to compare the asphalt thermal strain for different temperature ranges.

1.2. Objectives and scope

The main objective of this study is to evaluate the effect of seasonal temperature variation on the generation of thermal-induced strain in flexible pavement based on field observation and laboratory testing. The specific objectives are as below:

- Determine the variation of asphalt concrete thermal-induced strain in warm and cold seasons based on field observation.
- Investigate thermal-induced strain variation in different temperature ranges based on laboratory testing of an asphalt slab.
- Investigate the relationship between thermal-induced strain ratio for higher and lower temperatures based on laboratory testing of a cylindrical asphalt sample compared with that of laboratory slab sample and field observation data.

2. Research methodology

In this study, thermal-induced strain was measured in three different methods, as presented in Fig. 1. Method 1 is a field observation of five months' monitoring of a test road. Thermal-induced strain, air temperature and pavement temperature data were collected from the Integrated Road Research Facility (IRRF)'s test road, and the strain variations in warm and cold seasons were measured and compared. In Method 2, an asphalt slab was prepared and tested in the laboratory to observe the thermal-induced strain variation within a certain temperature range. The temperature range was selected as 31 °C to −34 °C based on the maximum and minimum air temperature from January 2014 to January 2015 according to field monitoring data. In this method, the strain was measured with an ASG inserted into the asphalt slab. The ASG was tested previously in an environmental chamber to determine its temperature dependency. Last, Method 3 is a laboratory test of a cylindrical asphalt sample. In this test, LVDTs measured thermal strain caused by slight variations of temperature within a small temperature range of 20 °C to −16 °C.

3. Field observation

3.1. Instrumented section

Field observation of this study was conducted at the IRRF's test road in Edmonton, Alberta, Canada, at the