ISSN 1822-427X print
ISSN 1822-4288 online

THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

http://www.bjrbe.vgtu.lt

2007, Vol II, No 2, 67–72

DETERMINATION OF SEASONAL EFFECTS ON THE STRUCTURAL STRENGTH OF ASPHALT PAVEMENTS

Giedrius Šiaudinis[1], Donatas Čygas[2]

Dept of Road, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
E-mail:[1] g.siaudinis@tkti.lt,[2] dcyg@ap.vgtu.lt

Abstract. Since 2000 the Equivalent Axle Loads on the main Lithuanian roads have increased twice. Deflections in asphalt concrete pavement, caused by the axle loads of the moving vehicles, is one of the essential causes of pavement degradation. Pavement deflections are widely measured by the Falling Weight Deflectometer (FWD), since, based on the measured deflection data, it is possible to calculate the deformation modulus of the whole pavement structure as well as separate structural layers. When designing pavement strengthening, values of the pavement deformation moduli are required, describing the weakest pavement condition. Today it is an urgent task to determine the effect of Lithuanian seasonal factors to the FWD-measured deflections in order to estimate the critical deformation modulus of the road pavement. According to the FWD-measured pavement deflections on the experimental road sections at a different time of the year the effect of seasonal factors was determined for the indices of structural strength of asphalt concrete pavements. Using the relationships of the effect of Lithuanian seasonal factors, determined by FWD measurements, it is possible to calculate the minimum indices of pavement structural strength.

Keywords: pavement deformation modulus, road pavement deformations, seasonal effect, road pavement strength.

1. Introduction

The rapidly increasing traffic volume on Lithuanian roads has changed the road network development priorities. Lithuanian road network has a rather uniform distribution and is sufficiently dense, though the earlier constructed roads are not able to hold out the increased loads and the growing traffic volume. The current road problems are mainly related to insufficient road capacity and durability.

On the main Lithuanian roads the Equivalent Axle Loads since 2000 have increased twice, whereas the total traffic volume by nearly 30 %.

Due to the increasing traffic volume and a significantly growing heavy traffic, the durability of road pavements has been decreasing.

The process of pavement deterioration is speeded up by the following main factors:

- a high traffic volume of heavy vehicles;
- the increased vehicle axle loads, which often significantly exceed the specified axle loads, earlier used in pavement design;
- the overloaded vehicles exceed the currently permissible axle loads.

Under the effect of the above-mentioned factors there is a need to strengthen road pavement, which was designed following the lower permissible axle loads (10 tonnes), set by the technical specifications of that time.

At present the main normative document, regulating the design of asphalt concrete pavements, is the Regulation on Motor Roads STR 2.06.03:2001 [1]. Requirements of this regulation are implemented following the recommendations R34-01 "Foundations of motor roads" [2] and R35-01 "Asphalt concrete and gravel pavements of motor roads" [3]. The mentioned documents regulate the selection of only typical road pavement structures based on the calculated indicator of heavy traffic. Pavement strengthening is not described in these documents. A bearing capacity of the existing pavement structures and the need for pavement strengthening are mostly determined by the investigations of pavement surface condition and structural strength. However, Lithuania has no experimentally justified and approved methodology, which would enable to determine an actual bearing capacity of the existing pavement structures and the methods and models for their strengthening. Road pavement strength is one of the main indices, describing the capacity to hold out the traffic-generated loads. For this purpose experimental investigations of the pavement structural strength were carried out by using the Falling Weight Deflectometer Dynatest 8000 FWD [4].

Deflections, caused by the axle loads of the moving vehicles, is one of the essential causes of pavement degradation. Thus a measurement of elastic deflection is the best evaluation of this effect. Today, pavement deflections are widely measured by the Falling Weight Deflectometer (FWD). Measurements, carried out by this device, make it possible for the road engineers to describe and explain the pavement structure behaviour. Based on FWD measured deflection data, it is possible to calculate the deformation modulus of the whole pavement structure as well as separate structural layers. Before the use of FWD, deflections in Lithuania were measured by a Benkelman Beam and dynamic deflectometer Dina-3M. Measurements were usually taken during the spring thaw, in order to calculate the deformation modulus of pavement structure at the weakest period. This period in Lithuania is very short, whereas the measurement procedure lasts long. Evaluation of the need for pavement strengthening is the task of pavement design, only under different initial conditions. When designing pavement strengthening, evaluation of the existing pavement strength is necessary. A constantly increasing amount of pavement strengthening design requires the values of the pavement deformation moduli, describing the weakest pavement condition. Therefore the FWD Dynatest 8000 is used in Lithuania to quickly measure deflections and determine the existing pavement strength [4]. Besides, the FWD measurements use a different input data about the climate, equivalent temperature values and frequency of design loads. All the European design methods are empirically calibrated and adjusted to the local climatic factors, building practise and the materials used [5]. This creates difficulties in applying design methods in other countries. It is an urgent task to determine the relationships of Lithuanian seasonal factors and, based on data of FWD deflection measurements at any time of the year, to estimate the value of the pavement deformation modulus, corresponding to the weakest pavement condition.

The aim of our investigation was to determine the decrease in pavement strength due to seasonal effects for different strength indices on the selected experimental road sections with different pavement structures.

2. Deflection measurements and evaluation of measuring results

Correction of deflections under standard conditions enables to compare the deflection data and to determine standard deviation of the deflections.

Measurements of asphalt concrete pavement deflections shall be corrected for a certain loading system and predicted climatic conditions. The loading system coefficient depends on the non-destructive device, loading frequency and level of the load. It is also well-known that the most critical seasonal factor, having the effect on the deflections of flexible pavement structures, is the temperature of asphalt layer [6].

During measurements all actual deflection values were reduced to deflection values, corresponding to the standard load and standard mean temperature of asphalt concrete pavement.

All the measurement data were calculated after it had been determined that the relationship between deflection and pressure is linear [7] (Fig 1). Deflection values were calculated at 708 kPa pressure, corresponding to the load of 50 kN.

In Lithuania deflections were measured at different periods of the year under different climatic conditions. The mean pavement temperature is used to determine a temperature adjustment factor, required for the calculation of deflection values at an assumed standard temperature of 20 °C [8]. The mean pavement temperature is measured by the electronic thermometer TE-100. The depth, where the mean temperature of asphalt concrete pavement layers was measured, is equal to half the thickness of asphalt concrete pavement layers. Temperature was measured in a bore-hole of the pavement.

When a direct calculation of deformations is carried out by the measured deflection data, the measured deflection basin shall be adjusted to a standard asphalt concrete temperature. The temperature adjustment factor depends on the thickness of asphalt concrete layer, temperature and distance from the FWD loading centre.

Deflections are divided by the temperature adjustment factor and, thus, the deflections and deflection differences are obtained at a standard temperature:

$$TAF = 1 + \left(a_1 + \frac{a_2}{h_1}\right)\left(T_A - 20\right) + \left(a_3 + \frac{a_4}{h_1}\right)\left(T_A - 20\right)^2, \tag{1}$$

where: *TAF* – temperature adjustment factor, T_A – asphalt

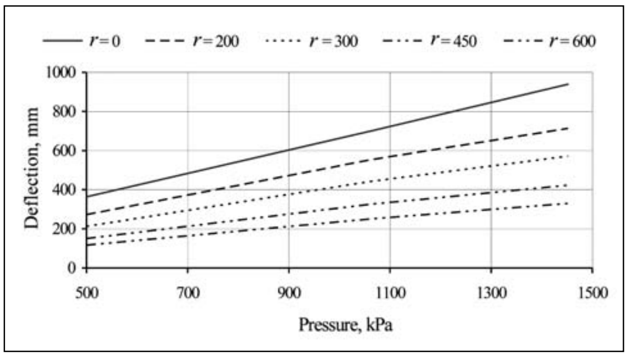

Fig 1. Relationship between deflection and pressure (*r* – distance from the loading centre, mm)

concrete temperature (°C), h_1 – thickness of asphalt concrete layer (mm), a_1, a_2, a_3, a_4 – factors in Table 1.

Adjustment factors a_1, a_2, a_3 and a_4 in Table 1 were determined for the centre deflection and several differences in deflection values. The standard temperature was selected as +20 °C.

Various indices could be used for evaluating and comparing the structural strength of road pavement. This paper analyses the deformation modulus E of the pavement structure and the pavement strength indices SN, SNSG and SNC, described in the world-wide used AASHTO [9] design method.

For comparing the readings of central sensor were used, re-calculated for the load of 708 kPa, taking into consideration the temperature adjustment factor.

Measuring results were calculated using the ELMOD (Evaluation of Layer Moduli and Overlay Design) software, designed by the DYNATEST company. This software enables to calculate the deformation modulus of each layer in a pavement structure of two, three or four layers using the Odemark–Boussinesq transformed cross-sectional method [10]. In order to calculate the deformation moduli for a four-layer pavement structure it is necessary either to know the ratio between the moduli of the second and the third layer or to calculate it by using the above-mentioned software from the thickness of the second and third layer. In the latter case the ratio developed by Dorman and Metcalf is used [11]:

$$\frac{E_n}{E_{n-1}} = 0{,}2{h_n}^{0{,}45}, \quad (2)$$

where: E_n – modulus of the top layer with thickness h_n; E_{n-1} – modulus of the lower layer.

In calculating the deformation modulus from the deflections, the layer thickness shall be not less than 80 mm; therefore the thinner layers should be joined together. Asphalt concrete deformation modulus depends merely on the temperature; seasonal variations are not taken into consideration. The pavement equivalent deformation modulus E_{eqv} is calculated by the formula [12]:

$$E_{eqv} = \frac{2(1-\mu^2)qa}{D_0}, \quad (3)$$

where: μ – Poisson's ratio; q – pavement pressure by a measuring device (kPa); a – radius of the loading plate (mm); D_0 – the centre deflection (μm).

Structural number of all pavement layers (SN) is determined by the relationship developed by Jameson [7]:

$$SN = 1{,}69 + \frac{842{,}8}{D_0 - D_{1500}} + \frac{42{,}94}{D_{900}}. \quad (4)$$

Table 1. Temperature adjustment factors for the FWD deflections

Variable	a_1 (°C^{-1})	a_2 (mm/ °C)	a_3 (0,001 °C^{-1})	a_4 (mm/ °C)
d_0	0,01661	–0,67095	0,28612	–0,01408
$d_0 - d_{225}$	0,05955	–2,73223	1,48011	–0,08171
$d_0 - d_{300}$	0,05398	–2,61130	1,28439	–0,07493
$d_0 - d_{450}$	0,04720	–2,39175	1,05022	–0,06371
$d_0 - d_{600}$	0,04190	–2,15168	0,87228	–0,05301

Subgrade structural number (SNSG):

$$SNSG = 3{,}51\log(CBR) - 0{,}85(\log(CBR))^2 - 1{,}43, \quad (5)$$

where $\log(CBR) = 3{,}264 - 1{,}018\log(D_{900})$; CBR – California Bearing Ratio.

A modified structural number of road pavement (SNC):

$$SNC = SN + SNSG. \quad (6)$$

3. Statistical analysis of measuring results and determination of the seasonal factors reliability

The decrease in pavement strength on each experimental road section due to seasonal effects (further – seasonal factor) is calculated by the algorithm, the scheme of which is shown in Fig 2.

Table 2 gives the maximum and minimum values of pavement strength during the three-year investigations of each experimental section.

The seasonal factors were calculated for the following strength indices:

- the equivalent deformation modulus of road pavement E_{eqv};
- deformation modulus of the roadbed soil E_g;
- structural number of the pavement SN;
- subgrade structural number SNSG;
- modified structural number SNC.

In the process of investigation the values of spring and autumn seasonal factors were determined. A statistical analysis of these values is given in Tables 3, 4. The tables

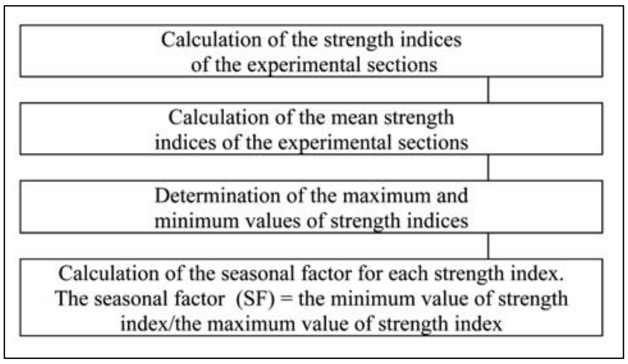

Fig 2. The scheme for calculating the seasonal factor

Table 2. Seasonal factors based on the three-year investigation results

Road section, km	Seasonal factor														
	K_{Eekv}			K_{Eg}			K_{SN}			K_{SNSG}			K_{SNC}		
	1*	2	3	1	2	3	1	2	3	1	2	3	1	2	3
A5 Kaunas – Marijampolė – Suwalki															
35,2 – 35,5	0,81	0,71	0,74	0,95	0,91	0,82	0,84	0,73	0,74	0,97	0,94	0,87	0,88	0,79	0,80
29,2 – 29,5	0,94	0,77	0,86	0,95	0,83	0,87	0,95	0,82	0,87	0,96	0,91	0,92	0,96	0,84	0,90
24,0 – 24,3	0,62	0,53	0,63	0,81	0,87	0,77	0,72	0,61	0,70	0,92	0,93	0,86	0,77	0,68	0,75
20,0 – 20,3	0,88	0,73	0,75	0,90	0,86	0,87	0,92	0,82	0,82	0,95	0,91	0,94	0,93	0,85	0,85
19,0 – 19,3	0,79	0,70	0,68	0,96	0,81	0,90	0,87	0,81	0,77	0,99	0,89	0,96	0,91	0,84	0,82
A4 Vilnius – Varėna – Grodno															
101,1 – 101,4	0,87	0,61	0,77	0,93	0,71	0,87	0,91	0,75	0,87	0,95	0,77	0,92	0,92	0,75	0,88
101,4 – 101,7	0,68	0,64	0,67	0,90	0,82	0,88	0,84	0,78	0,79	0,94	0,91	0,95	0,88	0,82	0,83
A6 Kaunas – Zarasai – Daugavpils															
15,3 – 15,6	0,45	0,65	0,53	0,83	0,88	0,82	0,64	0,80	0,70	0,93	0,96	0,94	0,71	0,85	0,77
16,8 – 17,1	0,49	0,66	0,54	0,76	0,85	0,80	0,69	0,81	0,74	0,93	0,96	0,96	0,75	0,85	0,80
32,7 – 33,0	0,69	0,83	0,84	0,81	0,82	0,84	0,78	0,88	0,88	0,81	0,92	0,94	0,83	0,89	0,90
34,5 – 34,8	0,76	0,80	0,82	0,54	0,72	0,75	0,83	0,84	0,87	0,78	0,90	0,92	0,87	0,88	0,88
A8 Panevėžys – Kėdainiai – Cinkiškiai															
26,7 – 27,0	0,81	0,71	0,70	0,86	0,84	0,78	0,87	0,80	0,73	0,93	0,93	0,92	0,89	0,84	0,77
28,7 – 28,0	0,73	0,79	0,78	0,82	0,83	0,75	0,82	0,87	0,85	0,90	0,94	0,93	0,84	0,89	0,88
32,2 – 32,5	0,66	0,67	0,68	0,84	0,85	0,81	0,76	0,76	0,77	0,92	0,90	0,91	0,80	0,80	0,80
208 south-eastern Utena by-pass															
0,1 – 0,4	0,49	0,71	0,57	0,84	0,74	0,81	0,72	0,84	0,74	0,88	0,88	0,93	0,77	0,87	0,79
1,5 – 1,8	0,42	0,66	0,42	0,79	0,83	0,79	0,70	0,82	0,70	0,83	0,87	0,83	0,74	0,83	0,74
206 (A17) Panevėžys by-pass															
9,9 – 10,2	0,74	0,77	0,70	0,83	0,76	0,72	0,83	0,84	0,79	0,90	0,92	0,91	0,86	0,87	0,82
7,9 – 8,2	0,79	0,81	0,74	0,78	0,79	0,70	0,85	0,85	0,81	0,91	0,94	0,92	0,87	0,88	0,84
7,2 – 7,5	0,79	0,81	0,74	0,81	0,77	0,73	0,85	0,84	0,80	0,93	0,94	0,93	0,87	0,87	0,83
160 Telšiai – Varniai – Laukuva															
1,0 – 1,3	0,71	0,65	0,65	0,87	0,67	0,74	0,83	0,79	0,77	0,91	0,82	0,88	0,85	0,80	0,80
1,7 – 2,0	0,60	0,67	0,69	0,83	0,73	0,77	0,77	0,78	0,80	0,88	0,87	0,91	0,81	0,80	0,83
129 Antakalnis – Jieznas – Merkinė															
73,0 – 73,3	–	0,65	0,60	–	0,83	0,81	–	0,74	0,69	–	0,91	0,92	–	0,78	0,75
73,3 – 73,6	–	0,60	0,60	–	0,82	0,82	–	0,71	0,71	–	0,92	0,91	–	0,76	0,75

* The numbers 1, 2, 3 refer to the year of investigation.

show that in spring the road pavement is in the weakest condition by all the criteria of pavement strength; therefore for further analysis the spring seasonal factors were only used.

The mean values and standard deviations of seasonal factors based on three-year investigation results are given in Figs 3–8.

Table 3. Results of the statistical analysis of spring factors

Factor	Mean	Range of reliability		Median	Minimum	Maximum	Variation factor	Standard deviation
		–0,05	+0,05					
K_{Eekv}	0,69	0,67	0,72	0,70	0,42	0,94	0,012	0,11
K_{Eg}	0,81	0,80	0,83	0,82	0,54	0,96	0,005	0,07
K_{SN}	0,79	0,78	0,81	0,80	0,61	0,95	0,005	0,07
K_{SNSG}	0,91	0,90	0,92	0,92	0,77	0,99	0,002	0,04
K_{SNC}	0,83	0,82	0,84	0,83	0,68	0,96	0,003	0,06

Table 4. Results of the statistical analysis of autumn factors

Factor	Mean	Range of reliability		Median	Minimum	Maximum	Variation factor	Standard deviation
		–0,05	+0,05					
K_{Eekv}	0,77	0,74	0,79	0,77	0,45	0,97	0,013	0,11
K_{Eg}	0,88	0,86	0,89	0,87	0,76	0,98	0,004	0,06
K_{SN}	0,84	0,82	0,86	0,85	0,65	0,97	0,005	0,07
K_{SNSG}	0,94	0,93	0,95	0,95	0,81	0,99	0,001	0,03
K_{SNC}	0,87	0,85	0,88	0,87	0,72	0,98	0,004	0,06

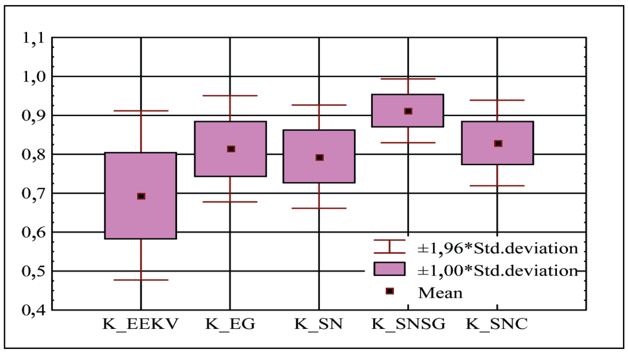

Fig 3. Mean values and standard deviations of seasonal factors

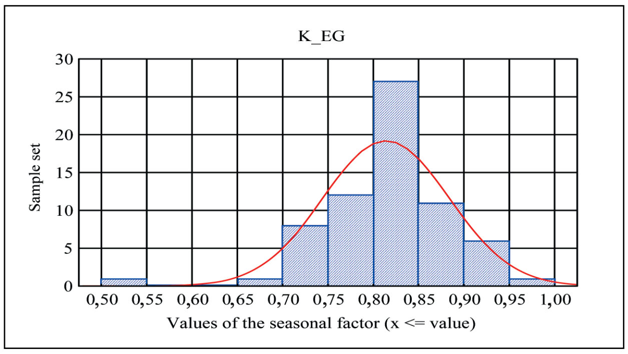

Fig 4. Distribution of the seasonal factors of the deformation modulus of road bed soil E_g

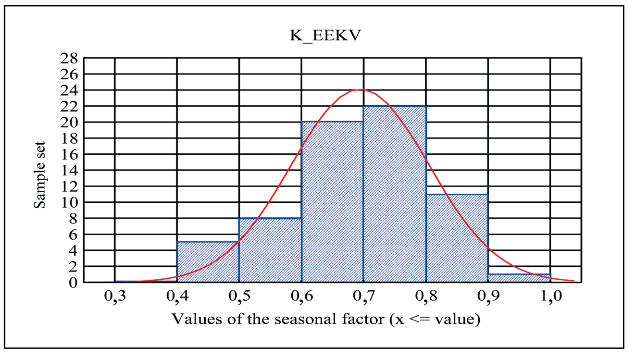

Fig 5. Distribution of the seasonal factors of the equivalent deformation modulus E_{eqv} of pavement structure

A statistical analysis showed that the seasonal factor of the equivalent deformation modulus of road pavement structure could be characterised by a largest dispersion of results. Therefore the analysis was carried out bythe relationship between the distribution of this factor and the maximum equivalent deformation modulus of the existing road section. Fig 9 shows the results.

As a result of investigations, the values of seasonal factors were determined for different strength indices. The values are given in Table 5.

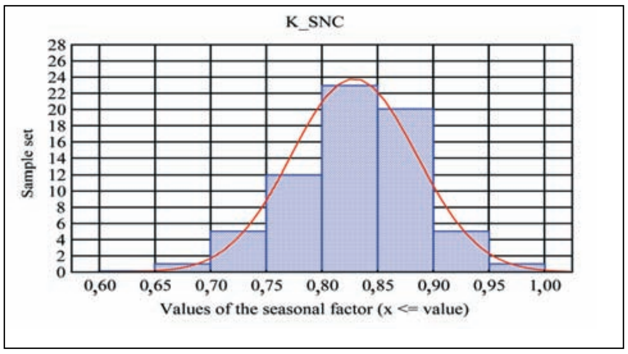

Fig 6. Distribution of the seasonal factors of a modified structural number SNC of pavement structure

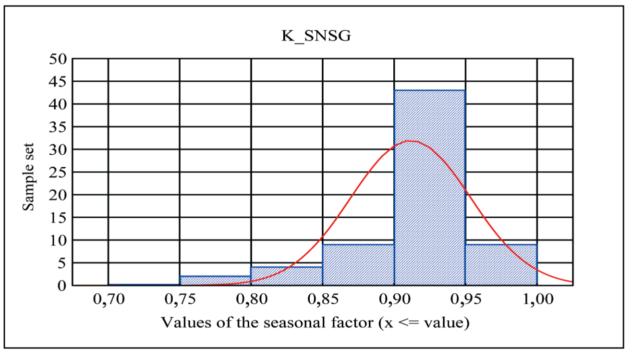

Fig 7. Distribution of the seasonal factors of the subgrade structural number SNC

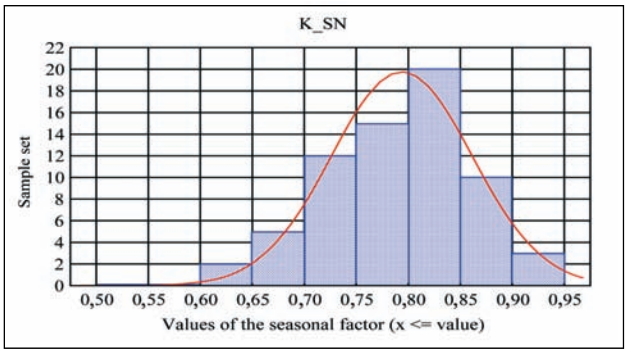

Fig 8. Distribution of the seasonal factors of the structural number SN of pavement structure

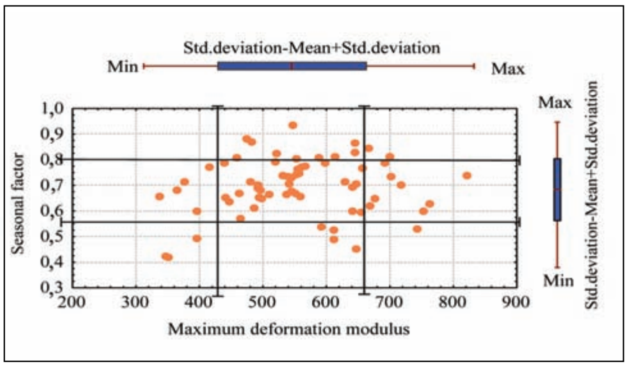

Fig 9. Relationship between the seasonal factor of the equivalent deformation modulus of road pavement structure and the maximum equivalent deformation modulus of the existing road section

Table 5. The values of seasonal factors for different strength indices

Strength index	Value of seasonal factor
The equivalent deformation modulus of road pavement E_{eqv}	0,58
Deformation modulus of the roadbed soil E_g	0,74
Structural number of the pavement SN	0,73
Subgrade structural number SNSG	0,87
A modified structural number SNC	0,77

4. Conclusions

1. When measuring pavement deflections of the Lithuanian roads, a modern device DYNATEST 8000 FWD is used, meeting the European Union requirements (COST 324, COST 325).

2. Based on the three-year investigations, the value of seasonal factors, determined by the strength indices E_{egv}, E_g, SN, SNSG and SNC, is the difference between the mean value of the spring factor and the value of standard deviation.

3. The results of three-year investigations on Lithuanian roads and the statistical analysis enabled us to:

- determine the asphalt concrete pavement condition by the Falling Weight Deflectometer and, taking into consideration the seasonal factors, to calculate the strength indices of the existing road pavement structure;
- to take into consideration the seasonal factors when calculating the strength indices SN, SNSG and SNC, used in HDM-III, HDM-IV and Lithuanian DAVASEMA systems for describing pavement structural strength;
- to select a proper and economically justified type of pavement strengthening, to calculate additional thicknesses for the road structure to be strengthened.

4. Data on the strength indices allows to methodically and substantially evaluate the condition of asphalt concrete road pavements, to forecast pavement deterioration and to determine the necessary measures for a rational use of road pavements.

References

1. STR 2.06.03: 2001 Regulation on Motor Roads (Techninių reikalavimų reglamentas. Automobilių keliai). Vilnius, 2002. 77 p. (in Lithuanian).
2. R34-01. Recommendations. Foundations of Motor Roads (Rekomendacijos. Automobilių kelių pagrindai). 120 p. (in Lithuanian).
3. R35-01. Recommendations. Asphalt Concrete and Gravel Pavements of Motor Roads (Rekomendacijos. Automobilių kelių asfaltbetonio ir žvyro dangos), 2001 (in Lithuanian).
4. Dynatest 8000 FWD Test System, Dynatest Engineering A/S, 1995.
5. ŠIAUDINIS, G. Relationship of Road Pavement Deformation Moduli, Determined by Different Methods. *The Baltic Journal of Road and Bridge Engineering*, 2006, Vol I, No 2, p. 77– 81.
6. HEE MUN PARK, Y. RICHARD KIM. Sunwoo Park Temperature Correction of Multiload-Level Falling Weight Deflectometer Deflections. *Transportation Research Record*, No 1806, Washington, DC, 2002, p. 3.
7. AASHTO Guide for Design of Pavement Structures. Washington: AASHTO, 1993.
8. BALTZER, S.; JANSEN, J. M. Temperature Correction of Asphalt – Moduli for FWD Measurements. In *Proc of the 4th International Conference on the Bearing Capacity of Roads and Airfields*. Minnesota: University of Minnesota, 1994, Vol 1, p. 754–767.
9. Pavement Notes for Design, Evaluation and Rehabilitation. WSDOT Pavement Guide. Washington: State Dept of Transportation, 1995.
10. PER ULLIDTZ. Modelling Flexible Pavement Response and Performance. Polyteknisk Forlag, Gylling, 1998. 205 p.
11. Design Curves for Flexible Pavements Based on Layered System Theory, Highway Research Record, No 71, 1965.
12. Pavement Design Based on Theory of Elasticity. Vejen: Phonix Pavement Consultants, 1993, p. 21.

Submitted 13 March 2007; accepted 25 May 2007