Structural Road Surveys Using a Curviameter Device. Analysis of the Temperature Effect on Asphalt Mixes Properties

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ABSTRACT: Non-destructive deflection testing is one of the most reliable methods available to determine the structural condition of an in-service pavement. The measured pavement deflection is used to determine the structural adequacy of a pavement, related to the number of allowable load repetitions. There are different systems used to measure pavement deflections. The curviameter is one of the most appropriate devices for the measurement of deflections in an extensive Roadway Network for a Pavement Management System. It enables areas with a homogeneous behaviour to be determined as well as to locate singular points of low bearing capacity. The measurement is done at a speed of 18 km/h, taking measurements every 5 m. The system determines the entire deflection bowl defined by sampling 100 points on each measurement. In addition, a literature review of the temperature effect on asphalt mixes behaviour is presented. Also, in order to analyze the effect of the pavement temperature during the test on the asphalt mixes elasticity modulus, an experimental test was carried out. It consisted of three deflection tests using curviameter device, at different temperatures, in a section of road with flexible pavement. A temperature adjustment factor for asphalt mixes elasticity modulus is obtained from the experimental study. Finally, this experimental factor and those deduced from the main existing models are compared. The comparative analysis performed shows, in general, a good agreement between the temperature adjustment factor obtained from the experimental study and those deduced from the existing models.

KEY WORDS: Curviameter, deflection bowl, road network, asphalt mix elasticity modulus, temperature adjustment factor.

1 INTRODUCTION

It is not possible to directly measure the bearing capacity of a road. However, it can be calculated on the basis of the information the deflection bowl gives about the size, shape and depth of the deflection being produced on the pavement’s surface when the road undergoes a certain load. The pavement deflections are used to define the structural condition of the road and allow for the decision making -among others- of the maintenance or rehabilitation steps needed to bear a specific traffic volume over a certain period of time.

The idea of bearing capacity is not solely limited to the overall behavior of a road’s pavement, but it must also be considered on each of the layers that make up the pavement, from its subgrade to the wearing course layer. That is, it is a concept that arises during the project stage and that includes all the construction stages. Nevertheless, this concept is really linked to the in-service roads' management and the pavement rehabilitation projects.

Below there is an explanation of the main features of the curviameter measuring system and the fields of application. Its suitability for the road network management by means of a systematic and high-resolution survey will be highlighted, which enables to establish well-identified and located areas with an indicator as sensitive as the deflection bowl.

In addition, an experimental analysis of the temperature effect on the asphalt mixes behaviour is presented. The results obtained are compared with different existing studies.

2 DEFLECTION MEASURING DEVICES

First of all, it is important to note that it must be possible to compare the obtained deflection measuring by means of any given device and the ones performed by the rest of measuring devices. In a nutshell, the main deflection survey devices currently used are included in table 1. It is important to note that table 1 only includes systems that measure the maximum deflection and the entire deflection bowl. There are different published correlation studies among these systems.

Table 1: Deflection measuring devices. (Benatov and Sánchez, 2007)

Measuring device	Test standard	Measuring speed
Benkelman Beam	NLT-356, 1988	Punctual
Falling Weight Deflectometer	NLT-338, 2007	Punctual
LaCroix Deflectograph	NLT-337, 1992	2 – 4 km/h
Curviameter	NLT-333, 2006	18 km/h

Regarding the standardization of the obtained data, we must indicate that there are several correlation tests among the different deflection systems, one of the most complete ones being the one included in the Action Cost 324, 1997, with the participation of many countries.

However, each country usually performs its own correlation tests and adopts the obtained conversion coefficients on their own roads.

3 DESCRIPTION OF THE CURVIAMETER SYSTEM

Curviameter test standards and documents (French NPF-98-200-7, 1991, Belgian 54.26, 2002, Spanish NLT-333, 2006, German FGSV 433 B 4, 2011, among others) include a detailed description of the measuring system and the test preparation, the sensors calibration, as well as the measurement's principle and procedure.

The curviameter is a measuring system made up of a Caterpillar-type chain (Figure 1) that, thanks to the needed mechanisms, rotates in a synchronized way with the truck on which it is installed. Said truck has two axes, 5 meters away from each other, whose back axe –a simple axe with twin wheels- applies a load that can be adjusted (between 80 and 130 kN), following what each country standard states.

The data acquisition is performed at a speed of 5 m/s (18 km/h) and is repeated every 5 m. On each point the entire bowl pavement deflection is determined over a length of 4 m, 3 of them corresponding to the back part of the truck, behind the back axe, where it is not affected by the front wheel. The bowl deflection is defined by 100 points on the said length of 4 m.

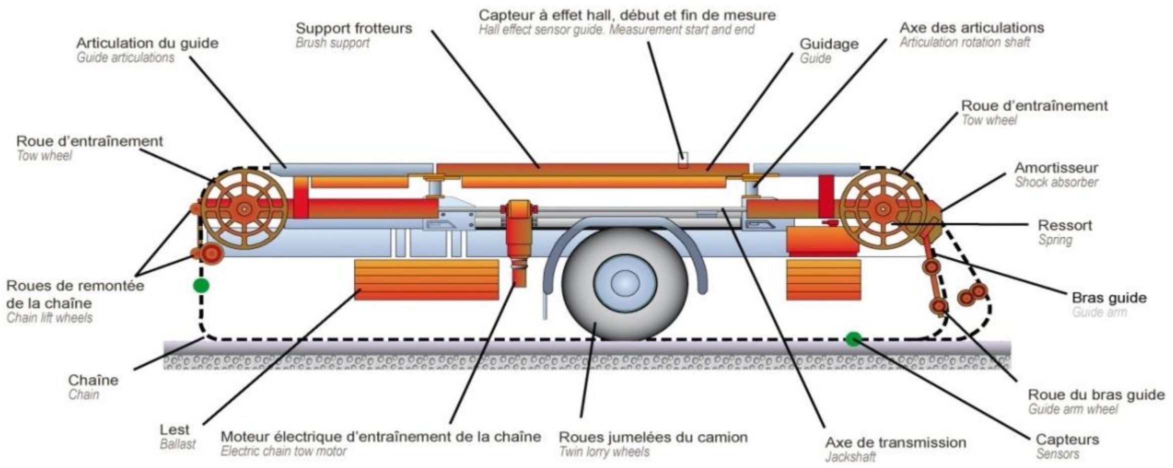

Figure 1: Diagram of the measuring system. (Sánchez and Ramos, 2007, Sánchez, 2008)

4 FIELDS OF APPLICATION

The curviameter is a device aimed at the measuring of deflections, which thanks to its high performance, -reaching more than 100 km of lane measuring on a single day, with a recording of 1 measurement point every 5 m- and the reduction of the time of lane occupation –the speed of measuring does not make it necessary to close the lane, thus improving the road safety- has been frequently used in different countries (Spain, France, Portugal and Belgium). Moreover, there has been an international repercussion reaching other countries, both in Europe (Germany and Poland among others), and America (like Mexico and Brazil).

Taking the performed surveys and the gained experiences, it has been proven that this device can be regarded on these fields of application (NLT-333 Standard, 2006):

- In the road network management area as a tool that enables the overall assessment of the structural conditions of the pavement.
- On a project level to be able to perform the technical decision-making to design the needs of rehabilitation the pavement has.
- During the construction control stage, evaluating the bearing capacity of the built layers, with the aim to perform the accepting of the finished units.

When performing the survey of a network -and always bearing in mind the final possibility of developing analytical models that enable to assess the pavement behavior- it is necessary for us to carry out automated inspections of the network's condition that, at least, measure the deflections, wearing course appearance longitudinal profile, macrotexture and the skid resistance, following what has been stated on the Cost Action 324, 1997.

Regarding the deflection, its measuring must be performed just as it is shown in the Cost Action 325, 1997, in order to achieve different goals, like the following among others: to research the need for rehabilitation, obtain the stiffness modulus of the different pavement layers, calculate the pavement's residual life, evaluate the structural capacity, identify areas with a worse behavior, establish priorities regarding the road rehabilitation, survey every layer of the pavement during the construction stage, plan the maintenance and new research.

In case of a vast road network, it would be convenient to determine the deflection with a device that combines the speed during the data acquisition and the possibility of recording the entire deflection bowl in order to analyze the pavement's behaviour. The features of the curviameter device make it the most suitable system to measure the deflection in a large road network with respect to a System of Pavement Management.

5 TEMPERATURE EFFECT ON ASPHALT MIXES BEHAVIOUR

The passing of traffic makes the pavement to deliver a response (stress and strains) on the load's affected area. The deflection is therefore known as the vertical strain that is produced on the surface. The pavement deflections are key to determine its bearing capacity.

In the case of flexible pavements, the response the materials -which make up the pavement and its subgrade- deliver to the application of a certain load depends mainly on the pavement's structure, the applied load and the maintenance condition of the constituent materials, as well as on environmental factors, like the pavement's temperature and the subgrade's moisture. Therefore, when analyzing the surveyed deflections, it needs to be considered that they can be affected by different factors beyond the measuring, among which the pavement's temperature and the subgrade's moisture (Álvarez y Carceller, 2008).

The majority of the factors that determine the response of the pavement vary over time in a progressive way, like the materials' condition or the subgrade's moisture. On the contrary, the temperature of asphalt mixes changes throughout the day.

In this regard, it should be indicated that the temperature of an asphalt mix is central in order to determine its behaviour. The stiffness of an asphalt mix depends considerably on both its temperature and the frequency of the applied load. Its stiffness increases as temperature decreases, thus behaving almost like an elastic solid, whereas it decreases as temperature increases, which emphasizes its viscose nature (Ortiz, 2004).

Table 2. Connections between E_T and T

Authors	E_T depends on:
The Asphalt Institute, 1982	E_{Tref}, T, T_{ref}
Ullidtz, 1987	E_{Tref}, T
Ullidtz and Peattie, 1982	E_{Tref}, T, T_{ref}
Great Britain Highways Agency, 2008	E_{Tref}, T, C
Baltzer and Jansen, 1994	E_{Tref}, T, T_{ref}
Kim et al., 1995	E_{Tref}, T, T_{ref}
Chen et al., 2000	E_{Tref}, T, T_{ref}
SHRP, 1993	T
St-Laurent, 2000	T
Lee et al., 1988	T
Ali and López, 1996	T

Throughout time, many studies connecting the asphalt mixes' elasticity modulus to the pavement's temperature have been developed. Table 2 (Ramos and Castro, 2011) shows some of the most important ones. These studies adopt a fixed load frequency, generally close to 10 Hz. It should also be pointed out that different relationships have been established for each case, since said studies depend on experiences, performed tests, and environmental and materials features for every area. Nevertheless, all of them have something in common –the asphalt mixes stiffness increases when the temperature decreases, and viceversa.

In general, the variables used in the models are the asphalt mixes elasticity modulus at test temperature (E_T) and the representative asphalt test temperature (T). Nevertheless, other variables, such as the adopted reference asphalt temperature (T_{ref}), the asphalt mixes elasticity modulus at reference temperature (E_{Tref}) and the cracking state (C) have been used.

6 EXPERIMENTAL STUDY

An experimental study was carried out with the aim to check -as an experimental approach- the effect the temperature has on an existing flexible pavement. Three deflection tests at different temperatures were carried out.

A 480 m long road section, which was located in the North area of Madrid around 200 km away, was selected. The pavement structure is composed of 150 mm of asphalt mixes over a 200 mm thick granular base. The subgrade consists of unbound granular materials. This studied road section exhibits a good appearance, with not important surface damages. This pavement structure was selected for research because it is one of the commonly used pavement structures in Spain for roads with a low-intermediate traffic volume (6.1-IC, 2003).

To ensure identical test conditions, all tests were carried out in the same day, thus removing the influence other factors might have on pavement behaviour, such as subgrade moisture changes or reductions in pavement residual life because of traffic loads.

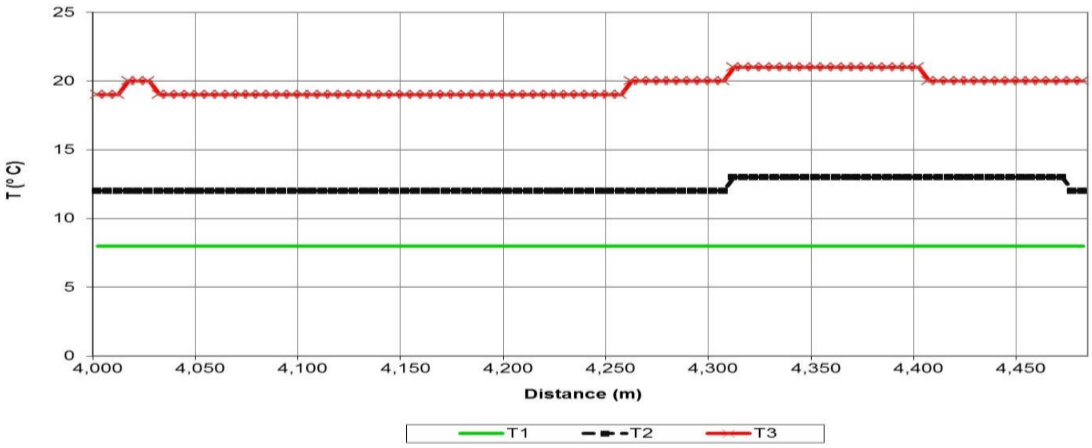

Figure 2: Test representative asphalt temperatures (T).

T1, T2 and T3 (figure 2) are the test representative asphalt temperatures obtained, using Bells3 equation, during tests 1, 2 and 3, respectively.

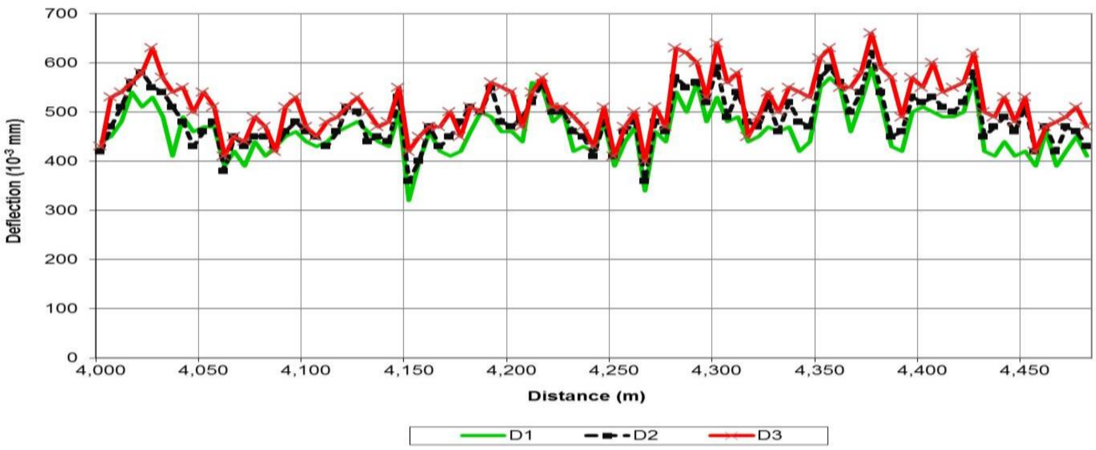

Figure 3: Measured pavement deflections using curviameter device.

The measuring device that was used in the experimental study was the curviameter. All of the measurements were performed with the same device. The tests took place on a cloudless

March 2012 day, with the intention of taking advantage of the pavement's temperature differences. On this point figure 2 shows representative asphalt test temperatures (T). These temperatures were obtained by applying the Bells3 equation, which is normally used in the routine test procedures. This equation (Lukanen et al., 2000) established that the representative asphalt test temperatures are function of the pavement surface temperatures registered by the device during the tests, of the depth that determines the asphalt mixes temperature, of the average air temperature the day before the test and the hour at the moment the test is carried out, which is expressed in decimal format in a 24-hour system. Additionally, two holes were performed on the pavement at the beginning and end of the section being tested, following the indications of the Cost Action 336, 1999. The results obtained from these punctual temperature measurements were very similar to the ones deduced from the application of the Bells 3 equation on said measuring points. This confirms the validity of the use of said formula on the section under study and the tested conditions.

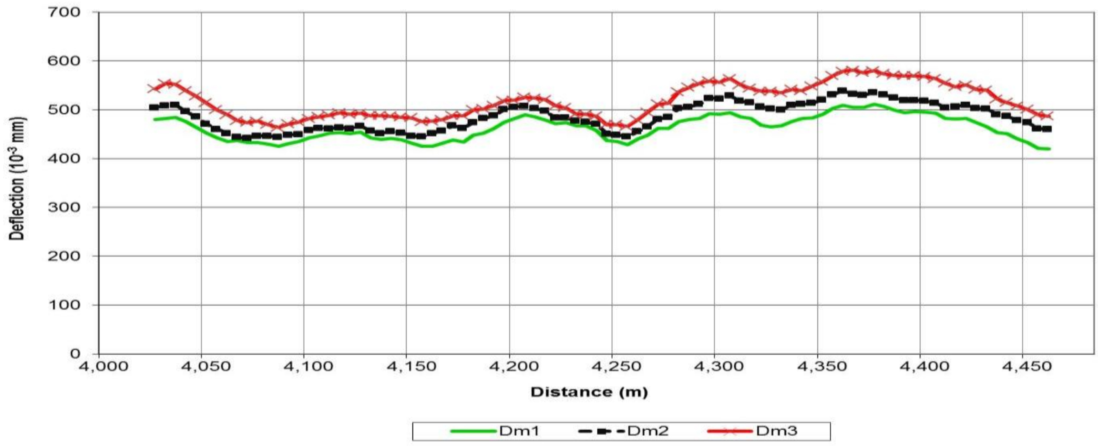

Figure 4: Measured pavement deflections. Moving average deflections every 50 m.

Figure 3 shows the deflections surveyed by the curviameter device (D1, D2 and D3). Additionally, the moving average deflections in intervals of 50 m long (Dm1, Dm2 and Dm3) are represented in figure 4. This average minimizes the effect that could produce a longitudinal displacement of the sensors at each measurement point among tests. The large number of data registered during each test run (97 entire deflection bowls in less than 2 minutes) makes it possible to carry out an analysis like the ones mentioned above (moving average). Both figures reveal the effect the temperature has on the performed measurements.

7 ANALYSIS OF RESULTS

This section analyzes the results of the surveys performed by the curviameter device. Firstly, we proceed to statistically analyze the data of each test run, taking advantage of the large volume of information, which enables to define in a detailed way sections with a homogeneous behaviour. Without delving too much, the used calculation method divides the areas depending on the variance, and once they have been separated, it checks whether each of the adjacent areas represents a standard population, if not, the cutting process is restarted.

Following the homogeneity criteria established in the Spanish standard, the surveyed deflections on the entire section under study (480 m long) are homogeneous, without the need to divide the section into several subsections with homogeneous behaviour. As the representative values of the recorded deflections on each test run, the average deflection value has been adopted (462.10^{-3} mm of maximum deflection in test 1, 486.10^{-3} mm in test 2 and 517.10^{-3} mm in test 3).

Secondly, the elasticity moduli at test temperature of each material that makes up the pavement and its subgrade have been obtained by means of back-calculation (see Table 3). To do so, the data recorded by the curviameter device -which determines the entire deflection bowl defined by sampling 100 points on each measurement- was used. Following the pavement structure information, it has been modelled in three independent layers: asphalt mix, granular base and subgrade (unbound granular materials).

It is important to stress that, in flexible pavements the temperature effect on the materials that make up the subgrade and the pavement -with the exception of asphalt mixes- is minimal (Chandra et al., 1988, Wolfe and Randolph, 1993, among others). Therefore, it has been fixed in the different test calculations that the elasticity moduli of the rest of materials are equal, where only the asphalt mixes elasticity modulus (E_T) is the one varying with temperature.

Table 3. Obtained elasticity moduli at test temperature

Test number	Elasticity moduli at test temperature (MPa)		
	Asphalt mixes (E_T)	Granular base	Subgrade
Test 1	4436	205	86
Test 2	5853	205	86
Test 3	7328	205	86

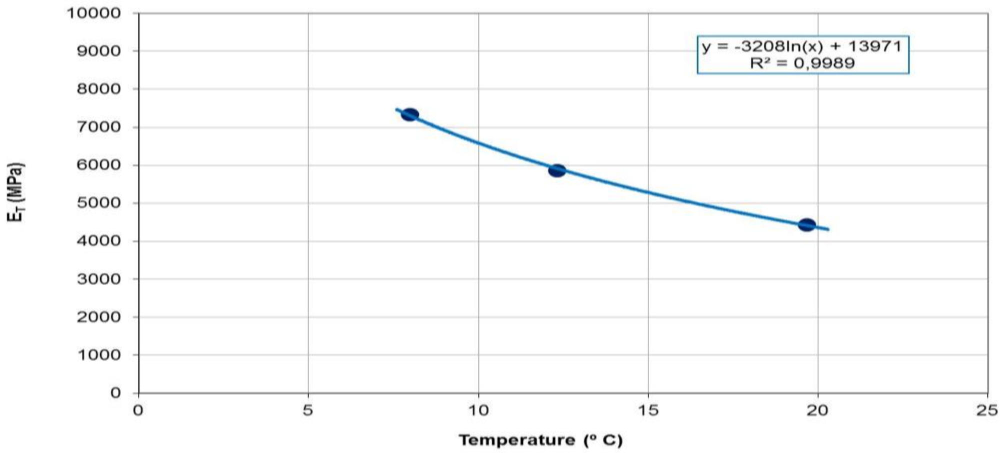

Figure 5: Asphalt mixes elasticity modulus (E_T) - Asphalt temperature (T)

Figure 5 shows the experimental curve obtained in this study that connects the asphalt mixes elasticity modulus at test temperature (E_T) to the test representative asphalt temperature (T). In this figure, the average value of T temperatures obtained in each test run is used (8.0º C in test 1, 12.3º C in test 2 and 19.7º C in test 3).

8 COMPARATIVE STUDY

A comparative analysis of the results obtained in this research has been carried out with some of the existing main studies that connect E_T and T (Table 2).

This comparative analysis is limited to the temperatures range recorded by the performed experimental tests. Moreover, the differences among the already existing models must be taken into consideration. As it has been pointed out, they depend on previous experiences, performed tests and environmental and material features on each area. Thus, in order to compare the different models with the experimental study in a simple way, a temperature adjustment factor has been calculated for each case, see equation (1). This factor should be applied to the E_T in the case of temperatures that are 10º C below T_{ref}, with the aim to obtain the E_T corresponding to the T_{ref} (E_{Tref}).

$$C_{-10} = E_{Tref} / E_T \quad (1)$$

where C_{-10} is the temperature adjustment factor using $T = T_{ref} - 10º$ C.

It should also be indicated that the existing models generally use a T_{ref} close to 20º C. On the other hand, a T_{ref} = 20º C has also been adopted for the results obtained through the experimental tests. This value is often used to establish the asphalt mix reference temperature, as shown in different standards, recommendations and studies (Cedex, 2003, Great Britain Highways Agency, 2008, among others).

Table 4. Obtained temperature adjustment factors C_{-10}

Authors	C_{-10}	Δ_{-10}
The Asphalt Institute, 1982	0.52	0.15
Ullidtz, 1987	0.67	0.00
Ullidtz and Peattie, 1982	0.60	0.07
Great Britain Highways Agency, 2008	0.65	0.02
Baltzer and Jansen, 1994	0.66	0.01
Kim et al., 1995	0.53	0.14
Chen et al., 2000	0.47	0.20
SHRP, 1993	0.57	0.10
St-Laurent, 2000	0.69	0.02
Lee et al., 1988	0.62	0.05
Ali and López, 1996	0.70	0.03
Experimental study obtained in this research	0.67	-

Table 4 shows the results of the C_{-10} obtained in the different models, and are compared to the one deduced by the experimental study. Δ_{-10} is the difference -in absolute value- between the C_{-10} of each existing model and the C_{-10} of the experimental test.

As it can be observed in table 4, in general, there is a good agreement between the C_{-10} factor obtained from the experimental study and those deduced from the existing models. Specially, this experimental factor is equal to the one defined by Ullidtz, 1987, and very similar to the ones established by Baltzer and Jansen, 1994, St-Laurent, 2000, Ali and López, 1996 and Great Britain Highways Agency, 2008.

9 CONCLUSIONS

The curviameter system enables the measurement of the entire deflection bowl produced in the pavement after the passing of a certain load (the main feature to determine its bearing capacity). Among other devices that measure the deflection, it stands out because of its high performance, reaching more than 100 km measured in one day with one deflection bowl being recorded every 5 m. It also has a reduced time of lane occupation since it measures at a speed of 18 km/h, which does not require the closing of the lane during the survey, resulting in a great improvement in road safety.

The system is used in the three application fields included in NLT-333, 2006: road network management, project level and construction control. The curviameter's features make it the most suitable system for the measurement of deflections on road networks with a view to a Pavement Management System. There are some correlation tests between different systems to measure deflections. The intention is to be able to compare any given deflection measurement obtained by a certain device with the ones performed by other measuring devices.

In addition, the effect of the pavement temperature during the deflection test on the asphalt mixes elasticity modulus is analyzed. An experimental test, which consisted of three deflection tests using a curviameter device at different temperatures, was carried out. The elasticity modulus of each material was obtained by using back-calculation. Taking these data, a temperature adjustment factor for asphalt mixes elasticity modulus is calculated and compared with those factors deduced from the main existing models. The performed comparative analysis shows, in general, a good agreement between the temperature adjustment factor obtained from the experimental study and those deduced from the existing models. Specially, this experimental factor is equal to the one defined by Ullidtz, 1987, and very similar to the ones established by Baltzer and Jansen, 1994, St-Laurent, 2000, Ali and López, 1996 and Great Britain Highways Agency, 2008.

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