

INTERACTION OF PHYSICAL PARAMETERS AND THE STRENGTH OF FROST BLANKET COURSE IN ROAD PAVEMENT STRUCTURE

LINA BERTULIENĖ^{1*}, LINA JUKNEVIČIŪTĒ-ŽILINSKIENĖ²,
HENRIKAS SIVILEVIČIUS³, ALFREDAS LAURINAVIČIUS⁴

^{1,2,4}*Dept of Roads, Vilnius Gediminas Technical University, Lithuania*

³*Dept of Mobile Machinery and Railway Transport,
Vilnius Gediminas Technical University, Lithuania*

Received 9 July 2017; accepted 23 August 2018

Abstract. This paper determines the interaction between the physical indicators of frost blanket course and its deflection modulus, measured by static and dynamic devices. The Pilot Road has been selected to examine the strength properties (deflection module) of frost blanket course. A Pilot Road consisting of 27 road sections, divided into 5 different road structures. A Pilot Road has been selected to examine the strength properties (deflection module) of frost blanket course. In this research was determined the strength of frost blanket course in road pavement structures of Pilot Road by four devices: Falling Weight Deflectometer Dynatest 8000, Light Weight Deflectometers Prima 100 and ZORN ZSG 02 and Static Beam Strassentest. The results showed no reliable correlation between the deflection modulus, measured by different devices, and the physical indicators of the frost blanket course of the road pavement structures in Pilot Road.

Keywords: deflection modulus, frost blanket course, road pavement structure.

* Corresponding author. E-mail: lina.bertulienne@vgtu.lt

Copyright © 2018 The Author(s). Published by RTU Press

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Introduction

A frost blanket course (FBC) protects road pavement structure from the damaging effect of frost. The course is performed from the non-frost-susceptible aggregate mixtures and soils. A frost blanket course is obligatory when the layers of the road pavement structure are constructed from water permeable materials, and the subgrade is moistened continuously or periodically. Besides a protective function, the purpose of FBC is to carry loads, generated by traffic and by layers of the road pavement structure, and to distribute them to the subgrade (Kavussi, Rafiei, & Yasrobi, 2010). Load effect, caused by motor vehicle wheels to the road pavement structure is one of the most deciding factors determining the behaviour of the road surface during its life cycle (Vaitkus & Paliukaitė, 2013). It is necessary to collect information about the properties of the available materials being optimally used for the construction of a road, as well as their reciprocity to one another (Bazi, Briggs, Saboundjian, & Ullidtz, 2015; Mateos & Soares, 2014; Rajaei & Baladi, 2015).

Moreover, FBC drains road pavement structure and evenly distributes loads on the formation level of the subgrade, and protects road pavement structure from the frost heaving. The primary conditions, which determine the required frost resistance of subgrade and road pavement structure, are as follows (Bilodeau & Doré, 2014; Vaitkus, Vorobjovas, Žiliūtė, Kleizienė, & Ratkevičius, 2012; Vennapusa, White, Siekmeier, & Embacher, 2012):

- the use of non-frost-susceptible soils for the construction of the upper part of subgrade located in a frozen zone;
- assurance of the required elevation of the road structure over the level of groundwater or surface water;
- perform of an FBC – the volume of the material of which does not change under the effect of frost and moisture, or the use of the thermal insulation materials, which withhold frost penetration into the underneath layers and reduce the depth of frozen subgrade;
- installation of draining or insulating layers – a draining layer ensures the extremely rapid water discharge from the subgrade; whereas, the insulating layers, e.g. geomembrane, prevent water from getting into the subgrade.

Long-term performance and durability of a road pavement structure built on expansive soils are mainly dependent on the effective stabilisation of the subgrade and compaction techniques adopted during construction (Bheemasetti, Pedarla, Puppala, & Acharya, 2015). Road pavement structure longevity and resistance to deformations are usually determined by measuring the strength of the road pavement structure.

The static and dynamic deflection measurement methods are used to determine the deflection module of the road pavement structure. The particular area is gradually loaded and unloaded while road pavement structure is measured by a static method. The essence of pavement structural strength evaluation is to add relative pressure to the road surface, which, according to the definition, corresponds to the load impact of a vehicle wheel at the pressure point. The disadvantage of the static method is that, under this method, it is impossible to examine the ability of the road pavement structure to convey the dynamic effect that occurs due to real vehicle loads. Dynamic methods precisely replicate the effect of the forces affecting road pavement structure because a load of the vehicle wheel is transmitted while the vehicle is moving on the road.

This paper determines the interaction between the physical indicators of FBC and its deflection modulus, measured by static and dynamic devices.

1. Static and dynamic methods

Dependencies between dynamic and static deflection modulus are rarely used in practice. The most commonly given threshold values of static and dynamic deflection moduli are E_{V_2} and E_{V_d} , respectively. Values of deflection modulus for layers of bulk materials are specified according to the compaction degree of the layer being tested.

Tompai (2008) conducted a static (B & C Small – Plate Device) and dynamic (Light Weight Deflectometer (LWD)) method comparative analysis. The possibility of reliable conversion among values of two dynamic deflection moduli (E_{V_d} , E_d) obtained by using an LWD and the E_{V_2} is briefly presented and justified. The new result of dynamic target values opens up the opportunity to perform the quality control and assess the bearing strengths of the tested layer, not only by Static Plate Load Test, which proved to be time-consuming and labour intensive but by dynamic devices as well. Figure 1 gives the summary of correlation results between the static and dynamic measuring methods in other countries.

Figure 1 gives correlation results between the static E_{V_2} (static deflection modulus by a static plate load) and dynamic E_{V_d} (dynamic deflection modulus) measuring methods. The formulas for calculating direct correlation are seldom used in practice, most frequently the limit values are given for both E_{V_2} and E_{V_d} . Four different German standards give similar limit values presented in Figure 1. It could be noticed that the value of static deflection modulus measured by static plate load at least twice exceeds the E_{V_d} . Some of the results represent an even

stronger correlation. Only two-literature sources give correlation less than 2, though they both refer to the deflection modulus values measured in only several points and at small distances. The E_{vd} values, presented in all German standards, are close to a correlation line indicating the ratio 2. Here, in analysed standards, when giving the limit E_{vd} values the weakest correlation ratio (or even weaker) is applied. Determination of direct correlation between the dynamic and static deflection moduli are seldom used in practice, the values of E_{v2} and E_{vd} are approved in Germany, Slovenia and some other countries.

Sulewska (2004) published results of research, using LWD ZFG 01. It was established the functional dependencies between static and dynamic deflection moduli (Eqs (1-3)):

$$E_D = f(I_s), \quad (1)$$

$$E_D = f(E_{v1}), \quad (2)$$

$$E_D = f(E_{v2}), \quad (3)$$

where E_D – dynamic deflection modulus of soil deformation, MPa E_{v1} and E_{v2} – primary and secondary static deflection moduli of soil deformation, MPa; I_s – value of soil degree of compaction, yd.

Light Weight Deflectometer is used as a control measure to determine the deflection modulus on the sand and gravel layers. Sulewska (2012)

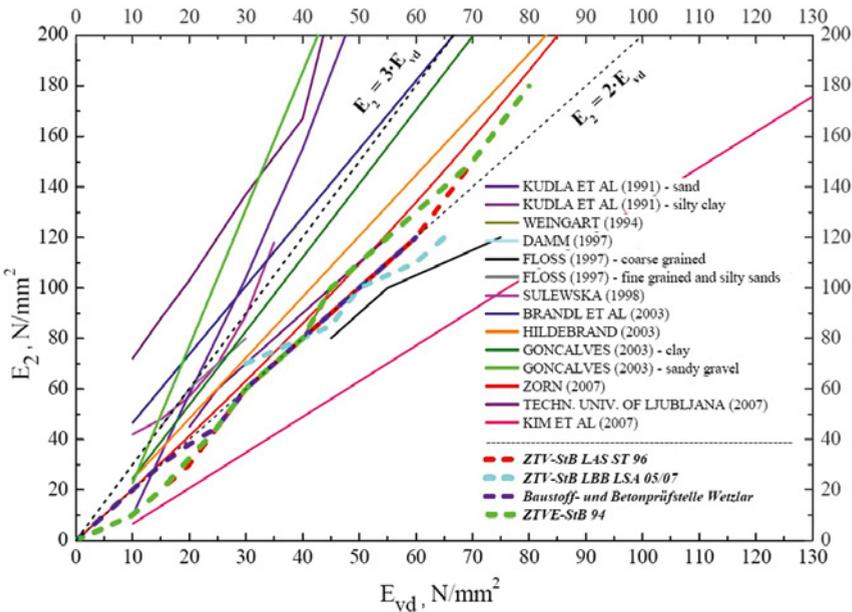


Figure 1. Correlation results of static and dynamic measuring methods based on international research (Tompai, 2008)

examined the soil compaction degree of embankments using LWD, as well. The tests were performed on unbound layers in the road pavement structure of North-Eastern Poland. Deflection modulus was measured using LWD. The objective of the study was to find a correlation between the deflection modulus, measured using an LWD, and the compaction rate. After analysing the results, it was found that it is necessary to perform a calibration test to strengthen the compaction control accuracy. Marginal values of the dynamic deflection moduli have to be determined based on the compaction rate (Bertulienė, 2012).

Approximate E_{V_d} (dynamic deflection modulus) transfer to the E_{V_2} (static deflection modulus) values according to *LST 1360.5:1995 Soils for Road Construction* are recommended in Lithuania.

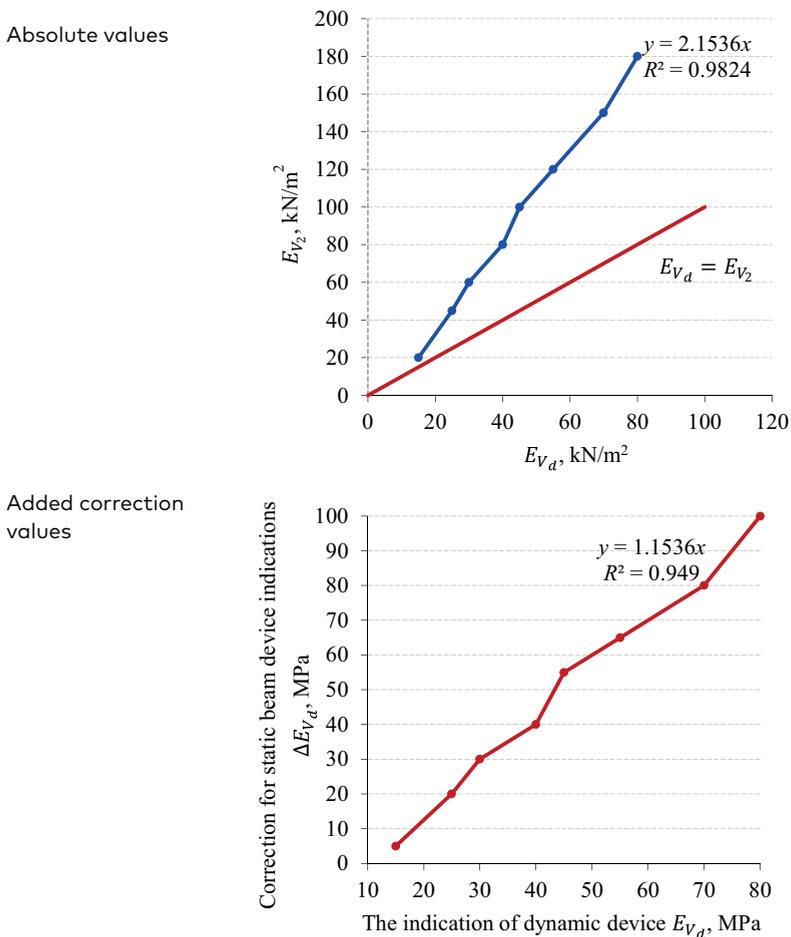


Figure 2. Dependencies of the E_{V_d} transfer to the E_{V_2}

Figure 2 shows dynamic and static deflection moduli value dependence is linear. The higher E_{v_d} value, the higher E_{v_2} the value. The graph (Figure 2) does not specify to which dynamic device it corresponds. It is likely that each different dynamic instrument reading correlation by static beam (SB) Strassentest readings are different.

2. The methodology of the experiment

The Pilot Road with experimental pavement structures (710 m of length) was constructed in an open area (Čygas, Laurinavičius, Paliukaitė, Motiejūnas, Žiliūtė, & Vaitkus, 2015). The cross-section parameters of the Pilot Road correspond to the III category of the road, the road pavement structure Class III by *KPT SDK 07 Rules for the Design of Standardized Road Pavement Structures of Motor Roads*. The Pilot Road was constructed as follows:

1. The existing asphalt pavement has been milled down to the base layer with the bulk material;
2. The base layer of the road pavement structure has been dug out to the design subgrade level;
3. Deflection modulus values, higher than normative, have been achieved while reconstructing the subgrade of the Pilot Road section and installing FBC (according to *IT SBR 07 Rules for the Installation of Non-Binder Layers of Road Pavement Structure for Road Pavement Construction*). Subgrade compaction values vary between 95–100% and the deflection modulus of the top layer – not less than 45 MPa. Similarly, based on the same standards, FBC compaction rate values have to be – 100–103%. Value of deflection modulus has to be at least 120 MPa of FBC in the road pavement structure of SV (the highest class) and I to IV classes. Value of deflection modulus has to be of at least 100 MPa and 80 MPa, respectively, of FBC in the road pavement structure of V and VI classes;
4. The total length of the Pilot Road is 710 m – consists of 26 sub-sections (the length of each is 30 m) and one sub-section in length of 20 m (Figure 3).

The following four devices were used to determine FBC strength of the road pavement structures in the Pilot Road: dynamic – FWD Dynatest 8000 (FWD), LWD Prima 100 (LWD), ZORN ZSG 02 (ZORN) and static – Strassentest (SB). Measurements were carried out using the same scheme (the measuring point varies ± 0.5 m) and under the same weather conditions (the average air temperature of 18 °C, without precipitation) in August.

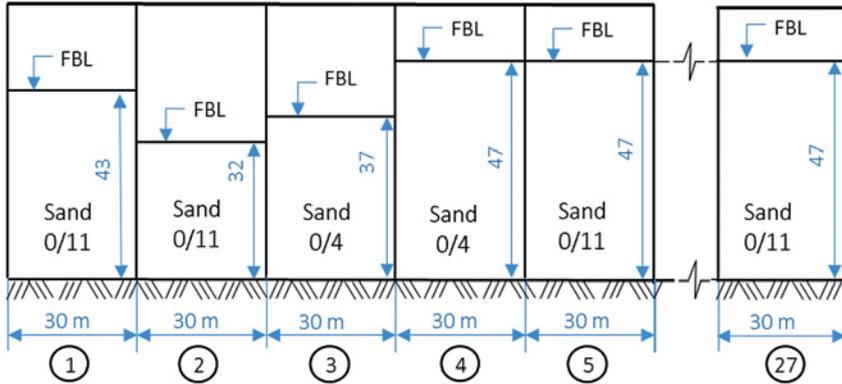


Figure 3. A fragment of the construction scheme of the Pilot Road

Deflection modulus E_{v_2} was found through measurements using SB, while E_{v_d} has been obtained from measurements using three dynamic measuring devices. 0/11 sand fraction (road pavement section No. 25) and 0/4 sand fraction (road pavement sections No. 3 and No. 4) were used for FBC construction. The thickness of FBC is 43 cm in the road pavement section No. 1, 32 cm – on section No. 2, 37 cm – on section No. 3, and 47 cm – on sections from No. 4 to No. 27.

3. Physical and mechanical parameter influence to deflection modulus

The standard and actual physical and mechanical properties of FBC presented in Table 1. Physical parameters data of all FBC sections are in Table 2.

After establishing the FBC filtration coefficient (Table 2) in road pavement sections No. 3 and No. 4, the obtained values vary from

Table 1. The comparison of standard and actual physical and mechanical properties of frost blanket course

Properties of FBC	Unit	Standard	Actual	
Values of deflection modulus	MPa	120	113.4–167.1	
The coefficient of filtration	m/day	≥ 2	4.0–15.0	
Total passing through	0.063 mm sieve	%	≤ 7	0.6–1.1
	2 mm sieve	%	28–80	73.3–82

4.0 m/day to 4.3 m/day (the recommendation is at least 2 m/day by *IT SBR 07 Rules for the Installation of Non-Binder Layers of Road Pavement Structure for Road Pavement Construction*). In all other road pavement sections values of the filtration coefficient ranged from 11.7 m/day to 15.0 m/day. Frost blanket course mineral mixture passing through a 2 mm sieve values ranged from 73.3% to 76.7% (by *IT SBR 07* the

Table 2. Data of physical parameters of frost blanket course

Road Pavement Section No.	Parameters of frost blanket course			
	Thickness	The coefficient of filtration	Passing	Retained
			0.063 mm sieve	2 mm sieve
	cm	m/day	%	%
1	32	12.4	0.8	73.6
2	37	13.7	0.9	76.3
3	43	4.3	0.7	82.0
4	47	4.0	0.7	81.0
5	47	12.4	0.8	76.4
6	47	13.6	1.1	75.4
7	47	15.0	0.8	76.3
8	47	14.0	1.0	76.3
9	47	13.3	0.7	76.3
10	47	12.6	0.7	73.3
11	47	13.4	0.7	76.3
12	47	14.6	0.8	76.4
13	47	13.0	0.9	76.2
14	47	12.0	0.7	76.2
15	47	14.0	0.9	76.1
16	47	13.9	1.1	76.3
17	47	12.8	1.0	75.9
18	47	13.3	0.8	76.1
19	47	12.7	0.6	76.4
20	47	13.2	0.8	76.2
21	47	-	-	-
22	47	13.4	0.8	76.7
23	47	-	-	-
24	47	13.9	0.9	76.2
25	47	-	-	-
26	47	11.7	0.7	73.5
27	47	12.6	0.9	76.2

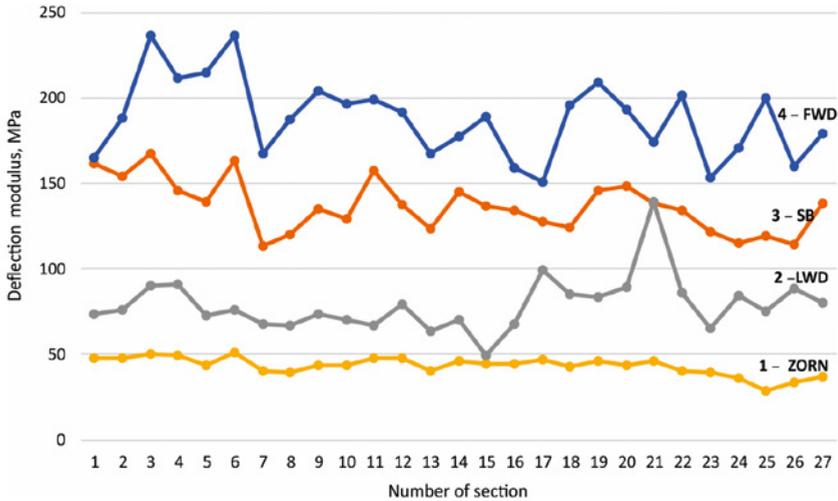


Figure 4. Deflection modulus of frost blanket course measured by all devices

recommendation is 28–80%) of the mixture weight. Passing through a 0.063 mm sieve values range from 0.6% to 1.1% of the mixture (by *IT SBR 07* the recommendation is up to 7%).

Devices and different physical indicators influence the different values of FBC deflection modulus: course thickness h , filtration coefficient k_f , gradation (per cent of quantities, passing through 0.063 mm) $p_{0.063}$, and remaining on the 2 mm sieve p_2) (Figure 4).

The measurement results of FBC deflection modulus show that the readings obtained by the static and dynamic devices in 27 separate sections are substantially different and vary (Figure 4).

Analysis of the results shows that the numerical values of the deflection modulus, compared to the SB, are different. Light Weight Deflectometer values of deflection modulus (E_{LWD}) are about 42.3% less than the SB (E_{SB}) measured the average numerical value of deflection modulus. Light Weight Deflectometer ZORN (E_{ZORN}) values are about 68.4% less than values measured by SB, and the FWD (E_{FWD}) values increased about 37.6%. According to the received results, it is observed that the lowest averages and lowest dispersion results have been received using an LWD ZORN device.

A statistical hypothesis about the equality of correlation coefficient values to zero to validate, the Student t -test was taken, and its statistic t was calculated as follows (Eq. (4)) (Podvezko & Sivilevičius, 2013):

$$t_{1-\alpha, m-2} = r \sqrt{\frac{m-2}{1-r^2}}, \quad (4)$$

where m – number of criteria ($m = 27$); r – coefficient of the pairwise correlation.

The minimum value of pairwise correlation coefficient r_{\min} is calculated by rearranging Eq. (5) as follows:

$$r_{\min} = \frac{t_{\alpha, \nu}}{\sqrt{m-2+t_{\alpha, \nu}^2}}. \quad (5)$$

Given significant level $\alpha = 0.05$ and t -statistic $t_{\alpha, \nu} = 2.06$.

A Pilot Road consists of 27 road pavement structures, taking a significance level $\alpha = 0.05$ and a degree of freedom $\nu = 27 - 1 = 26$, The critical value of the Student criterion is $t_{\alpha, \nu} = 2.06$. The minimum value of the correlation coefficient r_{\min} was calculated using the Eq. (5) and equal to 0.381. Values are correlated, and h and k_f (Table 3) show impact to the deflection modulus measured using SB. The only k_f affected the deflection modulus measured by LWD. There was no link between the physical indicators and the deflection modulus measured by ZORN device. Falling Weight Deflectometer Deflection modulus, measured by FWD depends only on k_f and p_2 .

This data shows no reliable correlation among the deflection modulus, measured by different instruments, and physical indicators of FBC of the road pavement structures in Pilot Road. It is likely that in a wider range, adjusting the physical indicators of FBC, the correlation might be stronger.

Value of deflections modulus measured by SB Strassentest and LWD ZORN decreases with increasing the thickness of FBC. However, the LWD and FWD showed the opposite result: as the thickness of FBC, the values

Table 3. The correlation coefficient of the deflection modulus dependency

Correlation coefficients r	Device				
		Static Beam	Light Weight Deflectometer	Falling Weight Deflectometer	
	Symbol	Strassentest	Prima 100	ZORN ZSG 02	Dynatest 8000
Course thickness	h	-0.486	0.041	-0.283	0.073
Filtration coefficient	k_f	-0.387	-0.433	-0.329	-0.424
Per cent of quantities, passing through 0.063 mm	$p_{0.063}$	-0.123	-0.189	-0.041	-0.262
Remaining on the 2 mm sieve	p_2	0.323	0.285	0.366	0.498

of the deflection modulus become greater. It has been determined that the coefficient of filtration goes up as the values of deflection modulus decrease. With increasing per cent of quantities, passing through the 0.063 mm sieve, the values of deflection modulus decrease, i.e. the fine passing (smaller than 0.063 mm). The weaker is the primer with increasing per cent of quantities, retained on the 2 mm sieve, the values of deflection modulus decrease.

Conclusions

1. Analysis of measuring results of frost blanket course by the static and dynamic devices showed that the strength of frost blanket course determined by Falling Weight Deflectometer is close to the strength determined by a static testing device. Value averages of deflection modulus measured by Light Weight Deflectometers Prima 100 and ZORN are 42.3% and 68.4% respectively. These average values were lower than the average values measured by the Static Beam Strassentest. Value average measured by Falling Weight Deflectometer is 37.6% higher than the received value of the deflection module measured by the Static Beam Strassentest.
2. The thickness of the frost blanket course affected only the deflection modulus measured by Static Beam. The deflection modulus was affected by the filtration coefficient measured by Static Beam, Light Weight Deflectometer, and Falling Weight Deflectometer. Per cent of quantities, passing through 0.063 mm sieve did not affect any instrument readings. Total per cent of quantities, retaining on the 2 mm sieve, influenced only the Falling Weight Deflectometer readings. This data shows no a reliable correlation between the deflection modulus, measured by different devices, and the physical indicators of the frost blanket course of the road pavement structures in the Pilot Road. It is likely that when adjusting the physical indicators of frost blanket course in a wider interval, the correlation would be stronger.
3. The research clearly showed that to give more justified conclusions it would be necessary to do additional research. The correction coefficient of road pavement base course of the load distribution would be necessary to correct in calculation methodology. This correction coefficient influences the value of deflection modulus. To obtain transfer coefficients from the statistical analysis, allowing dynamic meter readings to be exchanged by the Static Beam Strassentest readings.

REFERENCES

- Bazi, G., Briggs, R., Saboundjian, S., & Ullidtz, P. (2015). Seasonal Effects on a Low-Volume Road Flexible Pavement. *Transportation Research Record: Journal of the Transportation Research Board*, (2510), 81-89. <https://doi.org/10.3141/2510-10>
- Bertulienė, L. (2012). Assessment, Research and Use of Methods for Determining the Strength of Base Courses of Road Pavement Structure. *Baltic Journal of Road & Bridge Engineering*, 7(3): 228–236. <https://doi.org/10.3846/bjrbe.2012.30>
- Bheemasetti, T. V., Pedarla, A., Puppala, A. J., & Acharya, R. (2015). Design of Sustainable High-Volume Pavements Using Controlled Low-Strength Material from Native Soil. *Transportation Research Record: Journal of the Transportation Research Board*, (2509), 10-17. <https://doi.org/10.3141/2509-02>
- Bilodeau, J. P., & Doré, G. (2014). Direct estimation of vertical strain at the top of the subgrade soil from interpretation of falling weight deflectometer deflection basins. *Canadian Journal of Civil Engineering*, 41(5), 403-408. <https://doi.org/10.1139/cjce-2013-0128>
- Čygas, D., Laurinavičius, A., Paliukaitė, M., Motiejūnas, A., Žiliūtė, L., & Vaitkus, A. (2015). Monitoring the mechanical and structural behavior of the pavement structure using electronic sensors. *Computer-Aided Civil and Infrastructure Engineering*, 30(4), 317-328. <https://doi.org/10.1111/mice.12104>
- IT SBR 07 Rules for the Installation of Non-Binder Layers of Road Pavement Structure for Road Pavement Construction (in Lithuanian)*
- Kavussi, A., Rafiei, K., & Yasrobi, S. (2010). Evaluation of PFWD as potential quality control tool of pavement layers. *Journal of Civil Engineering and Management*, 16(1), 123-129. <https://doi.org/10.3846/jcem.2010.11>
- KPT SDK 07 Rules for the Design of Standardized Road Pavement Structures of Motor Roads (in Lithuanian)*
- Mateos, A., & Soares, J. B. (2014). Characterization of the stiffness of unbound materials for Pavement design: Do we follow the right approach?. *Journal of Transportation Engineering*, 140(4), 04014001. [https://doi.org/10.1061/\(ASCE\)TE.1943-5436.0000645](https://doi.org/10.1061/(ASCE)TE.1943-5436.0000645)
- Podvezko, V., & Sivilevičius, H. (2013). The use of AHP and rank correlation methods for determining the significance of the interaction between the elements of a transport system having a strong influence on traffic safety. *Transport*, 28(4), 389-403. <https://doi.org/10.3846/16484142.2013.866980>
- Rajaei, P., & Baladi, G. Y. (2015). Frost Depth: General Prediction Model. *Transportation Research Record: Journal of the Transportation Research Board*, (2510), 74-80. <https://doi.org/10.3141/2510-09>
- Sulewska, M. J. (2004). The application of the modern method of embankment compaction control. *Journal of civil engineering and management*, 10(suppl 1), 45-50.
- Sulewska, M. J. (2012). The Control of Soil Compaction Degree by Means of LFWD. *Baltic Journal of Road & Bridge Engineering*, 7(1): 36–41. <https://doi.org/10.3846/bjrbe.2012.05>

- Tompai, Z. (2008). Conversion between static and dynamic load bearing capacity moduli and introduction of dynamic target values. *Periodica Polytechnica Civil Engineering*, 52(2), 97-102. <https://doi.org/10.3311/pp.ci.2008-2.06>
- Vaitkus, A., & Paliukaitė, M. (2013). Evaluation of time loading influence on asphalt pavement rutting. *Procedia Engineering*, 57, 1205-1212. <https://doi.org/10.1016/j.proeng.2013.04.152>
- Vaitkus, A., Vorobjovas, V., Žiliūtė, L., Kleizienė, R., & Ratkevičius, T. (2012). Optimal Selection of Soils and Aggregates Mixtures for a Frost Blanket Course of Road Pavement Structure. *Baltic Journal of Road & Bridge Engineering*, 7(2): 50–54. <https://doi.org/10.3846/bjrbe.2012.21>
- Vennapusa, P. K. R., White, D. J., Siekmeier, J., & Embacher, R. A. (2012). In situ mechanistic characterisations of granular pavement foundation layers. *International Journal of Pavement Engineering*, 13(1), 52-67. <https://doi.org/10.1080/10298436.2011.564281>