LABORATORY & IN-SITU TESTING OF AN EXISTING THICK BITUMINOUS PAVEMENT STRUCTURE: CASE STUDY OF THE AREA A430 MOTORWAY

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ABSTRACT

AREA (Société des autoroutes Rhone-Alpes), subsidiary of the EIFFAGE Group since 2007, operates an existing 413 km network in the French Rhône-Alpes region, with connections to the APRR (Autoroutes Paris Rhin Rhône) network and to the Mont Blanc tunnel and Fréjus tunnel, which respectively link the French motorway network into the Swiss and Italian networks. AREA was created in 1971, its first road section between Lyon and Bourgoin-Jallieu opened in 1973.
The company's high-traffic network, for which it holds the concession until 2032, is characterized by thick bituminous pavement structures. Some sections, in particular the A430 motorway between Chambéry and Albertville, may be referred to as "perpetual pavements". Since its construction in 1990, no structural deterioration has been observed on the A430. Only a surface maintenance after 20 years of rather heavy traffic is needed. This paper presents the case study of the laboratory and in-situ testing of the A430 pavement structure, realized in the framework of a partnership between AREA, EIFFAGE Travaux Publics and -University of Lyon/ENTPE.
Laboratory characterization consisted in measuring the complex stiffness modulus and the residual fatigue resistance of the materials cored in-situ.
In-situ testing of the A430 pavement structure consisted in measurement of a rolling load deflection, ovalisation measurements, measurement of plate test static deformation modulus.

Keywords: laboratory testing, in-situ testing, thick bituminous pavement, perpetual pavement

INTRODUCTION

Currently, there is still no maintenance design guide for highway pavements in France. The used methods are based on new pavement design guides [1]. Before a renewal of pavement courses, investigations are carried out to determine the best maintenance requirements. These studies are mainly based on measurements of high-performance lift from the pavement, visual surveys and sample coring.
However, the different auscultations currently conducted do not allow accurate prediction of the future pavement behavior. Sometimes distresses occur earlier on the network while other structures supposedly in ruins remain in good condition. One limit of the current approach is the link between the theoretical calculation of the damage and the observed situation.

Therefore, AREA (French acronym for "Rhône-Alpes Highway Society"), a toll highway company initiates research to assess the state of the pavement on its network and predict their future evolution. This work is realized within the framework of a partnership between the University of Lyon/ENTPE (Civil Engineering Department), and companies AREA and Eiffage Travaux Publics. AREA, subsidiary of EIFFAGE Group since 2007, operates an existing 413 km network in the French Rhône-Alpes region. Its network has connections to the APRR ("Autoroutes Paris Rhin Rhône") network and to the Mont Blanc tunnel and Fréjus tunnel. These two infrastructures respectively link the French motorway network into the Swiss and Italian networks. The company holds the concession until 2032.

This paper presents the case study of a section of the network, A430. The studied section is first initroduced. Then, the state of the pavement structure is investigated with in-situ deflection measurements and laboratory complex modulus measurements. Fatigue tests results are also presented to evaluate the residual fatigue resistance of pavement materials, which have already undergone traffic loading. Finally, a modeling of the pavement structure is proposed and an estimation of its life duration is given.

1 PRESENTATION OF THE STUDIED PAVEMENT

The studied French toll highway A430 links the cities of Chambéry to Albertville (Figure 1). It was built in 1990 and opened to traffic in 1991 for the Albertville's Winter Olympic Games in 1992. It is 15 km long and the highway is dual carriageway. Since the construction, no maintenance work was performed for the pavement structure. Currently, the pavement structure does not show signs of weakness even if it should theoretically be considered at the end of its life. The pavement appears to be generally in good condition. Nonetheless, there is an uncontrolled cracking at the surface which is attributed to a hardening of bitumen due to radiation exposure.

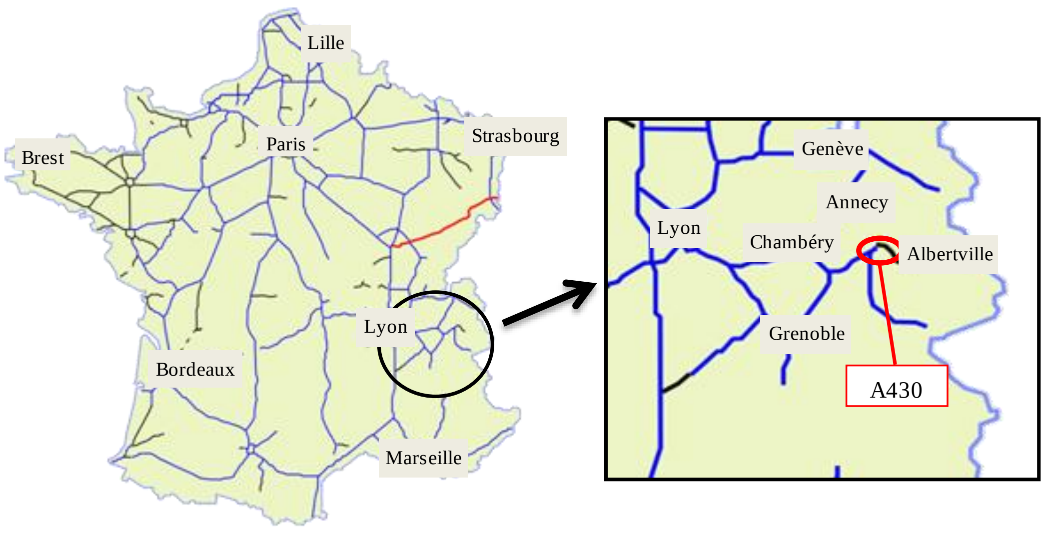


Figure 1: Location of the A430 on the French motorway network

The pavement is entirely composed of asphalt thick courses. The structure consists of three layers: a subbase of bitumen gravel 0/14 ("GB" in the French design guide [1], composed of aggregates from 0 to 14 mm and bitumen content around 3 or 4 ppc), a base course of the same material and a wearing course of semi-coarse asphalt ("BBSG" in the French design guide [1]) . The theoretical thickness of each layer is indicated in Figure 2. Some discrepancies may occur in-situ.

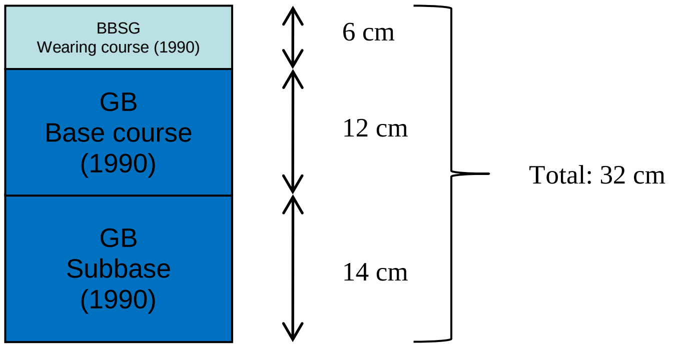


Figure 2: A430's structure

The trucks traffic has been measured on the studied highway using data collected in tolls. In 20 years of life, about 2.6 million trucks traveled on the road, which is very low compared to the average traffic observed on the French highway network.

According to the French pavement design guide [1] and considering the courses thickness and the cumulative traffic after 20 years of service, the pavement should have reached its end of life. The pavement surveys do not support this result.

2 IN-SITU TESTING

Two types of field studies were performed. In a first step, deflection measurements under a rolling load were carried out. In a second step, after extracting some sample, the bearing capacity of the subgrade was measured.

2.1 Deflection measurements under a rolling load

The A430 highway has been investigated with the French apparatus, named “curviamètre” [2], able to measure the deflection and the bending radius, every 5 meters, under a twin-wheel rolling at 18 km/h. These data are first used to cut up the road into homogeneous zones with similar characteristics. The used method for the cutting is not described in this paper. In this study, the homogeneous zones were used to choose the areas to be further investigated.
Two auscultation campaigns were conducted on the A430 studied section in 1999 and in 2010. The measurements of deflection and bending radius are shown in Figure 3 for the campaign of 1999. The characteristic values on homogeneous zones are also presented for both campaigns. The horizontal axis represents the location of the measurements, marked by the kilometric points (PK) along the road. The pavement was studied between the PK 125 and PK 140 (Albertville to Chambéry direction).

Between the two auscultation campaigns, there were an overall decrease of the deflections and an increase of the bending radii. This shows clearly that the pavement was damaged during this period. Furthermore, the damage seems to have occurred uniformly. The homogeneous areas calculated from the deflections in 2010 correspond to those calculated using the same method in 1999. However, some fragmentation of homogeneous zones appears in the last campaign auscultation, showing some local weak zones.

In order to characterize directly the pavement materials, an extensive laboratory analysis was planned. A sampling area was selected, based on these deflection measurements. The chosen area is representative of the overall state of damage throughout the section. It is shown in Figure 3. It is located on a relatively long homogeneous area, where the characteristic deflection is 25 1/100 mm and characteristic bending radius is 950 m. These characteristics values could be considered close to the mean values of the studied pavement section.

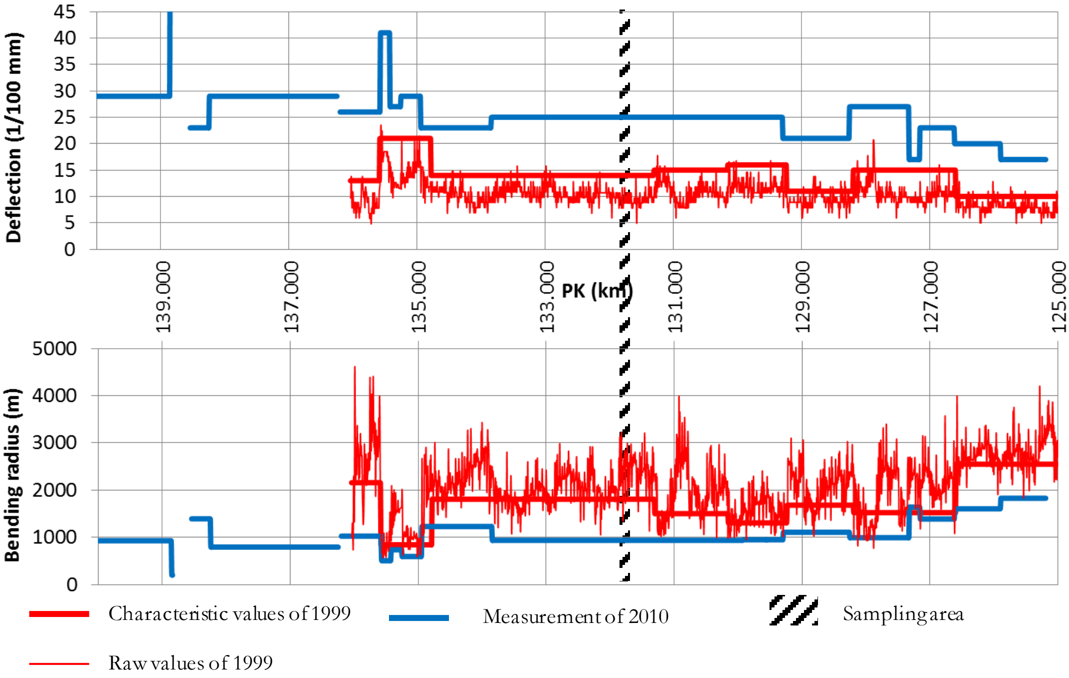


Figure 3: Deflection and bending radius data of A430 highway (Albertville to Chambéry direction) measured in 1999 and 2010

2.2 Measurement of plate test static deformation modulus

Measurement of the bearing capacity of the subgrade was carried out to assess its current state. Pavement blocks were extracted at the location presented before (Figure 3) in order to perform laboratory tests. Once the blocks removed, a plate was put on the platform and was loaded. For this test, two successive identical loading are performed. From the difference between the two measured sinking values the subgrade modulus is back-calculated, thanks to an isotropic linear elastic calculation based on the Boussinesq's theory [3].
The platform modulus measured after the second loading is 160 MPa.
This value seems high compared to the type of platform that was originally built using a module of 120 MPa.

3 LABORATORY TESTING

3.1 Complex stiffness modulus testing

Complex modulus tests [4] were carried out on cored specimen from in-situ blocks sample at the University of Lyon/ENTPE laboratory. These tests were conducted over a wide frequency range (from 10^{-3} Hz to 10 Hz) and a wide temperature range (-30 ° C to +40 ° C). For each temperature and each frequency, the specimens were loaded axially by controlling the axial deformation (50 µm/m) (Figure 4). The load applied and the axial and radial deformations are measured. These data were used to calculate the complex modulus and the complex Poisson's ratio of the pavement materials (Poisson's ratio are not presented in this paper).

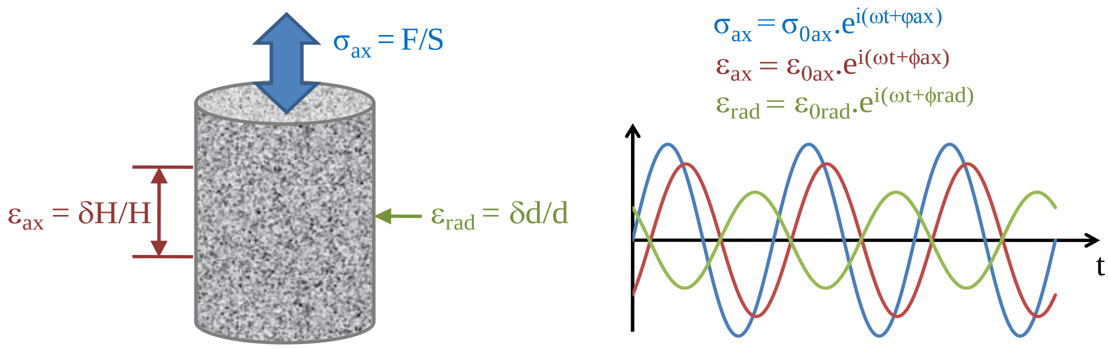


Figure 4 : Signals measured during the performed complex modulus test at University of Lyon/ENTPE laboratory

Equations (1) and (2) are used to determine the complex modulus E* from measurements.

$$E^* = \frac{\sigma_{soll}}{\varepsilon_{ax}} = \frac{\sigma_0}{\varepsilon_{0ax}} e^{i(\phi_{soll} - \phi_{ax})} \quad (1)$$

$$E_1 = \left|E^*\right| \cdot \cos(\phi_E) \text{ and } E_2 = \left|E^*\right| \cdot \sin(\phi_E) \quad (2)$$

Four specimens (Figure 5) were tested. Two were cored in the subbase layer (B1 and B2) and two others in the base layer (H1 and H2). The thickness of the surface layer does not allow obtaining specimen with satisfying size. The specimens were cored parallel to the direction of traffic (Figure 5).

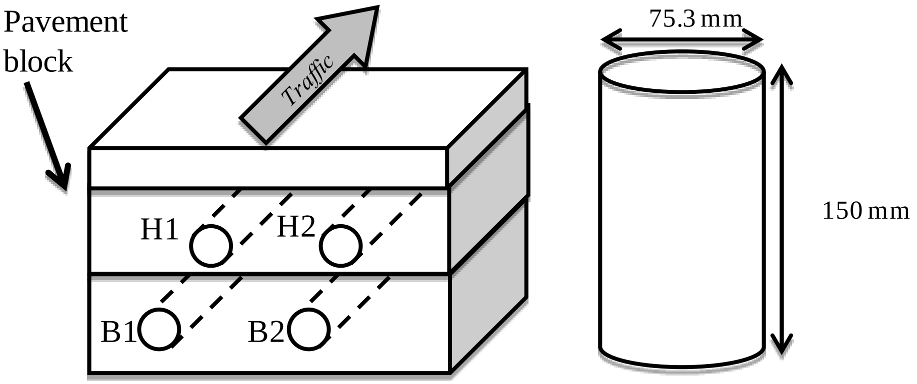


Figure 5: Source and size of specimens used for complex modulus test

The results of complex modulus tests are presented in Cole-Cole axes on Figure 6. For each material, the results of the two tests are very close, which shows a good repeatability of the tests.

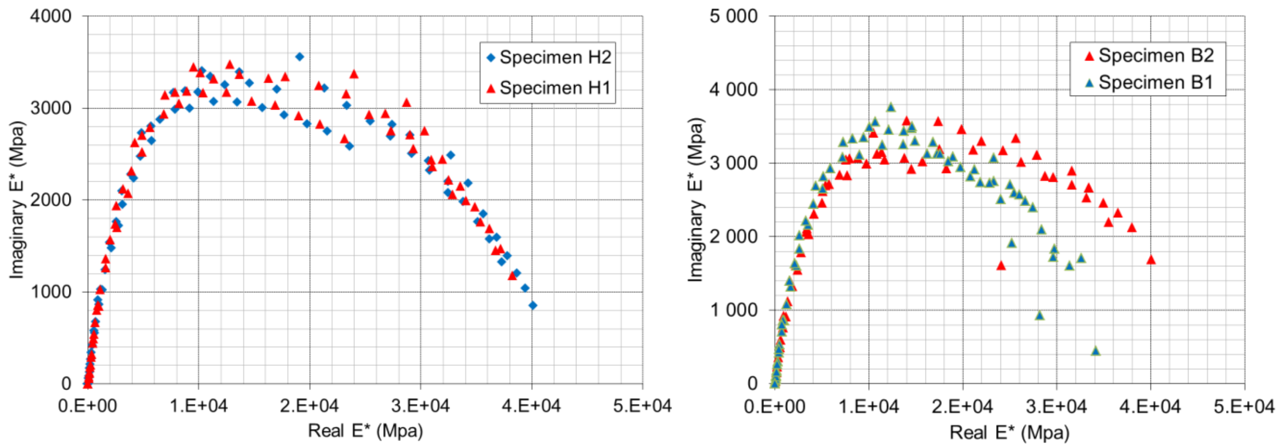
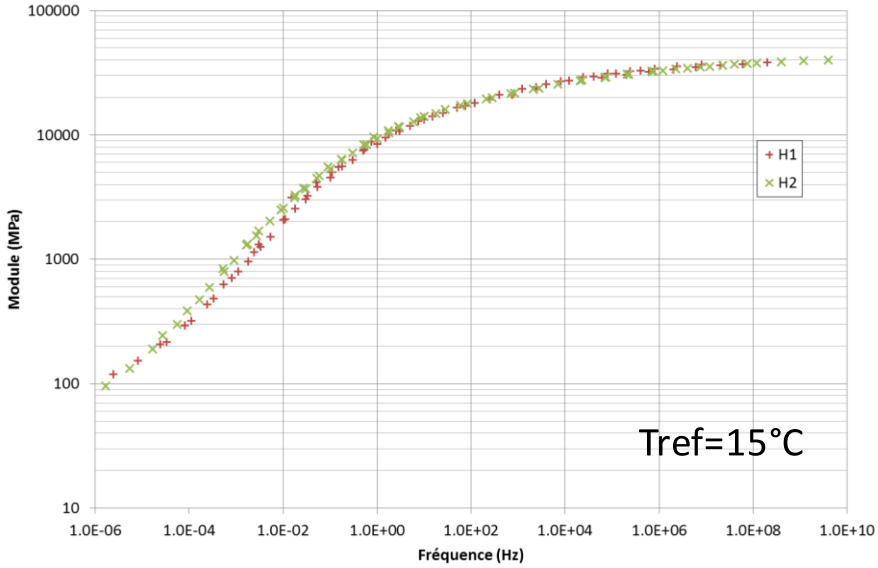


Figure 6: Complex modulus tests results in Cole-Cole axes : for materials from base course (on the left) and subbase (on the right)

The principle of time-temperature superposition seems verified and a single master curve could be obtained. The Figure 7 7 shows the master curve for the chosen reference temperature of 15 ° C for the two specimens from the base course. The shift factors are also presented.

This master curve enables to characterize entirely the visco-elastic behavior of the studied materials (the Poisson's ratio should also be known). This is necessary in order to perform a correct simulation of the pavement structure (for example to calculate the stress and strain fields under rolling wheel [5], [6], [7], [8].



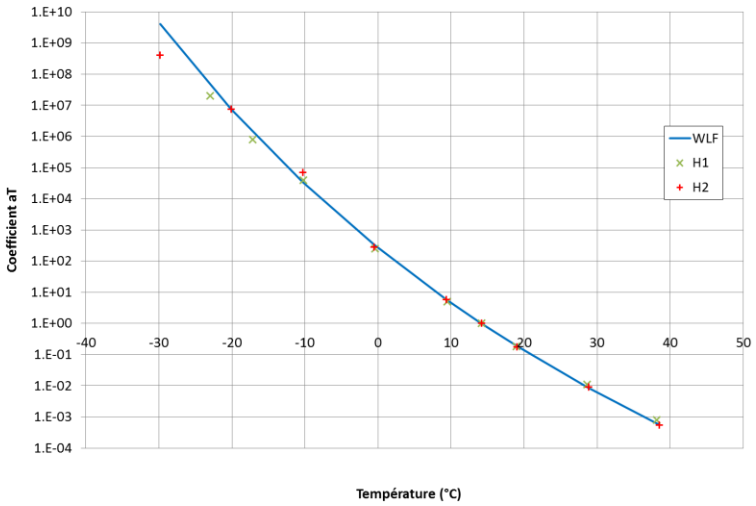


Figure 7: Master curve of complex modulus and shift factors, Tref = 15°C

From this curve, the modulus at reference temperature and frequency (15 ° C and 10 Hz) can be deduced: for the base course, this modulus is 14 200 MPa. This value seems to be very high compared to standard value for this type of material (9300 MPa) given in the French pavement design guide [1].

3.2 Measurement of the residual fatigue resistance of the materials

Fatigue tests were performed according to standard NF EN 12697-24. These tests assess the ability of the material to undergo cycles of loading. The objective of these tests was to determine the materials' ability to support additional cyclic loading and thus the remaining life of pavements.
The results of fatigue tests are shown in the Figure 8. The tests were conducted at three levels of strain on eighteen specimens of the subbase layer only.

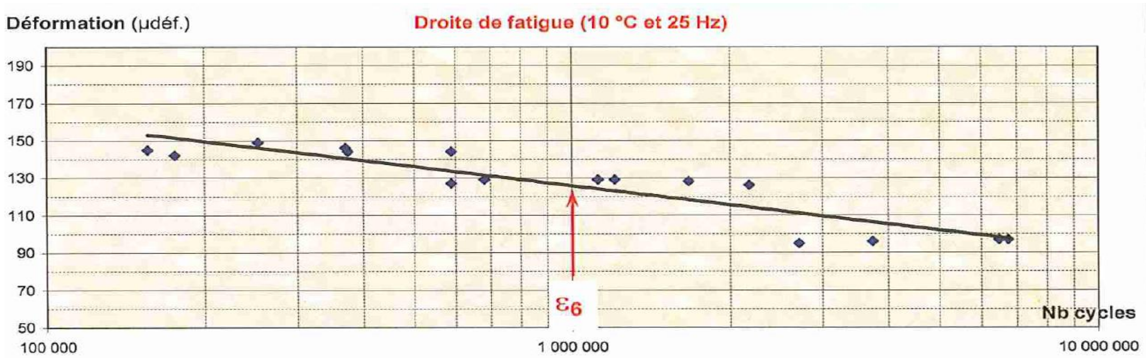


Figure 8: Fatigue Wohler curve of subbase material

This test gives a value of ε_6 (strain inducing the material break after 1 million load cycles) of 124 µm/m. This value is rather high compared to standard values given for this type of material (80 µm/m) [1]. Moreover, the slope of the fatigue is less important than for the standard values

The studied pavement has already undergone more than two million and half cycles. Theoretically, this should have influenced the fatigue characteristics. Such results appear surprising as the subbase seems to have still a high capacity to undergo cycles of stress.

4 MODELLING

Two modelling of the pavement were performed: a first, to determine the moduli of pavement courses by back calculation from the deflection and bending radius and a second to determine the residual capacity of the road to face cycles of traffic from the material parameters measured in the laboratory.

4.1 Back calculation of pavement layers modulus from in situ measurements

The deflection and bending radius measurements are used here in order to back-calculate the modulus of each bituminous layer and subgrade. The method exposed hereafter is based on the principle that the deflection value is mainly determined by the subgrade modulus and respectively, the bending radius determined by the moduli of pavement course. The calculation of deflection and bending radius are performed with Alizé-LCPC software. In this code, the pavement is modeled as an isotropic linear elastic multilayer. Each layer is considered perfectly bonded.

In a first step, the moduli of the bituminous courses are fixed at their standard value (French pavement design guide [1]). The subgrade soil is then cut into layers with different modulus (decreasing with depth until the considered subgrade modulus value) in order to approach the phenomenom of differential settlement due to compaction (from construction phase and under repeated traffic loading). The subgrade modulus is then back-calculated with the in-situ measured deflection.

In a second step, the modulus of bituminous courses is adjusted with the measured bending radius. The soil modulus is fixed to the previously determined value (first step). This method has some limitations since the solution is not unique. Different set of modulus values can lead to the same deflection value. The model therefore calls for the intuition of the user. Nevertheless, to limit the potential error, the subbase and base course modulus value were fixed close to the modulus value obtained from laboratory complex modulus test. Concerning the wearing course, its modulus was fixed to a maximum equal to the standard modulus divided by 2 (1630 MPa [1]) in order to take into account the cracking of the wearing course. It should be mentioned that after this step the calculated bending radius does not match the measured one.

In order to obtain bending radius and deflection consistent with the measured ones, it is necessary to repeat the first and second step as many times as necessary.

The results of this modeling are presented in the Table 1 and compared with modulus measured in laboratory and standard modulus.

Table 1: Comparison of modulus of pavement layers determined by different methods

		Modulus (MPa) (15°C, 10 Hz)			
Course	**Materials**	**In 1999**	**In 2010**	**Laboratory measurement**	**Standard values**
Wearing course	BBSG	1630	1630	/	5 400
Base course	GB	14000	12900	14 200	9 300
Subbase	GB	14000	13000	14 200	9 300
Subgrade	unbound gravel	340	220	160 (obtained from in-situ measurements)	120

It may be noted that the obtained modulus for subbase and base course are very close to those measured by the modulus complex test. In contrast, soil parameters seem to be far from expected values and seem unusually high compared to the measured value and the standard value.
Thus, in this example, the back-calculation of the pavement courses moduli appears to be consistent with the reality for the pavement courses but does not approach the subgrade modulus. This parameter is of outmost importance for pavement design and should be determined with accuracy.

Concerning the values of base course and subbase moduli, two points may be noticed:

- between 1999 and 2010, these moduli seem to have decreased, which could be explained by fatigue damage;
- the determined values are very high compared with the standard values. The values just after construction are not available, but it may be assumed that they were not so far from the standard ones. This evolution is opposite to the fatigue phenomenom and could be explained by a hardening of the bitumen and continuous compaction of materials.

4.2 Evaluation of residual life

The residual life of the pavement was evaluated. The used method is the same as for a new pavement, described in the French pavement design guide. First, a multi-layer linear elastic isotropic calculation was performed in order to determine the strain at the bottom of the subbase layer, under a standard wheel loading. The pavement was modeled using the parameters measured in the laboratory for base course and subbase. For the wearing course, the considered modulus is the standard modulus divided by two so as to take into account the in-situ cracking.
According to the Miner law, the traffic that can still be supported by the studied pavement could be determined with the fatigue characteristics determined in the laboratory (Table 2). The result is presented in Table 2 and is compared with the traffic already supported, and the traffic expected for the design.

Table 2: Comparison of modulus of pavement layers determined by different methods

Traffic can still be supported by the pavement	133 10^6 Trucks
Traffic has already circulated on the pavement	2.7 10^6 Trucks
Traffic expected from the design	1.98 10^6 Trucks

The studied pavement presents an incredible capacity to support additional loading cycles. This surprising result cannot be realistic and show that a correct method to evaluate the current state of pavement structure and their future evolution is necessary.

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