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EFFECTS OF CLIMATIC FACTORS ON THE SHAPE OF DEFLECTION BOWL

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Abstract

Although the pavement structures can be characterized by several condition parameters and thus qualified, some kind of load-bearing capacity parameter is one of the most important features. Nowadays there are many theoretical approaches and practical methods to define but the detection of the deflection of the structure caused by vertical load is still the most widely used. Presently the dynamic falling weight equipment is not only becoming more common but it is accepted in addition to the previous and widely recognized, so-called Benkelman beam method. This type of equipment called FWD is available in Hungary since the 90's. It is well known that this device can record not only the deflection under load, but the deflections also at arbitrary distance from load axle. So the new overlay design method that is currently under development by Hungarian Road Administration has been established based on this tool and, contrary to the previously used on, it experienced, requires the recording of the deflection bowl.

However, the deflection bowl and the shape factors describing it depend not only on the load-bearing capacity of the pavement structure and the magnitude of load force, but also the measurement conditions also, especially the climatic conditions during the measurement (e.g. temperature, precipitation conditions) have significant impacts on it. Because of these effects are quite environment specific, it is advisable to study their impacts through a more thorough examination of trial section so the distorting effect of these factors can be eliminated. In this paper, evaluations of four-year of meteorological data and deflection measurement series on a Hungarian road section were carried out to examine the change of the deflection bowl's parameters at different time points during the tests. In particular, the study focuses on the development of a correction factor that would be made based on the evaluation of the measuring results.

Keywords: pavement deflection, subgrade modulus, temperature, precipitation, seasonal effect

1 Introduction

The application of seasonal coefficient during the evaluation of deflection data is very important. The bearing capacity is one of the most important condition parameters of the pavement structures. This definition refers to a theoretical limit, showing the unsuitable condition for its intended use. It follows that this value cannot be measured directly in practice. Although today several measurement methods are available to make conclusions on the actual load-bearing capacity of the pavement structure, the deflection measurement is the most common method. The pavement condition can be characterized just limitedly by a single deflection value it, may even be misleading, so it would be more appropriate to record the whole deflection bowl. This problem has been overcome by the development of measurement method and appearance of falling weight deflectometer and that is widespread in the recording of the deflection curve. Two external factors complicate largely the study of the relationship between the deflection bowl and the load-bearing capacity of pavement.

One of the parameters is the strong temperature dependence of pavement layer. The instantaneous temperature of asphalt layers affects significantly the shape of deflection bowl. Several methods are available to overcome this effect, but the complexity of the problem does not allow the creation of a universal formula. The other important effect is the condition of the subgrade. The deflection measurement examines the integrated condition of pavement and subgrade, thus the condition change of subgrade influences the measured deflection data. Fig. 1 illustrates the influence of these two dominant effects on the deflection bowl.

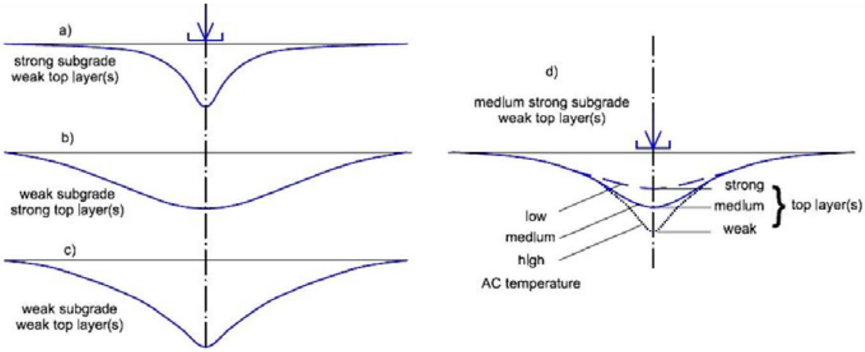

Figure 1 Deflection bowls of different pavement structure types [1]

Although this effect depends on the geographical location, but the period, when the highest deflection values can be measured because of the weak bearing capacity of subgrade after the wetting, occurs at the late winter snowmelt and the spring rains in the typically European climatic condition. This period is considered critical in terms of the remaining service life of pavement and these deflection values are considered as characteristic for the performance of structure. This critical period is also called as "spring deflection" in the literature. The deflection measurements are concentrated in this period in 60's and 70's, but later this measurement period extended to the summer and autumn months. As a result, the use of seasonal has seemed to be necessary.

According to the current Hungarian Standard [2], the deflection measurements must be done in the most unfavourable spring period March to May by reason of wetting before the year of overlaying. The results measured other periods must be converted for the most adverse period. The determination of correction factor is recorded in a Hungarian Standard [3]. It can be calculated using monthly measured deflection values at least for a year on a similar pavement structure, and comparable soil and hydrological condition, between 1 March and 15 June measured values divided by the values recorded at the time of measurement.

If it is not possible, correction factor's approximate values can be taken of Table 1.The seasonal factors can be obtained depending on the type of soil and the date of measurement. The value of seasonal multiplier equals to 1.0 in the characteristic period. The coefficients are good for the case of dry and wet region and hot mix asphalt layers above 100 mm total thickness, in other cases the values in brackets on Table 1 can be used.

However, the observed changes of climatic condition in the past decade have raised the need to update this element of Hungarian Regulation. Accordingly, the standards draft under development has a new approach. The correction of the standard subgrade condition is recommended to perform on the basis of the precipitation before measurement with the correction values indicated on Table 2. It means that the deflection values should be increased with the values on Table 2 that depend on the precipitation amount of previous two months (60 days) and the soil type.

Table 1 The seasonal correction factors [2]

Soil classification	The month of deflection measurement				
	April	May	June, July	August, September	October, November
I-II.	1.0	1.0	1.0	1.0	1.0
III.			1.1	1.1	1.2
IV-V.		1.1	1.3 (1.4)	1.5 (1.6)	1.5 (1.6)
VI-IX.	1.1	1.0	1.1 (1.2)	1.2 (1.4)	1.3 (1.5)

Table 2 Proposed correction values of the critic subgrade condition [4]

Soil class.	Negative difference of 60-day precipitation balance before deflection measurement multi-year average				
	No or positive difference	Below 10%	Below 20%	Below 30%	More than 30%
I-II.	1.0	1.0	1.0	1.0	1.1
III.	1.0	1.0	1.1	1.1	1.2
IV-V.	1.0	1.2	1.4	1.5	1.6
VI-IX.	1.0	1.1	1.3	1.4	1.5

This paper examines how close relationship can be observed between the precipitation conditions before measurement and the subgrade modulus estimated from FWD results. First, the deflection measurement results carried out every hour at the same cross-section in spring and summer reviewed, in order to estimate the effect of daily temperature fluctuation on subgrade modulus. Then it will be examined which relationship can be found between the measured data and the meteorological conditions of the period before measurement by using deflection series measured on Hungarian motorway traffic lanes.

2 The relationship between the temperature and the shape of deflection bowl

It is known that the temperature affects pavement layers moduli, thus also its load-bearing capacity and deflection. Earlier the relationship between the air and pavement temperature and deflection was investigated. The measurement was carried out by FWD device, therefore, it could be analysed the relationship between the temperature and not only the central deflection, but the whole deflection bowl. The measurements were carried out between 6 a.m. and 7 p.m. in April and August.

Fig. 2 shows the hourly deflection results. It can be seen that the deflection measured at any distance from load axle continuously progressively increased as temperature rise during the day, and then slowly reduce. The rate and extent of increasing and decreasing are not the same, because the changes of air and pavement temperature are at the same either. Difference of approximately 40% between the maximum and the minimum value of the central deflection has been experienced on the test days. The difference between the maximum and minimum values decreases gradually moving away from load centre. This difference can be even 15-18 % at the distance of 600 mm, while the fluctuation within a day is less than 10% at 900 mm and greater distance.

Temperature correction is generally used just for the deflection of first 4-5 sensors. Jansen developed correction formula for the deflection in 0, 200, 300, 450, 600 mm from load centre [5]. If the deflections (Fig. 2) under back sensors measured in April and August are compared, it can be seen that there is no relevant difference between the values, which is confirmed, that the temperature correction is not necessary for the deflection above 900 mm distance.

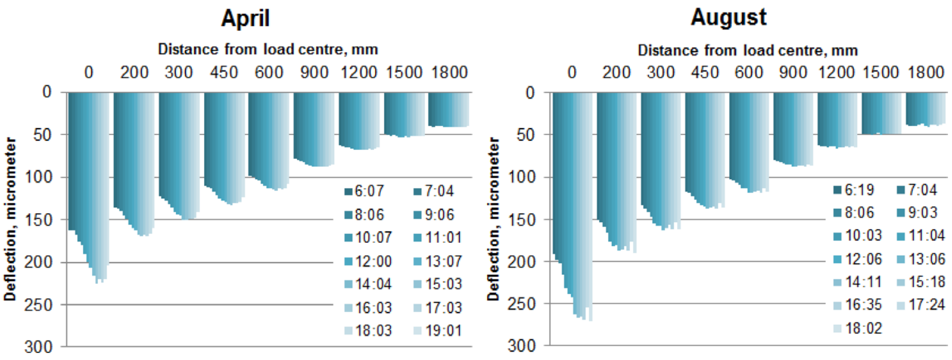

Figure 2 Hourly measured deflections

If the deflection bowls are plotted as a function of hourly recorded deflection, it can be seen that the shapes of the bowls are almost the same from the distance 900 mm. Many conclusions can be drawn for each pavement layer using the parameters (SCI, BDI, BCI) deduced from the shape of deflection bowl. While the difference between D0 and (typically) D300 provides information about the condition of top layer, the bearing capacity of subgrade can be estimated from the deflection values measured in a distance 900 mm or more. Hereafter the paper deals the relationship between the subgrade condition and deflection bowl.

3 The evaluation of subgrade condition using FWD measurement results

The performance of flexible pavements under load can be examined by the Boussinesq-formula with a good accuracy approximation, [6]. However, it is the generally accepted relationship that the modulus at distance “r” from the load centre is the same as the modulus of layer in depth “z=r” under the load centre.

$$E_{eq(r)} = \frac{\left(1-\nu^2\right)\sigma_0 a^2}{r * d_0} \tag{1}$$

where:

$E_{eq(r)}$ equivalent surface modulus at distance r from the load centre, MPa;
r distance from load centre, mm.

German researchers [7] analysed the currently used evaluation correlations of FWD test. The surface modulus calculated from the deflection at the distance of 1200 mm from load axle has chosen as the best characteristic of subgrade bearing capacity. It can be determined on the basis of Eq. (1). Jendia proposed the application of the deflection values of sensors in higher distance from load centre [8]. Jendia introduced the subgrade indicator (UI) as a definition. According to Swedish research works, the subgrade modulus can be properly estimated by the following formula [9]:

$$E_{subgrade} = \frac{52000}{d_{900}^{1.5}} \tag{2}$$

4 The subgrade modulus test series on a motorway section

The proposed Hungarian regulation takes into account the seasonal fluctuations because of the climatic effects with the correction in Table 1. However, just few measurement results are available to validate of these values; therefore the results of measurements carried out for other purposes were also examined here.

For four years, every six months the deflections of a Hungarian motorway section were compared with the precipitation of the given period. The FWD measurements were carried out in each (travel, overtaking lane, paved shoulder) lane, every 100 m, 45 cross-sections per lane (4500 m). Two-two measurements were done in November and December, and others in summer months. 6 million ESAL (100 kN) ran on the travel lane during the investigation. According to the weather station close to the section, the total amount of rain was 3000 mm. The temporal distribution of the last five years precipitation in each month is shown on Table 3.

Table 3 Cumulative monthly precipitation amount, [mm]

Year/Month	2009	2010	2011	2012	2013	Average	Total
1	53.6	82.9	22.9	30.9	58.8	49.82	249.10
2	48.2	71.5	15.0	22.9	84.5	48.42	242.10
3	48.8	20.9	43.5	0.4	92.8	41.28	206.40
4	1.8	71.7	20.3	18.5	19.9	26.44	132.20
5	41.1	160.6	40.9	23.6	106.8	74.60	373.00
6	84.5	83.9	59.0	95.0	61.5	76.78	383.90
7	34.9	87.8	57.6	98.3	0.1	55.74	278.70
8	46.8	77.9	5.3	1.1	39.0	34.02	170.10
9	14.4	95.5	1.1	48.5	24.7	36.84	184.20
10	28.3	24.7	14.9	77.0	42.2	37.42	187.10
11	89.2	73.3	0.0	15.4	42.7	44.12	220.60
12	43.6	121.7	69.9	48.9	1.1	57.04	285.20
Total	535.2	972.4	350.4	480.5	574.1	582.52	–

Extremely rainy months were not observed. The maximum of cumulative precipitation amount of the test period is in June, although this month was not the wettest in any of the five years. This is slightly different from our expectations, because April or May is considered the wettest months. Another interesting anomaly is that the wettest month of 2012 was the driest in 2013. These results did not confirm to the existence of the critical spring period, therefore the revision of Table 1 is justifiable. It is noted, that the impact of late winter snowmelt has not been taken into account. However, the deflection measurements were performed between May and December, so this effect does not influence the following results.

Many options are available to estimate the load-bearing capacity of pavement layers, as shown in Section 2. Other correlations also use D_{900} or D_{1200}. These values have strong correlation with each other, so the determined correspondences would be justified for the application of other estimation formulas of subgrade modulus. The estimated subgrade moduli were determined by Eq. (2), after that the characteristic was calculated. The strength of the relationship between subgrade moduli and the rain amount of 30, 60, 90 days before the measurement was examined. In the case of the overtaking lane, the subgrade moduli had a close correlation with the precipitation amount of 30 or 60 days, but this close relationship was not detected for 90-day values, Fig. 3 and Table 4 s that. The correlation between the 30-day precipitation and the subgrade moduli of paved shoulder is detectable, but it was not clear neither in the case of 60 and 90-day data, nor the results of travel lane.

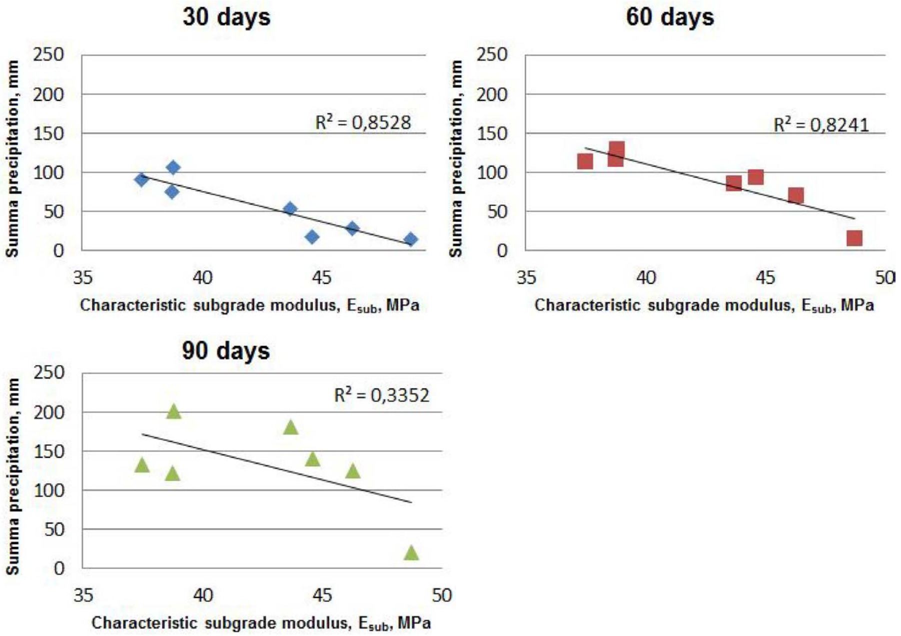

Figure 3 Correlation of overtaking lane

Table 4 Correlation between cumulative monthly precipitation amount and subgrade modulus

Number of examined days	Overtaking lane	Travel lane	Paved shoulder
30	0.85	0.21	0.64
60	0.82	0.12	0.38
90	0.34	0.00	0.08

In accordance with the above mentioned close relationship between the subgrade moduli based on deflection bowl and cumulative precipitation amount of the days prior to the measurement can be detected only under certain conditions. The results show that the closest connection was in the case of 30-day period before measurement, and worst values arose in the 90-days period. Furthermore, it is an important statement that the highest correlation was seen at the overtaking lane and the paved shoulder. Both lanes are connected directly to the unpaved shoulder and central reserve with one of their edges helping the direct entering of rain under these traffic lanes obviously. In case of paved shoulder, this connection is influenced by the condition, size and slope of shoulder, the height of embankment, etc. In our opinion, these factors affect the degree of wetting of paved shoulder together, so it results in weaker relationship. In this regard the situation of travel lane is special because it is not connected directly to the central reserve thereby it reacts slightly the precipitation preceding the measurement that the estimated moduli are not correlated with the cumulative 30-day amount of rain. It increases the importance of this statement that the traffic load of this lane is the characteristic in the course of overlay design. The temperature correction developed on this traffic lane does not correct but even worsens the results of load-bearing capacity.

5 Conclusion

The current Hungarian overlay design method is under revision, and our investigation shows that it is possible to convert the deflection results to “spring deflection” using factors depending on the actual month. The meteorological data and the accumulated experience show that the distorting effect of this approach can be significant.

In accordance with a new approach, the seasonal fluctuations of load-bearing capacity of pavement would be advisable to correct it using the amount of precipitation before measurement, it influences the subgrade modulus. The associated tests were done on low traffic load, 2*1 lane road with low height of embankment. The aim of this paper is the investigation that the proposed corrections can be applied if the drainage of motorway section functions well and the section is located on embankment.

In accordance with our results, it is verifiable that there can be a close relationship between the characteristic subgrade moduli and the previously cumulative precipitation. Although, based on our analysis, the relationship is closer in the case of the amount of 30-day precipitation than the 60-day one. The implied water movement will be different on a multi-lane motorway located on high embankment from that based on the behaviour of minor roads. Our proposal is that the correction mentioned could not be used for design of travel lane of motorway; separate correction should be created for it.

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