

RESEARCH AND EVALUATION OF METHODS FOR DETERMINING
DEFORMATION MODULUS OF A BASE COURSE OF ROAD PAVEMENTLina Bertulienė¹, Alfredas Laurinavičius², Audrius Vaitkus³^{1, 2, 3}Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, LithuaniaE-mails: ¹linak@vgtu.lt; ²alfla@vgtu.lt; ³audrius.vaitkus@vgtu.lt

Abstract. The continuously increasing need for the strengthening of road pavement structures in Lithuania induces to implement new road reconstruction technologies, to look for new alternatives in laying structural pavement layers, to carry out research of road pavement structures in their real operational conditions. This article studies methods for determining structural pavement strength, assesses the strength measuring devices using static and dynamic methods. In order to identify and compare the accuracy of test data collected by using static and dynamic methods the comparative measurements were carried out on a base course of experimental road section by four measuring devices, i.e. static beam Strassentest, dynamic devices - ZORN ZSG 02, light weight deflectometer Prima 100 and falling weight deflectometer Dynatest 8000. Further results of the research of this experimental road section, analysis and evaluation of these results will enable to select the most suitable measuring method for each structural pavement layer.

Keywords: road pavement, pavement structure, pavement strength, falling weight deflectometer (FWD), deflectometer, static beam.

1. Introduction

Road pavement is one of the most important structural elements of road. It is continuously affected by static and dynamic traffic loads, as well as climate change. Due to the impact of traffic and climate the physical and mechanical properties of subgrade soils and materials of structural pavement layers are changing. Critical conditions are created in winter and spring when, under the influence of cold, pavement materials become fragile and with a thawing ground they get to plastic due to excessive moisture. Unfavourable situation is caused in spring when separate structural pavement layers still contain excessive moisture, and asphalt pavement warms up under high temperatures. Therefore, subgrade soils and structural pavement layers undergo deformation and their strength decreases. In 2009 the scientists of Vilnius Gediminas Technical University carried out experimental research aiming to assess the temperature effect of asphalt layer on the stiffness and modulus of elasticity of asphalt layer. The stiffness of asphalt 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, reassess a temperature correction factor (Motiejūnas *et al.* 2010). Šiaudinis (2006) stated that falling weight deflectometer (FWD) is suitable to determine the structural strength of investigated road pavements and FWD measured results are close to results from measurements with static test-

ing device. After range of experimental research the seasonal factors for measurements with FWD for Lithuanian conditions were determined (Šiaudinis, Čygas 2007). Talvik and Aavik (2009) founded good relationship between equivalent E modulus measured with FWD and road pavement structure layers indicators. Relationship between measured E modulus and subgrade indicators was founded not very strong.

The quality of road pavement, designed according to the highest technical standards and laid using advanced technologies, has been gradually changing: its service properties worsens, various defects appear and develop, pavement strength becomes insufficient (Adamek *et al.* 2007; Brauers *et al.* 2008). Due to the impact of traffic and climate it is necessary to determine structural condition of the road pavement and to select a strategy for pavement strengthening.

Until restoration of independence of Lithuania asphalt concrete and other “black” pavements were designed according to the BCH 46-83: *Инструкция по проектированию дорожных одежд нежесткого типа (Instruction for the Design of Flexible Pavements)*. In 1995–1996 the new normative documents for motor roads came into force and the mentioned instruction was not further used. Asphalt concrete and other “black” pavements were started to be designed according to the PNTK-95 *Automobilių kelių projektavimo normos ir taisyklės (Standards and Rules for the Design of Flexible Pavements)*.

At present, in Lithuania the main normative document regulating the design of asphalt concrete and other “black” pavements on motor roads is *KTR 1.01:2008 Automobilių keliai (Motor Roads)*, which came into force in 2008. Technical measures and methods for implementing the requirements of this Regulation are defined by the *KPT SDK 07 Automobilių kelių standartizuotų dangų konstrukcijų projektavimo taisyklės (Regulations for the Design of Standardized Pavement Structures of Motor Roads)*.

All the above mentioned Lithuanian normative documents were prepared on the basis of German normative documents and standards.

The main problem is that any methodology must have a legal background for its application, i.e. it must be approved (approved) in the established order by the respective institutions. The use of methodologies having no legal background under certain conditions, for example if pavement structure fails during a warranty period, may cause criminal liability. Non-approved methodologies could be applied only as additional technical measures.

At present, Lithuania has no single methodology approved in the established order and defining the principles of strengthening design of asphalt concrete pavements on the existing roads.

The strength of separate layers of flexible pavement structures and of the total structure of road pavement can be calculated during their design (Dawson *et al.* 2009). When constructing and reconstructing roads it is necessary to control if the strength of structural pavement layers corresponds to their design strength. For this purpose various methods are used to determine the strength of structural pavement layers.

A continuously increasing need for the strengthening of road pavement structures in Lithuania induces to implement new road reconstruction technologies, to look for new alternatives in laying structural pavement layers, to make research of pavement structures in real conditions of their operation.

Static and dynamic methods for measuring structural pavement strength are widely used all over the world. Many foreign scientists made parallel researches but mostly using only several measuring devices and comparing them between each other. The scientists of Iraq have made a comprehensive evaluation of the potential use of portable falling weight deflectometer (PFWD) to reliably measure the elastic modulus of pavement layers. The results indicated that there is a good correlation between PFWD moduli and FWD and the California Bearing Ratio (CBR) results (Kavussi *et al.* 2010). In Hungary parallel experimental research was carried out by using static and dynamic measuring methods. The research showed that the newly introduced dynamic target values could open up the opportunity to perform the quality control and assess the bearing strengths of the tested layer not only by the static plate load test, which proved to be time-consuming and labour intensive, but also by dynamic devices (Tompa 2008). More research relative with evaluation of correlation of measuring methods for road pavement structure layers were done in last decade (Mehta, Roque 2003; Vaitkus *et al.* 2005).

This article gives the research results of the first experimental road pavement section in the Lithuanian road history consisting of 27 different pavement structures using static and dynamic measuring methods on a base course of the pavement. Initial results of this research were published in the previous articles (Bertulienė *et al.* 2008; 2010; Čygas *et al.* 2008). Further results of the research of this experimental road section, analysis and evaluation of these results will enable to select road pavement structures the best corresponding to the climatic and traffic conditions in Lithuania.

2. Static and dynamic methods for measuring strength

Structural pavement strength is one of the main indices describing pavement ability to carry traffic loads. The strength of separate layers of flexible pavement structures and of the total structure of road pavement can be calculated during their design. When constructing and reconstructing roads it is necessary to control if the strength of structural pavement layers corresponds to their design strength. For this purpose various methods are used to determine the strength of structural pavement layers. The static and dynamic non-destructive methods are worldwide used to determine the deformation modulus of pavement structures, however, in many countries when designing and constructing road pavement structures their strength is defined by a static deformation modulus.

In practice, the less complicated is a static strength measuring method. When using static measuring methods a certain area of road pavement structure is gradually loaded and unloaded. Generally, the following indices could be distinguished characterizing the static strength of road pavement, i.e. ability of the structure to resist: vertical stresses (σ_z) and horizontal stresses (σ_x, σ_y).

Ability to resist vertical stresses is expressed by the required modulus of elasticity; to resist horizontal stresses – by the quantity of permissible resistance to displacement. Comprehensive information about the static measuring method of strength could be given by a methodology aimed at a complex evaluation of all its components.

The essence of static methods for the evaluation of structural pavement strength is to create at road pavement surface a relative pressure which, according to its value, corresponds to the impact of load produced under the plate by vehicle wheel or dual wheels. In the first case the impact to the pavement surface is transferred through a rigid plate in an area which is equal to the calculated wheel track. Taking into consideration elastic deflection the total modulus of elasticity is calculated by the Eq (1):

$$E_i = \frac{P \times D}{l} (1 - \mu^2), \quad (1)$$

where P – vehicle wheel pressure to the pavement, Pa; D – diameter of the plate, m; l – forced inverse pavement deflection, m; μ – Poisson’s ratio.

In course of measurements and processing of test results one should take into consideration the effect of natural – climatic factors. In this case a “typical condition of

pavement structure” should be assumed described by the modulus of elasticity according to 218.1.052-2002 *Оценка прочности нежестких дорожных одежд (Estimation of Durability of Nonrigid Road Clothes)*:

$$E = A - B \times \left(\lg \sum_{i=1}^m \frac{t_{E_i}}{10} - 0.4 \right), \quad (2)$$

where A and B – empirical coefficients depending on the type of road pavement structure, calculated load and climatic factors; m – number of measurements per year; E_i – modulus of elasticity of road pavement structure in a reference point at a certain moment of time, MPa; t_{E_i} – duration with E_i .

The above tests basically describe the average statistical modulus of elasticity of road pavement structure during a period of pavement service time. Based on investigation data it is only possible to evaluate pavement ability to resist main vertical stresses. This test does not allow to fully describe the condition of road pavement structure and to predict its further worsening.

A common disadvantage of all static methods is that when using these methods it is impossible to evaluate the ability of road structure to essentially realize a dynamic impact caused by a real traffic movement (Илиополов, Селезнев 1997).

Static methods for calculating and evaluating road pavement strength are based on the max normal and tangent stresses. According to these criteria pavement failure takes place in a way of tear (according to max normal stresses) and shear (according to max tangent stress).

Generally, all the static calculation schemes and evaluation methods should be used to determine the structural pavement strength, ability of road structure to carry the significantly increasing traffic loads and, thus, to prevent the rapid failure of road structure. Based on the static strength results obtained with the help of dynamic coefficients and taking into consideration the rapidly increasing traffic flows and traffic loads – this is an empirical transition from static decisions of the theory of elasticity to the failure of insufficiently investigated road structures due to the impact of dynamic stresses. With the worsening pavement surface a dynamic impact of traffic is increasing. This is first of all showed by the increase in energy accepted by the road structure. Then, the tendency of changing relations between the different micro structural elements of road structure becomes obvious as well as of their failure.

In order to objectively evaluate road pavement condition it is suggested to use impact analogical to a real transport movement. Unlike the static measuring methods, dynamic methods make it possible to evaluate loads from moving transport.

When using dynamic measuring methods the load is produced by the drop of a falling mass cylinder in a very short period of time which causes deformations of structural pavement layers. Dynamic impact Q_d and loading time T_f are calculated by the approximation formulas according to 218.1.052-2002:

$$Q_d = Mg \sqrt{\frac{2H}{\delta}} k_d, \quad (3)$$

$$k_d = 0.5 \times \left(l + \frac{l'}{l} \right), \quad (4)$$

$$T_f = \pi \sqrt{\frac{\delta}{g}} \cong 0.1 \sqrt{\delta}, \quad (5)$$

where M – mass of the falling weight, kg; g – free acceleration of the falling weight, m/s^2 ; H – height of the falling weight, cm; δ – indicator defining a rigidity of suspension, m; k_d – energy-loss coefficient of the falling weight; l, l' – vertical deformations from the drop of the first and the second falling weight, cm.

Having made measurements with the use of dynamic measuring method the obtained elastic deflection is reduced to a comparative shape (static deflection) using coefficients of regression relationship (Илиополов, Селезнев 1997):

$$l_f = X_1 l_d + X_2, \quad (6)$$

where l_f – real deflection, mm; l_d – deflection measured by a dynamic device, mm; $X_{1,2}$ – empirical coefficients of regression relationship.

The studied foreign methods and devices were based on the solutions of dynamic tasks and in the course of measurements and calculations the characteristics of road pavement deflections were taken into consideration. It should be noted that progressive equipment use a dynamic impact, whereas, the most expensive and most effective equipment are based on the impact data of a moving vehicle. The main disadvantages – a high price of equipment and serious technical difficulties related to the calibration of the measuring equipment.

A similar approach to the determination of structural pavement strength is the most common. However, it is followed by the difficulties related to the necessity to correct calculation model for each part of one-type road (road pavement structure must be known beforehand). The solution is not the only, i.e. a more than one set of the modulus of elasticity can meet the experimentally determined displacement areas, and the calculation itself requires plenty of time even when using modern electronic calculation techniques. Therefore, all the mathematical models of modern high-efficiency falling weight equipment are oriented to the estimation of the general modulus of elasticity of the road structure.

The main advantage of dynamic methods is, by no means, their adequacy to real loads and traffic impacts. A wide experience of the use of dynamic analysis when testing road pavement proves a perspective development of these methods in the field of strength evaluation. The most informative is the analysis of the structural strength of dynamically loaded road pavement.

3. Construction of experimental road section

In order to determine the strength of subgrade and structural base courses of experimental road section four different devices were used different in their measuring methodology and their operational principles. This article describes the research carried out solely on a base course of the road pavement.

Same as in the previous research (which was carried out on subgrade and frost blanket course (Bertulienė *et al.* 2008; 2010) to determine the strength of a base course (on the left side of the road) of the experimental road section four different devices were used: dynamic – FWD Dynatest 8000, light weight deflectometer (LWD) Prima 100 and ZORN ZSG 02; static – static beam Strassentest. On the right side of the road – FWD and static beam Strassentest.

Measurements on each of the structural pavement layers were taken by the same selected scheme (location of a measuring point differs ±0.5 m) under the same weather conditions. Pavement deflections were measured by FWD Dynatest 8000 with 50 kN load.

In each segment the pavement structure of different composition was constructed. Three 30 m long segments are of the same pavement structure with the different type of geosynthetic materials installed in asphalt layers and base course. The cross-section of the base pavement structure and the required values of static deformation modulus of the base course are given in Fig. 1 (Čygas *et al.* 2008).

Other pavement structures were selected by varying the materials of all structural pavement layers compared to the base structure.

For the base course, besides the base material, the crushed dolomite mix 0/56 was used: crushed granite mix 0/56; crushed granite and sand mix 0/32; crushed fine sand mix 0/32; gravel and sand mix 0/32; aggregate – milled asphalt concrete.

When laying a base course of the experimental road section it was necessary to achieve the sufficiently equal strength of a base course, at least 100–120 MPa.

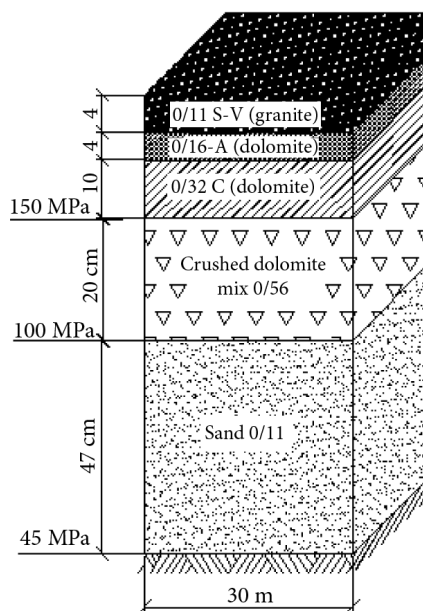


Fig. 1. The base structure of experimental pavements (Čygas *et al.* 2008)

Research of the strength of a base course was carried out and results were obtained using the static and dynamic measuring methods with four different measuring devices: dynamic – LWD Prima 100, FWD Dynatest 8000 and ZORN ZSG 02; static – static beam Strassentest.

4. Statistical analysis of research results on a base course

The research showed a clear relationship between the data obtained by static and dynamic devices. Analysis of measuring methods showed that there is a regular relationship between the static and dynamic methods.

The results in Fig. 2 and Fig. 3 show that the measuring data obtained by different measuring devices in different measuring points has a regular variation, though

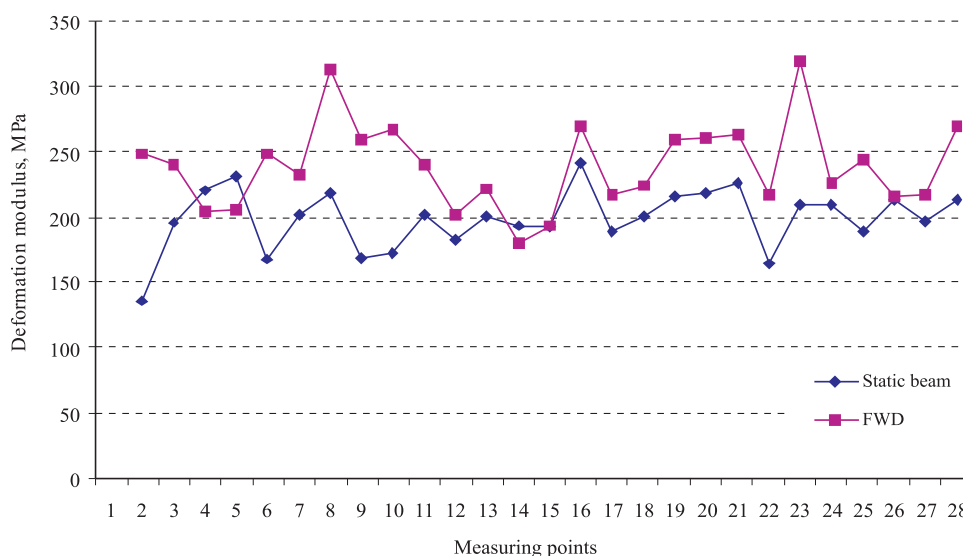


Fig. 2. Strength of a base course measured by all the above-mentioned devices (left side)

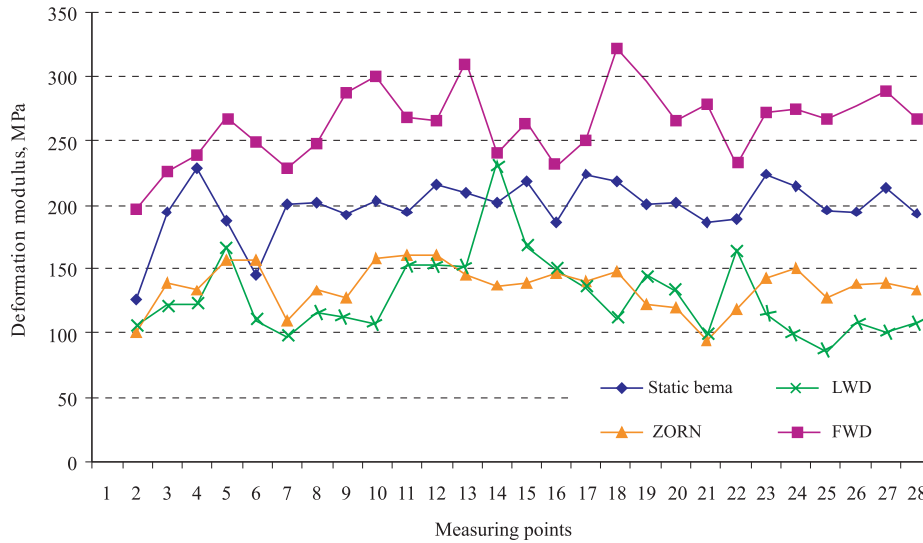


Fig. 3. Strength of a base course measured by static beam and FWD Dynatest 8000 (right side)

their values differ. Taking into consideration small distances between measuring points it could be stated that the layer has not been evenly compacted, heterogeneous materials have been used for this layer or the measurement was taken not accurately.

The left side of the road section is affected by several times larger loads than the right side since this road leads to Pagiriai query.

Analysis of measuring results obtained on a base course by the dynamic devices shows a regular relationship between different devices, though the numerical values of deformation modulus compared to the static beam reflect a larger variation and are lower. The values of LWD Prima 100 and dynamic device ZORN ZSG 02 are 31–35% lower than the average numerical value of deformation modulus measured by the static beam. The values of FWD Dynatest 8000 are 30% higher. This is explained by the difference in measuring and calculating methodologies. For example, in the calculation methodology of FWD the applied load distribution coefficient f influences the quantity of

deformation modulus. In the measurements $f = \frac{8}{3}$ was used where the values calculated at the coefficient $f = \frac{\pi}{2}$ are very close to the values measured by other 3 devices.

During the research of a base course of experimental road section for the analysis and evaluation of the obtained strength indices the mathematical statistical methods were used. For the analysis of the determination of the strength of a base course the static and dynamic methods were used. To determine the reliability of results the methods of probability theory and mathematical statistics were applied. For the reliability interval the upper limit of 95% (significance level) reliability was set.

Correlation results obtained by using all the devices are very poor. Correlation results obtained between the FWD and the static beam are given in Fig. 4.

Correlation between the FWD Dynatest 8000 and the static beam Strassentest on the left side is poor ($r = 0.4541$). This shows a poor relationship of measuring results of deformation modulus between the FWD Dynatest 8000 ($E_{V(FWD)}$) and static beam Strassentest ($E_{V(SB)}$). In this case, an estimate of the variable $E_{V(FWD)}$ – dependence of $E_{V(SB)}$ is described by the Eq (7):

$$E_{V(FWD)} = 147.4896 + E_{V(SB)} \times 0.5834. \quad (7)$$

Though methodologies of these devices are different the data is accurate.

Relationship between the static beam and all the dynamic devices is weak, and this is explained by different methodologies.

Dispersion diagrams of measuring results in Fig. 5 show a dispersion of results between each device. A large difference could be observed between the min and max value. The lowest dispersion of results on a base course was indicated by the dynamic device ZORN, the highest – by the FWD Dynatest 8000.

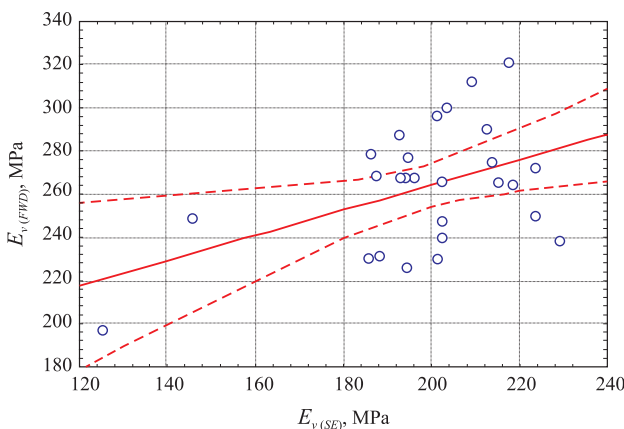


Fig. 4. Relationship between the measuring results of the FWD Dynatest 8000 and the static beam Strassentest on a base course (left side)

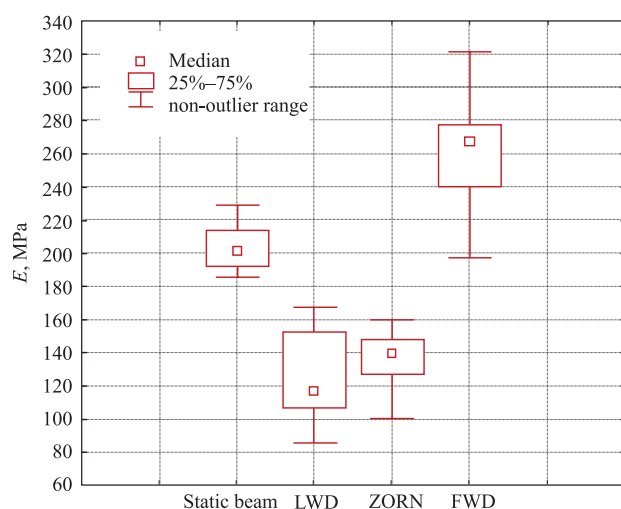


Fig. 5. Evaluation of measuring results on a base course layer by all the devices

5. Conclusions

The research was carried out and the results were processed on the experimental road section in Location of Pagiriai. Experimental road section was established by Dept of Roads and Road Research Laboratory of Vilnius Gediminas Technical University. Measurements on the experimental road section were implemented using the static and dynamic measuring methods with the following measuring devices: static beam Strassentest, dynamic FWD Dynatest 8000, LWD Prima 100 and dynamic device ZORN ZSG 02. Experimental research showed that the measurements with all devices are suitable for determining deformation modulus on a base course of pavement structure.

Analysis of measurement results collected by dynamic devices on a base course showed that there is a regular relationship between all the devices but the numerical values of deformation modulus compared to static beam vary, therefore, it could not be clearly decided which method is the best and the most acceptable.

Correlation results obtained by using all the devices on a base course are poor. The largest correlation coefficient of measuring results on a base course on the left side was determined between the static beam Strassentest and the FWD Dynatest 8000 ($r = 0.4541$). The research clearly showed that in order to give more justified conclusions it would be necessary to make additional research, taking into consideration thickness of layer, material composition, temperature and to carry out measurements under similar conditions. What concerns a base course it would be necessary to correct the load distribution coefficient used in calculation methodology, as this coefficient influences the size of deformation modulus.

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