Monitoring of Artificial Defects within a Pavement Structure with a NDT Method Based on a Mechanical Impact

Jean-Michel Simonin, Pierre Hornych

MONITORING OF ARTIFICIAL DEFECTS WITHIN A PAVEMENT STRUCTURE WITH A NDT METHOD BASED ON A MECHANICAL IMPACT

Jean-Michel Simonin[1], Pierre Hornych[1]

[1] *LUNAM Université, IFSTTAR, Route de Bouaye, CS4, F-44344 Bouguenais Cedex France*
jean-michel.simonin@ifsttar.fr

ABSTRACT

This paper presents a non-destructive testing (NDT) method used to monitor a pavement structure which contains artificial defects. A 25 m long pavement section has been built on the full scale accelerated pavement testing facility of IFSTTAR in Nantes. The structure is made of two bituminous layers (8 cm thick base layer, and 6 cm thick wearing course), over a granular subbase. Several types of defects have been included at the interface between the two asphalt layers (figure 1). Rectangular debonded areas of different size (of longitudinal or transversal direction) have been created artificially, using different techniques (sand, textile, absence of tack coat). The construction has been carried out by a road construction company, using standard road works equipment. Then, the pavement fatigue testing facility has been used to apply traffic loading on this pavement, to study the effect of such sliding interfaces on the mechanical behaviour of the pavement, and the evolution of the defects with traffic.

KEYWORDS : *Pavement monitoring, Interface defects, Non Destructive Technique, Fatigue testing, Frequency Response Function.*

INTRODUCTION

This paper presents a non-destructive testing method (NDT) used to monitor a pavement structure which contains artificial defects. The method is based on the variation of the Frequency Response Function which is sensitive to the presence of damage. A prototype has been developed to easily apply the method on roadways. A methodology has been adjusted to transform the FRF into a normalized damage matrix. The method has been used to survey an experimental pavement during a full scale fatigue test, and follow the evolution of the artificial defects with traffic.

1 PRESENTATION OF THE TEST SITE

A 25 m long pavement section has been built on the full scale accelerated pavement testing facility of IFSTTAR in Nantes. The structure is made of two bituminous layers (8 cm thick base layer, and 6 cm thick wearing course), over a granular subbase. Several types of defects have been included at the interface between the two asphalt layers (figure 1). Rectangular debonded areas of different size (of longitudinal or transversal direction) have been created artificially, using different techniques (sand, textile, absence of tack coat). The construction has been carried out by a road construction company, using standard road works equipment. Then, the pavement fatigue testing facility has been used to apply traffic loading on this pavement, to study the effect of such sliding interfaces on the mechanical behaviour of the pavement, and the evolution of the defects with traffic.

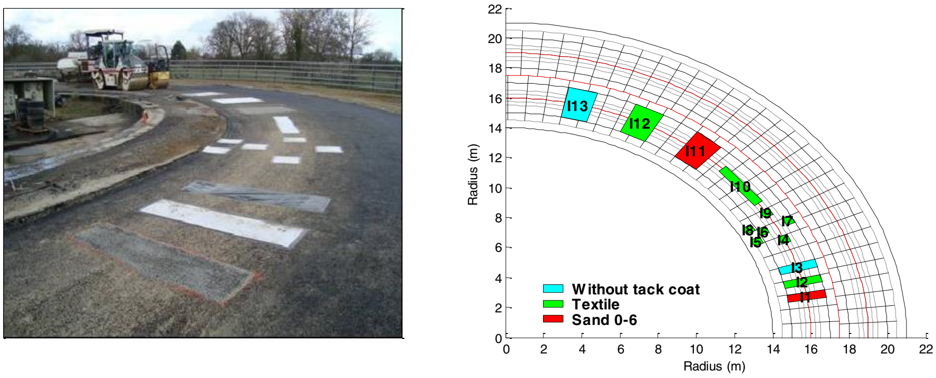

Figure 1. Interface defects before wearing course construction (left); Map of the different sliding areas (right)

Defects (table 1) were centered on the radius R = 16 m, which corresponds to the centre of the wheel-path. The total width of the wheel-path (with lateral wandering) was approximately 1.0 m (between 15.5 m and 16.5 m). The debonded areas I-1, I-2, I-3, I10, I11 I12 and I13 are centered on the radius of 16 m. I-4 to I-9 are small defects, 50 x 50 cm, with a textile interface, located in and outside the wheel path.

Table 1. Characteristics of the different defects introduced in the pavement

Defect zones	Type	Dimensions, m (length × width)	Position, m, along radius R = 16 m
I-1	Sand	0.5 × 2 m	[2.5, 3]
I-2	Textile	0.5 × 2 m	[3.5, 4]
I-3	Tack coat free	0.5 × 2 m	[4.5, 5]
I-4 to I-9	Textile	0.5 × 0.5 m	[6.5, 9]
I-10	Textile	3 × 1 m	[9.5, 12.5]
I-11	Sand	1.5 × 2 m	[13.5, 15]
I-12	Textile	1.5 × 2 m	[17, 18.5]
I-13	Tack coat free	1.5 × 2 m	[20.5, 22]

2 Description of the Test Method

2.1 Principle of the test method

Road pavements constitute continuous structures on which the complex FRF can be measured. For a healthy structure, the shock generates vibrations of the whole pavement. The presence of damage, such as interface defects or vertical cracks, reduces the stiffness of the structure and thus reduces the first Eigen frequency. This low frequency vibration mode corresponds to the vibration of a part of the structure (above the interface defect or close to the crack). Thus it is a good indicator of the presence of a discontinuity in the structure (presence of a debonded interface, or of a crack). The FRF modulus estimated for the damaged structure is thus higher than the one of the healthy structure. It increases at each of the eigen frequencies. Thus, a difference of FRF modulus can be observed in a sensitive frequency band. This band and particularly the lowest frequency, depends on the characteristics of the defect (extension, depth, nature).

2.2 Application to pavement

Application of this analysis method to a pavement [3] consists in collecting the FRF all along a pavement section. Then, the FRF modulus measured at each measurement point is compared with the “reference” FRF modulus representative of the healthy structure (measured at a point where the structure presents no damage). The objective is to identify the points where the FRF is significantly different from this “reference”. It has to be noted that the “reference” function is related to the investigated pavement section. So, we suppose that all measurements are recorded on a homogeneous structure (with identical materials and layer thicknesses). The variations observed are then representative of the presence of damage, which leads to a “softer” structure. On this homogeneous zone, data is processed in 2 steps:

- Definition of a reference function representative of the healthy structure;
- Calculation of a normalized damage.

To define the reference function modulus, it is assumed that a part of the tests was carried out on a healthy zone. This could be done voluntarily by investigating an un-trafficked zone such as an emergency lane. In practice we usually consider the set of FRF moduli, $|FRF(f_k, i)|$ measured at a fixed frequency, f_k, on the i points of the section. The reference value at this frequency, $|FRF_{ref}(f_k)|$, is defined as a percentile of this selected population. The percentile 20 % is usually adopted which allows obtaining a low value representative of the healthy structure and eliminating abnormal measurements. The set of reference values at different frequencies constitutes the reference transfer function representative of the healthy structure and is used to normalize the FRF modulus measured at each point, at each frequency. Thus, a damage value $D(f_k, i)$ is calculated for each frequency, according to equation (1). This value varies between 0 and 1. The matrix D represents the damage of the road section, for the different frequencies. It can be presented as a “damage mapping” where:

- The X-coordinate is the abscissa along the road section;
- The Y-coordinate is the frequency band;
- Colors represent the level of damage (between 0 and 1)

$$D(f_k, i) = \begin{cases} 0 \quad \text{if} \quad |FRF(f_k, i)| < |FRF_{réf}(f_k)| \\ 1 - \dfrac{|FRF_{réf}(f_k)|}{|FRF(f_k, i)|} \end{cases}$$

Figure 2 shows such mapping obtained over different artificial defects.

3 APPLICATION ON THE TEST SITE

3.1 Comparison between different defects

The method was used to monitor longitudinal profiles of the experimental pavement, at the radius of 16 m, above the different debonded areas. Above the larger defects (I11, I12 and I13), measurements were made at points spaced at a distance of 0.05 m close to the limits between debonded and bonded areas and at a distance of 0.20 m far from these limits. Figure 2 compares maps obtained with this method. Each map presents the damage level, as a function of distance (X) and frequency (Y). The colors represent the damage level from 0 (blue) to 1 (red). On each map, the debonded area is located between distances 0.5 and 2m. The method locates accurately the areas with defects, however the interface without tack coat is more difficult to locate (lower map). The method is very sensitive to the textile and sand interfaces, on a wide range of frequencies. It is less sensitive to the interface without tack-coat which represents a low level of interface damage.

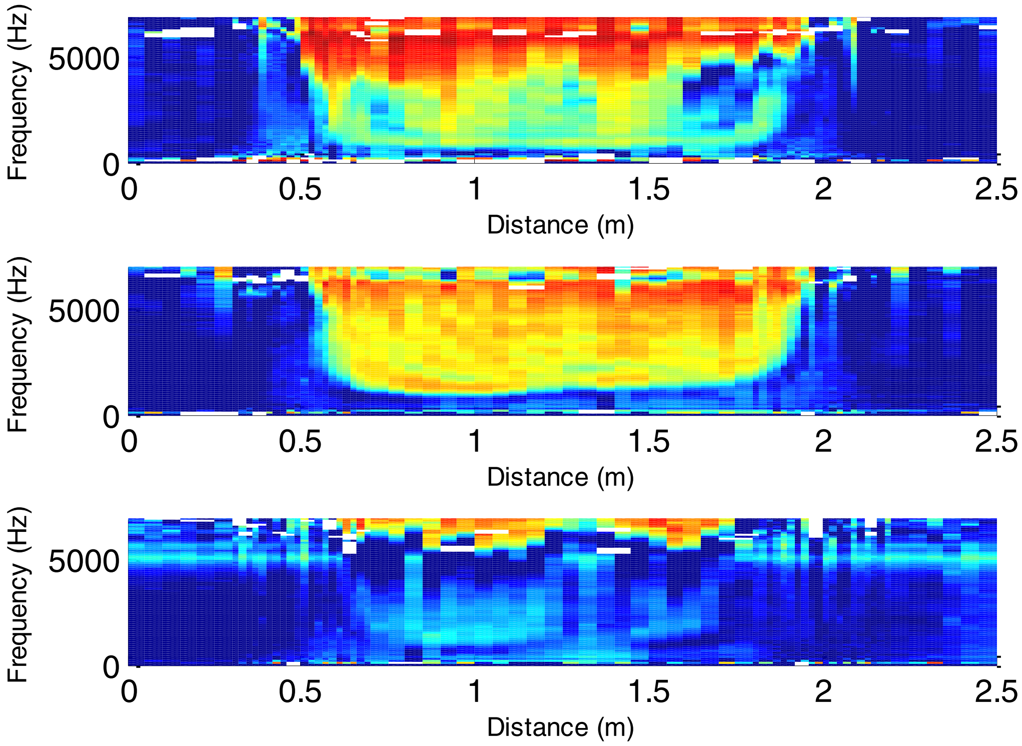

Figure 2. Map of damage level recorded above the 3 sliding interfaces

3.2 Monitoring of the evolution of defects with loading

One objective of the experiment was to follow the evolution of the defects during loading, and to evaluate their effect on pavement performance. This will be helpful in optimizing pavement monitoring with different NDT methods.

The experiment consisted in applying to the pavement 300 000 loads, with dual wheel axles, loaded at 65 kN. Investigations have been done at different stages of the experiment :

- At the beginning of the experiment to characterize the initial state of the pavement;
- After 10000 loads when the structure is consolidated;
- After 50 000, 100 000, 150 000, 200 000 and 300 000 loads to survey the structure.

The method was used to monitor longitudinal profiles at the 16 m radius above the debonded areas I1, I2, I3 I11, I12 and I13. It was also used to survey transverse profiles above the defect I10. Measurements were made at points spaced at a distance of 0.02m all along the transverse profile centred on the radius 16m. Figure 3 compares maps obtained with the FRF method along the transverse profile located at the middle of the defect I10. Each map presents the damage level, as a function of distance (X) and frequency (Y). The colours represent the damage level from 0 (blue) to 1 (red).
The debonded area clearly extends with traffic. It must be noted that the defect is located at a positive abscissa at the beginning of the experiment, and that it extends to a negative abscissa with traffic. Therefore, the width of the defect has increased laterally, covering the whole width of the

wheel-path at the end of the experiment. This confirms that the evolution of the debonded area is due to traffic.
Measurements on a second transverse profile above I10 show a similar evolution even if the lateral extension is more reduced. On the contrary, no longitudinal extension of the debonded area has been detected from the survey of longitudinal profiles.

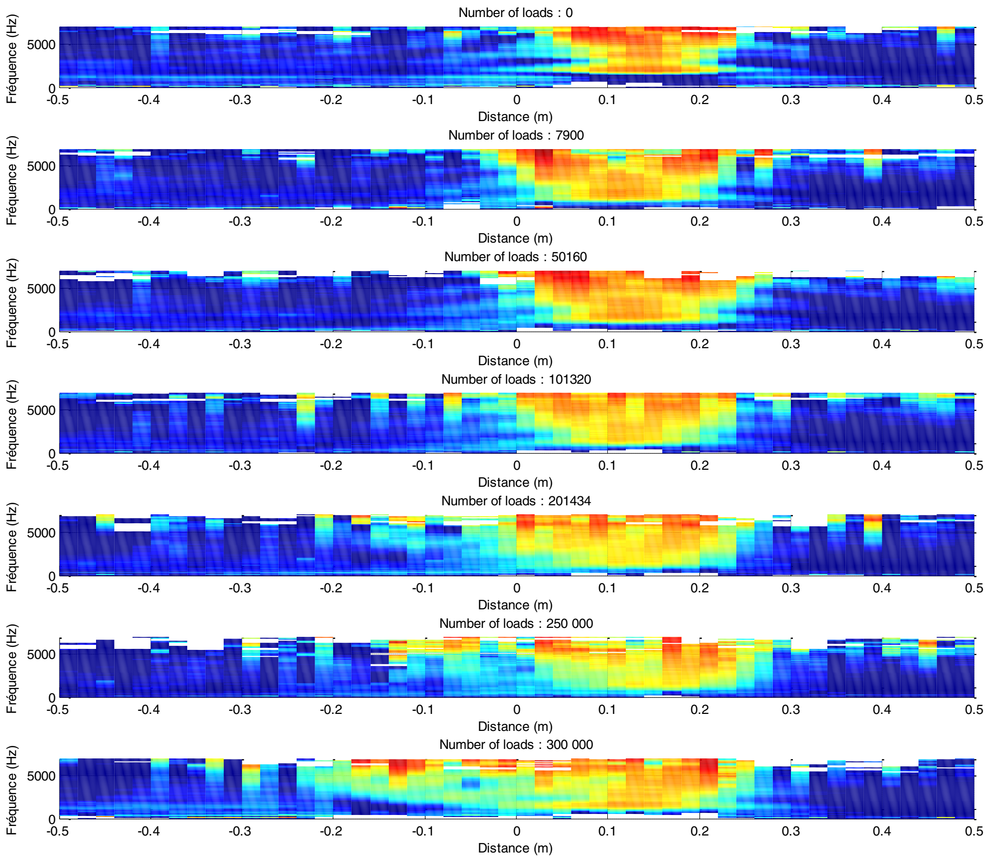

Figure 3. Mapping above a transverse profile of defect I10, illustrating the lateral extension of the defect in the wheel-path.

CONCLUSION

An experiment has been performed on the IFSTTAR APT facility on a bituminous pavement including different artificial debonded interfaces, between the two bituminous layers. A non-destructive testing method, based on mechanical wave propagation, and determination of the FRF function, has been used to calculate an indicator of damage and to survey their evolution under traffic. The method presents a good sensitivity to debonded areas. It has been clearly able to distinguish the different types of artificial interfaces (sand, textile, absence of tack-coat), which simulate different levels of damage.

After 300 000 loads, visual survey didn't detect any damage at the surface of the road. Results of the NDT method indicate an increase of the level of damage using the damage indicator, but no extension of the damage along the longitudinal profile. However a significant extension of the damage along the transversal profile has been observed.

As no damage has been observed yet at the surface of the pavement, it is planned to continue the experiment, in conjunction other APT programs, up to at least 500 000 loads. NDT tests will continue to be performed on the pavement at regular intervals. Research will also be carried out to optimize data processing and to develop numerical response models, to improve the interpretation of the results.

The new Colibri apparatus, an automated system, is able to apply the FRF method at a high rate (1 measurement per second). It can be used to investigate several hundred meter long pavement sections, to provide the road engineer with a picture of the internal damage of the road base and wearing course.

REFERENCES

[1] Ewins, D-J. (2000), Modal testing: theory, practice and application, Second edition. Letchworth: Research studies press LTD.
[2] Simonin, J-M. (2005). Contribution à l'étude de l'auscultation des chaussées par méthode d'impact mécanique pour la détection et la caractérisation des défauts d'interface. Thèse de doctorat. Rennes: INSA.
[3] Simonin J-M, Lièvre D., Dargenton J-Ch. (2009), Structural roadway assessment with frequency response function Bearing Capacity of Roads and Airfiels. Proc. Intern. Conf., June 2009.