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INFLUENCE OF HIGH WATER CONTENTS ON PAVEMENT LAYERS STIFFNESS CAUSED BY FLOODING

Abstract

Moisture inside the construction of road pavements is the problem for road engineers all around the world. This issue is mentioned in many European or the US papers and studies, but still it needs to be developed. From the road engineers' point of view, very important for solving above problems are the studies on the influence of water and moisture inside the construction of road pavement during deflection measurements using Falling Weight Deflectometer (FWD). The paper raises this issue by showing a short review of Polish and foreign literature and presenting the first step of research work at the test site on Voivodeship Road 933 in Poland.

Keywords

Falling Weight Deflectometer (FWD), non-destructive testing, water, moisture, deflection, pavement, road construction.

1 INTRODUCTION

One of the main objectives at the design stage as well as at the execution stage is not lead up to the occurrence of excess water in a pavement structure. Frequently the movement of water into pavement construction is observed. Presence of excessive moisture in pavements is primarily due to melting of ice lenses during spring thaw, capillary actions and infiltration through pavement surface, shoulders and various kinds of existing damages. Following numerously investigations on the behaviour of pavement structure it is proved that excess water accelerates the deterioration of the structure causing i.e. frost heave, rutting or reduction of unbound aggregate courses strength and stiffness. Particularly sensitive to impact of water is silty or clayey subgrade as well as subbase and base with high content of fine particles or dense-graded unbound aggregate layers. High sensitivity of mentioned granular and unbound materials is due to reduction of mutual reaction among each particles and increase of pore water pressure. It is especially shown in decrease of the resilient modulus value which is greatly affected by moisture.

In recent years many research on water impact on performance of flexible pavements were carried out using Falling Weight Deflectometer. In this purpose FWD tests help to investigate variations in moisture content and changes in resilient modulus value. In this paper introductory experiences with FWD tests at the test site in Poland on Voivodeship Road 933 near Jastrzębie-Zdrój and Pawłowice were carried out with reference to similar observations reported in the literature.

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2 PAVEMENT DIAGNOSIS METHODS

Examinations of road pavement structure damages can be made using numerous methods with different specialized equipment. Pavement diagnosis methods can be divided into three groups:

- destructive methods,
- semi-destructive methods,
- non-destructive methods.

In research aimed at water impact on performance of pavement structures by far the most examinations are executed using non-destructive testing such as deflection measurements, radar-technique examinations or surface parameters rating. In this group of methods deflection measurements using Falling Weight Deflectometer are primarily used.

2.1 Falling Weight Deflectometer (FWD)

Principle of operation of Falling Weight Deflectometer is similar to Light Weight Deflectometer, but allows to apply higher values of impact to imitate actual conditions of traffic load. FWD device measures vertical deflection of road pavement structure caused by falling of a fixed mass load from set height. Mass falls naturally and hits the damping arrangement which transfers impulse to plate bearing device. Vertical deflection induced by the plate is registered by group of geophones which are placed in different distance from the load axis. The load impulse value ranges from 7 to even 300 kN depending on the type of pavement structure. In FWD measurements on road pavements an impact load equal to 50 – 57.5 kN is mainly used [1]. FWD test operation scheme is shown in the Figure 1.

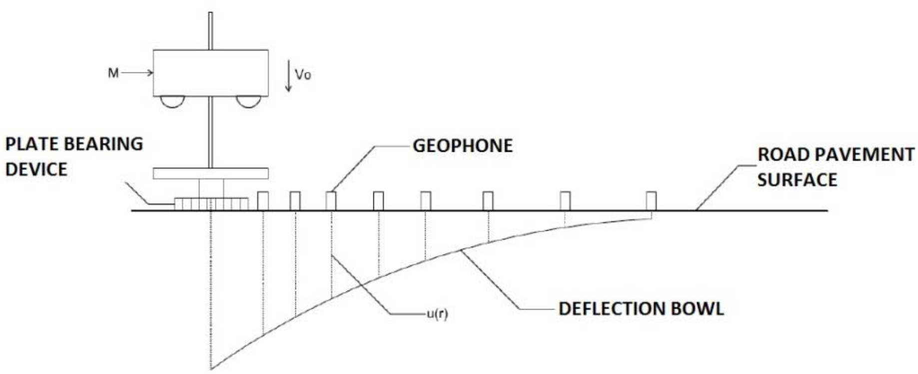


Fig.1: Falling Weight Deflectometer operation scheme [1]

3 FWD TESTS WITH PRESENCE OF EXCESS WATER – INTERNATIONAL EXPERIENCES

Many studies have been carried out to analyze the impact of excess water on pavement structure using Falling Weight Deflectometer tests. Great majority underlines the problem of excess water during the spring thaw because of seasonal variation of unbound layers stiffness. For subgrade, base and subbase decrease of stiffness can occur during winter short thawing periods and spring thaw. Winter fall of stiffness is usually less noticeable and is a short-term variation, while decrease of stiffness during spring thaw is more evident. After the spring thaw period is over, unbound pavement layers regain bearing capacity relatively quickly. However if the subgrade is fine-graded, recovery might last definitely longer [2]. The characteristic of unbound layers stiffness variation is shown in Figure 2.

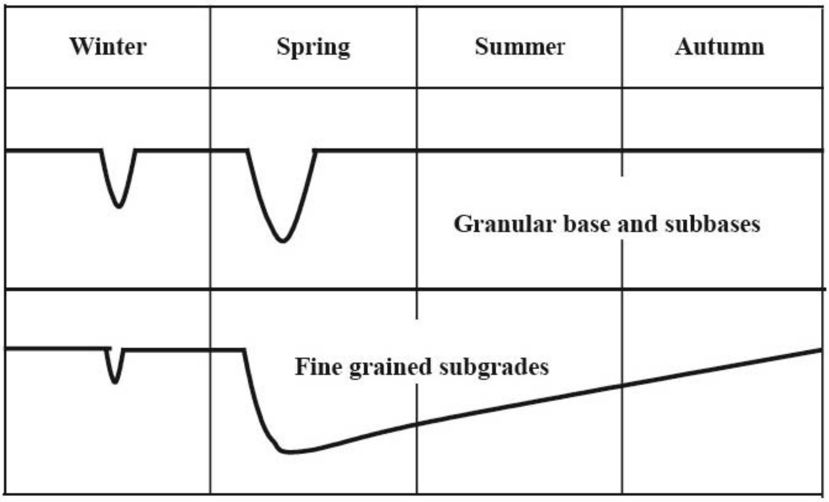


Fig.2: Schematic diagram of seasonal variation of unbound layers stiffness [2]

Freeze thaw phenomena, frost heave, high moisture content and decrease of stiffness and bearing capacity are problems which concern susceptible soils in cold climates. Canadian field studies carried out in Quebec raised this issue. In a full-scale experiment on an existing road deflection and water content measurements were performed. The pavement structure consisted of 18 cm of bituminous layers, 40 cm granular base and a 40 cm thick sand frost-protection layer over a silty subgrade. Large moisture content variation was caused by deep frost penetration (up to 1.5 meters) and greatly affected pavement deflections (Figure 3). The period of decreased pavement structure stiffness lasts about 2 months – generally between February and April [2].

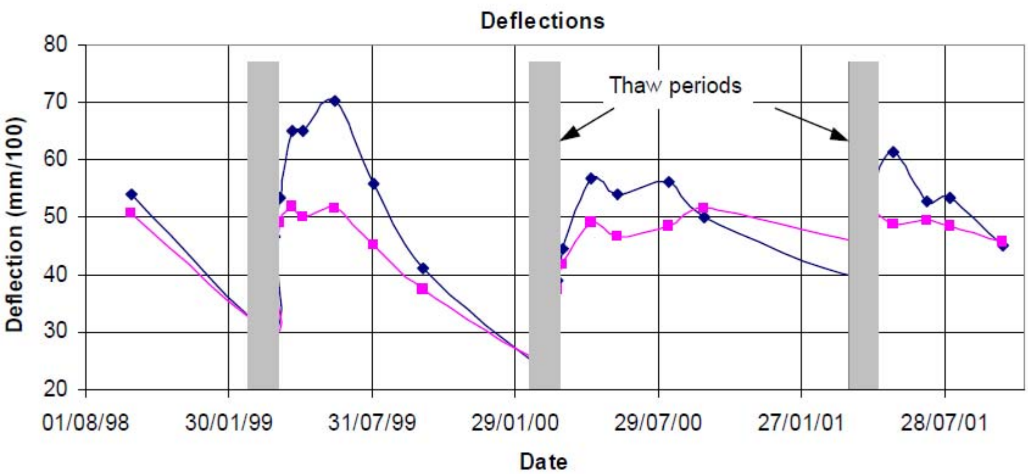


Fig.3: Deflections as a function of time during tests in Quebec. Gray – thawing periods [2]

Accelerated deterioration of pavement construction impacted by excess water was also the subject of Saevarsdottir and Erlingsson studies (2005, 2009) [3]. At the VTI full-scale indoor pavement test facility two road pavement structures (2005 – SE10, 2009 – SE11) were constructed in a 3.0 m deep, 5.0 m wide and 15.0 m long test pit. Both constructions were very similar and consisted of hot-mix asphalt (~3 cm), bituminous road base (7-8 cm), granular base course (7-9 cm), granular subbase (44-46 cm) and fine-graded sandy subgrade. Both road pavement constructions were equipped with:

- εMU coils (vertical strain measurements),
- Soil pressure cells (vertical stress measurements),
- Linear variable differential transducers (vertical deflection measurements),
- Asphalt strain gauges (horizontal strain),
- Moisture content sensors (volumetric water content measurements).

The pavement structure and instrumentation mounted on different depth is shown in Figure 4.

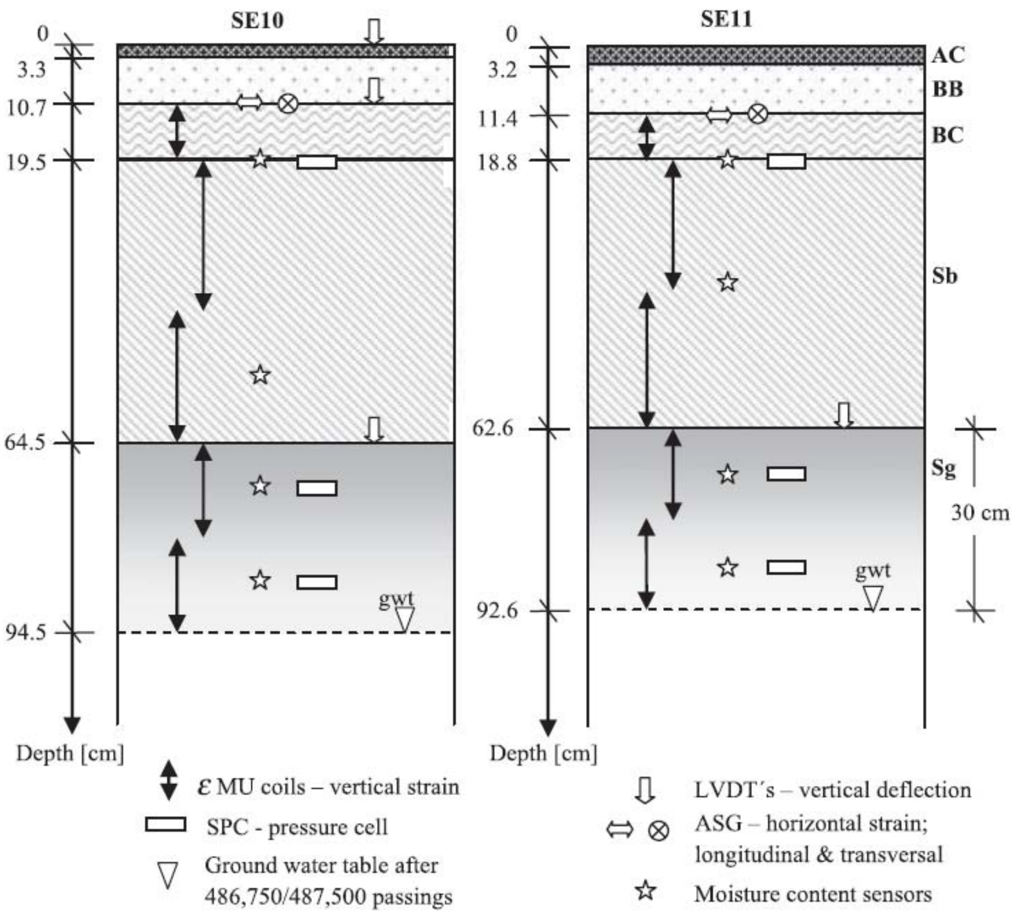


Fig.4: Cross-section of pavement structures SE10 and SE11 with mounted measuring equipment [3]

Tests performed on shown pavement structures using Heavy Vehicles Simulator were divided into three phases:

- Pre-loading phase (20 000 load repetitions),
- Response phase (20 000 – 100 000 load repetitions, various loadings),
- Main phase – accelerated loading test (around 1 million load cycles).

The first phase was performed with a 30 kN single-wheel load with a tire pressure of 700 kPa. In this step main objective was to achieve even compaction in the wheel path. In second phase the response of pavements structure was tested using single-wheel and dual-wheel configuration and different tyre pressures and axle loads. In the main phase development of permanent deformations was monitored using a dual-wheel with 120 kN axle load and 800 kPa tyre pressure. After about 487 000 repetitions test was stopped, water was pumped into the pavement construction pit until it stabilized at level of 30 cm below the top of subgrade layer and then tests were continued. After about 1.2 million repetitions tests were ended.

Erlingsson and Saevarsdottir concluded that raised water level had a great effect on pavement structure. When water was pumped into the construction more vertical strain and less vertical stress were observed in unbound layers and more tensile strain at bottom of the bituminous base was recorded. Water in pavement structure caused a reduced value of resilient stiffness in unbound layers as well as increased permanent deformation were obtained.

4 INTRODUCTORY EXPERIENCES – FIELD TEST ON VOIVODESHIP ROAD 933 (POLAND)

Present investigation objective carried out the response of road pavement construction to an applied variable load in FWD test in different moisture conditions. Research was based on FWD data registered in June 2010 on Voivodeship Road 933 near Jastrzębie-Zdrój in Upper Silesia region. The road has one carriageway with two traffic lanes – each lane in one direction (width of 3.5 m), hard shoulders (width of 1.5 m) and trapezoidal ditches on both sides. Road pavement structure consists of 25 cm AC layers and 35 cm dolomite base course with subgrade classified as silt. Testing site was located in mining activity area of coal mine KWK Pniówek. During the FWD test part of the road surface was permanently deluged, excess water occurred on the road surface, in ditches and on the adjacent area (Figure 5).

Fig.5: Deluged pavement surface of Voivodeship Road 933 in June 2010

The basic measurements performed at the site were FWD tests placed in fifteen reference points on the outer wheel path – seven on lane in direction to Pawłowice (right lane) and eight in direction to Jastrzębie-Zdrój (left lane). Reference points on right lane were located on 155.10 m long section as the points on left lane were arranged on 3.0 m long section. Only five out of fifteen reference points were situated on deluged area, as remaining ten FWD tests were performed on dry road surface (Figure 6). Deflection of pavement surface was registered by nine geophones placed with increasing distance from the centre of bearing plate. Loading plate was a circular disc with a radius of 15 cm. On the right lane in each reference point an impact load of 50 kN was executed, whereas on the left lane a variable impact loads were dropped. The impact load values in particular points are shown in the Table 1.

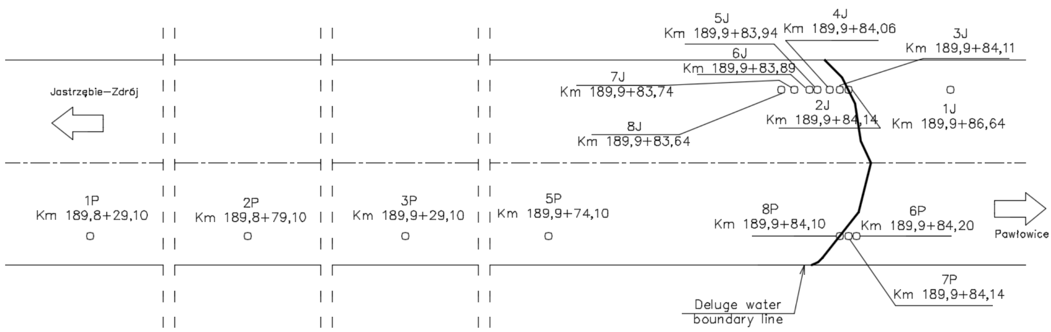


Fig.6: Reference points location on test site

Tab.1: FWD impact load values in particular reference points

	Right lane (Pawłowice direction)			Left lane (Jastrzębie-Zdrój direction)			
Reference point no.	1P; 2P; 3P	5P; 6P	7P; 8P	1J	2J; 3J	4J; 5J	6J; 7J; 8J
Load value [kN]	50	50	50	50	50; 57; 71; 81	50; 57; 71; 81	50; 57; 71; 81

In the article [4] authors divided back calculation methods into three groups (static, adaptive, dynamic) and then distinguished different approaches (i.e. empirical), behaviour of materials (linear, nonlinear) and different optimization procedures (i.e. genetic algorithm). The back calculation procedure was based on the overview of back calculation methods which is shown in Figure 7. FWD data registered on test site were back calculated using path: back calculation methods - static - conventional - linear - parameter identification. Moduli values were obtained using iterative optimization procedures unless the variation of approximation between measured and theoretical vertical deflections was acceptably low. Acceptable value of variation of approximation was described by functions [5]:

$$\Delta = \frac{\sqrt{F/k}}{\frac{\sum_{j=1}^{k} w_j}{k}} \tag{1}$$

In which:

$$F = \sum_{j=1}^{k} (w_j - u_j)^2 \tag{2}$$

where:

w_j - displacement calculated in the model; $w = f(E_i, v_i, h_i, n, a, q, r_j, z_j)$ [mm]

u_j - displacement measured at the surface of pavement at the distance r_j from the load [mm],

k - number of points on deflection bowl [-],

n - number of layers, $k \geq n$,

E_i - moduli value of each pavement layer [MPa],

v_i - Poisson's ratio of each pavement layer [-],

h_i - thickness of each pavement layer [mm].

Registered FWD data were used in a back calculation procedure to obtain layer moduli values. Back calculation analysis was made using Bisar 3.0. In pavement modelling an multilayered elastic half-space model was used corresponding to a non-linear behaviour of subgrade.

Pavement surface model was divided into four model layers:

- Bituminous layer (consists of all bituminous courses),
- Base course,
- Subgrade,
- Elastic half-space (infinite thickness).

As results, decreasing tendency for backcalculated values of subgrade moduli in the surface-deluged direction was obtained. Similar results were observed for unbound dolomite base course (Figure 8 & 9).

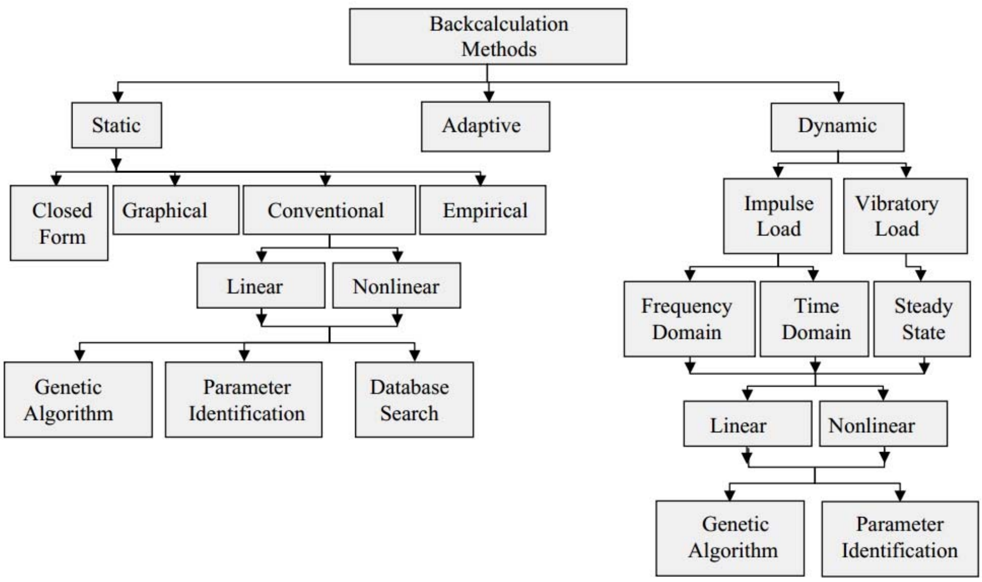
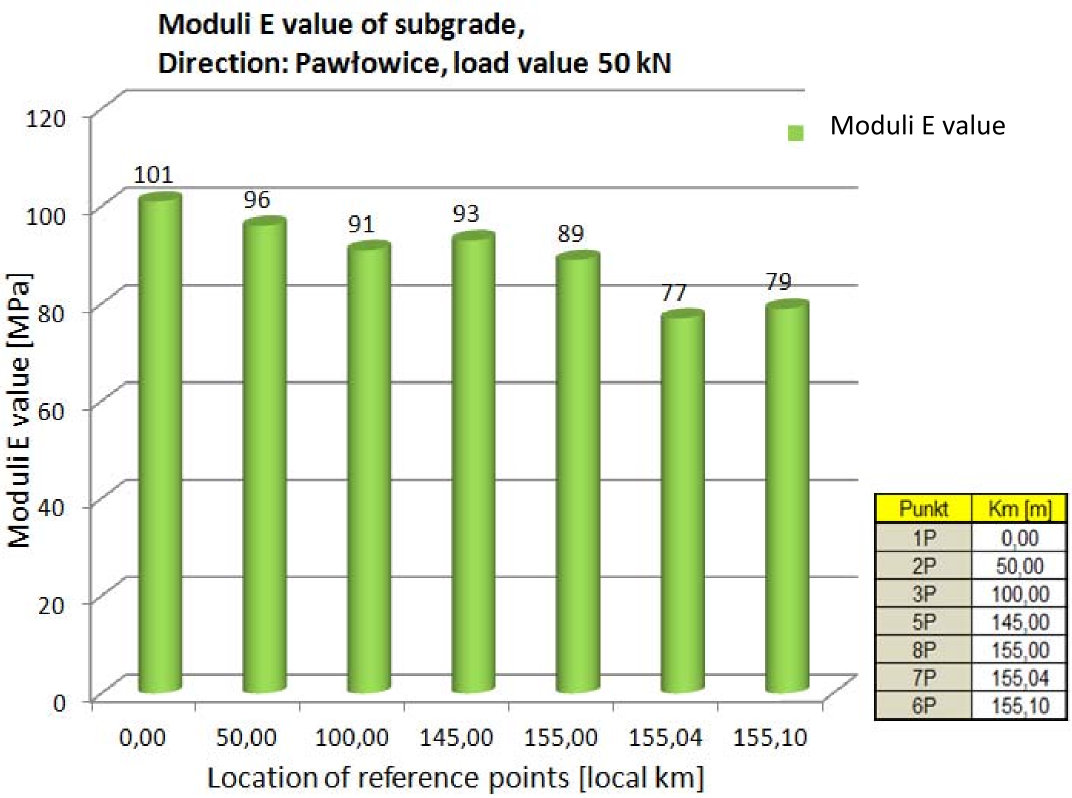


Fig. 7: Overview of back calculation methods [4]



Punkt	Km [m]
1P	0,00
2P	50,00
3P	100,00
5P	145,00
8P	155,00
7P	155,04
6P	155,10

Fig.8: Backcalculated moduli value of subgrade on right lane (direction: Pawłowice)

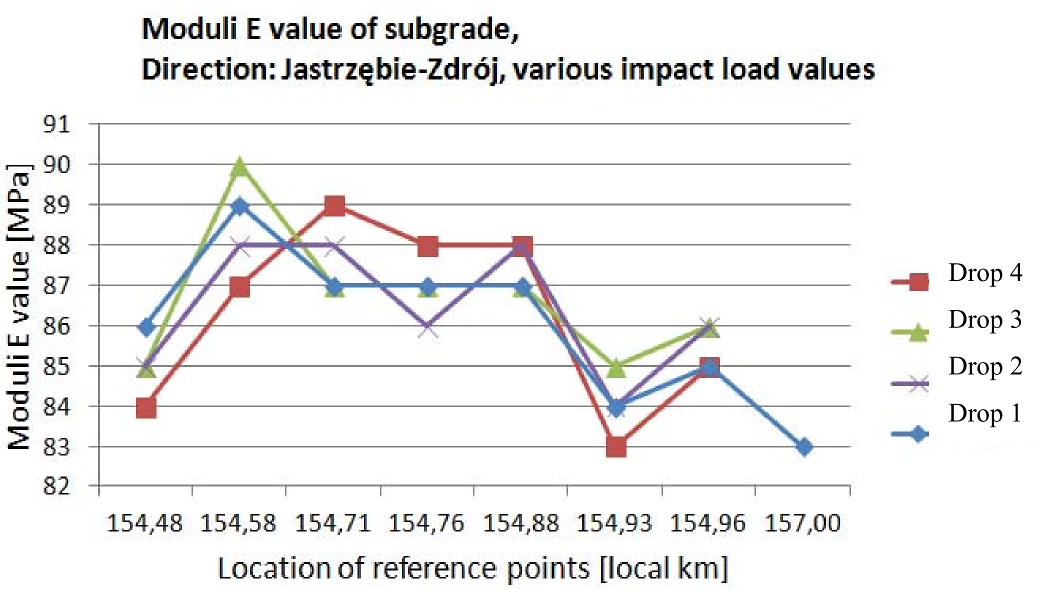


Fig.9: Value of backcalculated moduli subgrade on left lane (Jastrzębie-Zdrój direction)

Furthermore a comparison of field test and backcalculated deflection values based on deflection bowls was carried out. Average dissimilarity was compared using the coefficient of variation. Value of the coefficient alternates between 0.5% to 1.9% what is an acceptable result.

Finally the influence of variable load applied to a pavement structure was considered. This issue was analyzed only on the left lane (Jastrzębie-Zdrój direction) in seven reference points where various loads were applied. Three different parameters were taken into consideration: moduli value, average moduli value and standardized deflection value. Obtained values of moduli reached maximum when load equal to 71 kN was used (subgrade and AC layers) and for unbound base course using impact equal to 50 kN. Similar conclusions were made after analysis of average moduli. The greatest values of average moduli for subgrade and AC layers acquired applying load equal to 71 kN (Figure 10). Maximum value for dolomite base course was observed when the impact equal to 81 kN was applied. Considering standardized deflection values (standardization equal to 50 kN) conclusions were obvious – the highest values were obtained for the applied load equal to 81 kN.

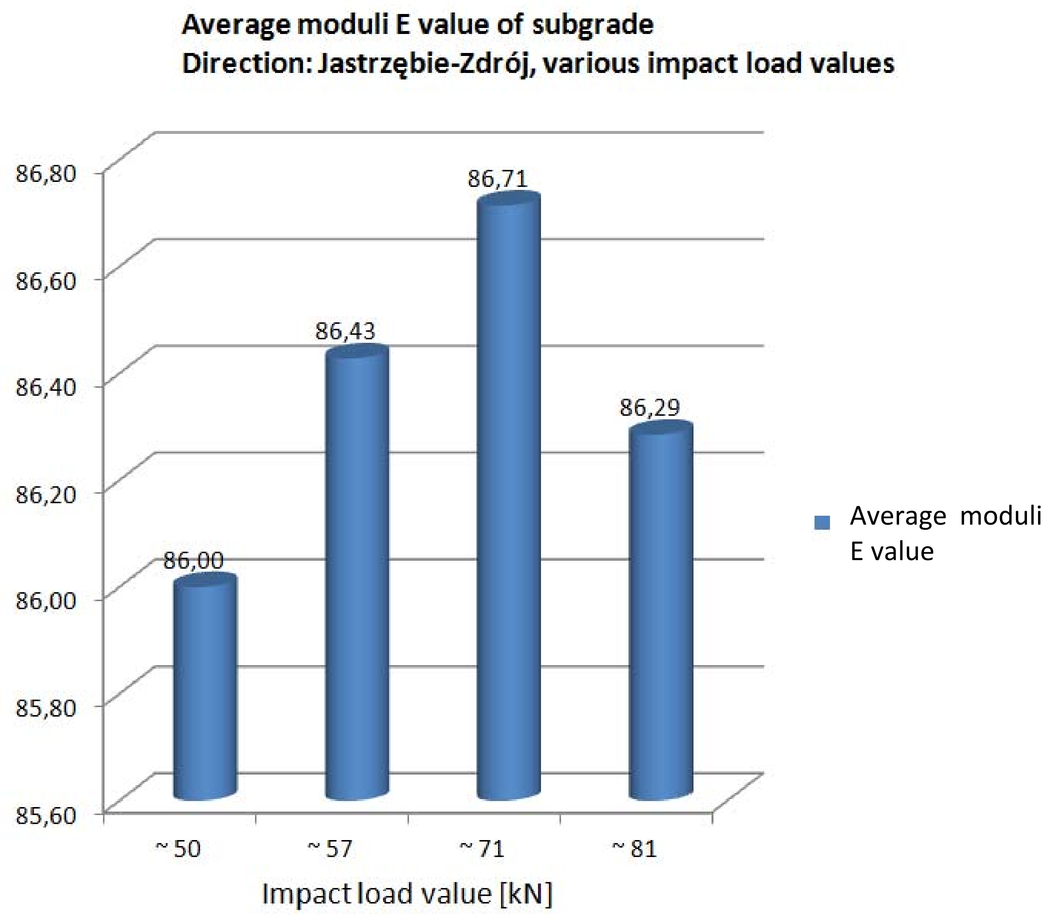


Fig.10: Average moduli E of subgrade obtained on left lane with various load impact values

5 CONCLUSIONS

To sum up, a different response of pavement structure was observed when variable value of load in FWD test was applied. Load value influenced the deflection measurements and hence standardized deflection, and as a result – the moduli value of particular pavement layers. Moreover, the backcalculated moduli values of subgrade show decreasing tendency in permanently deluged road surface direction. Introductory experiences underlined in this paper will be the groundwork for further research.

LITERATURE

[1] KRAWCZYK, B., *Identyfikacja parametrów modeli nawierzchni drogowych na podstawie impulsowych testów dynamicznych*, PhD thesis, Wrocław, 2012.

[2] CHARLIER, R. et al, Water influence on bearing capacity and pavement performance: field observations, *Geotechnical, Geological and earthquake engineering Vol. 5: Water in road structures. Movement, drainage & effects.* 2008, pp. 175-192. ISBN 978-1-4020-8561-1.

[3] SAEVARSDOTTIR, Th. & ERLINGSSON, S., Water impact on the behaviour of flexible pavement structures in an accelerated test, *Road Materials and Pavement Design.* 2013, DOI: 10.1080/14680629.2013.779308.

[4] GOKTEPE BURAK, A. et al, Advances in backcalculating the mechanical properties of flexible pavements, *Advances in engineering Software 37.* 2006, pp. 421-431, DOI: 10.1016/j.advengsoft.2005.10.001.

[5] SYBILSKI, D. et al, *Katalog wzmocnień i remontów nawierzchni podatnych i półsztywnych 2012*, IBDiM, Warszawa, 2012.

[6] SZYDŁO, A., *Statyczna identyfikacja parametrów modelu nawierzchni lotniskowych,* Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, 1995, ISSN 0324-9727.

[7] SIDDHARTHA, R. et al, Drainage and flexible pavement performance, *International Journal of Engineering Science and Technology Vol. 4,* 2012, pp. 1308-1311, ISSN: 0975-5462

[8] SAAD, B., Analysis of excess water impact on the structural performance of flexible pavements, *International Journal of Pavement Engineering,* 2014, pp. 409-426, DOI: 10.1080/10298436.2013.790546.

[9] SALOUR, F. & ERLINGSSON, S., Pavement structural behaviour during spring thaw. Interpretation of FWD measurements by monitoring environmental data from county road 126 at Torpsbruk, *VTI rapport 738A,* 2012, ISSN: 0347-6030.

[10] ZHOU, H., Comparison of backcalculated and laboratory measured moduli on AC and granular base layer materials, in: *Tayabji SD, Lukanen EO, editors. NDT of pavements and backcalculation of moduli, 3. Special technical publication, STP 1375 vo. 3-37,* 2000, pp. 161-172.

[11] MERA, R. F., *Dynamic nondestructive testing of pavements,* PhD thesis, Austin, 1995.