

RESEARCH ON THE DEPENDENCE OF ASPHALT PAVEMENT STIFFNESS
UPON THE TEMPERATURE OF PAVEMENT LAYERSAlgirdas Motiejūnas¹, Miglė Paliukaitė², Audrius Vaitkus³,
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Abstract. The falling weight deflectometer (FWD) is the device most commonly used for the measurement of strength of road pavement structure. Using this device the impact of the wheel of heavy vehicle to the pavement is imitated for the assessment of pavement strength. The stiffness of asphalt pavement layers, as well as E_0 modulus values, measured using the FWD, strongly depend on the pavement temperature. When we use deflectometer for measuring asphalt pavement strength at different environmental conditions and in different season the values of E_0 modulus should be reduced to the assumed standard temperature. During this research at the experimental asphalt pavement structure the temperature correction factor was revised. The use of this factor enables to reduce the values of the stiffness of asphalt pavement layers measured by the falling weight deflectometer to the standard temperature of +20 °C. In this way the influence of the temperature of asphalt pavement layers upon asphalt stiffness and E_0 modulus could be evaluated.

Keywords: road pavement, pavement strength, pavement stiffness, temperature factors, E_0 modulus, falling weight deflectometer (FWD).

1. Introduction

When planning road maintenance works, implementing economic evaluation of road construction, reconstruction and repair projects and determining project priorities the specialists are faced with the necessity to forecast road pavement condition. Juknevičiūtė-Žilinskienė (2009) suggest to introduce a climatic coefficient in every region, which will help more easily solve the issues of road design, construction, repair and maintenance in Lithuania, taking into consideration the effect of climatic factors.

Structural pavement strength is one of the most important strength indexes defining the ability of pavement structure to carry vehicle loads. In many countries all over the world evaluation of road pavement strength is most widely carried out by deflection measurements with the falling weight deflectometer (FWD). Deflection measurements give a possibility to rapidly and accurately determine the strength of pavement structure.

Stiffness of asphalt pavement layers, as well as deflections measured by the falling weight deflectometer and the calculated E_0 modulus values, depend on pavement temperature. Due to temperature variations E_0 modulus of asphalt pavement decreases as the temperature increases and increases with the drop of temperature. When measuring

road pavement deflections in a different season, in different days and different time of the day due to climatic and technical factors it is difficult to ensure analogical measuring conditions: load, mean temperature of air and asphalt layer. Therefore, in order to obtain accurate measuring results these parameters have to be first of all reduced to their equivalent values under standard temperature and load. Pavement temperature should be known not only for the reduction of measuring results into standard conditions but also before the start of measurements. If the temperature of asphalt pavement layer is too high or too low, reduction of measuring results into standard temperature will be inaccurate. Asphalt layers, having very different E_0 moduli at the pre-determined standard temperature, under low temperature can have similar E_0 moduli and this will unavoidably distort measuring results. It is the most ideal to know the precise temperature variation in asphalt layer from the top to the bottom, though practice shows that even the less accurate measurements of asphalt layer are sufficient enough.

The FWD measuring method shall be adjusted to concrete conditions. Therefore, the scientists seek to improve measuring methodologies for the FWD. Choi *et al.* (2010) suggests methodology based on constrained extended Ka-

lman Filter (EKF). Talvik and Aavik (2009) recommend to use the FWD deflection basin parameters (SCI, BDI, BCI) for pavement condition assessment. For the evaluation of the properties of non-rigid structural pavement layers Seo *et al.* (2009) recommends a pseudo-static analysis procedure of the falling weight deflectometer. In order to assess reliability of these methodologies the comparative laboratory investigations are carried out for the materials and their properties calculated by the FWD methodologies (Dawson *et al.* 2009; Vaitkus *et al.* 2009; Vorobjovas *et al.* 2007). To adapt methods for the determination of the properties of structural pavement layers Vaitkus *et al.* (2005) made the analysis of static and dynamic measuring methods. In order to find out and compare the accuracy of testing results of using FWD and other static and dynamic methods was carried out the comparable measurements analyse of the subgrade and frost blanket course of a test road section (Bertulienė *et al.* 2008). On a test section of the experimental road pavement structures the measurements were carried out using different methods in order to determine and evaluate the specific features in the variation of strength of non-rigid pavement structures (Čygas *et al.* 2008).

The strength of road pavement structure and its dependence on temperature and seasonal effects are studied by the scientists of many countries. One of the largest polygons for testing road pavement structures was established in 1989 in the French Central Laboratory of Roads and Bridges. Here, the scientists of various countries tested and valued the performance of 3 different pavement structures by loading them with loads of different size. The readings of the sensors of deformations, stresses, temperature and moisture were recorded. In 2006–2007 testing of pavement structures by the use of 6 different sensors was carried out in the University of Maine (Lauren 2007). The sensors were installed in different structural pavement layers to determine the seasonal effects on the structural strength of road pavement. In USA investigations of experimental pavement structures were carried out in order to find out the change in the strength of a separate layer during freeze – thaw periods (Shoop *et al.* 2008). Here, with the use of FWD the structural strength of pavement layers was measured in a different period of the year to determine the resistance of separate layers to the impact of cold. Within the framework of COST 333 “European Cooperation in the Field of Scientific and Technical Research” the analysis was carried out of the reduction of asphalt layer stiffness and road pavement temperatures. Temperature values recommended in the reports of this research vary from +15 °C to +25 °C and the most common temperature is +20 °C. It was recommended that a reduction procedure shall be carried out with the measured deflections when they are directly used to calculate deformations. However, by COST 336 “Use of Falling Weight Deflectometers in Pavement Evaluation” if the stiffness modulus of various layers is obtained from the measured deflections the stiffness of asphalt layer could be reduced to standard conditions. A relationship between the temperature and asphalt layers stiffness, currently used in Europe, determined by the Dy-

natest ELMOD program in Denmark, United Kingdom, Portugal and Netherlands.

In order to evaluate the dependence of road pavement strength on the temperature and the dependence of E moduli of different pavement layers on the seasonal effects, comprehensive researches were carried out on the roads of Lithuania aiming at the development of the Lithuanian Road Management System (Braga 2005; Puodžiukas *et al.* 2002; Šiaudinis *et al.* 2007; Šiaudinis 2007).

2. Methodology for the research of dependence of asphalt pavement layers stiffness on pavement layers temperature

In the last decade the following methodology was used in Lithuania for the reduction of the values of pavement structure deflections (measured by the falling weight deflectometer) and the calculated E_0 modulus values to the temperature of +20 °C:

- the measured deflections are reduced to the pre-determined load according to linear dependence. Most commonly the pre-determined load is 50 kN. This load, when the diameter of a loading plate is 300 mm, corresponds to 707 kPa contact pressure;
- reduction of measuring data to the standard asphalt pavement temperature of +20 °C is carried out having determined the reduction (correction) factor of asphalt pavement temperature. It is calculated by the Eq (1) according *Asphalt Institute Manual “Asphalt Overlays for Highway and Street Rehabilitation”*:

$$k_T = 10^{-\alpha(T-20)}, \quad (1)$$

where k_T – temperature correction factor; $\alpha = 0.000169 \times h_{asf}^{1.4635}$; h_{asf} – asphalt layer thickness, cm; T – mean temperature of pavement layers measured during research, °C; E_0 modulus values on pavement surface are calculated by the Eq (2):

$$E_0 = \frac{2 \times (1 - \mu^2) \times q \times a}{D_0}, \quad (2)$$

where E_0 – measured deflection reduced to 50 kN load and to standard temperature of +20 °C; μ – Poisson’s ratio assumed as 0.35; q – pressure to road pavement, kPa; a – radius of the plate affected by load, mm; D_0 – deflection in a loading point, μm .

This methodology was used for several years to determine pavement stiffness of the existing roads; however, with the change of road building materials due to vehicle loads and climatic factors, the stiffness of asphalt layer also changes. It was noticed that the larger temperature difference, measured during research, from the standard temperature the larger are doubts about the reduction of measuring results to the standard temperature of 20 °C.

At the end of 2007 in Lithuania, not far from Vilnius (in Pagiriai settlement) a test section of experimental road pavement structures was constructed. Parameters of the cross section of experimental road pavement structures correspond to the road category III and to the pavement

structure class III according to the *Construction Technical Regulation STR 2.06.03:2001*. A test section with the total length of 710 m consists of 23 segments of the same length (30 m) and one 20 m long segment. Each segment has a different-composition road pavement structure. For the research of the influence of temperature on the performance of road pavement structure one of the pavement structures was selected using comparative indices. The pavement structure is made of the wearing course 0/11 S-M PMB (SMA 11 S PMB), the base course 0/16-A (AC 16 AS), the road base 0/32-C (AC 32 PS), the sub-base layer from the mixture of crushed dolomite 0/56 and the frost-blanket course from sand 0/11. In this road pavement structure 7 12-Bit Temperature Smart Sensors were installed in 2009: temperature sensor T1 was installed on the surface of the wearing course; T2 – in the wearing course, i.e. at a 2 cm distance from pavement surface; T3 – at the contact of the wearing course and base course (at a 4 cm distance from pavement surface); T4 – at the contact of the base course and the road base (at a 8 cm distance from pavement surface), T5 – in road base (at a 10 cm distance from pavement surface); T6 – at the contact of the road base and the sub-base layer from crushed dolomite (at a 18 cm distance from pavement surface) and temperature sensor T7 was installed in the subgrade (at a 125 cm distance from pavement surface), Fig. 1.

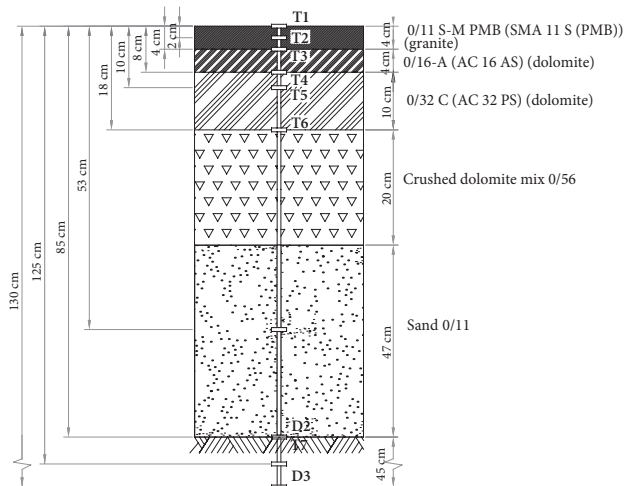


Fig. 1. Road pavement structure No. 12 equipped with temperature sensors

Temperature sensors installed in one of the pavement structures of a test section gave a possibility to check the currently valid Lithuanian methodology for the reduction of pavement deflections (measured by the falling weight deflectometer) and the calculated E_0 modulus values to the temperature of +20 °C under real conditions. To ensure measuring accuracy the thicknesses of asphalt pavement layer were revised: cores were taken and measurements by a georadar were made. In order to achieve the max and min temperature values in the road base two experimental researches were carried out. The first research was carried

out in summer 2009, the second – in autumn 2009. Temperature of the road base was measured by the electronic thermometer TE-100 (at a 10 cm distance from pavement surface) and was compared to the temperature values measured by the temperature sensors at the same depth.

In both experimental researches measuring points were selected according to the measuring results of the thicknesses of asphalt pavement layer using georadar. Measuring points were marked every 0.5 m, on the right side of the road.

In the first experimental research 45 points were measured 3 times each time with the rise of temperature by 1 °C. Since in the first research the weather temperature was high and there was no possibility to achieve a low temperature of asphalt pavement, therefore, the repeated measurements were carried out in autumn 2009. During the second research 26 points were measured where the lowest and the highest day-time temperature was achieved in the base layer (at a 10 cm distance from pavement surface).

3. Experimental research results and their analysis

During experimental research the temperature of asphalt pavement layer at a depth of 10 cm was recorded within the interval from +5 °C to +33 °C. The temperature of asphalt pavement layer measured by the electronic thermometer TE-100 differed from -1 °C to +4 °C from the temperature measured in the pavement structure by the temperature sensors. The curves of the measured temperatures of asphalt pavement layer in Fig. 2 shows that only from +11 °C to +13 °C temperature of asphalt layer measured by the sensors at a depth of 10 cm is lower than the temperature measured by the electronic thermometer TE-100 at the same depth. In all other measuring points' temperature measured by the temperature sensors is high-

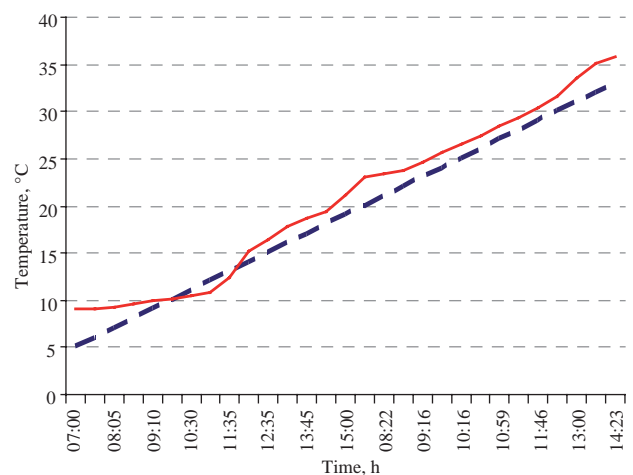


Fig. 2. Comparison of temperature values measured by the electronic thermometer TE-100 and the temperature sensors in asphalt pavement layer: - - - temperature measured by thermometer TE-100 in 10 cm depth of asphalt layer; — temperature measured by sensor of temperature in 10 cm depth of asphalt layer

er or equal to the temperature measured by the electronic thermometer TE-100. This could be explained by the accuracy of temperature sensors which is $\pm 0.2\text{ }^\circ\text{C}$, the accuracy of electronic thermometer TE-100 which is $\pm 0.5\text{ }^\circ\text{C}$ and the differences in the thickness of asphalt pavement layer (temperature sensors were installed in the middle of road pavement).

Asphalt pavement deflections measured during experimental research were reduced to 50 kN load and this corresponds to 707 kPa contact pressure.

Fig. 3 gives the results of experimental research showing the dependence of E_0 modulus of non-rigid pavement on the asphalt pavement temperature.

Figs 2 and 3 shows that at the standard asphalt layer temperature of $+20\text{ }^\circ\text{C}$ the E_0 modulus is equal to 892 MPa and, having applied the temperature correction factor, the calculated values of E_{T0} modulus (pavement temperature limits $T = (+5\dots+30)\text{ }^\circ\text{C}$) will be equal to the values of E_{020} modulus. Measuring results obtained during research were evaluated by mathematical – statistical methods. Correlation of the obtained values was determined (Fig. 4), also reliability intervals (Fig. 5) and other statistical parameters.

The above figure shows that with the increasing temperature the values of E_0 modulus are decreasing. There is a high correlation between both variables, since the correlation coefficient $r = -0.9939$. The dependence between deformation modulus (E_{020}) and temperature (T) is described by the following regression equation $E_{020} = 1066.9005 - 8.7498 \times T$.

It could be stated from the above chart (Fig. 5) that under higher asphalt pavement temperature the stability of E_0 modulus as well as of pavement strength is lower than under lower pavement temperature. This means that under higher temperature ($+30\dots+35\text{ }^\circ\text{C}$) the layers of asphalt pavement loose part of their smoothness. Therefore, E_0 modulus is recommended to be measured when the temperature of asphalt layers varies within the limits of the interval ($+5 \dots +25\text{ }^\circ\text{C}$).

Taking into consideration dispersion of experimental research data, standard deviation and statistical indices the following temperature correction factor was obtained:

$$k_T = 10^{-0.000221} \times h_{asf}^{1.0229} \times (T - 20) \pm 9 \text{ MPa.} \quad (3)$$

4. Conclusions

In order to properly and cost-efficiently select methods for pavement strengthening, the condition of existing road pavement structure shall be assessed by the measuring data of the falling weight deflectometer.

When measuring road pavement deflections by the falling weight deflectometer in a different season and different time of the day it is necessary to determine the dependence of road pavement strength and E_0 modulus on pavement temperature and load.

In order to evaluate the values of road pavement strength and E_0 modulus, the obtained measuring results

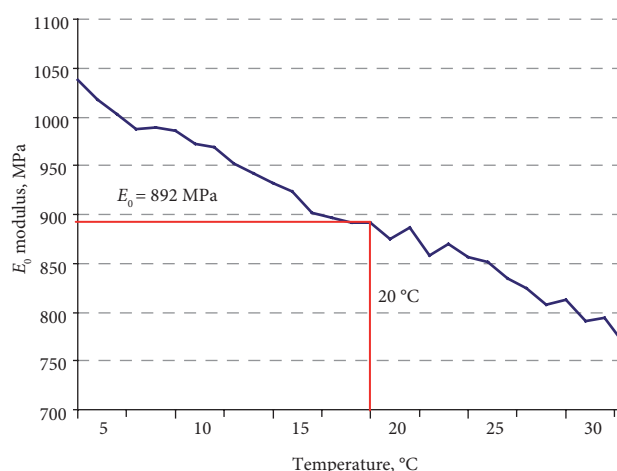


Fig. 3. E_0 modulus values obtained during research

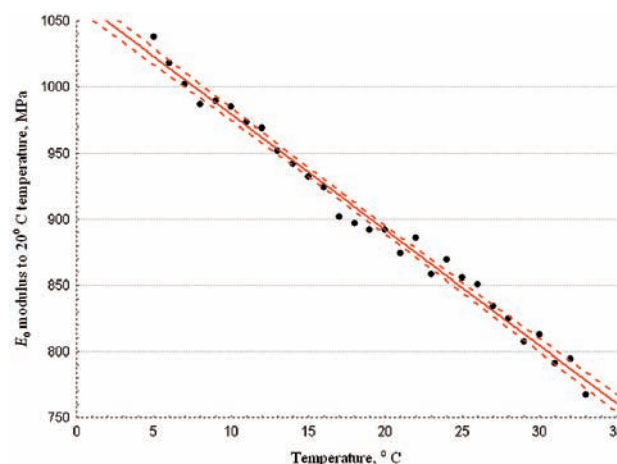


Fig. 4. Correlation of the temperature of structural pavement layers at a 10 cm depth and the E_0 modulus values obtained during research

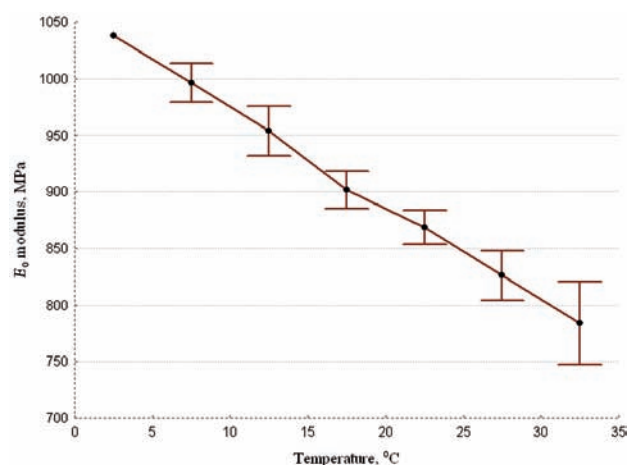


Fig. 5. Reliability intervals of E_0 values measured during research in the asphalt layer of road pavement structure: ● – mean; ┆ – mean ± 0.95 confidence interval

shall be reduced to their equivalent values under standard temperature and load.

Based on the analysis of experimental investigation results it is recommended to measure pavement deflections by the falling weight deflectometer when the temperature of asphalt pavement layers varies within the interval (+5...+25) °C, except cases when special investigations are carried out during winter freeze and spring thaw periods.

If the falling weight deflectometer is used to measure strength of non-rigid pavements when asphalt pavement thickness is ≥ 18 cm and the temperature of asphalt pavement layer varies within the interval (+5...+25) °C it is recommended to use a temperature correction factor identified during this experimental investigation.

The stiffness of asphalt pavement layer depends on material properties, temperature, load size and time of impact, climatic and other factors, therefore, it is recommended to monitor and assess the fatigue of asphalt layers and, having identified it, to reassess a temperature correction factor.

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