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A MODEL FOR THE PAVEMENT TEMPERATURE PREDICTION AT SPECIFIED DEPTH

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This paper examines the existing models for predicting pavement temperatures at a certain depth and formulates a new one using the regression equation to predict the minimum and maximum pavement temperatures at the specified depth depending on the surface pavement temperature and its depth.

Key words: model, temperature, pavement, prediction, depth

INTRODUCTION

One of the most important environmental factors that significantly affect the mechanical properties of asphalt mixtures is temperature.

The structural capacity of the hot mix asphalt concrete layers depends on many factors including its temperature. Moreover, tempe-rature can be a major contributor to several types of distresses.

Therefore, temperature is a significant factor that affects the performance and life span of a pavement.

After the introduction of the Superpave pavement temperature estimation procedures in 1993, many researchers expressed concerns regarding the accuracy of the temperature algorithms and the implications of using the estimated values.

The objective of this study is to make a valid model for predicting the pavement temperature at a certain depth for characteristic region.

Like the modern logistics systems bring us back to the beginning of scientific development [1], accurate prediction of the asphalt pavement temperature at different depths based on air temperatures and other simple weather station measurements can help engineers in performing back calculations of asphalt concrete modulus and in estimating pavement deflections.

The temperature distribution of flexible pavements is directly affected by the enviro-nmental conditions, to which it is exposed, Figure 1 [2].

The main task, then, is to determine physical and mechanical properties of materials in the conditions equivalent to the conditions in the real pavement structure [3].

Pavement temperature is very important in evaluating frost action and frost penetration. Modeling pavement surface temperature as a function of such weather condition (air temperature, dew point, relative humidity and wind speed) can provide an additional component that is essential for winter maintenance operations [4]. Like heat transfer properties for nanofluids [5] and other materials and structures are very important, for pavement structures are especially important.

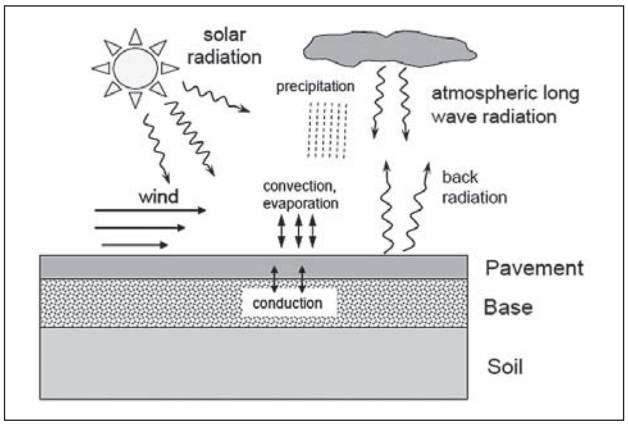

Figure 1 Energy balance on the surface of the pavement [2]

STATE OF THE ART

The purpose of the review is to find out the strengths and the weaknesses of available models in order to provide the basis for more detailed evaluations, selection and improvement of models.

Several pavement performance prediction models have been proposed over the years. Many of these models are developed for application in a particular region or country under specific traffic and climatic conditions. Hence, they cannot be directly applied in other countries or conditions.

Strategic Highway Research Program (SHRP) formed the Long-Term Pavement Performance (LTTP) program in 1987 as a product of 20-year-long research for better defining the pavement characteristics in situ. 64 (LTTP) locations were selected as a part of the Sea-

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sonal Monitoring Program (SMP). The result of the SMP research is the SUPERPAVE (Superior Performing Asphalt Pavement) method for designing asphalt courses [6].

Updated versions of the SHRP models for predicting pavement temperatures at depth were developed by Mohseni, 1998 [7].

Lukanen et al. (1998) presented their own maximum and minimum pavement temperature prediction models based on an expanded set of SMP data [8].

Bosscher et al. (1998) were also interested in determining the pavement temperature as it varied with depth in relationship to the low air temperature [9].

Ovik et al. (1999) presented an analysis of temperature data from the MnRoad test site in Minnesota [10].

Park et al. (2001) developed a model that could be used to predict pavement temperatures given the surface temperature and the time of day for use with FWD analysis [11].

Marshall et al. (2001) presented another temperature prediction model for usage with FWD analysis [12].

The research of Marshal et al. [12], and Denneman et al. [13] provide an empirical model that enables the user to estimate the temperature profile of the pavement structure during any part of the day.

EXPERIMENTAL PART

Instrumentation

In total, six sensors for measuring the pavement temperature at specified depth were set.

Data was measured during the experimental research by setting the temperature measuring sensors at the depth of the flexible pavement structure, at the university campus, in the street Dr Ilije Đuričića, Novi Sad, Serbia.

To measure the asphalt layer temperature in the pavement structure, the temperature sensors DS18S20 manufactured by Dallas Semiconductor (i.e. Maxim) were selected.

DS18S20 measures temperatures in the range between 55 °C and +125 °C, which is a wide enough temperature range for the application with asphalt, while their measuring precision is better than 0,5 °C.

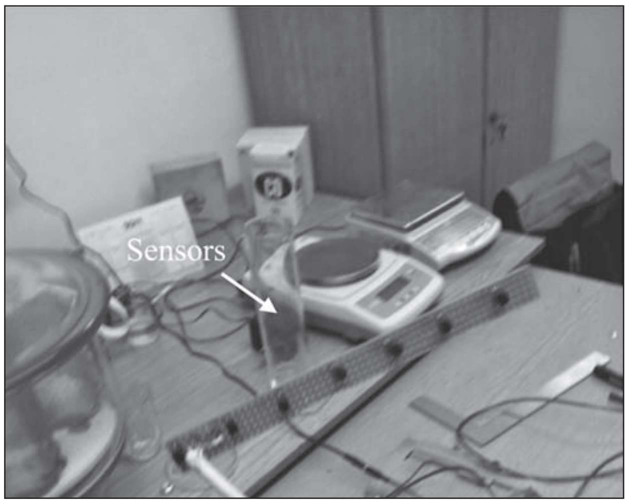

Figure 3 Sensors for pavement temperature measurement at a specified depth: sensors DS18S20 before being set in asphalt

The realized measuring system comprises 6 temperature sensors, micro controller PIC16F877 and a computer (PC), Figure 2.

On setting the sensors on a Pertinax board, they are insulated with the heat shrink material to ensure their function without physical damage (Figure 3).

Data utilized in model formation were gathered in the period December (2011 ÷ 2012).

The analysis was performed on a flexible pavement structure where there were two bearing courses (15,0 cm Base course - crushed stone 0 ÷ 31 mm and 20,0 cm Subbase course - crushed stone 0 ÷ 63 mm) and two asphalt courses (5,0 cm Wearing course and 9,0 cm Binder course), Figure 4. The overall thickness of asphalt layers was 14,0 cm.

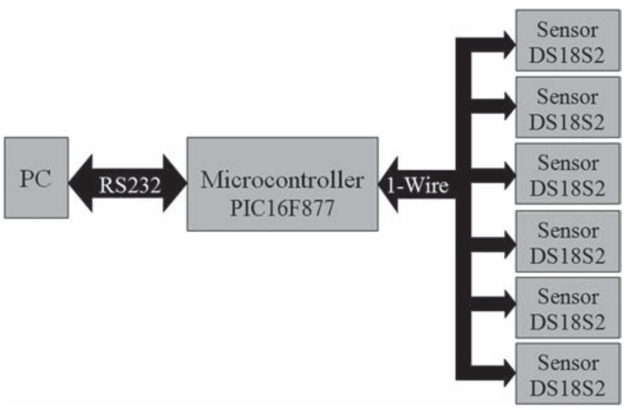

Figure 2 Block diagram for the measuring system

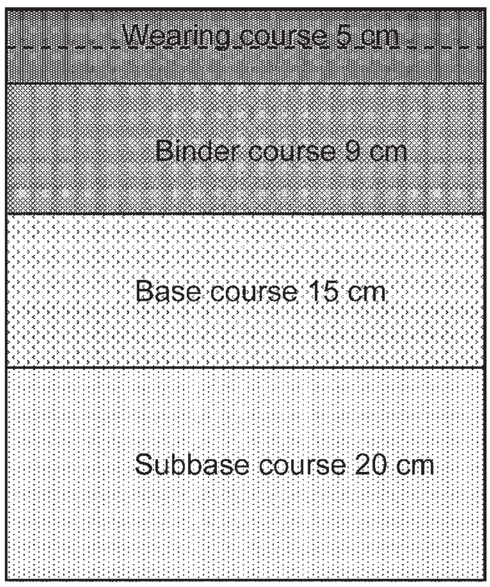

Figure 4 Overview of the analyzed pavement structure

RESULTS AND DISCUSSION

Methodology and anticipated results

The model developed with the objective of predicting pavement temperature at depth is based on the regression data analysis. Regression equations are formed to predict maximum and minimum pavement temperatures at depth, depending on the maximum and minimum surface pavement temperature and depth.

Regression equations

The model predicting maximum pavement temperatures at specified depth can be presented by the following equation:

$$y_{max} = 0,963288x_{max} - 0,151137x_d + 4,452996 \quad (1)$$

Standard model deviation is 0,83 °C. Corre-lation coefficient is 0,973.

The model predicting minimum pavement temperatures at specified depth can be presented by the following equation:

$$y_{min} = 1,004801x_{max} - 0,1992731x_d + 0,051532 \quad (2)$$

Standard model deviation is 0,9 °C. Corre-lation coefficient is 0,985.

Model validation

Based on the formulated model for predicting maximum and minimum pavement temperatures at specified depth (1, 2), the model validation has been performed by comparing measured and predicted pavement temperatures at depth (Figure 5).

The mean absolute error (MAE) between measured and predicted maximum pavement temperatures at depth is 0,700457, and between measured and predicted minimum pavement temperatures MAE is 0,782117.

On comparing measured and predicted pavement temperatures at depth, it can be concluded that the models predict pavement temperatures with adequate accuracy.

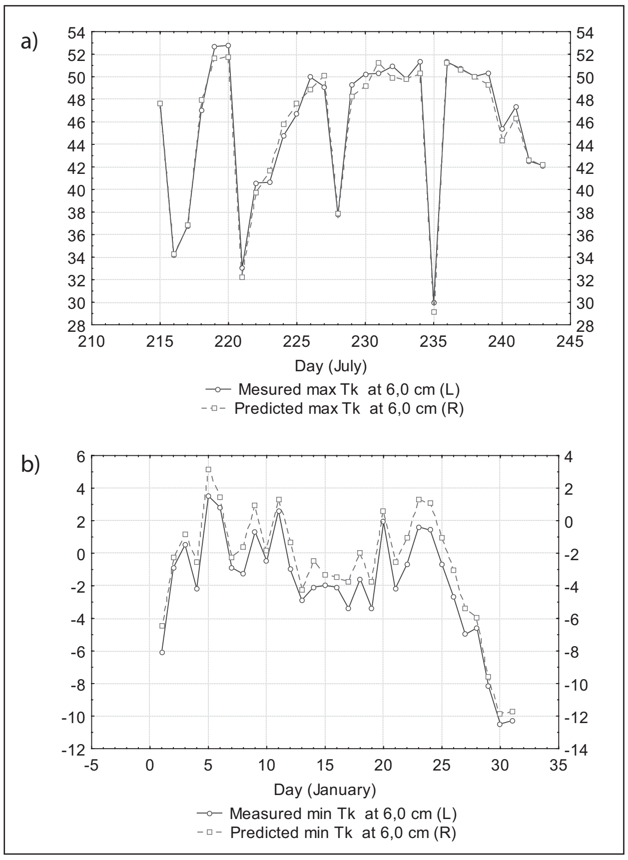

Figure 5 Validation of the model for predicting maximum (a) and minimum (b) pavement temperatures at depth, for characteristic months: July and January (for example, at 6,0 cm)

CONCLUSION

The paper formulates new models for predicting minimum and maximum pavement temperatures at specified depth using the regression equations, in dependence on the surface pavement temperature and pavement depth.

During the data analysis and the formation of the pavement temperature prediction model for specified depths, it has been determined that temperatures behave differently depending on the pavement surface temperature, daylight, pavement surface depth, and the part of the day.

It can be concluded that temperatures at certain layers become lower in the periods without solar radiation on the pavement surface, and that temperature become higher in the period after the sunrise, and especially during the solar radiation peak between 12:00 and 18:00.

Furthermore, it can be concluded that the pavement layer temperature at certain depth is influenced by the pavement temperature from the day before, since temperatures in pavement layers alter significantly slower in relation to the surface pavement temperature, Figure 6.

With greater depth, the ratio between surface pavement temperature and the temperature at certain depth decreases, i.e. surface pavement temperature varies a greater deal more in relation to the temperatures at a certain depth.

Based on the correlation coefficient, standard model deviation and mean absolute error (MAE), it can be concluded that these models can be utilized with the adequate accuracy for predicting maximal and minimal pavement temperature at depth; yet the model for predicting maximal pavement temperature at certain depth provides a somewhat more accurate result.

Also, the model validation has been conducted. Based on the correlation coefficient, standard model deviation and mean absolute error (MAE), it can be concluded that the models predict pavement temperatures at depth well and that they can be utilized for calculations in practice.

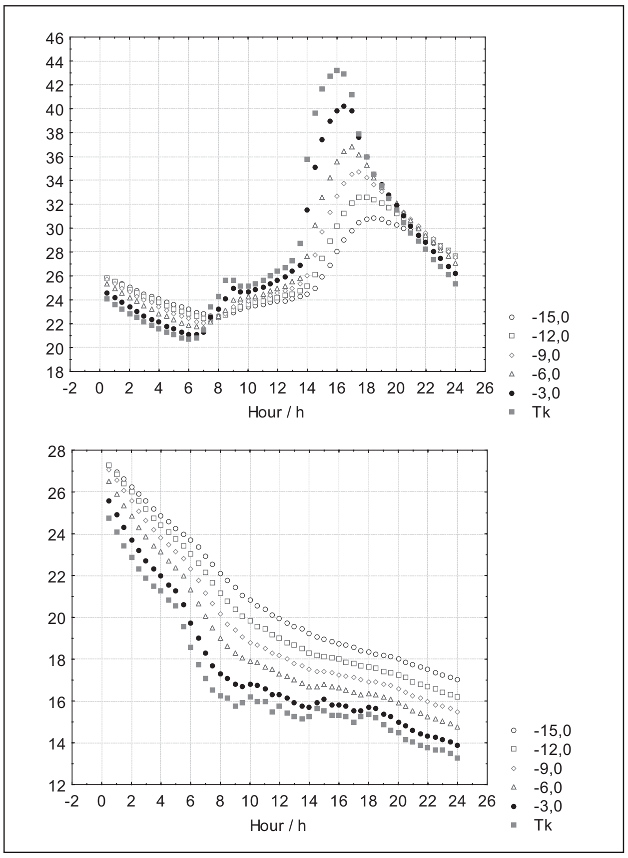

Figure 6 Temperature overview of the pavement structure layer for two consecutive days

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Legend of symbols

y_{max} predicted maximum pavement temperature at depth /°C,

x_{max} daily maximum surface pavement temperature /°C,

y_{min} predicted minimum pavement temperature at depth /°C,

x_{min} daily minimum surface pavement temperature /°C and

x_d depth from the surface /cm.

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Note: The responsible translator to the English language is V. Bogdanović, Faculty of Technical Sciences, Novi Sad, Serbia