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DEVELOPMENT AND EVALUATION OF THE MODEL FOR THE SURFACE PAVEMENT TEMPERATURE PREDICTION

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Preliminary Note – Prethodno priopćenje

This paper examines the existing models for predicting pavement temperatures and formulates a new one using a regression equation to predict the minimum and maximum pavement surface temperatures depending on the air temperature. Also, the paper presents a model for pavement temperature prediction according to the Superpave methodology and conducts the validation of the model for measured temperatures.

Key words: temperature, pavement, prediction

Razvoj i ocjena modela za predikciju temperature površine kolničke konstrukcije. U članku su predstavljeni postojeći modeli za predikciju temperature kolnika i formuliran je novi model pomoću regresione jednadžbe kojom se predviđaju minimalne i maksimalne temperature površine kolnika u ovisnosti od temperature zraka. Također je predstavljen i model za predikciju temperature prema Superpave metodologiji i izvedeno je vrednovanje modela za izmjerene temperature.

Ključne riječi: temperatura, kolnik, predikcija

INTRODUCTION

Well-known facts and the experience prove us that, apart from traffic load, temperature and material moisture in the courses of the pavement structure and subgrade have the most significance in comparison to all external factors. Since the regime of the moisture in the pavement and in the subgrade largely depend on the heating regime, it can be concluded that temperature is a factor with a very wide and significant influence on the behaviour of the pavement structure.

Pavement structure is a multi-layered system composed of diverse materials whose behaviour is more or less dependent on the temperature.

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. In this sense, with the bitumen-bound materials, it is important to determine their characteristics in the range of temperatures in the pavement structure, with the special consideration on the impact of extreme temperatures, as shown in Figure 1 [1].

The damage of the pavement structure depends on the demanded functional pavement characteristics, which are defined primarily in relation to the following: traffic volume, participation and weight of cargo vehicles, ambient conditions, valid vehicle speed, exploitation costs, and maintenance costs. Figure 2 presents a

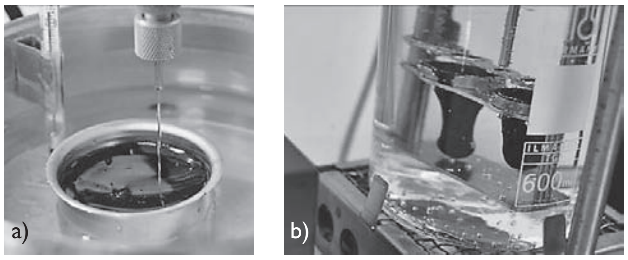

Figure 1 Examination of physical and mechanical properties of bitumen depending on the temperature: a) penetration and b) melting point [1]

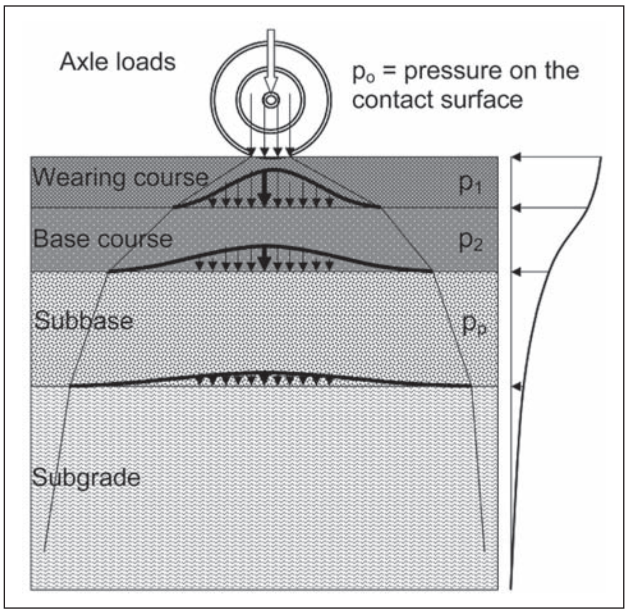

Figure 2 Flexible pavement and load distribution [2]

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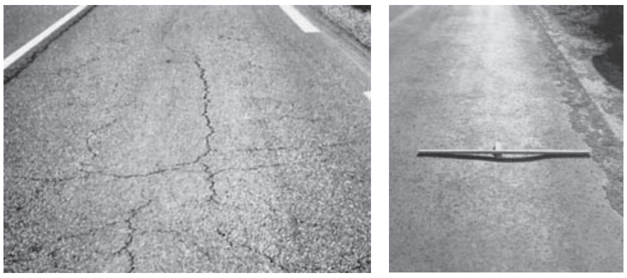

a) b)

Figure 3 Pavement damage: a) line and grid cracks and b) rutting [1]

scheme of load transfer from the vehicle axis, through the pavement courses, subbase, and subgrade.

In the case when the selected materials do not satisfy the appropriate bearing capacity in diverse types of load and different ambient conditions (temperature and moisture), diverse damage and defects in the pavement structure can occur, and they can be manifested in all courses (longitudinal and transverse cracks) or only in upper courses (surface damage of asphalt courses).

Figure 3 provides an overview of some characteristic cases of the pavement structure damages.

CALCULATIONS ON PAVEMENT TEMPERATURE

The occurrence of high temperatures in the warmest periods of the year can significantly increase the influence of the viscous component in the behaviour of the asphalt mixture and can lead to greater pavement deformations, especially with the action of heavily loaded wheels moving slowly or standing still (extreme example are bus stations, traffic lanes for heavy vehicles on a hill, etc.).

Due to this reason, it is extremely important to determine the danger of the appearance of deformations in the condition with extreme temperatures, and primarily to determine the height and duration of these temperatures, as well as to analyse traffic load in detail. Therefore, pavement temperature largely depends on the season and the position of the Sun, as presented in Figure 4.

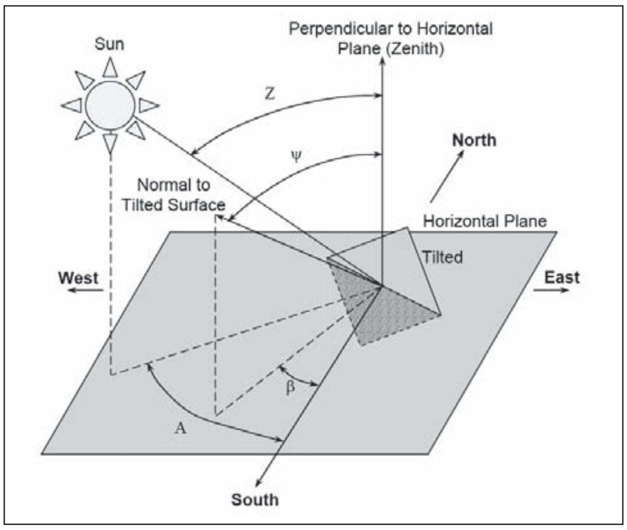

Figure 4 Defining the position of the Sun [3]

State of the art

One of the first researchers examining the problem of calculating maximum pavement temperatures based on the weather reports was Barber in 1957. Dempsey [4] developed a simulation model based on the theory on heat conductivity and energy balance on the pavement surface. Strategic Highway Research Program (SHRP) formed the Long-Term Pavement Performance (LTTP) programme 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 Seasonal Monitoring Program (SMP). The result of the SMP research is the SUPERPAVE (Superior Performing Asphalt Pavement) method for designing asphalt courses.

From the initial (SHRP) tests to SMP, models for defining pavement temperature were developed in order to help in the formation of adequate asphalt courses; they were provided in the conditions of PG (Performance Grade) [5].

The comparison of the selected PG and the real temperatures was investigated by Mohseny and Symons [6], Bosscher et al. [7] and Diefenderfer et al. [8]. The research of Marshal et al. [9], Denneman et al. [10] provide an empirical model that enables the user to estimate the temperature profile of the pavement structure during any part of the day.

DETERMINATION OF PAVEMENT TEMPERATURES USING THE SUPERPAVE METHOD

After several years long research (LTTP and SMP) on the behaviour of pavement structure under traffic load and in environmental conditions, the method for designing asphalt pavements, called SUPERPAVE, has been formed.

The process of calculating pavement temperature from air temperature is as follows:

- Convert average 7-day maximum air temperature to pavement surface temperature,
- Calculate 7-day maximum pavement temperature at the design depth,
- Convert minimum air temperature to minimum pavement surface temperature,
- Calculate minimum pavement temperature at the design depth.

Environmental conditions are specified in terms of average 7-day maximum pavement design temperature and minimum pavement design temperature. The average 7-day maximum pavement design temperature is the average of the highest daily pavement temperatures for the 7 hottest consecutive days in a year. The lowest annual pavement temperature is the coldest temperature of the year. The asphalt binder specification uses the designation PG x-y, where PG = Performance Graded, x = high pavement design temperature, and y = low pavement design temperature [4].

The pavement surface temperature can be calculated using the following regression equation (Huber 1994):

$$T_{s(\max)}=T_{a(\max)} - 0{,}00618\cdot\phi^2 + 0{,}2289\cdot\phi^2 + 24{,}38 \quad (1)$$

The equation for minimum asphalt surface temperatures recommended in the Superpave is as follows:

$$T_{s(\min)}=0{,}859\cdot T_{a(\min)} +1{,}7 \quad (2)$$

MODEL FOR PAVEMENT SURFACE TEMPERATURE PREDICTION

Data used for model formation

The data for the model formation were collected during the period of nine consecutive years, with breaks related to technical and organizational issues. Monitoring temperature changes in the air, and pavement courses was conducted at several diferent locations.

Methodology and anticipated results

The model developed with the objective of predicting pavement surface temperature is based on the regression data analysis. Regression equations are formed to predict maximum and minimum pavement surface temperatures, depending on the maximum (at 3:00 p.m.) and minimum (at 7:00 a.m.) air temperature.

Data analysis is performed in the programme STATISTICA. The analysed pavement structure is presented in Figure 5. The analysis was done on a half-rigid pavement structure where two bearing courses (15 and 20 cm) were stabilized by a hydraulic binder. Other courses and pavement were the same as with flexible pavements, so methodologically they can be treated as flexible pavements.

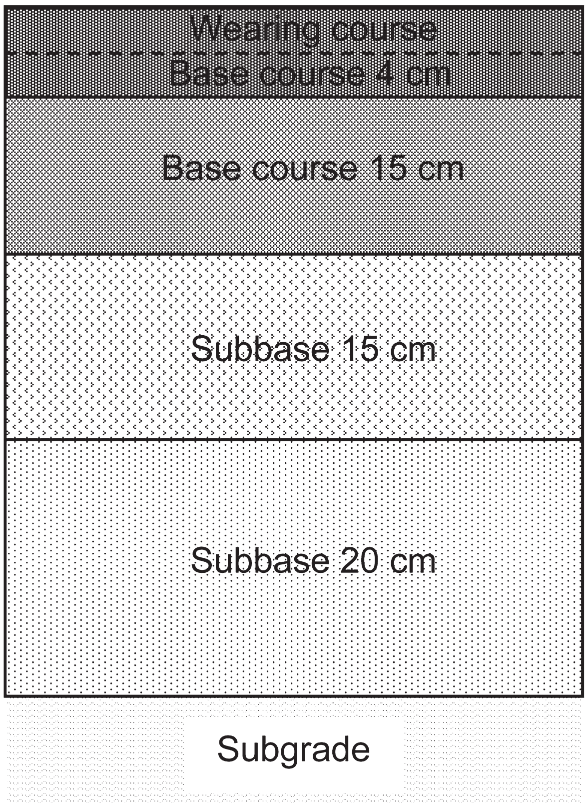

Figure 5 Overview of the analysed pavement Structure

Regression equations

The model predicting maximum temperatures in the pavement surface can be presented by the following equation:

$$Y_{p,\max}=0{,}065567 + 1{,}268887\cdot X_{a,\max} \quad (3)$$

Standard model deviation is 3,0016. Correlation coefficient is 0,972651.

The model predicting minimum temperatures in the pavement surface can be presented by the following equation:

$$Y_{p,\min}=0{,}318933 + 1{,}10967\cdot X_{a,\min} \quad (4)$$

Standard model deviation is 1,8569. Correlation coefficient is 0,980397.

MODEL VALIDATION

Based on the formulated model for predicting maximum and minimum pavement surface temperatures (3, 4), the model validation has been performed by comparing measured and predicted pavement temperatures (Figure 6).

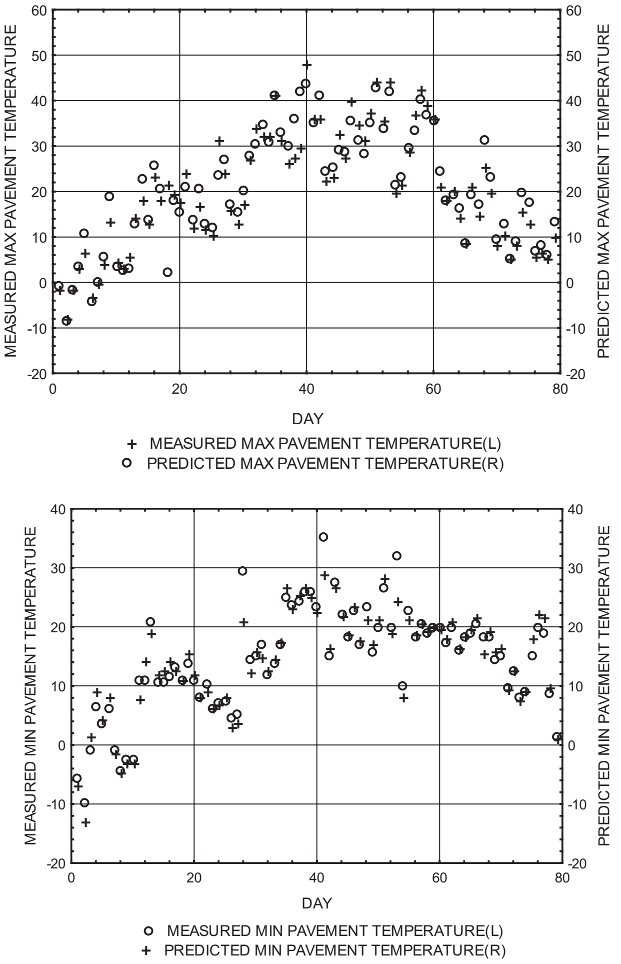

Figure 6 Validation of the model for predicting maximum (a) and minimum (b) pavement surface temperatures

The mean absolute error (MAE) between measured and predicted maximum pavement temperatures is 2,291912 while standard deviation of error (SDE) is 5,091 and between measured and predicted minimum pavement temperatures MAE is 1,169958 and SDE is 1,816 (Figure 6). On comparing measured maximum pavement surface temperatures and temperatures according to the SUPERPAVE methodology, it has been determined that the MAE is 18,68676 and SDE is 5,194 while the MAE between measured and predicted minimum pavement temperature is 2,197991 and SDE is 2,833.

CONCLUSION

The paper formulates new models for predicting minimum and maximum pavement surface temperatures using regression equations, in dependence on the ambient air temperature. Furthermore, model validation has been conducted. Based on the correlation coefficient, standard model deviation and the mean absolute error (MAE) and standard deviation of error (SDE) between measured and predicted pavement temperatures, it can be concluded that the models predict pavement surface temperatures well and that they can be utilized for calculations in analysing air temperature influence on a pavement structure.

On validating the model for pavement temperature prediction according to the SUPERPAVE methodology and in relation to the measured temperatures, the conclusion is that the model does not predict pavement temperature with adequate accuracy.

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Legend of symbols

p_0	pressure on the contact surface /Pa
p_1, p_2, p_p	pressures at the specified depth of pavement /Pa
$T_{\alpha(\max)}$	the daily maximum air temperature /°C
$T_{s(\max)}$	the daily maximum asphalt surface temperature /°C
Φ	latitude of the desired location /degrees
$T_{s(\min)}$	the daily minimum surface temperature /°C
$T_{\alpha(\min)}$	the daily minimum air temperature /°C
$Y_{p,\max}$	predicted maximum daily surface pavement temperature /°C
$X_{a,\max}$	measured maximum daily air temperature /°C
$Y_{p,\min}$	predicted minimum daily surface pavement temperature /°C
$X_{a,\min}$	measured maximum daily air temperature /°C

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