

A Model for Pavement Temperature Prediction

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ABSTRACT

A finite element model has been developed to calculate the temperature of a pavement located in the Northeast of Portugal. The goal of the case study presented in this paper is the validation of this model. Input data to the model are the hourly values for solar radiation and temperature, and mean daily values of wind speed obtained from a meteorological station. The thermal response of a multilayered pavement structure is modeled using a transient thermal analysis for four months time-period (December 2003 - April 2004) and the analysis was initiated with the full depth constant initial temperature obtained from field measurements. During these four months, pavement temperature was measured at a new pavement section, located at IP4 main road, near Bragança, in the north of Portugal. At that location, seven thermocouples were installed in the AC layers, at seven different depths. These pavement data was used to validate this simulation model, by comparing model calculated data with measured pavement temperatures.

As conclusion, the 3-D finite-element analysis proved to be an interesting tool to simulate the transient behavior of asphalt concrete pavements. The suggested simulation model can predict the pavement temperature at different levels of bituminous layers with a good accuracy.

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1 - INTRODUCTION

Bituminous overlays have been the most used method in pavements rehabilitation. The service life of an overlay depends on its performance in different distress modes. In an overlay placed on a cracked pavement, the cracks will develop and propagate to the pavement surface, directly above cracks in the existing pavement under static and repetitive loading, during the first few years of service. This mode of distress is traditionally referred as “reflective cracking” and is a major concern to highway agencies throughout the world. Thus, the asphalt concrete overlay is exposed to great strains and stresses when subjected to traffic and thermal loadings. Several authors (1) and (2) suggest that different mechanisms have been identified as the origin and propagation of cracks in overlays of pavements (1):

1. Thermal stresses from thermal fatigue, which occurs when temperature variations induce cyclic openings and closures of cracks in the pavement, which induce stress concentrations in the overlay.
2. Thermal stresses as a result of rapid cooling down of the top layer, which induces critical tensile stresses on overlay.
3. Repetitive traffic loads induce additional distress in the overlay and increase the rate of crack propagation, whether or not these cracks originate from thermal stresses;
4. Soil movements – settlements (downwards), frost.

The literature review (2) also revealed that temperature variations, daily and seasonal, and associated thermal stresses, could be a cause of premature overlay cracking, affecting the predictive overlay service life of conventional and asphalt rubber mixes.

In regions that experience large daily temperatures variations or extremely low temperatures, the thermal conditions plays a major role in the reflective cracking response of a multilayered pavement structure. On one hand, binder properties (stiffness, ageing, penetration, etc...) are sensitive to temperature variations. The combination of the two most important effects: wheel loads passing above (or near) the crack and the material (overlay) above the crack being under tension due to rapidly decreasing or low temperatures, have been identified as the most likely causes of high states of stress and strain above the crack and responsible by the reflective cracking (3).

Daily temperature variations have an important influence in the pavement thermal state on depth below the surface of few decimeters. Depending on the level of temperature variation, stress is induced in the overlay in two different ways, which need to be distinguished: through restrained shrinkage of the overlay and through the movements of the existing slabs.

Firstly, restrained shrinkage of the overlay itself causes transverse and longitudinal tensile stresses, which are dependent of: overlay mix stiffness, overlay mix thermal coefficient of contraction, overlay mix Poisson ratio and pavement thermal gradient. These stresses have their maximum at the pavement surface, not only due the larger temperature variation, but also because of the rate dependent asphalt behavior. Due the fact that bitumen aging takes place at surface, the phenomenon described above induces the crack to initiate and propagate from the pavement surface downward. The use of softer asphalts presents as good option to delay (or arrest) reflective cracking in overlays. This thermal restrained shrinkage phenomenon occurs not only in overlays but also in new pavement structures.

Secondly, the movements of the existing slabs exert a repeated splitting at the bottom of the overlay inducing an important stress (or strain) state in the overlay. The thermal movements of cracked layer as result of thermal shrinkage are dependent of overlay mix stiffness, cracked layer mix stiffness, cracked layer mix thermal coefficient of contraction, overlay thickness, degree of friction between the overlay and distance between cracks.

Consideration should therefore be taken to the lowest expectable temperatures of the asphalt concrete. These temperatures of course differ on the weather conditions at different locations. In order to calculating thermal effects, one needs to evaluate the temperatures evolution on many depths of bituminous layers throughout typical twenty-four hours periods. The temperature distributions calculated for different times during the day allow to calculate thermal effects in the zone above the crack and can be used to investigate other affects, such as, temperature influence on layer's material properties (like stiffness) when only traffic load is considered.

Thus, the estimation of thermal response has shown that they are important. In order to consider their effects, a more precise knowledge of the temperature distribution is needed. The pavement thermal time variation state is controlled by the climatic conditions, i. e., the thermal diffusivity, as function of thermal conductivity, specific heat and density, of the materials and the depth below the surface (2) and (4).

The temperature distribution throughout the pavement structure can be obtained through field measurements, using temperature-recording equipment (Datalogger associated with thermocouples) or estimated by using mathematical models. The option of use the field measurement is desirable because actual temperature