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TEMPERATURE CHANGES IN ASPHALT PAVEMENTS IN SUMMER

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Abstract

This report discusses the experimental determination of temperature conditions in asphalt pavements. Methods applied to evaluate collected data are presented. The experience gained by data related to wearing courses heating and cooling gradients during summer months is promising. Further directions for research are proposed as well.

Keywords: temperature fluctuation, gradients, pavements.

1. Introduction

Hungary is located in the temperate climatic zone to which both positive and negative extremities of temperature are characteristic, which is considered as disadvantageous from the point of view of highway engineering. The temperature often exceeds $30 - 35\,^\circ$C in summer and could decrease under $-15\,^\circ$C in winter time. The fluctuation in temperature within a year is significant, the four seasons are separated sharply from each other [2].

The inner temperature of a pavement made by bituminous binding material exceeds considerably that of the air. The fluctuation mentioned influences the quality of asphalt pavements disadvantageously, it can even shorten their service life, because the rheological features of bitumen depend substantially on temperature and its fluctuation, and the aging process of bitumen may also be accelerated. Too hard bitumen could not be applied because in winter, in case of severe cold weather, thermal cracks would appear, while the pavement made of asphalt with too soft bitumen becomes susceptible to irreversible deformation, and hereby to wheel tracking. This latter is detrimental in the summer months, especially when slow and heavy traffic goes on the road, which occurs frequently. Since the temperature of asphalt structures and the speed of its fluctuation is so important, the local and regional climatic features are serious aspects to be taken into consideration at choosing pavement structures [1]. At the laboratory of the Department of Highway and Railway Engineering the problem has been examined in details. The measurement of pavement temperature is also important in light of the adaptation of SHRP asphalt mixture planning system to the Hungarian temperature conditions, which system selects the type of bitumen to be applied in function of the air and pavement temperatures.

The fluctuations of temperature in asphalt trunks were examined in Germany. For this experiment such meteorological stations were engaged which were able to register the meteorological effects on asphalt trunks [3]. Our experiments differ from this in that we measured only the temperature of the pavement structures of the highways, the other meteorological data were collected from the National Meteorological Service (OMSz).

The research started in 1995 as a pilot program, led by Dr. Kálmán AMBRUS, MSc in Civil Engineering. Thermometers were built into the courses of the 405 Road, which was constructed at that time. The electronic elements of the thermometers were planned and made by Csaba FORRÁSY, MSc in Electrical Engineering.

After the creation of the above mentioned measurement site, three further sites were equipped, and the first one was updated in the mean time, so currently pavement temperature data are collected on 4 different locations in the country. For selecting the location of the measurement sites the climate conditions, the vicinity of meteorological stations and that of traffic counting stations enabled to implement continuous counts combined with axle-load measurements, were taken into account. In that way it became possible to examine the traffic and temperature data together.

2. Measurement Sites

The configuration of thermometers at measurement sites are shown in *Fig. 1*. The thermometers should be inserted into the specified depth with cm accuracy. The operation is made after the completion of the road section's construction. Gaps should be sawn into the pavement (appr. 2 cm wide) as many as thermometer is needed (in our case 7). The depth of the gaps is given, it is about 2–3 cm. Under the thermometers the gaps should be deepened to the required depth of 1 cm, 5 cm, 10 cm and 15 cm, respectively (*Fig. 2*). Using a different process the implementation of a measurement site becomes significantly and unnecessarily more expensive because the gaps should be filled in by expensive synthetic resin. The thermometers should be inserted into the gaps and should be connected to the electronics placed into a steel cabinet deployed on the roadside. Then the gaps should be filled by synthetic resin. To measure exactly the temperature at the actual depth the thermometers could not be placed above each other along a vertical line, but sufficient distance should be kept between them. This explains the V-shape formation. The configuration is shown in *Fig. 1*.

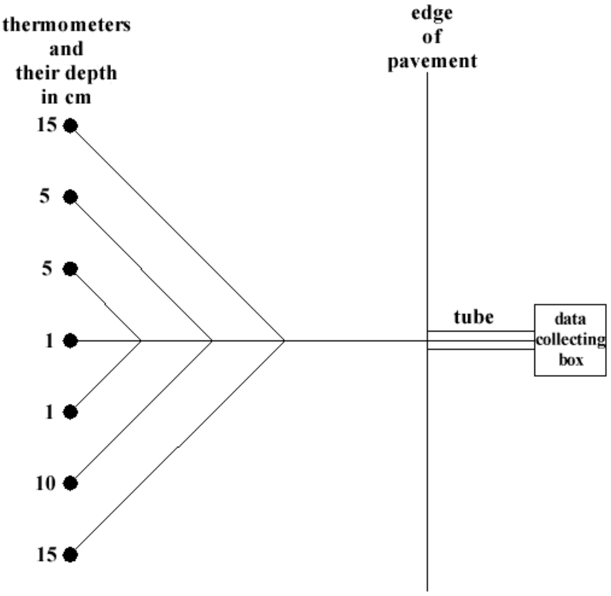


Fig. 1. Configuration of thermometers at measure locations

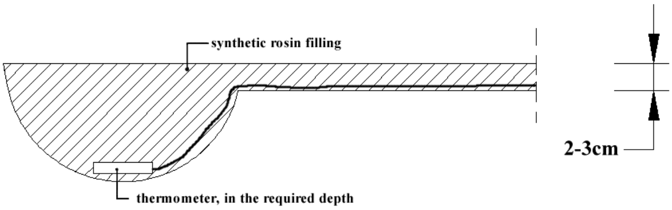


Fig. 2. Cross-sectional configuration of thermometers

3. Data Collection

The data collection is made digitally. The resistance of thermometers depends on the temperature, if the temperature fluctuates, the electrical resistance changes as well. The resistance of the thermometers is recorded by an electronic equipment. The reading is made in every half an hour. The number of the data that can be stored depends on the capacity of the memory unit. Currently the memory can store data for a 3–4 months period. The larger the capacity of the memory is the less frequently the site should be visited and the data should be saved for processing. Increasing the storage capacity the costs might be decreased. The measuring accuracy of the thermometers is 0.5 °C.

3.1. Data Processing and Evaluation

During the data procession widespread information could be gained, such as the following, without claiming completeness:

- The fluctuation of temperature in different pavement layers become known.
- The time delay between the fluctuation in lower layers and that of the uppermost one could be determined.
- The data collection is made in every half an hour, this way the gradient, the specific fluctuation per time unit could be calculated.
- The fluctuation curves representative for seasons, months or even for weeks will be known.
- Knowing the real gradients, the conditions of certain measures or asphalt design operations could possibly be modified. This regards also cold and hot behaviour of asphalt structures. (Modification could mean aggravation or improvement as well which could be originated in technical considerations: neither overdimensioning nor underdimensioning of structures is considered as economically efficient.)
- The implementation of SHRP design system under Hungarian conditions becomes possible.

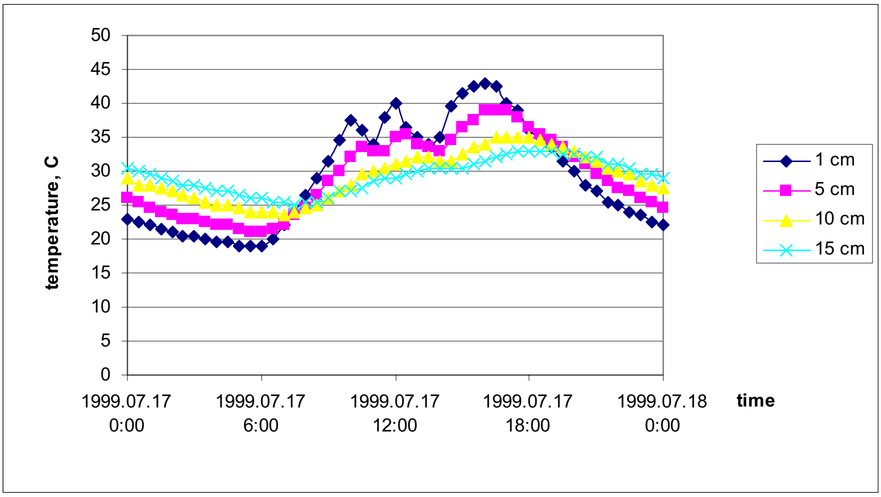
In summer the temperature of the wearing course becomes very hot. The heating begins at approximately 6 a.m. This heating section lasts till 2 p.m. then the temperature starts to decrease. This cooling lasts until 6 p.m. but it remains relevant in the early evening hours too, because the speed of decreasing is very slow only after that time , and the fluctuation curve becomes almost linear (*Graphs 3* and *4*).

During data processing both graphical and computer methods are practical to use, in itself none of them is being effective. If data were processed only graphically that would result unnecessarily and unmanageable too many figures. In case of only computing the incidental mistakes cannot be screened out. This way if the result of computing gives an extremely high or low value, it is expedient to draw the fluctuation graph. This problem will be mentioned below.

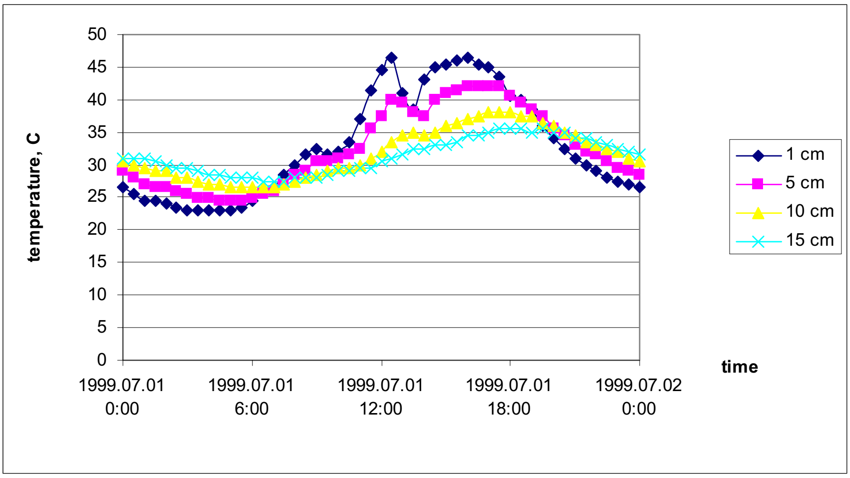
4. Methods to Determine the Gradient, the Evaluation of the Results

4.1. Gradient in Half an Hour Time Intervals

First it is possible to determine the gradient for half an hour and then find out the maximum positive and negative gradient values (maximum positive gradient means the maximum warming up speed, maximum negative gradient means the maximum cooling down speed). The difference of the values at the end of a half an hour time interval – i.e. the difference of two consecutive values – is multiplied by two. This way 48 gradient values are calculated per course and per day.



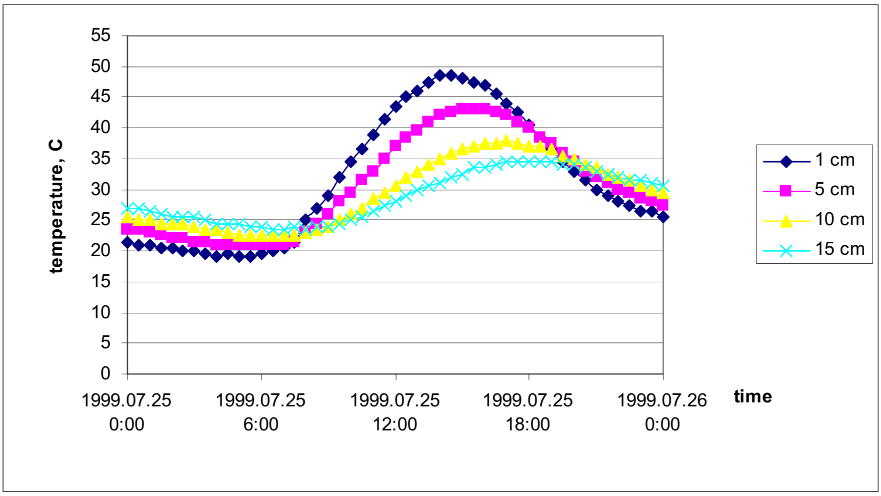
Graph 1. Fluctuation curves for each depth, on 17/07/1999



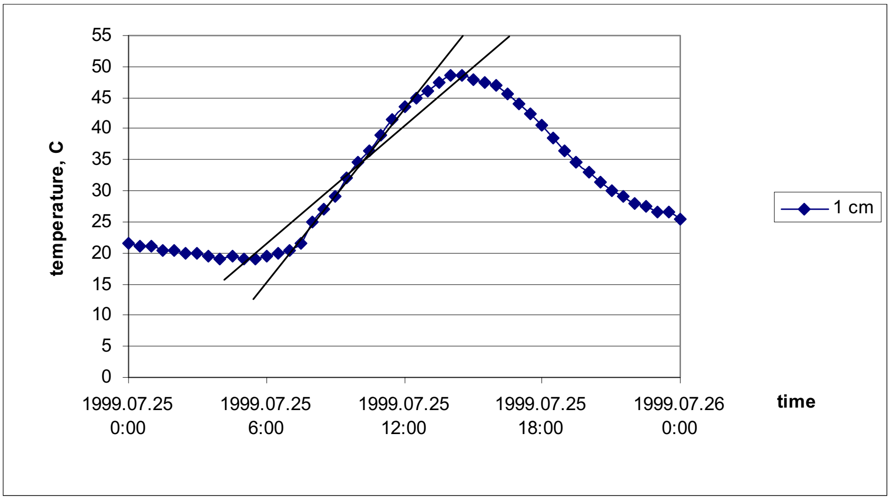
Graph 2. Fluctuation curves for each depth, on 01/07/1999

4.1.1. The Evaluation of the Results

The calculations give the following results: the daily maximum positive and negative gradients are very high in the summer months, they exceed the 5°C/h value but a few exceptions and even the 8 – 10 °C/h values are not rare. Some higher values occur too, but they are very extraordinary and come from short, quick fluctuations



Graph 3. Fluctuation curves for each depth, on 25/07/1999



Graph 4. Tangents drawn to fluctuation curve (1 cm depth, on 25/07/1999)

(*Graphs 1* and *2*).

The advantage of this calculation method is its simplicity. Its disadvantage, however, that the extreme values occur with high possibility (when the shape of the curves is 'not regular' – it could be identified by drawing the fluctuation curves of days with extreme values) and the calculated gradient is valid only for half an hour, say not lasting. Further disadvantage is that the rules of error spreading, of which traffic engineering application is discussed in [4], are valid for this calculation as well.

4.2. The Gradient in Hourly Time Intervals

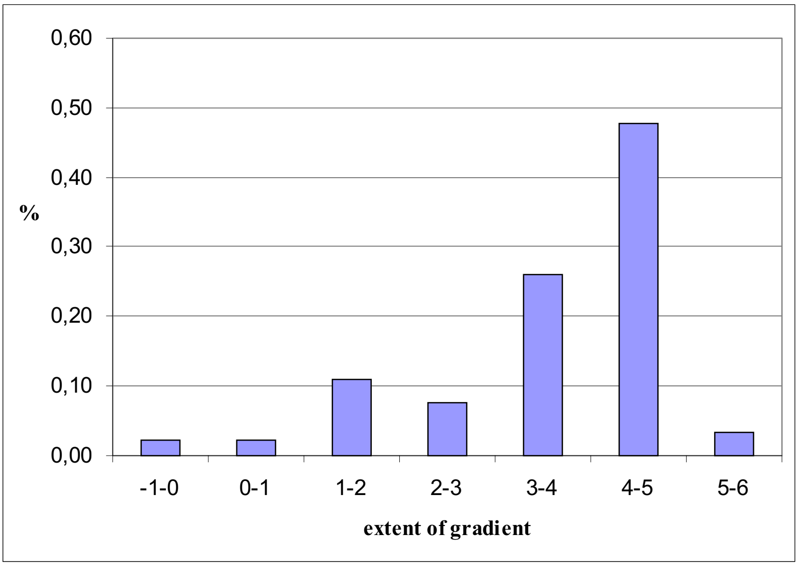
Another possibility is to calculate the gradient from measurements made with one an hour difference. This gives °C/h value directly, in this case the multiplication is not needed. In that case 48 data are calculated per day and per course as well. The disadvantages are the same as in the case mentioned above, furthermore it could yield meaningless results (even 0) around the daily maximum or minimum temperature (see local maximums and minimums of *Graph* 1 between 6 a.m. and 6 p.m.). Its accuracy would be sufficient if the fluctuation within the hour were insignificant. However, if the fluctuation is significant (local maximum or minimum, namely the direction of fluctuation is changed) as in the morning section of *Graph1*, the results cannot be interpreted any more. (0). Because of the problems mentioned above, this evaluation method should be disregarded for this research.

4.3. The Gradient Determined from the Highest and Lowest Daily Temperature

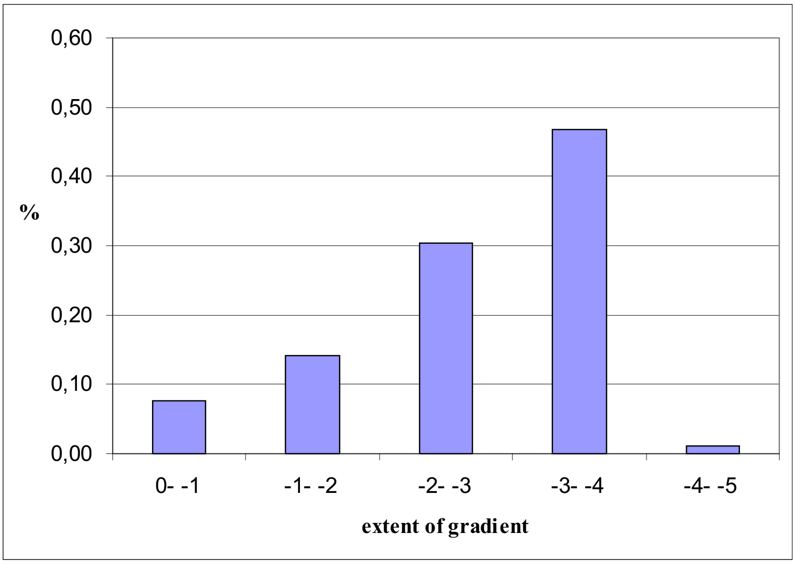
In the third method the difference between the highest and lowest measured temperature values is calculated and divided by the length of the time interval between the maximum and minimum values. Its accuracy is not sufficient, although its duration is suitable and gives treatable amount of data (one positive and one negative value per day). The inaccuracy derives from the fact that fluctuation – especially in case of the uppermost course, because this course is the most influenced by the weather conditions – shows anomalies (random oscillations, the above mentioned local maximums and minimums) in most cases. This method would be incorrect even in case of regular fluctuation curves without this oscillation day by day, such as in *Graphs* 3 and 4. (For justification see *Graph* 4). During the morning heating section the fluctuation is increasing first, then constant for a while and in the vicinity of the maximum – say at the end of the heating – is decreasing. Including all of them into the gradient, the result is less than the steepness of the nearly linear section (see the steepness of the two lines in *Graph* 4). These are valid for the cooling section as well, as it could be detected on the graphs. This calculation method should be disregarded too.

4.4. Gradient Determined as the Steepness of the Quasi Linear Section

A fourth possibility is to determine the steepness of the quasi linear section both in the heating and the cooling section. This seems to be the most suitable approach for the further applications, since it is the most lasting and the most relevant because



Graph 5. Distribution of positive gradient, in percentage of all the cases



Graph 6. Distribution of negative gradient, in percentage of all the cases

of its extent. The fact, that this linear section falls between 8 a.m. and 12 a.m. at heating and between 4 p.m. and 8 p.m. at cooling in most cases, is duly taken into consideration at the determination of the gradient. It is a good estimation to divide the difference in temperatures belonging to the starting and ending time, by the length of the time interval, let us say 4 hours. Fast and lasting heating and cooling are observed in the above mentioned time intervals in summer months.

4.4.1. Evaluation of Results

For the determination of the quasi linear section, the problems mentioned above could be screened out. It could be stated that the extent of fast and lasting heating exceeds very rarely the 5 °C/h value (see *Graph* 5). *Graph* 5 shows that the extent of fast heating remained between 4 and 5 °C/h in 48% of all cases, and between 3 and 4 °C/h in 26% of all cases. The intervals could be refined further, but for the time being the 1 °C/h interval is acceptable. For the three months period under consideration (June 21- September 21) a good approximation of the gradient is received. The other values occur because of the random versatility of the weather conditions, as it was discussed earlier. This random versatility probably reflects the volatility mentioned in [2].

For cooling, similar results were received with a different sign, as it is shown in *Graph* 6.

5. Conclusions, and Proposed Further Research

From the point of view of the gradient the winter months seem to be really dangerous for asphalt pavements. Another report is in preparation, to assess the data related to the winter months, and based on the preliminary results of the gradient different from the critical value. It could be stated that the critical (heating and cooling) fluctuation occurs neither in the summer nor in the winter months, though these are the extreme seasons of our climate. The next step should be the overview of the Spring and Autumn data. A further important question from practical point of view is the fluctuation of the binding course. The time delay between the fluctuation of different layers of the pavement could be also interesting.

6. Summary

The thermometers which are settled into the pavement in certain depths collect data in every half an hour. From these data the temperature and its fluctuation in the pavement could be determined, and used to study the current problems of deformations. The thermometers are located close to other measurement sites (such as traffic counting and axle load measuring stations), this way the impacts on pavements of weather changes and traffic load could be examined together.

A farther objective is to forecast the fluctuation in pavement structures based on the collected data and those measured by the OMSz.

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