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

Lina Bertulienė[1], **Alfredas Laurinavičius**[2]

Dept of Roads, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania,
E-mails: [1]linak@ap.vgtu.lt, [2]alfla@ap.vgtu.lt

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 1st and repeated loading, are calculated according to the slope of secant between the points 0,3 σ_{1max} by the formula:

$$E_v = 1{,}5 \times r \frac{\Delta\sigma}{\Delta_s}, \tag{1}$$

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.*

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

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 ($\mu = 0{,}3$); 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)

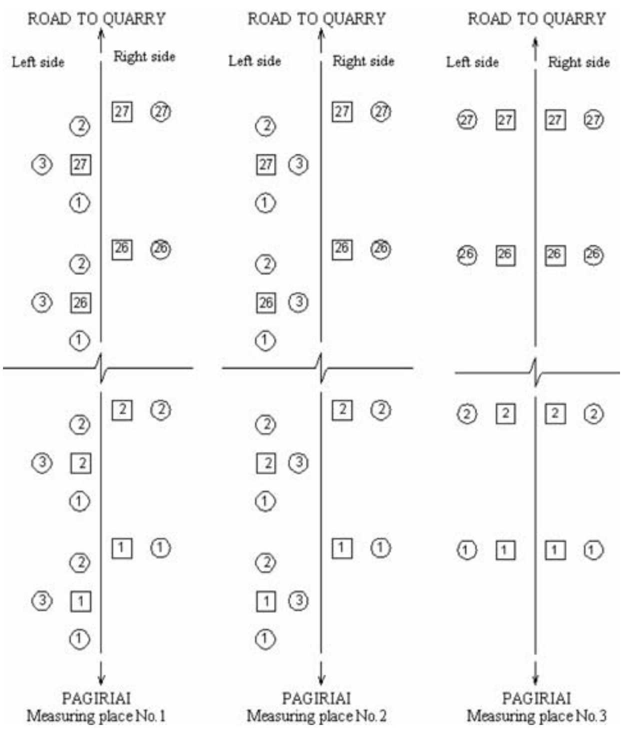

Fig. 5. Measuring scheme

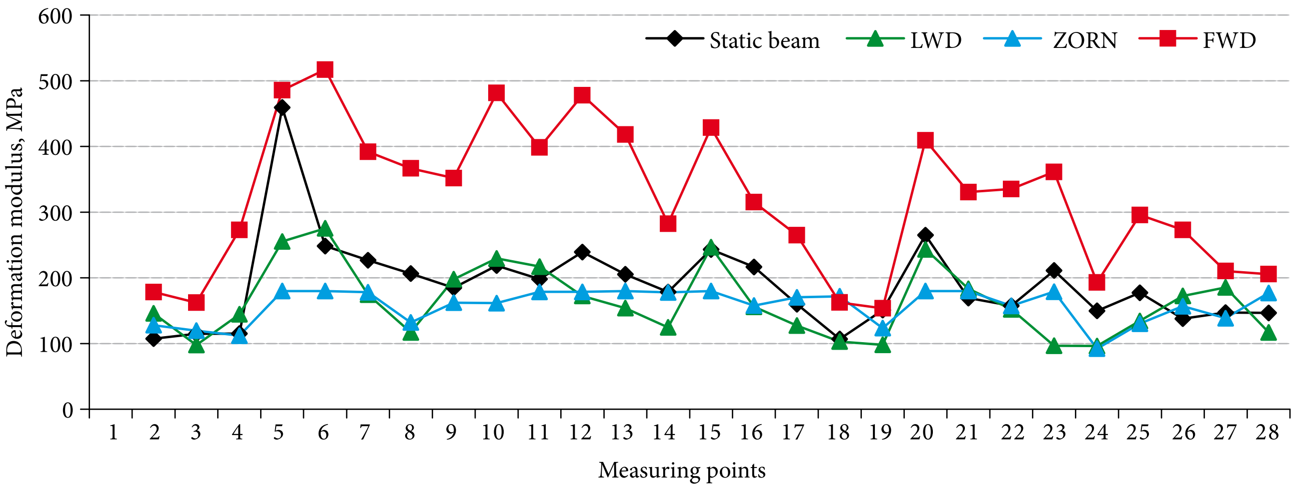

Fig. 6. Measuring results of the subgrade (left side)

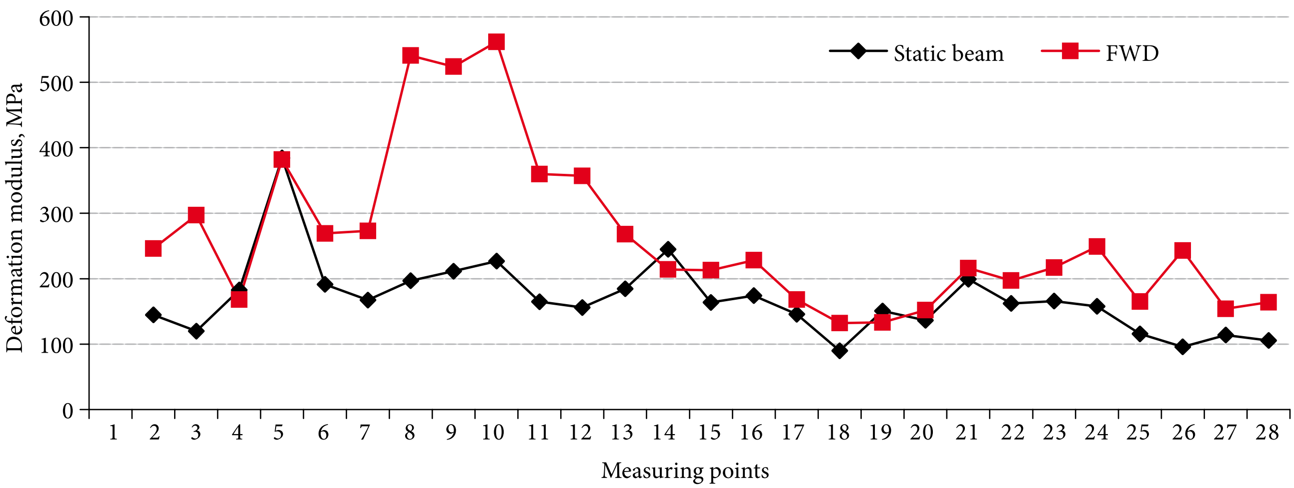

Fig. 7. Measuring results of the subgrade (right side)

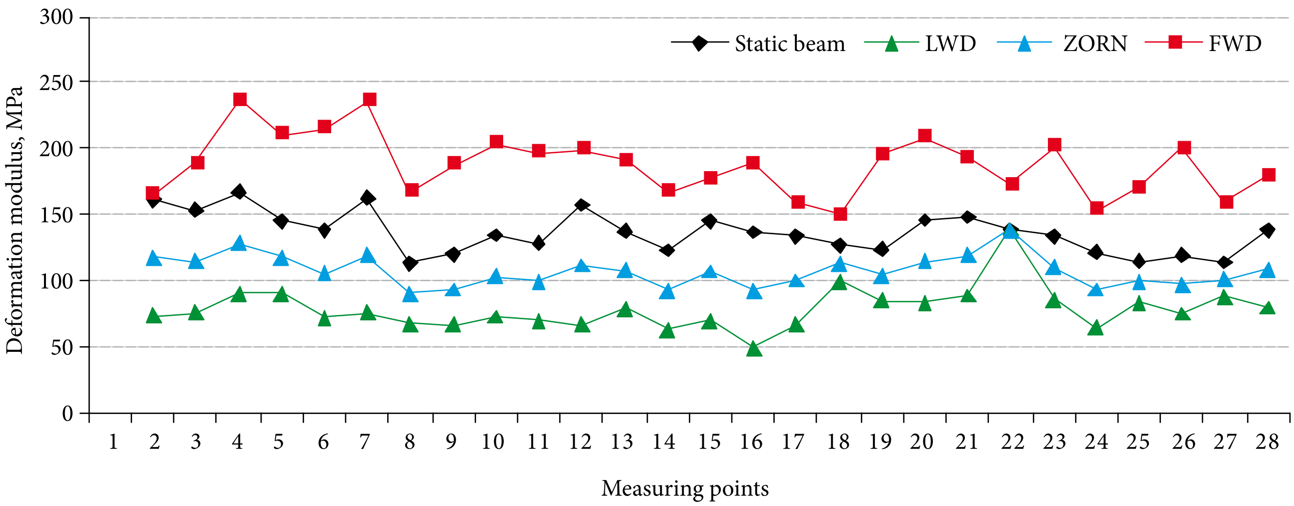

Fig. 8. Measuring results of frost blanket course (left side)

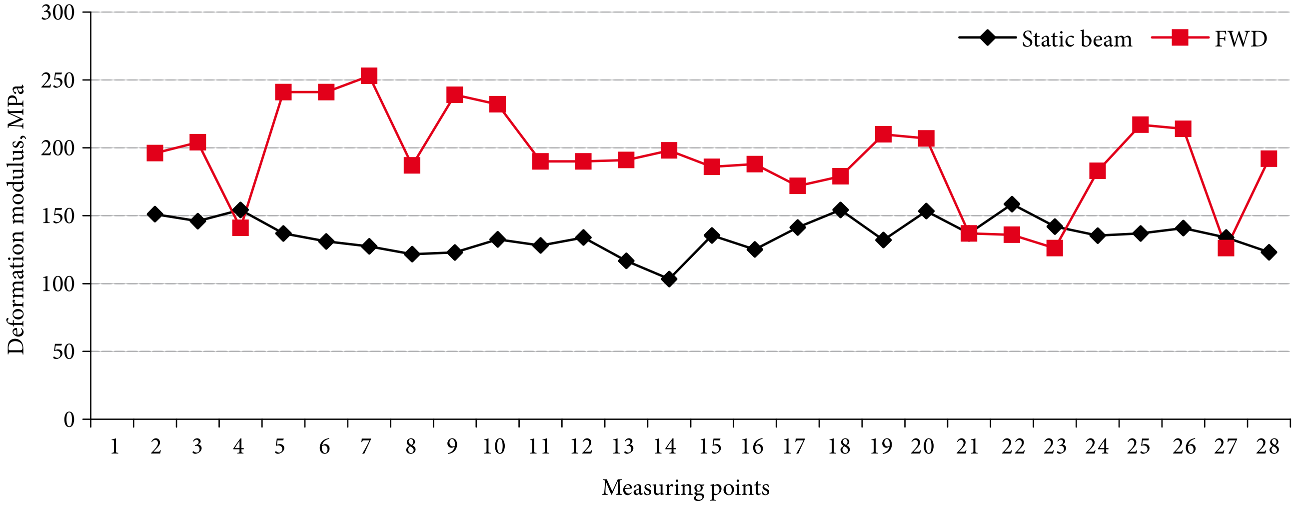

Fig. 9. Measuring results of frost blanket course (right side)

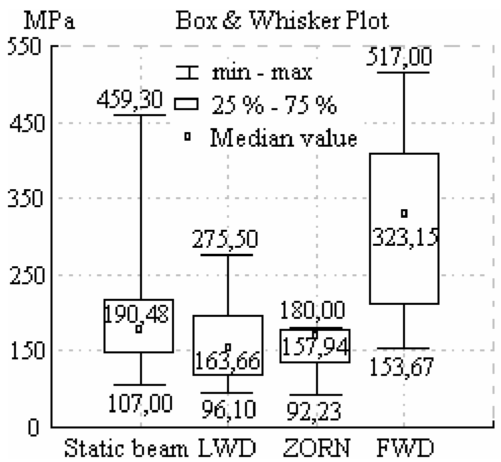

Fig. 10. Dispersion plot of the measuring results on the subgrade (left side)

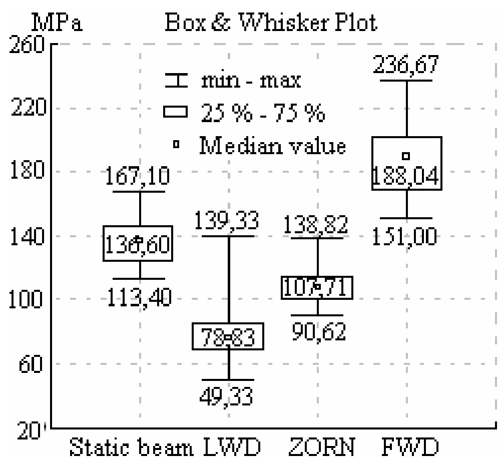

Fig. 11. Dispersion plot of the measuring results on the frost blanket course (left side)

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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