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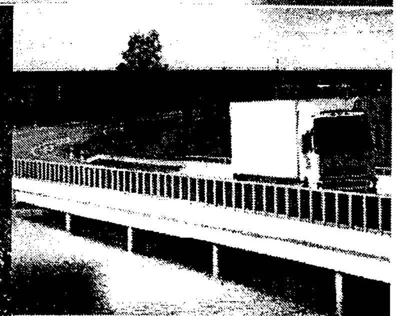

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RESEARCH AND EVALUATION OF METHODS FOR DETERMINING DEFORMATION MODULUS OF ROAD SUBGRADE AND FROST BLANKET COURSE

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Abstract. Pavement structural strength is one of the main indices determining pavement ability to carry traffic loads. In determining deformation modulus of pavement structure the static and dynamic non-destructive methods are worldwide used, however, in many countries, when designing and building pavement structures, the strength of road pavement structure is characterized by a static deformation modulus. In order to find out and compare the accuracy of testing results of using the static and dynamic methods, in 2007 the Automobile Road Research Laboratory of the Vilnius Gediminas Technical University carried out the comparable measurements of the subgrade and frost blanket course of a test road section with the help of four measuring devices. Measurements were carried out with each device on the same layer of the road pavement structure. Based on the study findings, the dependence of device measuring results on the subgrade and frost blanket course is presented.

Keywords: road pavement deformation, dynamic deformation modulus, static deformation modulus, Falling Weight Deflectometer (FWD).

1. Introduction

In Lithuania the strength of road pavement and its structural layers is regulated by a static deformation modulus. Most frequently deformation modulus is determined by non-destructive static and dynamic methods (Vaitkus *et al.* 2005). In static method deformation modulus is determined using the Benkelman beam (for flexible pavements) and static press (for base layers from unbound materials). In dynamic method the following equipment are used: light dynamic device (for base layers from unbound materials) and Falling Weight Deflectometer (FWD) (for all pavement structural layers). When taking measurements with dynamic devices, the load is produced by the impact of a falling cylinder in a very short period of time on a certain area, a large weight and transmitted to the pavement through a circular load plate. Dynamic load causes deflections of pavement structure. When taking measurements with a static device, a certain area of pavement structure is being gradually loaded and unloaded.

For the determination of deformation modulus of pavement structure the static and dynamic non-destructive methods are worldwide used. Since 1996 Estonia has been using the Falling Weight Deflectometer (FWD) to determine the structural strength of road pavement. Aavik (2003) carried out the analysis of road pavement structural strength and adapted the use of FWD to Estonian conditions. In Lithuania an experimental research of the change in the pavement structural strength was performed taking into consideration Lithuanian climatic conditions was carried out by Šiaudinis (2007). Based on researches carried out in Lithuania (Šiaudinis 2006) and other countries according *American Association of State Highway and Transportation Officials (AASHTO) Guide for design of pavement structures* an assumption could be made that there is a clear relation between the measurements carried out with static and dynamic devices. So far Europe has not had a unanimous evaluation methodology of the results obtained from measurements carried out with FWD or according to the static method. Analysis of measuring methods shows a regular dependency of the devices used, thus, it cannot be unambiguously decided which method is really the best and the most acceptable. In order to find out and compare the accuracy of testing results of using the static and dynamic methods, in 2007 the Automobile Road Research Laboratory of the Vilnius Gediminas Technical University carried out the comparable measurements of the subgrade and frost blanket course of a test road section with the help of four measuring devices.

2. Methods for measuring strength

Lithuania uses various devices to measure road pavement structural strength, and they are different in their measuring methodology and principles (Laurinavičius, Oginskas 2006).

When constructing the experimental test section the deformation moduli of separate pavement structural layers and

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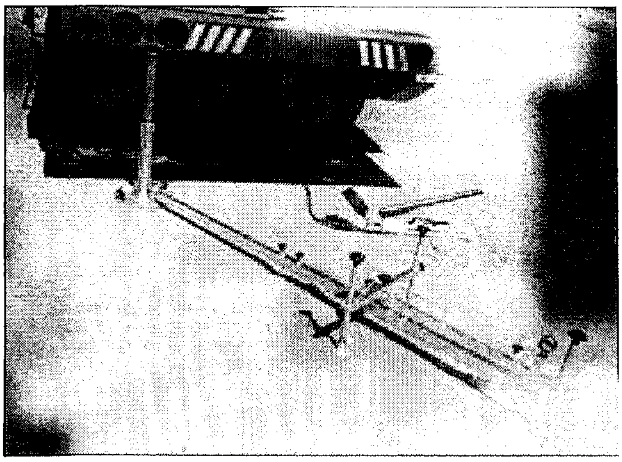


Fig. 1. Static beam "Strassentest"

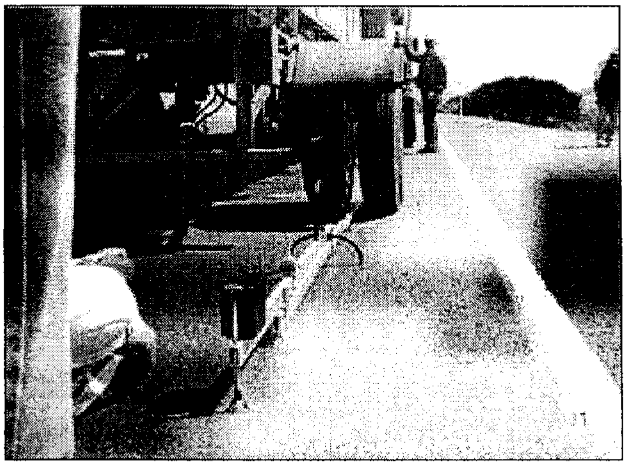
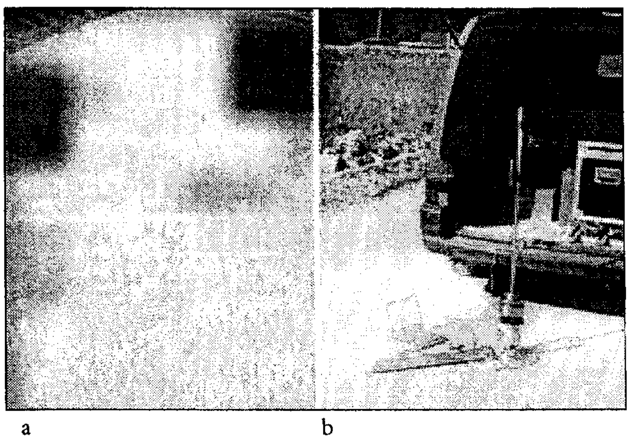


Fig. 2. Benkelman Beam (Washington State Department of Transportation 2006)



a b

Fig. 3. Dynamic devices:
a - LWD "Prima 100"; b - "ZORN ZSG 02"

the whole pavement structure were determined by using static and dynamic methods and the following equipment:

- in static method: static beam (press) "Strassentest" and Benkelman Beam "Infratest";
- in dynamic method: light dynamic device "ZORN ZSG 02", LWD "Prima 100" and FWD "Dynatest 8000".

A static beam (press) is the oldest and the most widely used device to determine the structural strength of road pavement. It measures pavement deflection caused by 60 kN static load transferred to a 300 mm diameter plate. When measuring with a static beam (Fig. 1), a structural pavement layer is gradually loaded and unloaded by a loading plate and then the test is repeated again. This device is used for the pavement structural layers built from unbound materials. A static plate load test could be used for course-grained, multi-grained and solid fine-grained soils. The test of quickly-drying sand soils, subsided, temporary softened soils or of those the upper part of which is destroyed is carried out only after this soil is removed. Density of the measured soil must remain unchanged. For fine-grained soils (clay) this method could only be applied if the soils are of solid consistency according Lithuanian standard *LST 1360.5:1995 Road soils. Testing methods. Plate load test.*

Soil deformation modulus E_v is a parameter of soil's ability to be deformed. Its values, when having a deflection curve of the 1^{st} and repeated loading, are calculated according to the slope of secant between the points 0,3 σ_{1max} by the formula:

$$E_v = 1{,}5 \times r \frac{\Delta\sigma}{\Delta_s}, \quad (1)$$

where E_v – deformation modulus, MPa; r – radius of a loading plate, mm; $\Delta\sigma$ – change in stresses under the beam, in the centre, mm; Δ_s – change in soil deformation in the centre of the beam, mm.

A measuring method by using Benkelman Beam (Fig. 2) is based on the determination of pavement structure deflections under a static load. The road pavement structure is loaded with a static 50 kN load – two-axle truck the rear axle of which (100 kN) has dual wheels – causing pavement deflection. Benkelman Beam measures deflection under the truck load transferred to the pavement through dual wheels. Using mathematical formulas deformation modulus of the pavement surface is calculated according *Specification for the use of Benkelman Beam to measure deflections.*

$$E_v = \frac{k \times P \times D \times \left(1 - \mu^2\right)}{l_p}, \quad (2)$$

where k – load transfer coefficient measured by deflection indicator and vehicle wheel (k = 0,85); P – pressure of vehicle wheel on pavement, MPa; D – reduced wheel patch diameter, m; μ – Poisson's ratio (μ = 0,3); l_p – reduced pavement deflection, m.

Testing with a light dynamic device (Fig. 3) is carried out to check the strength of soils and road base layers built from aggregates. This method is mostly suitable to course-grained and multi-grained soils with the particles less than 63 mm. The load is generated by a falling cylinder. Duration of the load is about 18 ms. This causes soil deformation. The determined dynamic deformation modulus E_{vd} differs from static deformation modulus E_{v2} determined by a static beam. To determine dynamic deformation modulus a portable device with a falling cylinder and a 300 mm diameter loading plate is used.

This testing method enables to determine dynamic deformation modulus E_{vd} from 10 MN/m^2 to 125 MN/m^2 according *Specification for the test using a dynamic device*. Deformation modulus is calculated by the formula

$$E_{vd} = 1{,}5 \times r \times \frac{\delta}{s}, \qquad (3)$$

where r – radius of a loading plate, cm; δ – dynamic load equal to 0,1 MN/m^2; s – soil deformation under the loading plate, mm.

In testing with a LWD "Prima 100" (Fig. 3), the impact force is transferred to the soil through a rigid plate causing a dynamic load δ, equal to 0,1 MN/m^2.

By making 3 drops a measuring site is prepared to ensure a better pressing of the plate to the soil. The weight is freely dropped from a pre-determined height and after each drop and rebound from the bumper it is caught.

3 drops are made and with the help of deformation measuring device the respective deformations are measured.

Dynamic deformation modulus E_{vd} MN/m^2 is found from the formula (3). Knowing the magnitude of dynamic load under the plate δ = 0,1 MN//m^2, plate diameter $2r$ = 300 mm and the mean value of measured deformations s (mm) dynamic deformation modulus could be found from the formula:

$$E_{vd} = \frac{22{,}5}{s}, \qquad (4)$$

where E_{vd} – dynamic deformation modulus, MN/m^2; s – soil deformation under the loading plate, mm.

For modelling purposes of road and street pavement structures the FWD was developed (Fig. 4) and it measures deflections under a temporary load. The advantages of this method are as follows: a non-destructive test device, one man operational, accurate and fast measurements (up to 60 test points/h), wide loading range (7–120 kN), designed for multi-purpose measurements ranging from road to airfield pavements (Hudson *et al.* 1987; Hoffman, Thompson 1982).

Surface E-modulus at an equivalent depth r is approximately equal to the modulus of a pavement layer equivalent to the pavement layers situated below the equivalent depth $h_e = r$.

Surface E-modulus in the load centre (equivalent depth is 0 mm) is calculated by the formula:

$$E_0 = \left[\frac{f\left(1-\mu^2\right)\sigma_0 l}{r}\right], \qquad (5)$$

where E_0 – surface modulus in the centre of the loading plate, MPa; f – stress distribution ratio (f = 2 – even (segmented loading plate), $f = \pi/2$ – rigid plate, f = 8/3 – granular soils, rigid plate, f = 4/3 – cohesive soils, rigid plate); μ – Poisson's ratio; σ_0 – contact pressure under the loading plate, kPa; r – radius of the loading plate, mm; l – deflection, mm.

3. Measuring results of subgrade and frost blanket course of a test road section

In order to determine the strength of subgrade and frost blanket course of a test road section (left side of the road) 4 different devices were used: dynamic – FWD, LWD, ZORN ZSG 02; static – static beam (press) "Strassentest". On the right side of the road – FWD and a static beam "Strassentest".

Measurements on each of pavement structural layers were taken according to the same selected scheme (location of a measuring point differs ± 0,5 m) under the same weather conditions (Fig. 5) (Čygas *et al.* 2008).

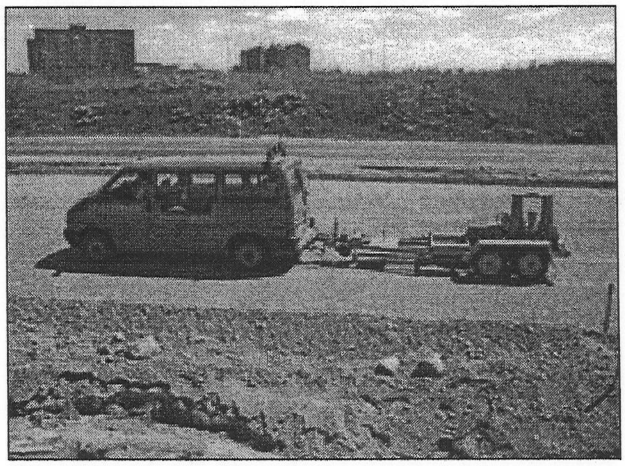


Fig. 4. Falling Weight Deflectometer (FWD)

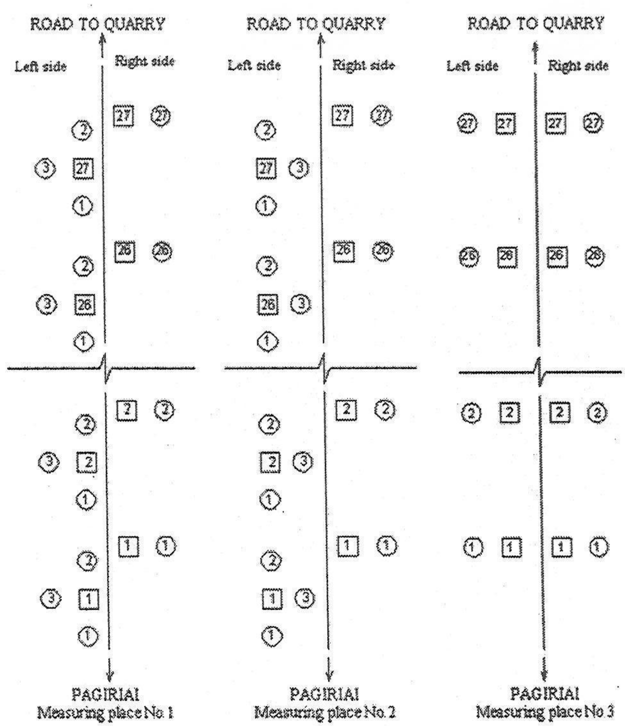


Fig. 5. Measuring scheme

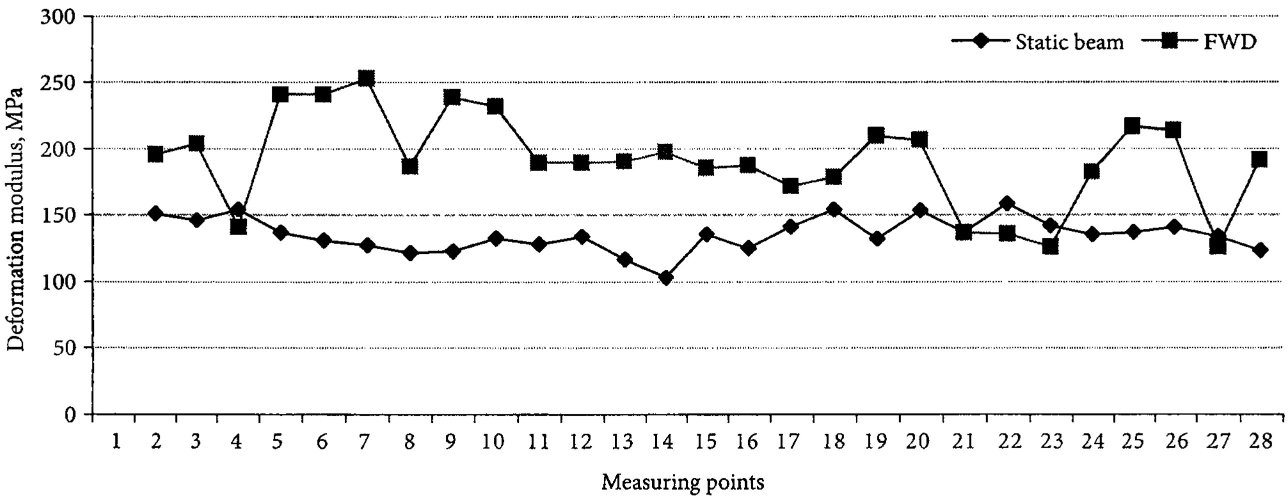


Fig. 9. Measuring results of frost blanket course (right side)

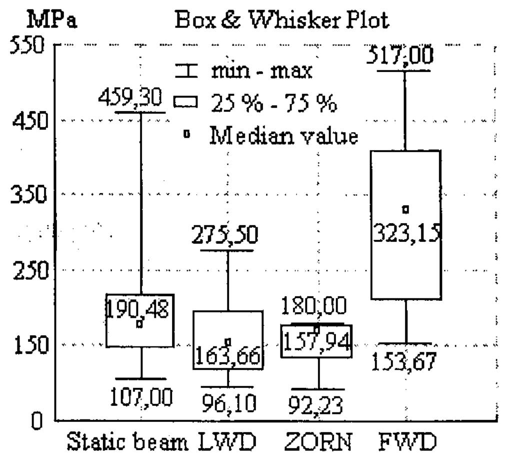


Fig. 10. Dispersion plot of the measuring results on the subgrade (left side)

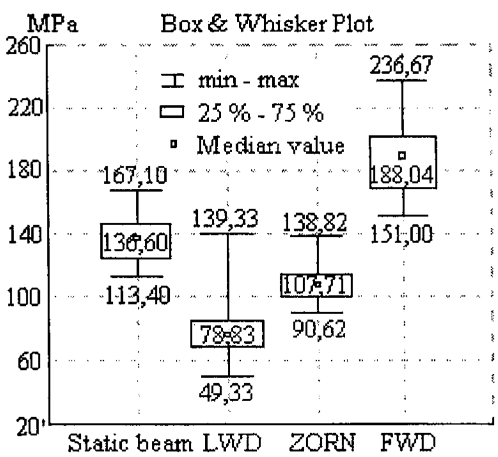


Fig. 11. Dispersion plot of the measuring results on the frost blanket course (left side)

Analysis of the measuring results is better described by the measurements carried out on low-bound materials. The measured values of the subgrade are presented in Figs 6 and 7.

Figs 6, 7 show that there are certain regularities between the measuring results of different devices. Taking into consideration small distances between the measuring points, it could be stated that the layer has been unevenly compacted or heterogeneous materials have been used for this layer. The static values of deformation modulus, if compared to a static beam, vary and are lower. This could be explained by the difference in measuring and calculating methods.

Analogical results were obtained by the measurements of the frost blanket course (Figs 8, 9).

In order to determine the dispersion and interdependence of measuring results, a statistical analysis was carried out (Fig. 10). Dispersion plots of the measuring results in Fig. 10 show a dispersion of inter-results of each device. A large difference could be observed between the min and max value. Analogically, the interdependences were determined between all 4 devices on the frost blanket course (Fig. 11).

Dispersion plots of the measuring results in Fig. 11 show a dispersion of inter-results of each device. A large difference could be observed between the min and max value.

4. Conclusions

Measurements of the road pavement structural strength were carried out by static and dynamic measuring methods using a static beam (press) "Strassentest", light dynamic device "ZORN ZSG 02" and Falling Weight Deflectometers: LWD "Prima 100" and FWD "Dynatest 8000". The analysis of the measuring results resulted in these conclusions.

1. The measuring results by dynamic devices on the subgrade shows that there is a regular dependence between all the measuring devices, though the numerical values of deformation modulus, if compared to a static beam, are lower and more varying. The values of LWD "Prima 100" and dynamic device "ZORN ZSG 02" are by 14–17 % low-

er that the mean numerical value of deformation modulus measured by a static beam, and the values of FWD "Dynatest 8000" are by 70 % higher. This explains the differences in measuring methods and calculation methodologies.

Dispersion plots of the measuring results show the lowest dispersion of results on the subgrade by "ZORN ZSG 02" device.

2. The measuring results by dynamic devices on the frost blanket course show that there is a regular dependence between all the measuring devices, though, the numerical values of deformation modulus, if compared to a static beam, are lower and more varying. The values of LWD "Prima 100" and dynamic device "ZORN ZSG 02" are by 33–43 % lower that the mean numerical value of deformation modulus measured by a static beam, and the values of FWD "Dynatest 8000" are by 40 % higher. This explains the differences in measuring methods and calculation methodologies.

Dispersion plots of the measuring results show the lowest dispersion of results on the frost blanket course by "ZORN ZSG 02" device.

3. Based on carried out research, extra measurements to obtain dependable conclusions need to be performed.

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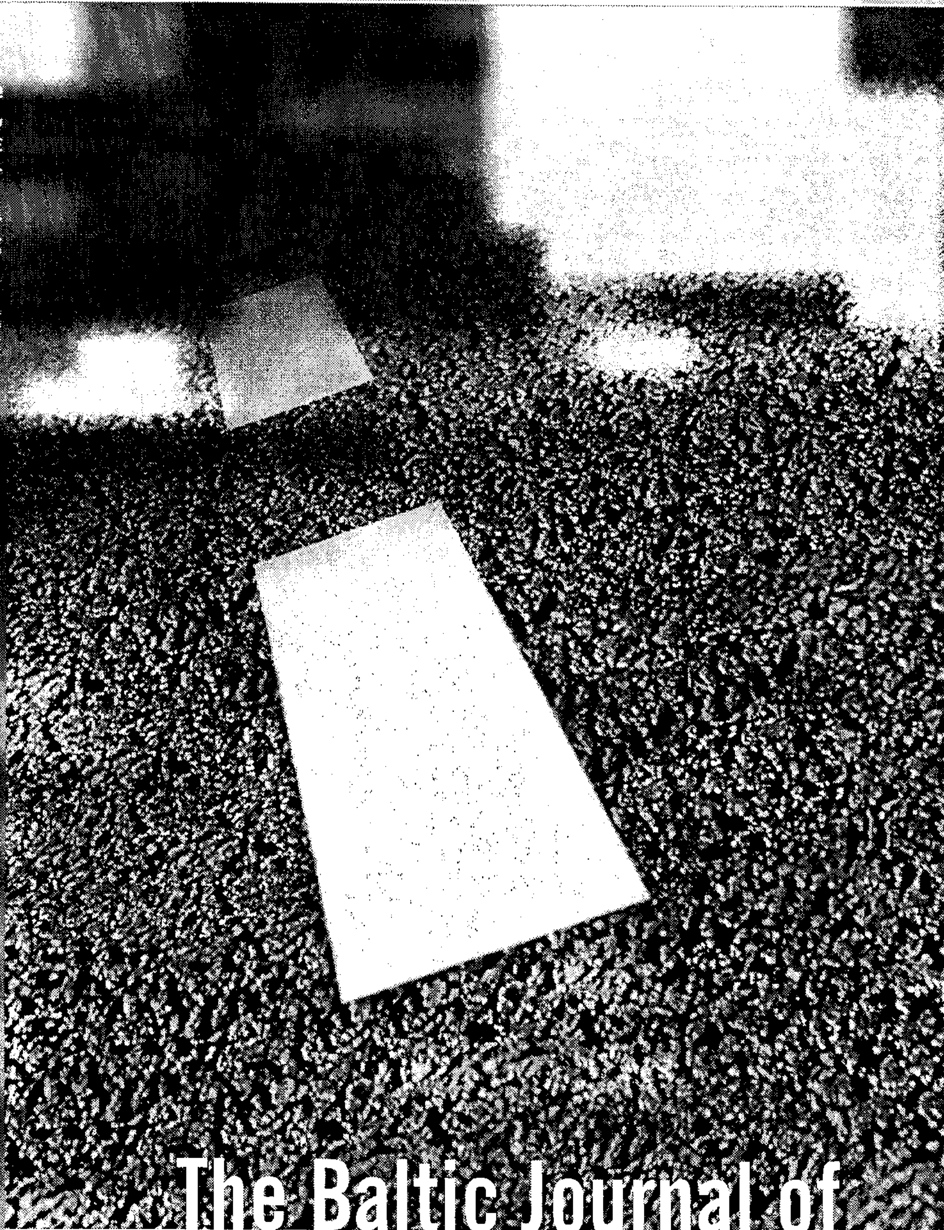

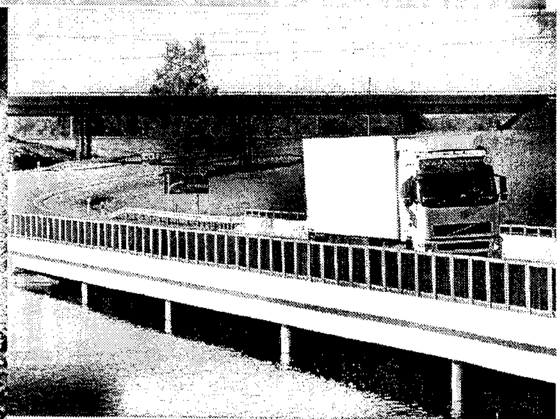

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RESEARCH AND EVALUATION OF METHODS FOR DETERMINING DEFORMATION MODULUS OF A BASE COURSE OF ROAD PAVEMENT

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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 testing 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).*

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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 (approbated) 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-approbated methodologies could be applied only as additional technical measures.

At present, Lithuania has no single methodology approbated 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 (Tompai 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 нежёстких 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 massif 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*:

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

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

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

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 aswphalt 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.

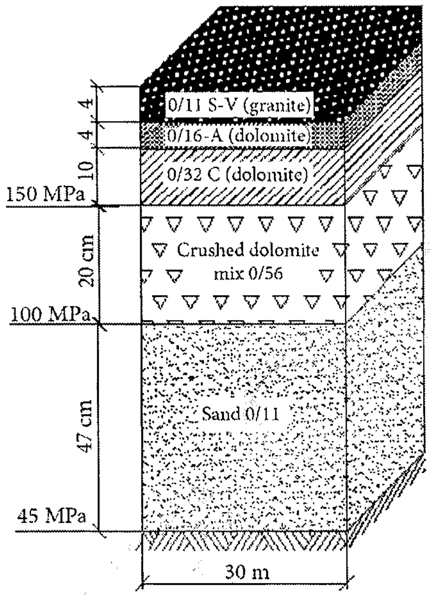

Fig. 1. The base structure of experimental pavements (Čygas *et al.* 2008)

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

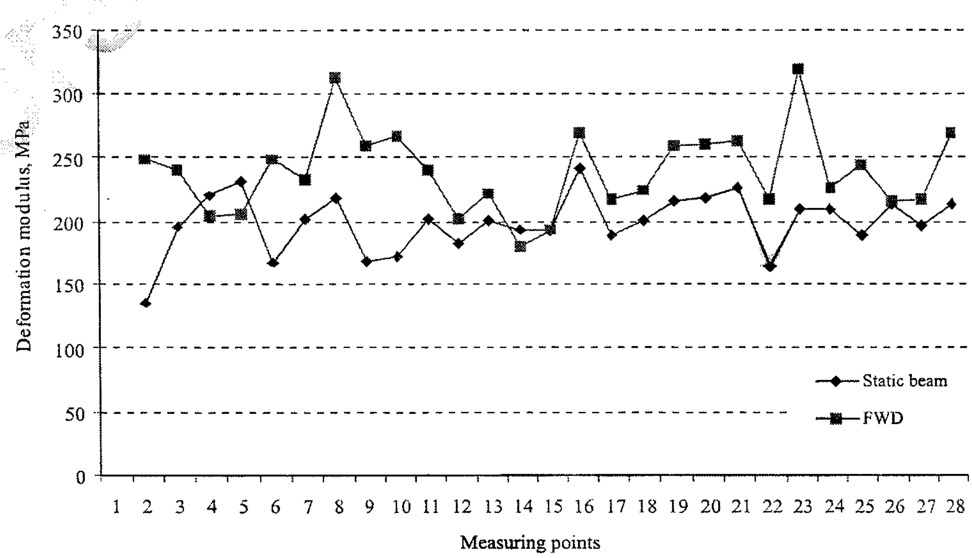

Fig. 2. Strength of a base course measured by all the above-mentioned devices (left side)

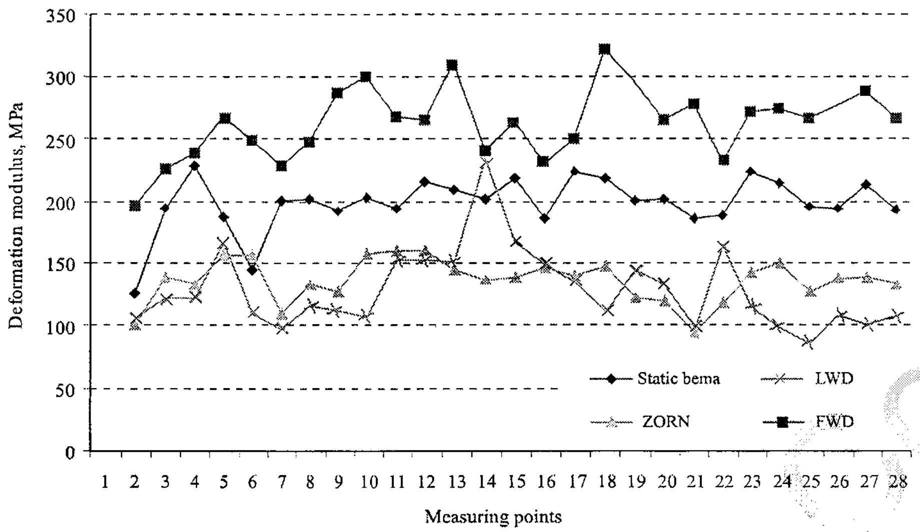

Fig. 3. Strength of a base course measured by static beam and FWD Dynatest 8000 (right side)

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.

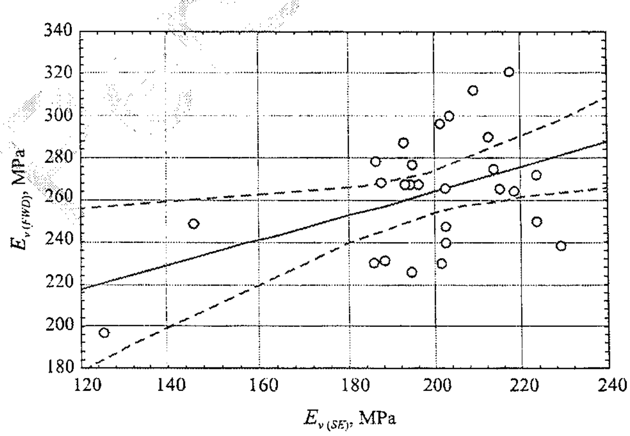

Fig. 4. Relationship between the measuring results of the FWD Dynatest 8000 and the static beam Strassentest on a base course (left side)

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.

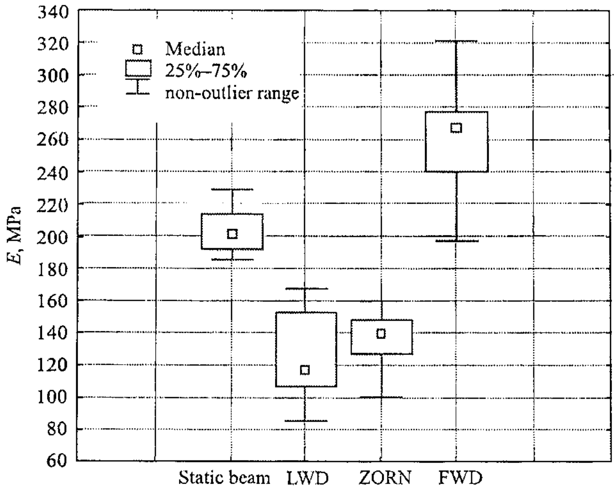

Fig. 5. Evaluation of measuring results on a base course layer by all the devices

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 pore. 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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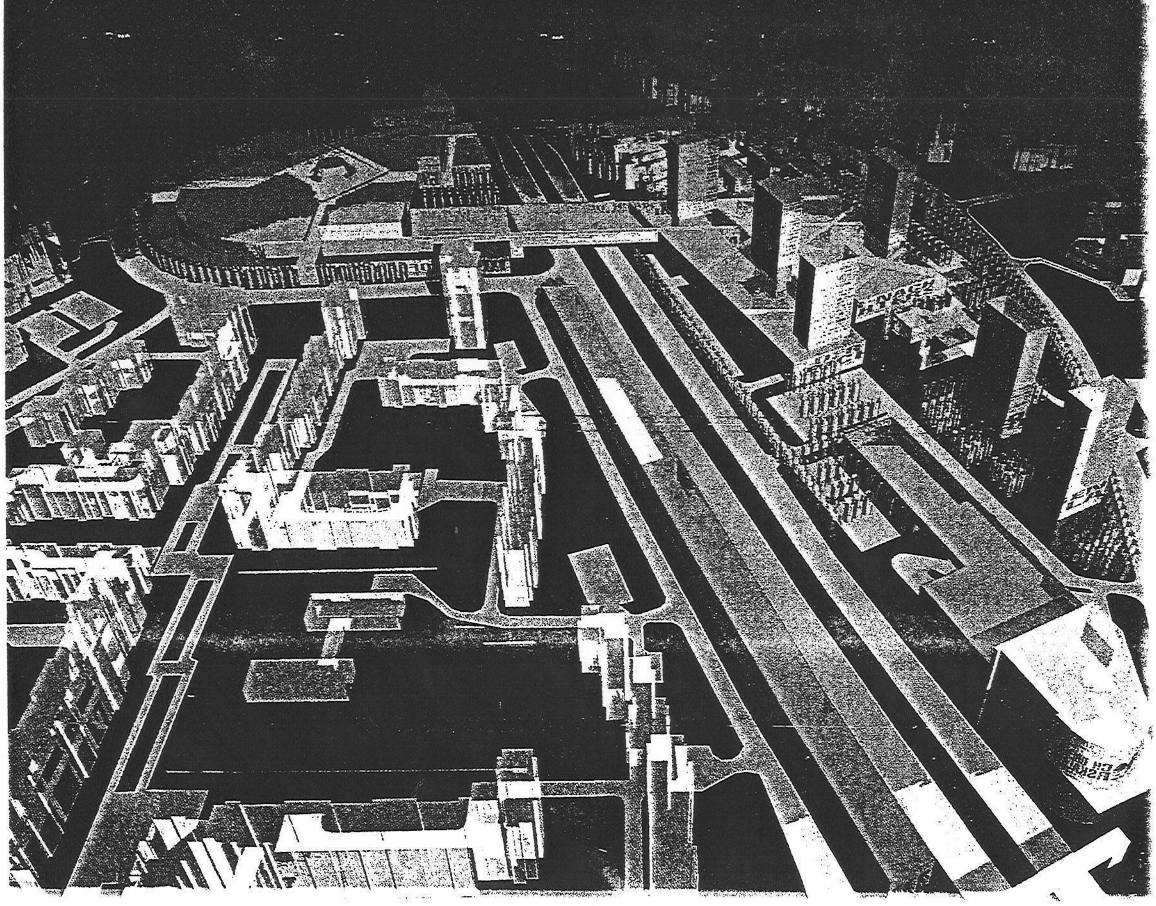

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ANALYSIS OF RESULTS ON TESTING ASPHALT PAVEMENTS REINFORCED BY GEOSYNTHETIC MATERIALS

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Abstract. This article analyses experiments performed on asphalt concrete pavements reinforced by geosynthetic materials. The experiments were performed on the experimental section with a purpose to determine the way the geosynthetic materials influence the rheological characteristics of asphalt concrete and changes in the depth of rutting. The article presents the main statistical methods and criteria on the basis of which the statistical data analysis was performed. In addition, in the article was evaluated the impact of the geosynthetic materials on the abovementioned characteristics and analyses separate samples as well as finds differences between them. Finally, the evaluations of the statistical analysis as well as the conclusions are presented.

Keywords: geosynthetics material, rutting, ANOVA, post hoc, statistic method.

1. Introduction

Each group of experimental data is processed in one or another way. This involves determination of differences between the samples, dependency of one group of factors on the other group of factors, strength of relations, etc.; if the samples are big enough, statistical analysis encounters no major problems. In experimental research, however, it is not always possible to perform as many tests as is necessary. Such a situation is due to different reasons: the performance of a test is expensive, a test is a long lasting one, there are restrictions on the duration of an experiment, etc. If there is a lack of data, the results of their statistical analysis may be interpreted incorrectly. Inaccuracy and errors may in principle distort the importance of the experiment as a whole or distort the evaluation of the results obtained. For this purpose in statistical analysis non-parameter values alongside with the parameter criteria are used. Their purpose is to analyze the samples, that do not distribute themselves in line with the normal distribution or when there are no clear elements of norm, as well as small samples.

The experiments on asphalt concrete pavements reinforced by geosynthetic materials are expensive and some of them last for a long time. Due to these reasons the value of certain variable samples is not suitable to be used in normal statistical analysis.

This article analyses the results of experiments performed on asphalt concrete pavements reinforced by geosynthetic materials on the basis of both parameter and non-parameter tests.

2. Experimental tests on pavements reinforced by geosynthetic materials

The experimental section was constructed in autumn of 2005 with a purpose to determine the way the geosynthetic materials influence the formation of ruts in the upper layers of asphalt concrete [1, 2].

During the tests the rheological characteristics of asphalt concrete were determined (elasticity module of asphalt concrete E and viscosity of asphalt concrete η) and depth of ruts. The tests were performed by means of a statistical test stamp and a three meter ruler [3].

The results are presented in the Fig 1 – Fig 3 below.

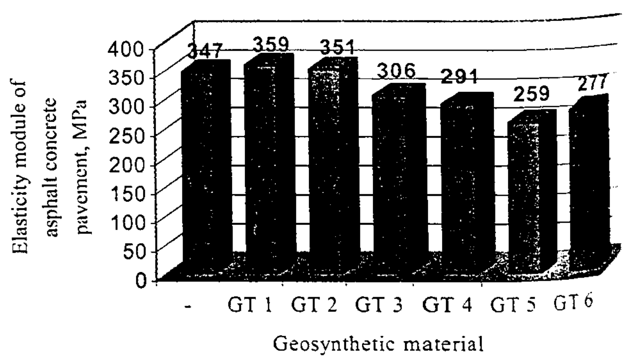

Fig 1. Dependency of the elasticity module of asphalt concrete pavement on geosynthetic materials

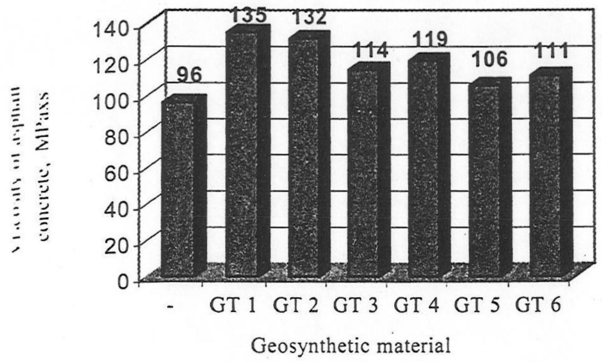

Fig 2. Dependency of asphalt viscosity on the type of geosynthetic materials

The depth of ruts was measured after the cold season and after the hot season.

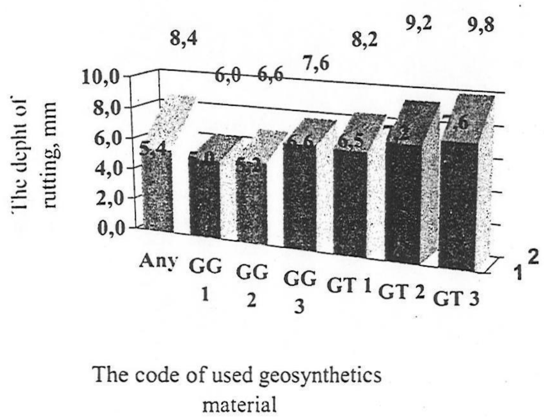

Fig 3. Measurements of the depth of ruts

Note: numbers 1 and 2 reflect measurements of ruts in spring and autumn respectively.

3. Methods of data analysis

3.1. Determination of sample distribution

During the first stage it was examined whether the data obtained are distributed according to the normal distribution. This is taken into account when selecting other tests. In order to check the above-mentioned statistical hypothesis, the Smirnov–Kolmogorov test was selected. The essence of this test is as follows: the distribution of the data obtained during the test is compared with the theoretical distribution. This test calculates the greatest differences between the measured variable parameters and theoretical distribution parameters. In case the hypothesis on the normal distribution is being checked, the average sample and standard deviation is used.

At the end of the test the value of p is calculated that indicates whether the data of the investigation distribute themselves according to the normal distribution. If the value of p is lower than 0,05, it is possible to state that the distribution of the sample does not correspond to the normal distribution [4].

3.2. Stjudent criterion for dependent and independent samples

The above-mentioned criterion is applied aiming to determine whether the two samples for statistical purposes are different. When applying to independent samples the criterion t is calculated:

$$t = \frac{\bar{x} - \bar{y}}{\sqrt{(n-1)S_x^2 + (m-1)S_y^2}} \sqrt{\frac{nm(n+m-2)}{n+m}}; \quad (1)$$

Where: $\bar{x}$, $\bar{y}$ – average of different samples, n, m – values of different samples, S_x^2, S_y^2 – dispersions of different samples.

In case of dependent samples the criterion t is calculated as follows:

$$t = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{S_d^2}{n}}} \quad (2)$$

Where: $\bar{x}$, $\bar{y}$ – average of different samples, S_d^2 – dispersion of differences.

The samples are not similar, if $|t| > t_{\alpha/2}(n-1)$, $t_{\alpha/2}(n-1)$ is the critical value of Stjudent distribution with (n-1) degree of freedom $\alpha/2$ level. If $|t| \leq t_{\alpha/2}(n-1)$, then it is possible to state that the samples for statistical purposes do not differ. α is the level of importance, which in the present case is equal to 0,05.

Stjudent criterion could be used only in case the data is distributed according to the normal distribution.

3.3. ANOVA method

ANOVA (Analysis Of VAriance) method is applied in cases when the number of samples is more than two. The presumptions of this method are as follows:

1. variables are distributed according to the normal distribution,
2. the dispersions of variables are equal,
3. variables are independent.

In order to check the ANOVA hypothesis, the statistics F is used [4]:

$$F = \frac{MSB}{MSW} \quad (3)$$

Where: MSW – evaluation of dispersion inside of variable groups, MSB – evaluation of dispersion between variable groups.

The obtained statistics F is compared with the critical value of the Fisher distribution $F_\alpha(m,n)$. If this value is lower than all the F values, thus it is possible to state that there is a difference between separate samples.

This method illustrates the statistical difference between separate samples, but not between which certain samples. For this purpose the „post hoc“ test is used. It relies on the same ANOVA model and uses three criteria: Tukey's HSD, LSD, Bonferroni [5].

Tukey's HSD criterion is based on the so-called 'stjudentized' distance Q statistics:

$$Q(i,j) = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{MSW}{n}}}; \qquad (4)$$

Averages $\bar{x}$ and $\bar{y}$ are different, if $|Q(i,j)| > Q_\alpha(nk-k,k)$; here α – the selected level of importance, $Q_\alpha(nk-k,k)$ – critical value of Q statistics at α level, taken from references.

LSD criterion comparing all the pairs by using t criterion.

Bonferroni criterion is as follows: the level of importance of the experiment α_E is chosen and all the pairs are compared by applying the Stjudent criterion, when the importance level is $\alpha = \frac{\alpha_E}{C}$; here $C = k(k-1)/2$. When two samples are compared, the Bonferroni criterion BSD_{ij} is calculated [5]:

$$BSD_{ij} = t_{\alpha/2}(N-k)\sqrt{MSW\left(\frac{1}{n_i} + \frac{1}{n_j}\right)}; \qquad (5)$$

Where: N, k – total number of samples, $\alpha = 2\alpha_E/(k(k-1))$, α_E – the selected level of importance of the experiment, $t_{\alpha/2}(N-k)$ – critical value of Stjudent distribution with (N–k) degree of freedom of $\alpha/2$ level. Averages $\bar{x}$ and $\bar{y}$ for statistical purposes are markedly different, if $|\bar{x} - \bar{y}| > BSD_{ij}$

3.4. Wilcoxon sign criterion

It is used in cases when the condition of normality is not satisfied or if it is not possible to check it. In addition this method is effective in the presence of small samples. This method is applied for independent samples.

The essence of the application of this method is as follows: the difference between the data of each pair is calculated $d_i = x_i - y_i$, i = 1, …, n. Next, the absolute size of all d_i is determined $|d_i|$, they are ranked. The rank that corresponds to the negative value of d_i is called the negative rank, the rank that corresponds to the positive value of d_i is called the positive rank. The sum of positive T^+ and negative T^- ranks is calculated. The calculated T^+ is compared with the importance level α and if it is lower, it is possible to state that the distributions are not equal [5, 6].

3.5. Kruscal–Wallis ranking criterion

This criterion is applied in cases when it is necessary to compare three or more population distributions. This method is applied for independent samples. The essence of this method lies in the fact that certain rank is attributed to each measurement. Next, the statistics H is calculated:

$$H = \frac{12}{n(n+1)}\sum_{j=1}^{k}\frac{R_j^2}{n_j} - 3(n-1); \qquad (6)$$

Where: k – number of variables, n_j – number of observations on the j variable, R_j^2 – j sample rank sum in square. If $H > \chi^2_{0,05}(k-1)$, then we consider that distributions are not similar.

3.6. Criterion of the sum of Mann–Whitney–Wilcoxon ranks

Mann–Whitney–Wilcoxon criterion is a non-parameter analogue to Stjudent criterion for two independent samples. It is applied, when the samples are small. By applying this method two samples are connected to form one sample and their members are situated in ascending order from the smallest to the largest observation. Ranks are attributed to the members of the line. Next, statistics are being calculated [5, 6]:

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \qquad (7)$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2 \qquad (8)$$

Where: R_1 and R_2 – sum of ranks, attributed to the members of the first and the second sample respectively.

If U_1 is not higher than the larger critical value of the binary criterion, it is supposed that distributions are not similar.

4. Analysis of experimental data

Having performed the measurements, the data were processed by means of the statistical package SPSS.

The following hypotheses are formulated when determining the distribution:

$$\begin{cases} H_0: & \text{Variables of the sample are distributed according to the normal distribution,} \\ H_1: & \text{Variables of the sample are distributed according to another distribution.} \end{cases}$$

At the end of the test the value of p is calculated, which indicates, whether the data of investigation distribute according to the normal distribution. If the value of p is lower than 0,05, it can be stated that the distribution of the sample does not correspond to the normal distribution. The results of the test are presented in Table 1.

Table 1. Results of Smirnov–Kolmogorov test

Geosynthetic material	Depth of ruts after the first measurement	Depth of ruts after the second measurement	Difference in the depth of ruts	Elasticity module
–	0,301	0,570	0,646	0,152
GT1	0,134	0,456	0,100	0,977
GT2	0,863	0,354	0,137	0,590
GT3	0,196	0,284	**0,020**	0,980
GT4	0,109	0,288	0,536	0,928
GT5	0,064	0,502	0,776	0,951
GT6	0,285	0,215	0,463	0,981

Table 2. Results of the Stjudent test

Value	$PR_{1K}-$ $-PR_{2K}$	$PR_{1GT1}-$ $-PR_{2GT1}$	$PR_{1GT2}-$ $-PR_{2GT2}$	$PR_{1GT3}-$ $-PR_{2GT3}$	$PR_{1GT4}-$ $-PR_{2GT4}$	$PR_{1GT5}-$ $-PR_{2GT5}$	$PR_{1GT6}-$ $-PR_{2GT6}$
t	-9,033	-5,870	-5,264	-2,606	-3,878	-5,653	-5,508
p	0,000	0,000	0,000	0,021	0,001	0,000	0,000

Table 3. Results of the Wilcoxou test

Value	$PR_{1K}-$ $-PR_{2K}$	$PR_{1GT1}-$ $-PR_{2GT1}$	$PR_{1GT2}-$ $-PR_{2GT2}$	$PR_{1GT3}-$ $-PR_{2GT3}$	$PR_{1GT4}-$ $-PR_{2GT4}$	$PR_{1GT5}-$ $-PR_{2GT5}$	$PR_{1GT6}-$ $-PR_{2GT6}$
Z	-3,176	-2,972	-2,242	-2,721	-3,209	3,293	-3,541
p	0,001	0,003	0,025	0,007	0,001	0,001	0,000

The next step in statistical analysis is to determine, whether ruts formed after the hot season differ from the depth of ruts formed after the cold season, i.e. whether the depth of ruts formed during the summer is important. For this purpose statistical hypotheses are formulated if it is supposed that the data is distributed according to the normal distribution:

$$\begin{cases} H_0: & \bar{x}_X = \bar{x}_Y, \\ H_1: & \bar{x}_X \neq \bar{x}_Y. \end{cases}$$

Aiming to check the aforementioned hypotheses, the t test on dependent samples was used.

H_0 is rejected, if $|t| > t_{\alpha/2}(n-1)$, $t_{\alpha/2}(n-1)$ – critical value of Stjudent distribution with (n-1) degree of freedom of $\alpha/2$ level. If $|t| \leq t_{\alpha/2}(n-1)$, the hypothesis H_0 is not rejected. α – importance level, which in the present case is 0,05. Values of t and p are presented in Table 2.

Since the data is not enough, in addition, the Wilcoxon sign criterion test on two dependent samples is performed.

The hypotheses are formulated:

H_0: Depths of ruts after the first and the second measurement are similar

H_1: Depths of ruts after the first and the second measurement are not similar

H_0 is rejected, if $|Z| > z_\alpha$, z_α – critical importance level, selected according to the tables. In this case it is: z_α=1,96. Data in the table indicates that any $|Z| > z_\alpha$. Z and p values are presented in Table 3.

Statistics $p \leq 0,05$ (all values are lower than the importance level). Thus the hypothesis H_0 may be rejected. It is possible to state that the depth of ruts formed in all the sections during the hot season is important. It is indicated by the results of t test and Wilcoxon test as well.

The next step of the analysis is to determine, whether geosynthetic materials make influence on ruts, formed on different sections, and on the elasticity module of a pavement. For this purpose it is necessary to compare different samples and determine, whether they differ. The parameter, determining whether there is a difference between separate sample averages, is statistics F. It is determined by means of the ANOVA (ANalysis Of VAriance) method.

The hypotheses are formulated:

$$\begin{cases} H_0: & \bar{x}_1 = \bar{x}_2 = \bar{x}_3 = \bar{x}_4 = \bar{x}_5 = \bar{x}_6 = \bar{x}_7, \\ H_1: & \text{At least two averages differ.} \end{cases}$$

The obtained statistics F is compared to the critical value of the Fisher distribution $F_\alpha(m,n)$. This value $F(6,98)$=2,2. This value is lower than all the F values, thus it is possible to state that there is a difference between separate samples. The results of the examination are presented in Table 4.

Since it is not clear, whether the variables of the samples are distributed according to the normal rule, and the samples are not big enough, thus the non-parameter criteria are used. Kruscal–Wallis test determines, whether there is a difference between separate samples.

The hypotheses are formulated:

$$\begin{cases} H_0: & \text{distributions of variables are similar} \\ H_1: & \text{distributions of variables are not similar} \end{cases}$$

The distributions of variables are similar, if the importance level is $\alpha > p$. p – value, obtained after the Kruscal–Wallis test. If $\alpha \leq p$, it is supposed that distributions are different. In this case $\alpha=0,05$, p values are presented in Table 5.

Both the ANOVA, the Kruscal–Wallis test indicate that there is a difference between separate samples, however it is not clear which groups do differ, and which do not. For this purpose a multiple Mann–Whitney tests are performed.

The statistical hypotheses are formulated:

$$\begin{cases} H_0: & X_i \text{ and } Y_i \text{ distributions are similar,} \\ H_1: & X_i \text{ and } Y_i \text{ distributions are similar.} \end{cases}$$

The results of ANOVA test are presented in Annex 1.

This test uses three criteria: Tukey's HSD, LSD, Bonferroni.

Table 4. The results of ANOVA test

Parameter		Sum of squares	Degrees of freedom	Values of dispersion	Statistics F
PG_1	of groups internal total	117,53 300,705 418,058	6 96 102	19,559 3,132	**6,244**
PG_2	of groups internal total	109,375 156,314 265,689	6 96 102	18,229 1,628	**11,195**
ΔPG	of groups internal total	34,645 145,957 180,602	6 96 102	5,774 1,520	**3,798**
E	of groups internal total	142093,483 49697,903 191791,386	6 98 104	23682,247 507,121	**46,699**

Table 5. The results of the Kruscal–Wallis test

	PG_1	PG_2	ΔPG	E
p values	0,000	0,000	0,004	0,000

Table 6. The results of the Mann–Whitney test

Comparison	PG_1	PG_2	ΔPG	E
K – GT1	0,744	**0,050**	**0,010**	0,074
K – GT2	0,290	0,112	0,561	0,174
K – GT3	**0,010**	0,539	**0,001**	**0,000**
K – GT4	**0,030**	0,367	0,137	**0,000**
K – GT5	**0,000**	**0,021**	0,056	**0,000**
K – GT6	**0,000**	**0,002**	**0,033**	**0,000**
GT1 – GT2	**0,018**	**0,006**	**0,020**	0,250
GT1 – GT3	**0,000**	**0,037**	0,345	**0,000**
GT1 – GT4	**0,010**	**0,000**	0,106	**0,000**
GT1 – GT5	**0,000**	**0,000**	0,233	**0,000**
GT1 – GT6	**0,000**	**0,000**	0,252	**0,000**
GT2 – GT3	0,880	0,063	**0,010**	**0,000**
GT2 – GT4	0,780	0,217	0,425	**0,000**
GT2 – GT5	0,123	0,519	0,252	**0,000**
GT2 – GT6	**0,011**	0,734	0,194	**0,000**
GT3 –GT4	0,461	0,106	**0,023**	**0,003**
GT3 –GT5	**0,074**	**0,003**	0,106	**0,000**
GT3 –GT6	**0,008**	**0,000**	0,112	**0,000**
GT4 –GT5	0,015	0,174	0,653	0,000
GT4 –GT6	**0,003**	**0,006**	0,591	**0,023**
GT5 –GT6	0,123	0,112	0,880	**0,005**

Since the samples are small, it is purposeful in this case to perform the non-parameter tests as well. One of such tests is the Mann–Whitney test. The results of this test are presented in Table 6.

Since the analysis made by means of the ANOVA method needs much space, in authors' opinion there is no need to present all the results. The article presents the final evaluation of the results.

The data in Table 7 indicates, whether there is a difference between separate samples by applying parameter and non-parameter sample comparison methods. The first sign indicates the existence or non-existence of a difference by applying parameter methods, the second sign indicates the existence or non-existence of a difference by applying non-parameter methods.

Although the average values of parameters differ in separate sections, however, according to the statistical analysis, in certain sections there is no important difference.

Table 7. Summary of assessment results

Comparison	Difference between separate samples			
	PG_1	PG_2	ΔPG	[illegible]
K – GT1	-/-	+/+	+/+	-/-
K – GT2	-/-	-/-	-/-	-/-
K – GT3	+/+	-/-	+/+	-/+
K – GT4	+/+	-/-	-/-	-/+
K – GT5	+/+	-/+	-/-	-/+
K – GT6	+/+	-/+	-/+	-/+
GT1 – GT2	-/+	+/+	-/+	-/-
GT1 – GT3	+/+	-/+	-/-	-/+
GT1 – GT4	+/+	+/+	-/-	-/+
GT1 – GT5	+/+	+/+	-/-	-/+
GT1 – GT6	+/+	+/+	-/-	-/+
GT2 – GT3	-/-	-/-	+/+	-/+
GT2 – GT4	-/-	-/-	-/-	-/+
GT2 – GT5	-/-	-/-	-/-	-/+
GT2 – GT6	-/+	-/-	-/-	-/+
GT3 – GT4	-/-	-/-	-/+	-/+
GT3 – GT5	+/+	-/+	-/-	-/+
GT3 – GT6	-/+	+/+	-/-	-/+
GT4 – GT5	-/+	-/-	-/-	-/+
GT4 – GT6	+/+	-/+	-/-	-/+
GT5 – GT6	-/-	-/-	-/-	-/+

Note: „+" means that there is a difference between separate samples, „-" means that there is no difference between separate samples.

5. Conclusions and recommendations

1. Having finished experimental research, it is possible to approve those differences between various parameters exists, but whether there is a statistical difference it is possible to tell only after statistical analysis.

2. When applying parameter or non-parameter methods the results are in fact similar. Only in 19 % of cases the results of parameter and non-parameter methods differ.

3. The results of statistical analysis depend on the methods and criteria selected. Aiming to avoid discrepancies, it is advisable when making statistical analysis of data in the presence of small samples to use both parameter and non-parameter values.

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RESEARCH OF STRENGTH MEASUREMENT METHODS ON SUBGRADE OF EXPERIMENTAL ROAD PAVEMENT

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Abstract. Pavement is one of the most important structural elements of road. It is continuously affected by static and dynamic traffic loads and climate change. Due to the impact of traffic and climate the physical and mechanical properties of subgrade soils and materials of the structural pavement layers change. A rapidly increasing heavy traffic volume, a growth of normative axle load from 10 to 11,5 t on the main roads of Lithuania force the scientists to look for new durable road building materials and their mixtures. 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. The article studies methods for the determination of road pavement structural strength, gives the evaluation of equipment used for static and dynamic determination of pavement structural strength. In order to determine and compare the accuracy of testing results carried out by static and dynamic methods the comparative measurements were carried out on the experimental road section using four measuring devices on subgrade. Further results of the research of experimental road section, their analysis and assessment will allow to select the most suitable measuring method for each structural pavement layer.

Keywords:. traffic loads, road pavement, pavement strength, static and dynamic methods, subgrade.

1. Introduction

The sector of Lithuanuan transport accounts for more than 10 % of the gross domestic product (GDP), and most of which is falling on road transport. This may be explained by the density of road network as well as the state and technical parameters of road (Sivilevičius and Šukevičius 2009).

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 (Vorobjovas *et al.* 2007). Therefore, the subgrade soils and structural pavement layers undergo deformation and their strength decreases.

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

Until restoration of independence of Lithuania phalt concrete and other “black” pavements were signed according to the “Instruction for the Design Flexible Pavements VSN 46-83“. In 1995 – 1996 the r normative documents for motor roads came into fc and the mentioned instruction was not further used. phalt concrete and other “black” pavements were sta to be designed according to the “Standards and Rules the Design of Flexible Pavements PNT – K95".

At present, in Lithuania the main normative do ment regulating the design of asphalt concrete and o “black” pavements on motor roads is the Construct Technical Regulation KTR 1.01:2008 “Motor Roa which came into force in 2008. Technical measures methods for implementing the requirements of this Re lation are defined by the “Regulations for the Desigr Standardized Pavement Structures of Motor Roads K SDK 07“.

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 (approbated) 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-approbated methodologies could be applied only as additional technical measures.

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

Detail designs of pavement strengthening and repair of roads of all forms of ownership outside the limits of residential areas are currently prepared according to the requirements and provisions of KTR 1.01:2008.

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)(Markevičiūtė and Atkočiūnas 2006). When constructing and reconstructing roads it is necessary to control if the strength of structural pavement layers correspond to their design strength. For this purpose various methods are used to determine the strength of structural pavement layers.

This article gives the initial results of structural investigations of experimental road section, consisting of 27 different pavement structures, constructed for the first time in the Lithuanian history of roads (Čygas et al. 2008). Further results of investigating this experimental road section, their analysis and evaluation will allow to select road pavement structures the best corresponding to the climatic and traffic conditions in Lithuania. A separate chapter describes methods for measuring structural pavement strength on the selected experimental road section with the use of four measuring devices.

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 correspond 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.

2.1. Static method for measuring strength

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); 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 formula:

$$E_i = \frac{P \cdot D}{l}\left(1-\mu^2\right), \qquad (1)$$

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 (Оценка...2003):

$$E = A - B\left(\lg \sum_{i=1}^{m} \frac{t_{E_i}}{10} - 0{,}4\right), \qquad (2)$$

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 in 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 a 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 and Селезнев 1997).

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

2.2. Dynamic method for measuring strength

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 massif 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 (Оценка...2003):

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

$$k_d = 0,5(l + \frac{l'}{l}), \qquad (4)$$

$$T_f = \pi\sqrt{\frac{\delta}{g}} \cong 0,1\sqrt{\delta}, \qquad (5)$$

where M – mass of the falling weight, kg;
g – free acceleration of the falling weight, m/c^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 and Селезнев 1997):

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

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

The studded 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 moduli 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 layers of experimental road section four different devices were used different in their measuring methodology and their operational principles. This article describes investigations carried out solely on the subgrade.

To determine the strength of subgrade (on the left side of the road) of the experimental road section (Fig 1) four different devices were used: dynamic – FWD Dynatest 8000, LWD Prima 100 and ZORN ZSG 02; static – static beam (press) Strassentest. On the right side of the road – FWD and static press 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.

Fig 1. Experimental road section

When laying subgrade for the experimental road section it was necessary to achieve the sufficiently equal subgrade strength, at least 100 MPa. The previously laid subgrade consisted of various building waste, the soil was heterogeneous. It was decided that the subgrade strength of more than 100 MPa will have no large influence on the strength of all pavement structures as well as their operational indicators. The subgrade strength of more than 100 MPa was achieved (Bertulienė and Laurinavičius 2008).

Investigations of the subgrade strength were carried out and the results were obtained using the static and dynamic measuring methods with four different measuring devices: dynamic – LWD Prima 100 (mini FWD), FWD Dynatest 8000 and ZORN ZSG 02; static – static beam (press) Strassentest.

4. Statistical analysis of investigation results on the subgrade

Investigations showed a clear interrelation between the data obtained by static and dynamic devices. Analysis of measuring methods showed that there is a regular dependence between the static and dynamic methods.

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

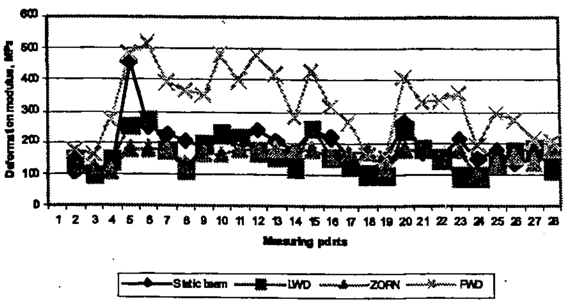

Fig 2. Results of the subgrade strength measured by all the mentioned devices (left side)

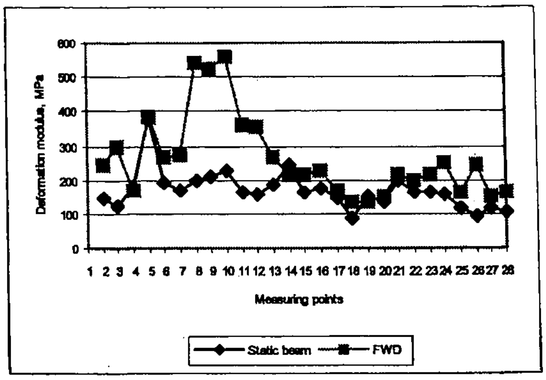

Fig 3. Results of the subgrade strength measured by static beam and FWD Dynatest 8000 (right side)

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

Analysis of measuring results on the subgrade shows that there is a regular dependence between all the measuring devices but the numerical values of deformation modulus (MPa), compared to static beam, vary and are lower: mini FWD and ZORN – 14 –17 % from the average, the values of FWD – 1.7 -2 times higher. This is explained by the difference in measuring and calculating methodologies (Čygas et al. 2008). For example, in the calculation methodology of FWD the applied load distribution coefficient f influences the quantity of deformation modulus. In the measurements $f = 8/3$ was used where the values calculated at the coefficient $f = \pi/2$ are very close to the values measured by other 3 devices.

During investigations of the subgrade of experimental road section for the analysis and evaluation of the strength indices obtained the mathematical statistical methods were used. In the analysis of the determination of subgrade strength 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.

The best results of correlation were obtained between the FWD Dynatest 8000 and the static beam (Fig 4).

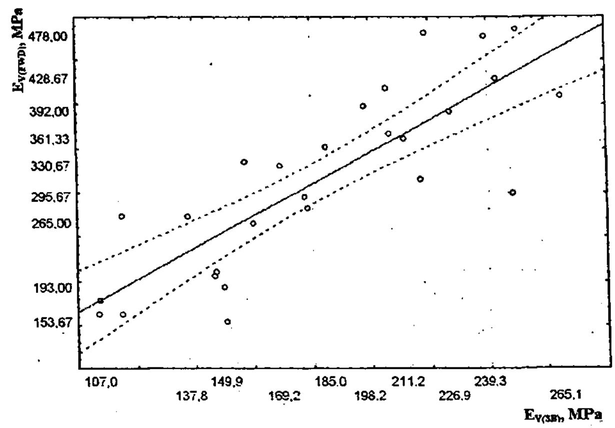

Fig 4. The chart of interdependence between the measuring results of the FWD Dynatest 8000 and the static beam Strassentest on the subgrade (left side)

Correlation between the FWD Dynatest 8000 and the static beam Strassentest on the left side is strong (R = 0.8332). That shows the dependence of measurement results of deformation modulus between the FWD Dynatest 8000 (EV(FWD)) and static beam Strassentest (EV(SB)). The analysis of the linear regression equation shows that one variable depends on another variable. In this case, an estimate of the variable EV(FWD) – dependence of EV(SB) is described by the equation:

$$E_{V(FWD)} = -15.8385 + E_{V(SB)} \cdot 1.8111, \qquad (7)$$

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

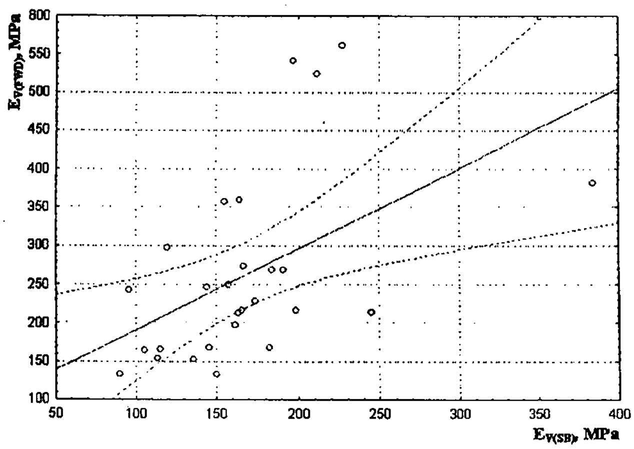

Fig 5. The chart of interdependence between the measuring results of the FWD Dynatest 8000 and the static beam Strassentest on the subgrade (right side)

Correlation between the FWD Dynatest 8000 and the static beam Strassentest on the right side is weak (R = 0.5013) (Fig 5). That shows the poor relationship of measurement 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 EV(FWD) –dependence of EV(SB) is described by the equation:

$$E_{V(FWD)} = 85.9621 + E_{V(SB)} \cdot 1.0484, \qquad (8)$$

Data dispersion diagrams show a rather large difference between the maximum and minimum value. The higher correlation is represented by two different devices, i.e. the FWD and the static beam on the left side, though on the right side the correlation is significantly lower. However, interrelation between the static beam and other dynamic devices is not very strong, and this is explained by different methodologies.

Dispersion diagrams of measuring results in Fig 6 show a dispersion of results between each device. A large difference could be observed between the minimum and maximum value. The lowest dispersion of results on the subgrade was indicated by the dynamic device ZORN ZSG 02, the highest – by the FWD Dynatest 8000.

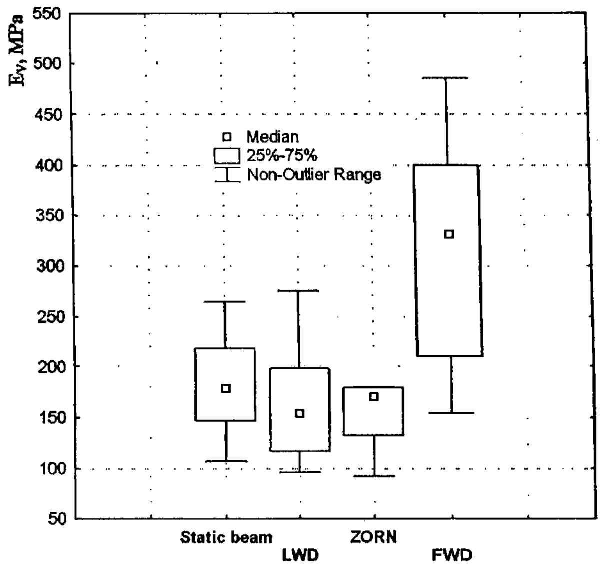

Fig 6. Static evaluation of measuring results on the subgrade layer by all the devices

Conclusions

Investigations were carried out and results wer processed on the experimental road section of the Scien tific Laboratory of Roads of the Vilnius Gediminas Tech nical University which was constructed in Pagiriai set tlement. Measurements of the experimental road sectio were implemented using the static and dynamic measur ing methods with the following measuring devices: stati beam Strassentest, dynamic Falling Weight Deflectome ter FWD Dynatest 8000, Light Weight Deflectomete LWD Prima 100 and dynamic device ZORN ZSG 02. I could be stated after the measurements that all the abov devices are suitable for determining deformation modu on the subgrade.

1. According to the results of previous investigation it could be noticed that measuring devices and methods t determine pavement strength shall be applied based o the use of measuring results:

- Static beam – most suitable for determining de formation moduli on the surface of paveme layers consisting of loose materials.
- Deflectometer – for detail investigations of th condition of the whole road pavement structur

2. The highest correlation coefficient of measurin results on the subgrade was determined between the stat beam Strassentest and the Falling Weight Deflectomet FWD Dynatest 8000. Correlation coefficient on the le side R = 0.8332.

3. Analysis of results of the measurements taken b dynamic devices on the subbgrade showed that there is regular dependence between all the devices but the n merical values of deformation modulus, compared static beam, vary and are lower, therefore it could not b uniquely decided which method is the best and the mo acceptable.

4. Having made the analysis of measuring results assumption could be made that interrelation between t

devices could be as follows: if data of the measuring results of the static beam Strassentest are equated to = 1, the following coefficients could be used (suggested) for other devices: FWD Dynatest 8000 = 1.7 – 2.0; LWD Prima 100 = 0.75 –0.85; ZORN ZSG 02 = 0.7 – 0.8.

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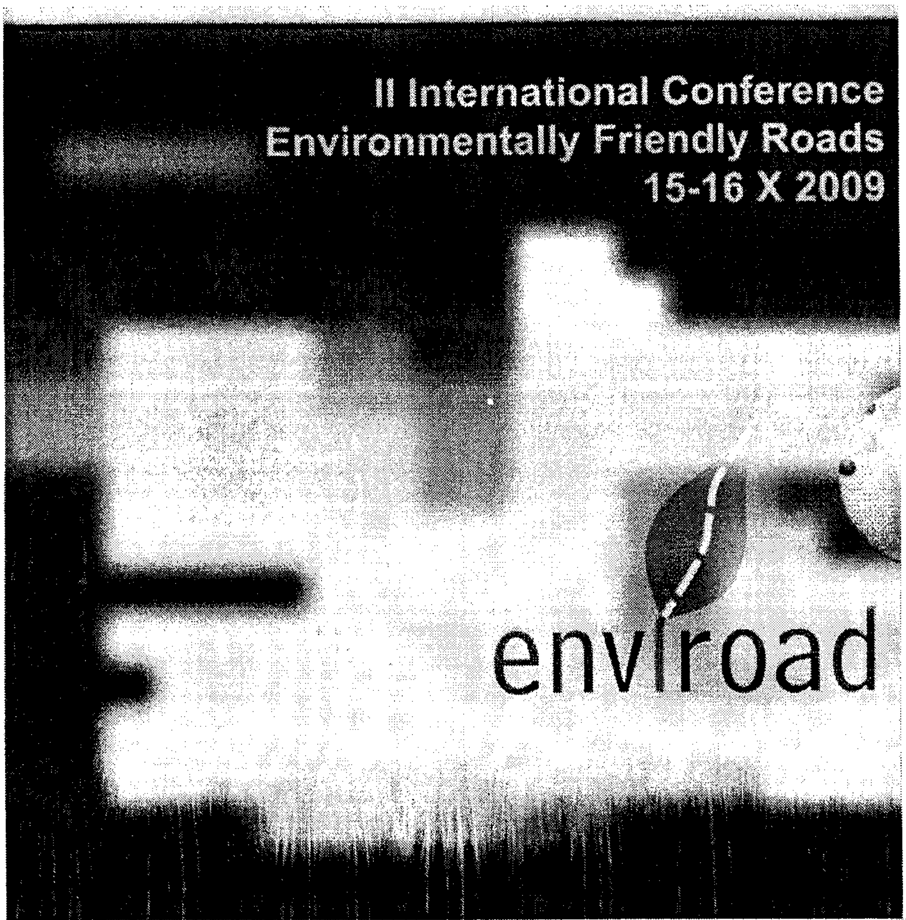
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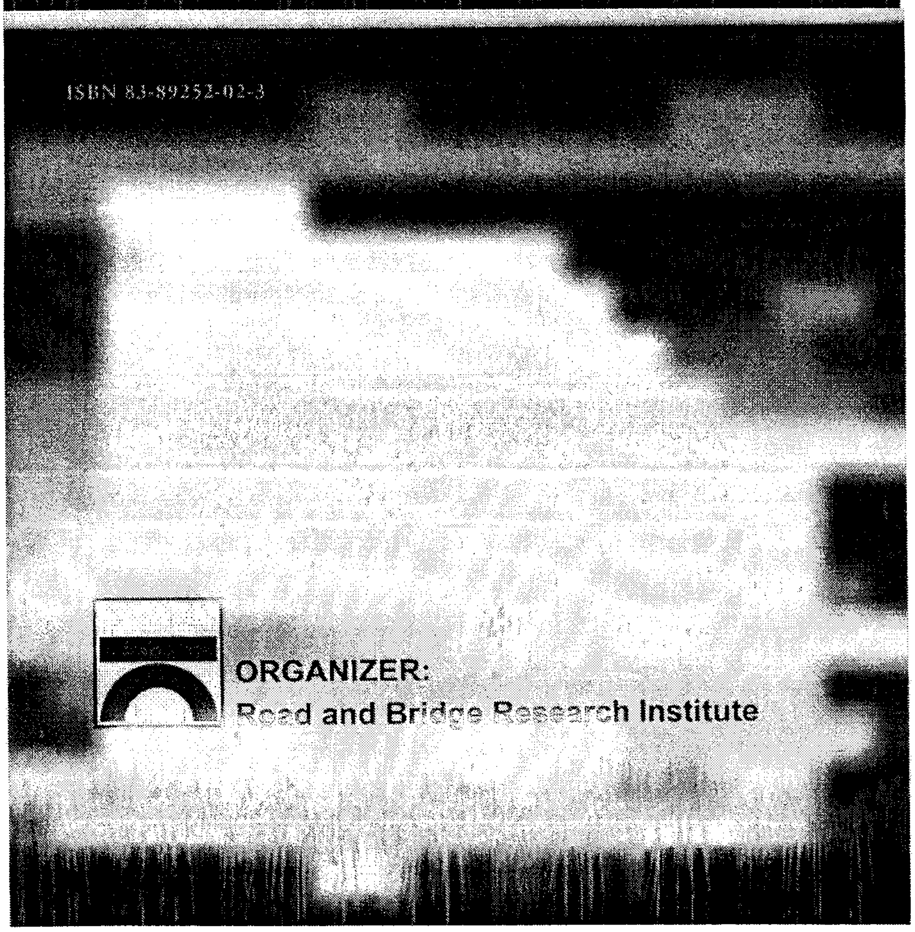
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RESEARCH OF EXPERIMENTAL ROAD PAVEMENT STRUCTURES IN LITHUANIA

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ABSTRACT

The rapid growth of heavy traffic, the increase in the standard axle load make scientists to look forward for new durable road building materials and their mixes. The continuously increasing need for the strengthening of road pavement structures induces to use new road reconstruction technologies, to search for new methods in constructing pavement structural layers and investigate pavement structures under real conditions. Consequently in summer of 2007 experimental road was constructed in Lithuania. The article presents construction of this experimental road with 24 different pavement structures of 30 metres length. Three pavement structures were subdivided in two parts of 15 metres length. In this three pavement structures different kinds of geosynthetic materials in different layers were used. The article also describes the installation process of stress and strain transducers in different layers of experimental pavement structures and results of stress and strain measurements. Stress and strain measurements are carrying out each time after passage of 20 000 ESAL' s calculated to 100 kN.

1. Introduction

The rapid growth of traffic volume, loads and the flows of heavy traffic on Lithuanian roads have large influence on their condition. Pavement is one of the most important structural elements of the road. Pavement repair and reconstruction takes the largest proportion of road construction costs and pavement condition has large influence on road capacity and traffic safety (Cygas et al., 2004). The change in road pavement condition, its long-term monitoring under real loading and climatic conditions allows to determine a mechanism of pavement degradation, to choose durable road building materials and their mixes (Oginskas et al., 2005), to more rationally use asphalt pavement building technologies, to improve quality control.

The scientists in many countries give much attention to the assessment of pavement structural performance under real conditions and forecasting of pavement condition worsening. Professor of the Technical University of Denmark P. Ullidtz – to modelling pavement performance and response (Ullidtz 1998), the scientist of the Cambridge University D. Cebon – to the impact of heavy vehicles on pavement structures (Cebon, 1993), the Dutchmen A. Scarpas and van Gurp – to simulation of damage development in asphalt concrete pavements by the method of finite elements (Scarpas, 1994), the Germans H. Buseck and W. Schulte – to monitoring and analysis of indices of the selected road section performance (Buseck, 2004 and Schulte, 1987), the Estonian scientist A. Aavik – to the assessment of pavement structural strength by the Falling Weight Deflectometer (Aavik, 2003) and many others.

In last decade the road specialists and scientists use to identify pavement structural performance under real conditions also in special test polygons. One of the largest test polygons was established in 1989 in the French Central Laboratory of Roads and Bridges (Road Transport Research OECD, 1991). Here the scientists of various European countries tested and evaluated performance of three different pavement structures. Three experimental road pavements – two flexible and one semi-rigid structure – were tested under the effect of different loads, readings of the transducers of stresses, pressure, temperature and moisture were recorded, tendencies for the development of defects in the wearing courses were identified. In 2006 – 2007 testing of road pavement structures was carried out in the University of Maine by using six different transducers (Lauren et al., 2007). Transducers were installed in different pavement structural layers to determine seasonal effect 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 (Vincent et al., 1992). The Falling Weight Deflectometer was used here to measure pavement structure in different periods of the year and to define the resistance of each pavement layer to frost effect.

Having the purpose to determine pavement structural strength, performance indices, stresses and strains in pavement structural layers under real loading and climatic conditions, in Pagiriai settlement near Vilnius at the end of 2007 the experimental road section was built with the total length of 710 m. The road section was divided into 30 separate segments. Each segment had the different pavement structure corresponding to the pavement structure of class III. Three 30 m long segments were subdivided in half. In one experimental pavement structure between the frost blanket course and sub-base the separation textile was installed. In another segment of experimental pavement structure under the asphalt base courser a geonet was installed with a mounting geotextile. In the third pavement structure a geonet was installed between the asphalt base course and wearing course under the sub-base. In each different experimental pavement structural layers the stress and strain transducers were installed. At the bottom of the asphalt wearing course, base course and sub-base 80 special horizontal strain transducers were installed. On the surface of the crushed stone sub-base, frost blanket course and subgrade 11 stress transducers were installed. Stress and strain transducers were installed in the axis of the first track from the road shoulder. As the main (base) pavement structure (Fig. 1) for the research the most widely used in Lithuania pavement structure was assumed (Cygas et al., 2008).

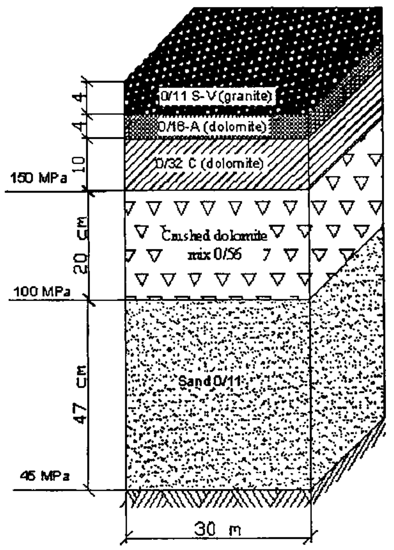


Figure 1. The base structure of experimental pavements

2. Research of experimental pavement structures of a test road section

In the first research year the pavement structural strength, stresses and strains were measured on a test road section. Strength measurements were carried out during construction of pavement structures and after the full completion of construction works. The strength of road pavement and its separate structural layers in Lithuania is regulated by a static deformation modulus (Bertuliene et al., 2008). Deformation modulus of experimental pavement structures was determined by non-destructive static and dynamic methods. In static method deformation modulus was determined using the Benkelman Beam and static press (for sub-base layers from unbound materials). In dynamic method the following equipment were used: light dynamic device (for sub-base layers from unbound materials) and Falling Weight Deflectometer (for all pavement structural layers). The readings of stress and strain transducers were registered after the passage of 20 000 ESAL's of the heavy vehicles.

In the second year of research measurements of the structural strength, stresses and strains and performance of pavement structures were continued. Deformation modulus of the experimental pavement structures was determined by static method using the Benkelman Beam and by dynamic method using the LWD (Mini FWD) and FWD. Measurements of pavement structural strength were carried out in spring (April), summer (August) and autumn (October). At the same time investigations of pavement performance were also executed. Longitudinal and transverse gradients, pavement evenness, roughness, friction coefficient and depth of ruts were determined. The readings of stress and strain transducers were registered after the passage of 40000, 60000, 80000, 100000 ESAL's of heavy vehicles.

3. Results of pavement structural strength, stresses and strains in experimental structures

This chapter describes the measurements of structural strength of experimental pavement structures using the deflectometer FWD which were carried out in spring (April), summer (August) and autumn (October) on 30 m long road sections. Measurements were taken in 4 points of each section in the track of the right wheel at the shoulder and between the tracks of the wheel. In shorter sections 2 points were measured. Measuring points were located chequerwise keeping a 2 m distance from the transducer (in the middle of the section of different pavement structure) and from the beginning (end) of another pavement structure. Distance of the right wheel track from the shoulder was 0,7 m, the track between the wheels – 1,8 m. Fig 2 gives the distribution of average values of deformation moduli in the wheel track of the asphalt wearing course of different experimental pavement structures measured by the FWD under different weather conditions, Fig 3 – under same weather conditions.

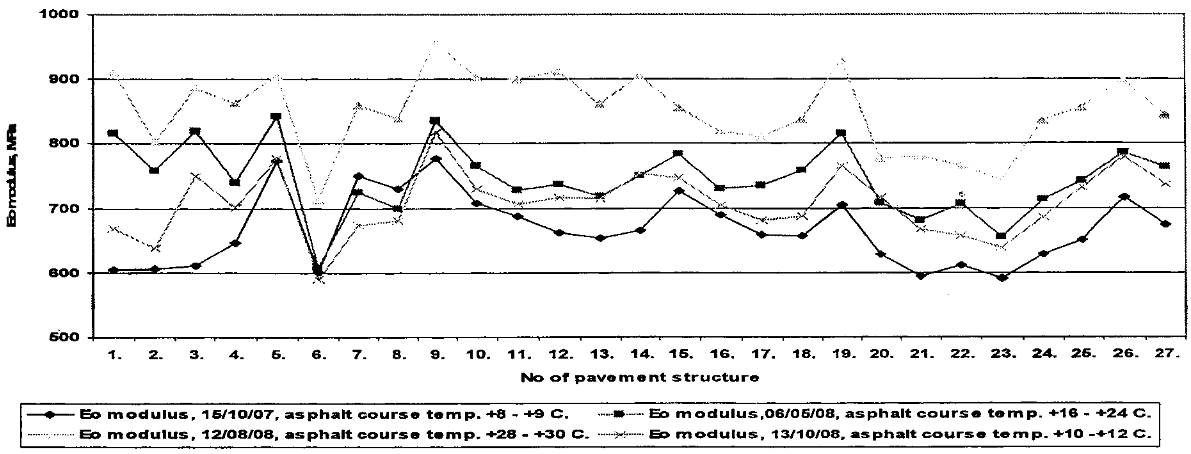


Figure 2. E moduli in the track of experimental pavement structures under different weather conditions

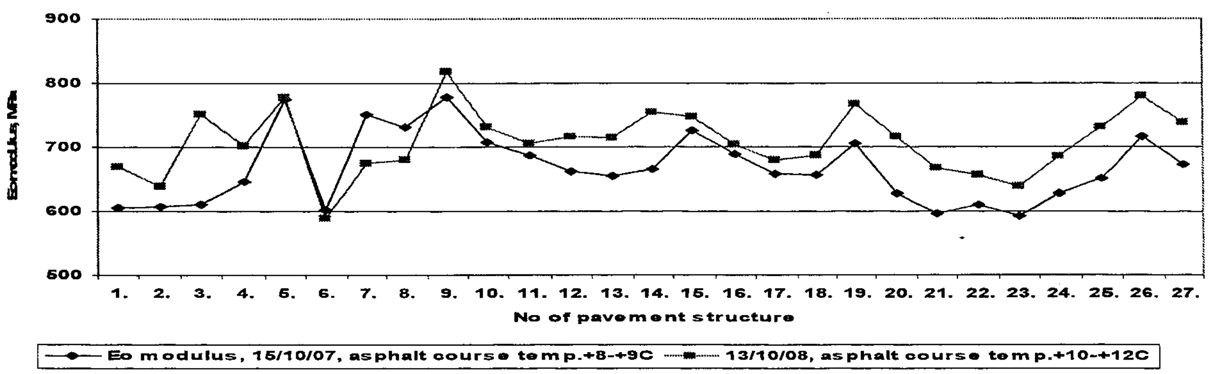


Figure 3. E moduli in the track of experimental pavement structures under same weather conditions

The values of stresses and strains measured in the base pavement structure of a test section after the passage of 40000, 60000, 80000, 100000 ESAL's of heavy vehicles are given in Fig 4, Fig 5.

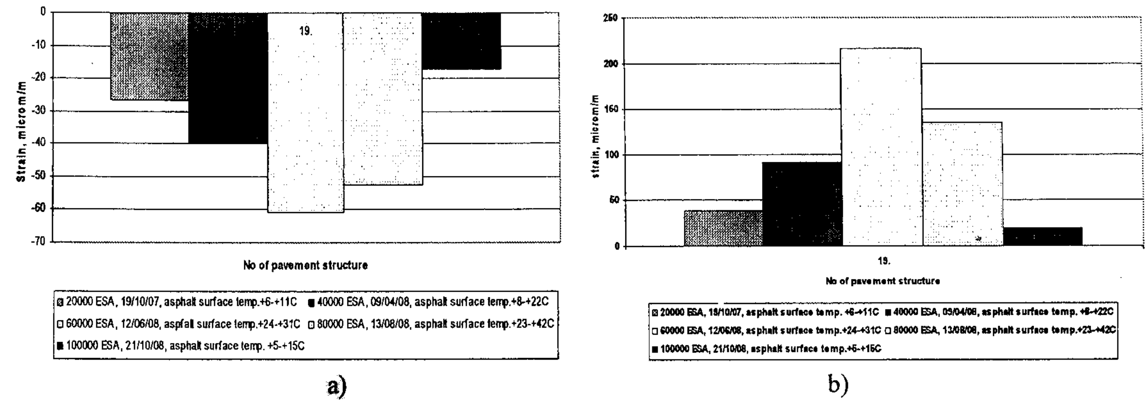
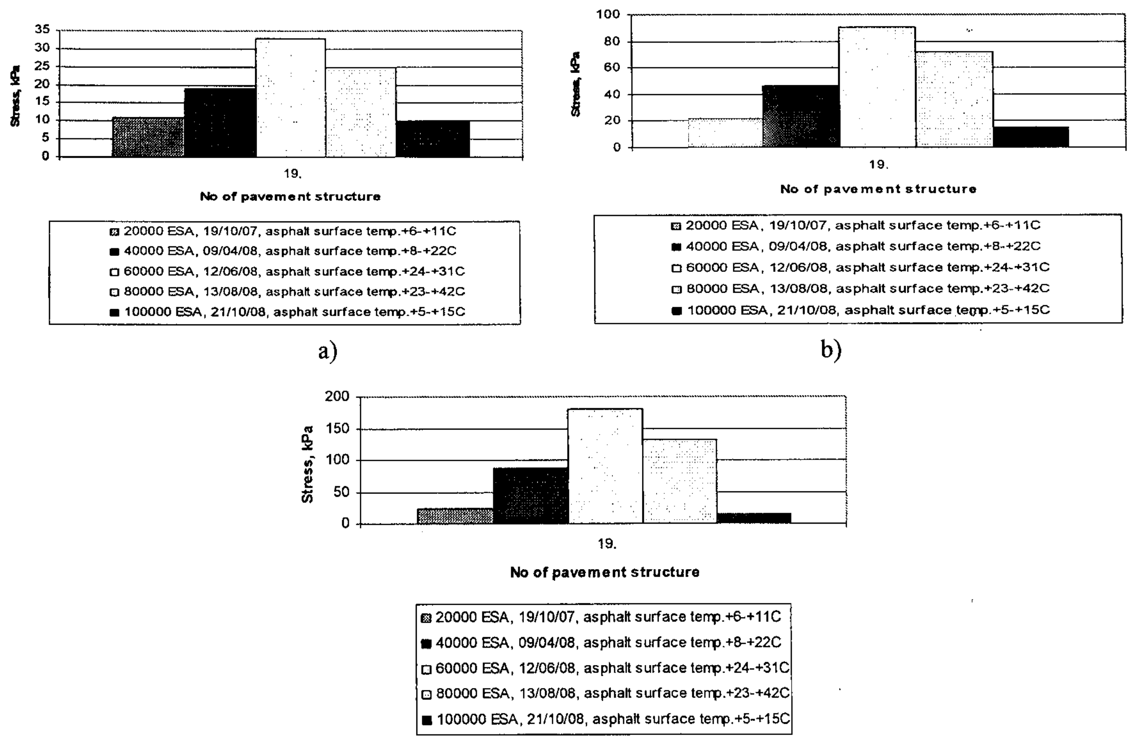


Figure 4. The charts of strains in the base pavement structure of a test section: a) transverse relative strain at the bottom of asphalt wearing course, b) transverse relative strain at the bottom of sub-base



c)

Figure 5. The charts of stresses in the base pavement structure of a test section: a) stresses on the surface of subgrade, b) stresses on the surface of frost blanket course; c) stresses on the surface of sub-base

Measurements of stresses and strains were carried out by a two-axle vehicle the rear axle of which had dual wheels. Dual wheel load - 50 kN, measuring speed - 50 km/h.

4. Conclusions and recommendations

1. Measurements of pavement structural strength on a test road section shows that deformation moduli measured under different weather conditions in various segments of pavement structures vary from 589 MPa in December to 957 MPa in October – when using deflectometer FWD.
2. Analysis of measuring results of pavement structural strength on a test road section shows a considerable change and tendency in deformation moduli and that the deformation modulus of the whole pavement structure depends on weather temperature and pavement temperature. This is confirmed by the analysis of measurements of pavement structural strength on a test road section using deflectometer FWD.

The compared Eo moduli were measured on 15 October 2007 under the temperature of asphalt courses +8 – +9°C and on 12 August 2008 under the temperature of asphalt courses +10 – +12°C. The change in the numeric values of the measured deformation moduli – 6 %.

If Eo moduli measured on 15 October 2007 under the temperature of asphalt courses +8 – +9°C and on 13 October 2008 under the temperature of asphalt courses +28 – +30°C are compared the change in the numeric values of deformation moduli – 21%.

3. Special strain transducers installed in asphalt courses of the base structure of a test section recorded a larger transverse relative strain when the temperature of pavement surface was higher than +20°C. The largest transverse relative strain was recorded on 12 June 2008 after the passage of 60000 ESAL's of heavy vehicles under the pavement surface temperature of +24 – +31°C: at the bottom of asphalt wearing course -61 microm/m (compression), at the bottom of sub-base – 216 microm/m (extension).

4. The transducers installed in the base structure of a test section on 12 June 2008 after the passage of 60000 ESAL's of heavy vehicles under the pavement temperature +24 – +31°C recorded the largest stresses on the surface of subgrade – 33 kPa, on the surface of frost blanket course – 91 kPa, on the surface of sub-base – 181 kPa.

   On 21 October 2008 after the passage of 100000 ESAL's of heavy vehicles under the pavement temperature +5 – +15°C the smallest stresses were recorded: on the surface of subgrade – 10 kPa, on the surface of frost blanket course – 15 kPa, on the surface of sub-base – 15 kPa.

5. Under real traffic and climatic conditions the measured strength, stresses and strains in different experimental pavement structures are highly influenced by weather temperature and pavement temperature, climatic seasons and moisture in the courses of unbound materials.

6. More accurate and comprehensive comparison of measuring methods and instruments will be carried out having a larger amount of measuring data and after the installation in pavement structural layers of additional temperature and moisture transducers.

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БНТУ

НАУКА –
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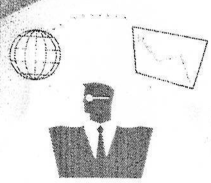
Материалы Седьмой международной научно-технической конференции



УДК 625.7/8.691

Климатический фактор в эксплуатации автомобильных дорог

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В северо - восточной Европе климатический фактор играет большую роль в эксплуатации дорог. Зимний период может продолжаться до 5 месяцев, которые самые сложные при обеспечении безопасности дорожного движения и эксплуатации дорог. Соотношение осадков в летнее и зимнее время в Литве состоит 60/40 процентов. Последние годы зимы стали мягче и с меньшим количеством снега, но переходов температуры через ноль градусов стало больше и они составляют до 75 раз в зимний период.

Таблица 1 – Риск дорожных происшествий зависимости от состояния дорожного покрытия

Состояние дорожного покрытия	Условный риск
Сухое чистое покрытие	1,0
Мокрое чистое покрытие	1,3
Мокрый снег	1,5
Твердый снег	2,5
Легкий снег и ледяное покрытие	4,4

Наибольшие трудности представляют гололед, метель, осадки в виде дождя и снега, туман и ветер. В такой последовательности они могут быть расположены по степени их воздействия на условия движения.

Анализируя вероятность появления опасных и особо опасных метеорологических факторов, необходимо отметить, что наиболее неблагоприятный зимний период, когда трудные условия могут сложиться под влиянием семи метеорологических факторов (табл.2) и их сочетаний. Весной и осенью такие условия могут быть под влиянием шести метеорологических факторов, а летом только четыре метеорологических фактора.

Таблица 2 – Метеорологические факторы, создающие трудные условия движения

Зима	Осень-весна	Лето
1.Метель	1.Гололед	1.Дождь
2.Гололед	2. Дождь	2.Туман
3.Снегопад	3.Туман	3.Ветер
4.Туман	4.Ветер	4.Высокая температура
5.Низкая температура воздуха	5.Отрицательная температура	
6.Ветер	6.Высокая влажность	

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НАУКА образованию, производству, экономике

Материалы Восьмой
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конференции

УДК 625.768

Статические и динамические методы оценки состояния дорожных конструкций в Литве

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Прочность дорожных покрытий является одним из основных показателей определяющих способность выдерживать нагрузки транспортных средств. Для того, чтобы сравнить результаты статических и динамических испытаний и определить точность измерений, с 2007 года Вильнюсский технический университет им. Гедиминаса проводит сравнительные измерения в слоях дорожного покрытия.

Прочность дорожного покрытия в Литве оценивается модулем статической деформации, который определяется статическими и динамическими методами.

При статическом методе для установки модуля деформации нежестких дорожных покрытий используется балка Бенкельмана, для основания из несвязанных минеральных материалов используется статическая балка.

Динамический метод обеспечивается следующим измерительным оборудованием: легкое динамические устройство дефлектометр (для основания из несвязанных материалов), дефлектометр FWD (все слои дорожного покрытия). В отличие от статических подходов, динамические модели напряженно-деформированного состояния теоретически способны учесть эффекты, обусловленные подвижностью нагрузки.

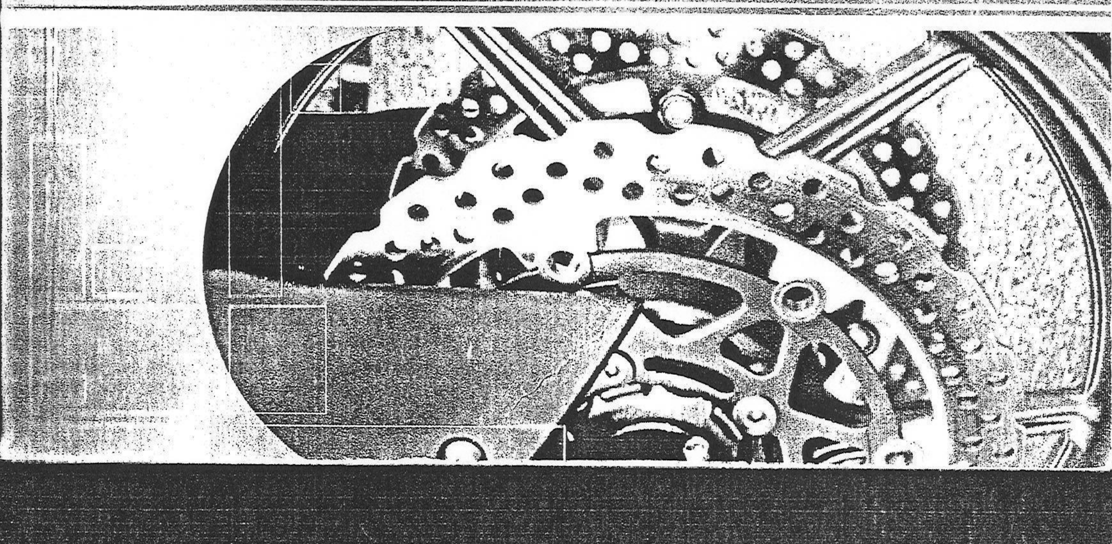
Многие страны проводят исследования использования статических и динамических методов измерений. Начиная с 1996 года Эстония использует для установления прочности покрытий автомобильных дорог дефлектометр (FWD). Профессор А. Авик (Эстония) провел детальный анализ исследований оценки прочность дорожной конструкций с использованием FWD. В Литве были проведены аналогичные исследования. Доктором Г. Шяудинисом в работе «Методы определения прочности конструкции», экспериментально исследованы дорожные покрытия с учетом климатических условий Литвы.

На основании этих исследователей и нашего опыта, можно предположить, что между данными, полученными измеряя статическими и динамическими устройствами есть взаимосвязь. Однако по имеющимся результатам мы не можем однозначно определить, какой метод действительно является более эффективным и наиболее надежным. Для определения точности результатов испытаний, будут проводиться дополнительные исследования и изучаться зависимости.

Transportas

9-osios Lietuvos jaunųjų mokslininkų konferencijos
„Mokslas – Lietuvos ateitis“,
įvykusios Vilniuje 2006 m. gegužės 25 d., pranešimų rinkinys

1280



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„VOLVO" BUS TECHNICAL SERVICE AND MAINTENANCE IN JOINT-STOCK COMPANY „VILNIUS BUSES"

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In the paper reviews buses technical service governing system, technical service and maintenance operating and formation. The main purpose of paper is to establish trustworthiness index and make a suggestions to improve technical status for buses depot.

KELIO DANGOS KONSTRUKCIJŲ SLUOKSNIŲ STIPRUMO MATAVIMO METODŲ ANALIZĖ IR VERTINIMAS

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1. Įvadas

Mokslo tyrimo darbai įvairiose pasaulio šalyse išaiškino priklausomybes tarp apkrovos kelio dangai dydžio, kelio dangos įlinkio ir konstrukcinių dangos sluoksnių deformacijos modulių. Šios priklausomybės, apskaičiuotos naudojant apkrovą, gali būti taikomos įvertinat dangos stiprį. Vertinant kelio dangos stiprumą, atliekamas įlinkių matavimas atskiruose kelių ruožuose. Dangos stiprumas yra vienas iš pagrindinių kelio eksploatacinių rodiklių, lemiančių jos sugebėjimą atlaikyti eismo apkrovas.

Remiantis kitose šalyse (Danijoje, Švedijoje) atliktais tyrimais, galima daryti prielaidą, kad pastebimas aiškus ryšys tarp matavimų atliktų statiniu ir dinaminiu prietaisais. Matavimo metodų analizė parodo dėsningą naudotų prietaisų priklausomybę, todėl negalima vienareikšmiškai nuspręsti, kuris metodas iš tikrųjų yra geriausias ir priimtiniausias.

Iki šiol nėra sukurtos vieningos matavimų su FWD ir statiniu metodu gau rezultatų įvertinimo metodikos. 2004 m. VGTU Automobilių kelių moks laboratorija atliko palyginamuosius matavimus keturiais matavimo prietaisais.

2. Tyrimams naudoti prietaisai ir bandomojo ruožo parinkimas

Norint palyginti skirtingais prietaisais nustatytas deformacijos modulių reikšme buvo pasirinkti keturi matavimo prietaisai: statinė sija STRASSENTEST, dinamin prietaisas DYNATEST 8000 FWD, dinaminis prietaisas MINI FWD PRIMA 10 dinaminis prietaisas ZORN ZSG 02.

Rankinis krintančio svorio deflektometras MINI PRIMA 100 FWD y patogus, kompaktiškas ir atitinka visus krentančio svorio deflektometrui reikalingu reikalavimus. MINI PRIMA 100 veikia su duomenų perdavimo sistema, ku užtikrina patogų duomenų registravimą [1]. Šio matavimo prietaiso programin įranga išskaičiuoja dangos deformacijos modulį iš atliktų atskirų jos sluoksni matavimų. Matuojant šiuo prietaisu įlinkiai fiksuojami 3 davikliais. Prietaisas ga būti naudojamas bet kurių kelio dangos konstrukcijos sluoksnių deformacijc modulio nustatymui išskyrus asfaltbetonio dangas [2].

Krintančio svorio deflektometras DYNATEST 8000 FWD leidžia: modeliuo jėgos amplitudę ir jos trukmę, kuri apytikriai lygiavertė judančio automobilio rat apkrovos poveikiui į kelio dangą; atlikti tikslius įlinkų matavimus dideliuos atstumuose nuo apkrovos centro. Kelio dangos įlinkiai fiksuojami 9 seisminiai įlinkų davikliais. Specialia programa išskaičiuojamas deformacijos modulis ar matuojamo paviršiaus ir ant atskirų dangos konstrukcijų sluoksnių. Šis prietaisa gali būti naudojamas visų dangos konstrukcijos sluoksnių deformacijos moduli nustatymui [3].

Statinis deformacijos modulis gali būti nustatytas statine sija SRASSENTES Bandant štampu gruntas po spaudimo plokšte laipsniškai apkraunamas be nukraunamas. Po to bandymas vėl kartojamas. Grunto įtempimai δ_0 po štampu ir j deformacija s vaizduojami deformacijos kreive [4]. Deformacijos modulis E nustatomas naudojant 300 mm skersmens štampą. Apkrova didinama tol, ko pasiekiama 5 mm deformacija arba grunto įtempimai po plokšte yra api 0,5 MN/m^2. Šis prietaisas naudojamas žemės sankasos, šalčiui atsparaus sluoksnio i dangos pagrindo sluoksnio deformacijos modulio nustatymui.

Dinaminis prietaisas ZORN ZSG 02 naudojamas atliekant kelių tiesimo žemė darbus ir įrengiant dangos pagrindus. Jis gali būti naudojamas tikrinant gruntų i pagrindų konstrukcinių sluoksnių stiprumą. Bandymo dinaminiu prietaisu apkrov sukeliama krintančio masyvaus cilindro smūgiu. Apkrovos trukmė siekia apie 1 ms. Tai sukelia grunto deformaciją. Grunto po apkrovos plokšte apskaičiuota dinaminis deformacijos modulis E_{vd} skiriasi nuo deformacijos modulio E_{v2}, nustatyt

PRIMA 100, didesnė – ZORN ZSG 02. Didžiausią rezultatų sklaidą gavome atlikę matavimus DYNATEST 8000 FWD prietaisu. Didžiausia koreliacija tarp matavimo rezultatų, gautų prietaisais FWD – ZORN ZSG 02 (koreliacijos koeficientas r=0,764).

4. Išvados

1. Parinktame bandomajame ruože buvo atlikti tyrimai su keturiais skirtingais prietaisais: statine sija STRASSENTEST; dinaminiu prietaisu DYNATEST 8000 FWD; dinaminiu prietaisu MINI FWD PRIMA 100; dinaminiu prietaisu ZORN ZSG 02. Matavimai parodė, kad gautų rezultatų sklaida yra didelė. Koreliacija tarp atskirų prietaisų skiriasi: vienų prietaisų matavimo rezultatų kombinacijos yra patikimesnės ant apatinių dangos konstrukcijos sluoksnių, kitų – ant viršutinių dangos sluoksnių. Matavimus atliekant ant silpnesnių dangos konstrukcijos sluoksnių patikimesni rezultatai gaunami su MINI FWD PRIMA 100, ant asfaltbetonio sluoksnių patikimesni rezultatai su FWD.
2. Matavimo rezultatų analizė rodo, kad matavimo patikimumui didelę įtaką turi oro sąlygos (oro temperatūra, drėgmė), grunto savybės (tipas, drėgmė) bei matavimo taškas.
3. Matavimo rezultatai rodo, kad tiriamasis kelio ruožas nėra tolygiai sutankintas visuose matavimo taškuose, nors ruožo ilgis sąlyginai yra mažas (200 m).
4. Galima daryti prielaidą, kad matuojant su „Mini FWD Prima 100“ galima būtų naudoti tokius koeficientus pervedimui į E_{v2}:
   - silpnesnės medžiagos (sankasa, šalčiui atsparus sluoksnis, dangos pagrindas) – koeficientas 1,3÷1,5;
   - stipresnės medžiagos (asfaltbetonio sluoksniai) – koeficientas 0,8÷1,0.
5. Siekiant gauti patikimus pervedimo koeficientus kitiems sluoksniams reikia atlikti papildomus matavimus naujuose bandomuosiuose ruožuose, užtikrinant visiškai identiškas matavimo sąlygas skirtingais prietaisais.

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ANALYSIS OF THE STRENGTH MEASUREMENT METHODS OF ROAD PAVEMENT

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One of the main parameters, characterising road pavement quality is the strength which specify reasons to resist strains of the transport means. Assessment of the road pavement strength is comparing measured deflections chosen road section.
This work analyses the strength measurement methods which were made in chosen road section with four instruments of the road pavement deflection measurement was compared.
This paper presents results of strength measurement of road construction layers, research results of soil and research data analysis of chosen road section.
Based on the study findings, the dependence of device measuring results is presented. The coefficients of devices measuring values reduction into the static deformation modulus are recommended.

TURBOKOMPRESORIAUS PARAMETRŲ ĮTAKA KIBIRKŠTINIO UŽDEGIMO VARIKLIO RODIKLIAMS

Giedrius BORISEVIČIUS
Vilniaus Gedimino technikos universiteto Transporto inžinerijos fakulteto Automobilių transporto katedros magistrantas

Straipsnyje pateikta kibirkštinio vidaus degimo variklio su turbokompresoriumi lyginamųjų degalų sąnaudų priklausomybė, variklio galios priklausomybė ir variklio sukimo momento priklausomybė esant skirtingiems turbokompresoriaus slėgiams siurbimo vamzdyje.

1. Įvadas

1999 m. Lietuvoje pradėjo sparčiai populiarėti, ypač jaunimo tarpe, laisvalaikio praleidimo būdas – automobilių lenktynės „Drag“. "Drag" lenktynės – tai įsibėgėjimo varžybos tarp dviejų automobilių tam tikroje distancijoje, startuojant iš vietos. Tokiose varžybose dažniausiai laimi automobiliai turintys galingus turbokompresorinius variklius.

Turbokompresoriaus pripūtimo principą išrado ir 1905 m. užpatentavo šveicaras dr. A. Biuchi. Šiuo metu visame pasaulyje yra labai domimasi šiomis lenktynėmis ir variklių galios didinimu.

Variklio litrinę galią galima padidinti, didinant alkūninio veleno sukimosi dažnį arba vidutinį efektyvųjį slėgį. Tačiau, didinant sūkių dažnį didėja mechaniniai nuostoliai, blogėja cilindrų pripildymas, didėja alkūninio mechanizmo detalių inercijos jėgos ir jos intensyviau dyla.

Vilnius Gediminas Technical University

Вильнюсский технический университет им. Гедиминаса

Faculty of Transport Engineering

Факультет инженерии транспорта

TRANSPORTAS

Dešimtosios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis“, įvykusios Vilniuje 2007 m. gegužės mėn. 3 d.,

PRANEŠIMŲ RINKINYS

TRANSPORT

PROCEEDINGS

of the 10th Conference of Young Scientists of Lithuania

„Science – Lithuania's Future“
held on 3 May 2007 in Vilnius, Lithuania

ТРАНСПОРТ

СБОРНИК ДОКЛАДОВ

10-й конференции молодых ученых Литвы

„Наука – будущее Литвы“,
состоявшейся 3 мая 2007 года в Вильнюсе, Литва

Vilnius „Technika“ 2007

5. Išvados

1. Panaudojant sudarytą VDV termohidrodinaminio proceso matematinį modelį, nustatyta, kad temperatūra T_Z yra maksimali degimo temperatūra ir ji didėja, didėjant cilindrų užpildymo koeficientui α. Didėjant benzino oktaniniam skaičiui, didėja dujų temperatūra cilindre degimo pradžioje.
2. Panaudojant sudarytą VDV termohidrodinaminio proceso matematinį modelį, galima pilnai aprašyti VDV režimus ir išnagrinėti deginių judėjimą VDV išmetimo sistemoje.

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MATHEMATICAL MODELLING OF INTERNAL-COMBUSTION ENGINE OXIDE THERMODYNAMIC PROCESS

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The article shortly reviews and presents thermodynamic process mathematical model of internal-combustion engine, oxide making in exhaust system, repartition of phases in every cylinder. Also there are the temperature curve, which depends on petrol sort.

NESTANDŽIŲ KELIŲ DANGŲ KONSTRUKCIJŲ DEFORMACIJOS MODULIO NUSTATYMO METODAI

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1. Įvadas

Prižiūrint automobilių kelių dangas labai svarbu žinoti esamos kelio dangos laikomąją galią. Dangos laikomoji galia nustatoma dviem būdais: matuojant ją vietoje bei netiesioginiai. Šiam tikslui atliekami dangos įlinkių matavimai arba dangos laikomoji galia nustatoma skaičiuojant kompiuteriu.

Pasaulyje naudojama įvairi tyrimų įranga, kuria remiantis nustatytu įlinkiu leidžia spręsti apie liekamąjį kelio amžių ir visos konstrukcijos būvį, nesuardant kelio dangos [1, 2]. Pagal esminius skirtumus visą šią įrangą galima suskirstyti į šešias kategorijas:

- Statinio įlinkio matavimo įranga;
- Automatizuotos sijos įlinkio matavimo įranga;
- Dinaminio įlinkio matavimo įranga;
- Įlinkio prietaisai su harmonine apkrova;
- Įlinkio matavimo įranga su impulsine apkrova;
- Bangų sklidimo matavimai.

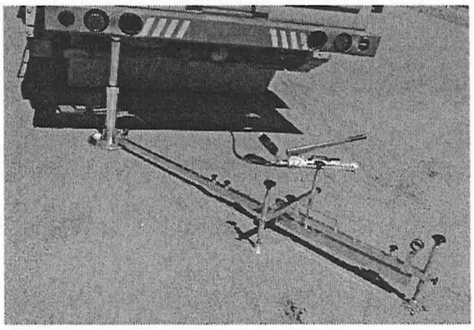
Vertinant kelio dangos stiprumą, atliekamas įlinkių matavimas atskiruose kelių ruožuose, dangos stiprumas yra vienas iš pagrindinių kelio eksploatacinių rodiklių, lemiančių jos sugebėjimą atlaikyti eismo apkrovas. Šiame darbe pasirinkome statinį ir dinaminį matavimo metodus.

Remiantis kitose šalyse (Danijoje, Švedijoje) atliktais tyrimais, galima daryti prielaidą, kad pastebimas aiškus ryšys tarp matavimų atliktų statiniu ir dinaminiu prietaisais. Matavimo metodų analizė parodo dėsningą naudotų prietaisų priklausomybę, todėl negalima vienareikšmiškai nuspręsti, kuris metodas iš tikrųjų yra geriausias ir priimtiniausias.

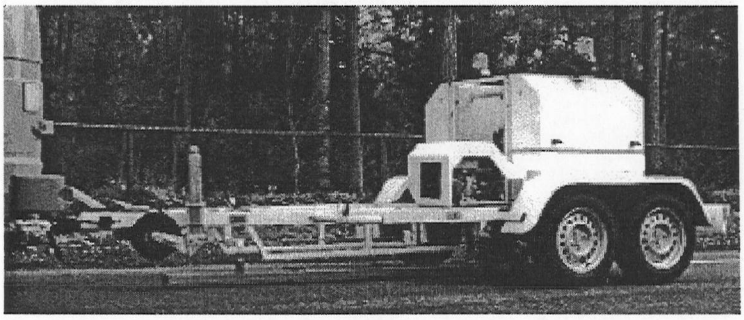
2. Bandomojo ruožo parinkimas

Palyginamiesiems matavimams atlikti buvo pasirinkti keturi deformacijos modulio nustatymo prietaisai:

Statine sija „Strassentest“ (1 pav.); Dinaminiu prietaisu „FWD“ [3] (2 pav.); Dinaminiu prietaisu „Mini FWD Prima 100“; Dinaminiu prietaisu „ZORN ZSG 02“ (3 pav.).



1 pav. Matavimai atliekami statine sija „Strassentest“

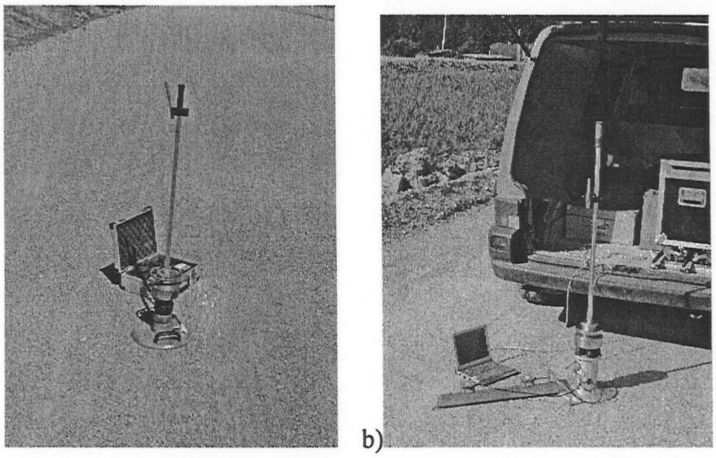


2 pav. Krinatnčio svorio deflektometras FVD

Matavimai buvo atliekami Kauno miesto vakarinio aplinkkelio ruože 16,1 – 16,4 km (Garliavos skirtingų lygių sankryža), pasirinktuose 20-tyje taškų.

Visi matavimai ant kiekvieno dangos konstrukcijos sluoksnio buvo atliekami pagal tą pačią pasirinktą schemą, su visais keturiais prietaisais identiškuose taškuose ir esant tom pačiom oro sąlygom.

Iš kiekvieno dangos konstrukcijos sluoksnio buvo paimamos medžiagos laboratoriniams tyrimams.



a) b)

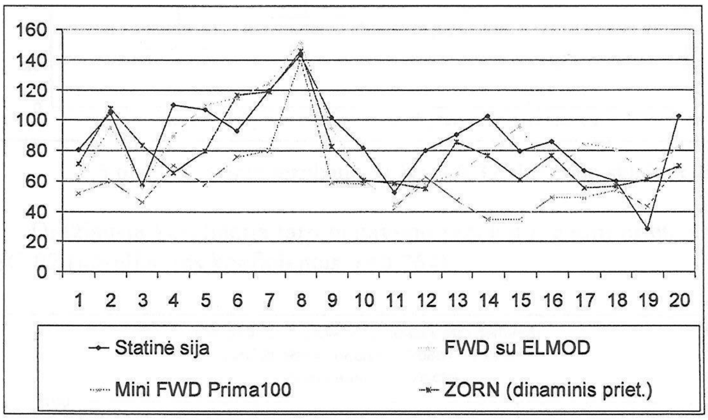
3 pav. Dinaminiai prietaisai a) - „Mini FWD Prima 100“; b) - „ZORN ZSG 02“

3. Bandomo ruožo tyrimų rezultatų analizė

Kiekviena eismo kryptimi deformacijos moduliai buvo matuojami 10-tyje taškų važiuojamosios dalies ašyje kas 20 metrų.

Gauti bandomojo ruožo matavimų rezultatai ant kiekvieno dangos konstrukcijos sluoksnio buvo palyginti tarpusavyje, bei įvertinta šių rezultatų tarpusavio priklausomybė statistinėmis programomis.

Iš šio bandomojo ruožo pateikiami žvyro sluoksnio frakcijos 0/32 stiprumo matavimo rezultatai ir jų analizė, kurie geriausiai atspindi atliktus matavimus ant mažai rišlių medžiagų. Matavimų reikšmės ant šio sluoksnio yra pateiktos 4 pav. Atsižvelgiant į mažus atstumus tarp matuojamųjų taškų (20 m) galima teigti, kad sluoksnis yra netolygiai sutankintas (deformacijos modulis kinta nuo 80 iki 120 MN/m^2) [4], arba naudotos nevienalytės medžiagos šio sluoksnio įrengimui.



4 pav. Žvyro sluoksnio frakcijos 0/32 stiprumo matavimo reikšmių pasiskirstymo grafikas

Siekiant nustatyti rezultatų sklaidą ir tarpusavio priklausomybę atlikta statistinė analizė (5 ir 6 pav.). Mažiausią rezultatų sklaidą parodė MINI FWD PRIMA 100, didesnė – ZORN ZSG 02. Didžiausią rezultatų sklaidą gavome atlikę matavimus DYNATEST 8000 FWD prietaisu.