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Temperature predictions for asphalt pavement with thick asphalt layer

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HIGHLIGHTS

- A statistical model was developed to predict temperatures of thick asphalt layer.
- Five sites were selected to collect measured temperatures and meteorological data.
- Q_N and $\bar{T}_{aN}$ can largely affect pavement temperatures.
- T_m was incorporated for the impact of the ground temperature on pavement.

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ABSTRACT

Temperature is one of the most important factors affecting functional as well as structural performance of asphalt pavements with thick asphalt layer (>30 cm). For a successful pavement design, it is vital to accurately predict the pavement temperatures at various depths. However, most previous researches focused on the temperature predictions for conventional asphalt pavements, of which the asphalt thickness is less than 30 cm. This suggests their proposed models are applicable in top layers, but may not be so effective for temperature predictions at deeper depths. As a result, the primary objective of this research was to develop a statistical model to predict temperatures at deep depths. Three test sites were selected, and they were instrumented with a number of sensors and a data logger to record the pavement temperature hourly. Also, all test sections can provide meteorological monitoring to collect hourly air temperatures and hourly total solar radiation. The recorded meteorological conditions were found to have cumulative effect on the measured pavement temperatures at various depths. On basis of their relationship, a statistical regression was performed, and the temperature prediction model was determined as a function of depth, average air temperature and total solar radiation calculated in the cumulative time. For an improvement in applicability, historical mean monthly air temperatures were also incorporated into the mode. The accuracy and applicability of the improved model were validated by applying it to additional sites for which the measured pavement temperatures and meteorological data were available. Also, by comparing with existing models, the developed model was testified to be more effective for asphalt pavements with thick asphalt layer, promising the model's potential use.

1. Introduction

Functional as well as structural performance of asphalt pavements can be greatly affected by pavement temperatures. At low temperatures, asphalts stiffen and the cracking of asphalt layers is accelerated due to shrinkage. At high temperatures, asphalts soften and the distortion of asphalt layers is increased due to bleeding of asphalts [1,2]. Therefore, it is vital to know the range of temperatures over which an asphalt pavement will be subjected. This importance calls for special attention and interest in research to develop procedures for pavement temperature predictions.

Approaches for temperature predictions within asphalt pavement have been proposed by a number of researchers. These approaches can be divided into two categories. One is analytical approach, which is based on the heat transfer theories and thermal properties of asphalt pavement. The other is statistical method, which uses regression models to obtain the relationship between measured pavement temperatures and climatic data.

In 1975, among the first researchers taking analytical approach, Barber [3] presented a method for calculating maximum pavement

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temperatures from weather report and thermal diffusion theory. Based on his pioneering work, Dempsey [4] developed an analysis program named Climatic-Materials-Structural (CMS) model in 1970. The CMS model was improved by Thompson [5] in 1987, and temperatures were computed by a one-dimensional, transient finite-difference heat transfer model with climatic data input. In 1993, Solaimanian and Kennedy [6] discussed an analytical approach for predicting critical temperature extremes in pavements. Similarly, it uses the theories of heat and energy transfer. Based on their approach, Hermansson [7] proposed a simulation model to predict maximum pavement temperatures in 2000. Although all the models mentioned above do calculate temperatures with reasonable accuracy, the large number of inputs makes approach rather cumbersome and hard to use.

As a result, more and more researchers adopt statistical approach to predict pavement temperatures. From 1960 s to 1980 s, due to the limitations of temperature sensors and data recorders, just a few studies measured pavement temperatures and climatic data. In 1968, Southgate and Deen [8] presented two sets of figures for temperature predictions. Pavement temperatures in the top 2 in. are directly dependent upon surface temperatures, whereas temperatures at depths greater than 2 in. are assumed to be a function of the surface temperatures and 5-day mean air temperature history. In 1970, Rumney and Jimenez [9] developed empirical nomographs to predict pavement temperatures at the surface and at a depth of 2 in. These nomographs suggested that measured pavement temperatures have a good relationship with air temperatures and hourly solar radiation in Tucson, Arizona.

By the 1990 s, the Strategic Highway Research Program (SHRP) started. It developed the binder and mixture specifications that closely related to yearly maximum and minimum pavement temperatures. Therefore, the aim of studies was to determine critical pavement temperature extremes with sufficient accuracy for various regions. For this purpose, Bosscher et al. [10], Marshall et al. [11], and Diefenderfer et al. [12] all developed statistical models between measured pavement temperatures and meteorological data. These data are from initial SHRP testing, or Seasonal Monitoring Program (SMP), or other data sets.

More recently, efforts have been made to predict pavement temperatures on a smaller time scale. In 1994, Baltzer et al. [13] proposed the BELLS model to predict pavement temperatures at different time. It is based on a statistical regression analysis using infrared surface temperatures and previous 5-day air temperatures before testing. In 2000, several modifications were made to the BELLS model by Lukanen et al. [14]. The sine functions of BELLS model were replaced by two sine functions to approximate the shape of the warming and cooling trends. Besides, average air temperature the day before testing was a substitute for previous 5-day air temperatures in BELLS model. After that, Park et al. [15] developed a statistical temperature prediction model in 2001. It takes into account temperature gradients due to diurnal heating and cooling cycles and needs fewer parameters than BELLS models. Additionally, Jia et al. [16] determined a regression model for

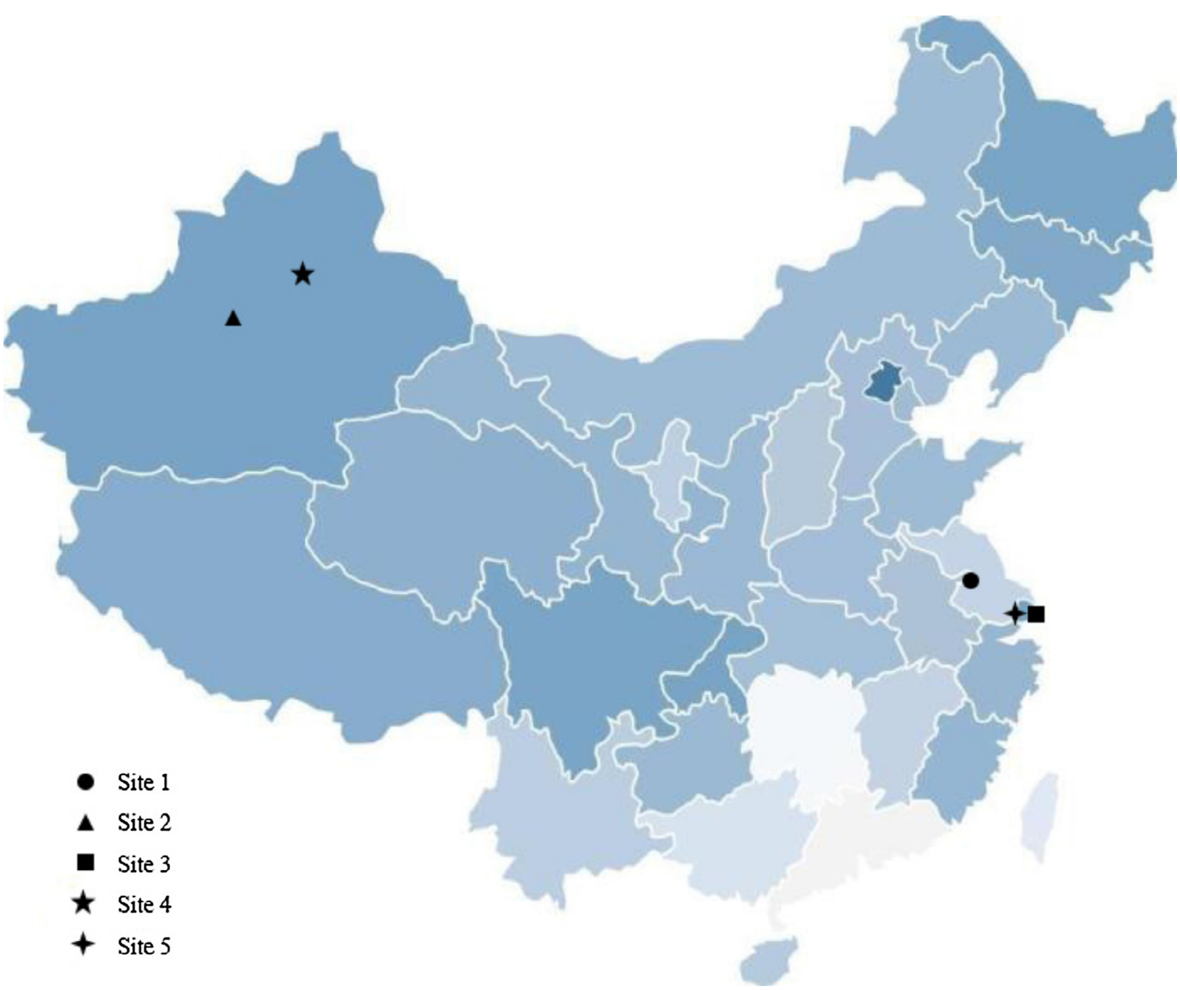

Fig. 1. Location of test sites.