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Rapid and Continuous Imaging for Crack Monitoring during APT Experiments

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Abstract Accelerated pavement testing (APT) is well known as a very effective way to investigate the actual behaviour of pavement structures. Feedback from the test can be obtained in a couple of months through measurements and monitoring made during the experiment. Among them, pavement surface cracking is one of the most important parameters for the evaluation of experimental pavement performance. Generally, crack monitoring during APT tests is still carried out manually for every specific loading period. This classical approach is time-consuming and interesting information may be lost if a measurement is missed. For this reason, a Rapid and Continuous Imaging (RCI) technique has been developed and tested at IFSTTAR, for the monitoring of crack development on the pavement surface during APT experiments. The principle of this technique consists in taking images of the experimental pavement surface continuously along the test track, at intervals depending on the moving speed of the heavy traffic simulator, i.e. the road fatigue carousel. A crack map, representing an overview of visible cracks on a pavement section can then be rapidly created using an ad hoc image processing tool. The application of this pavement crack mapping technique for crack monitoring on an asphalt pavement during a recent APT experiment showed interesting results.

Keywords Pavement, APT, Monitoring, Crack mapping.

1 Introduction

Accelerated full-scale experiments have been proved as an effective method to monitor and analyze pavement performance (Autret et al. 1987, Gramsammer et al. 1999, Nguyen et al. 2017, Blanc et al. 2019 among many others). Pavement cracking represents a crucial parameter for pavement assessment (Hornych et al. 2008, Nguyen et al., 2020). Generally, crack monitoring during APT tests is still carried out manually for every specific loading period (Figure 1). This classical approach is time-consuming and interesting information may be lost if a measurement is missed. Moreover, cracks are usually sketched by experts, and this leads to some approximations and simplifications. Additionally, one of the issues of this method is the lack of objectivity in this quantitative analysis.

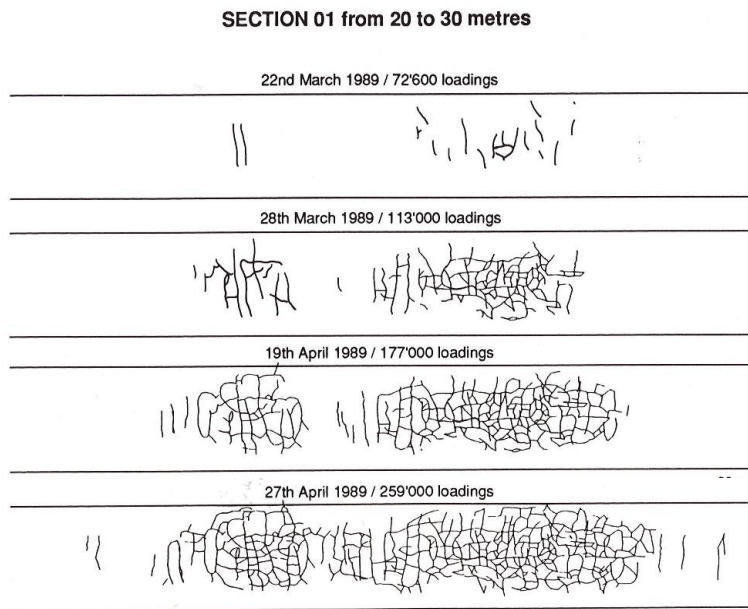


Fig. 1 Example of crack monitoring using manual measurements (*OECD Full-Scale Pavement Test 1991*)

Several techniques of crack monitoring have been developed to replace manual methods. Automatic approaches such as image-based crack detection procedures (Mohan and Poobal 2017) could reduce greatly the time needed for crack detection. However, most of these methods are only used for monitoring on pavement networks for road management. There are very few developments of this technique for research, especially with dynamic monitoring, and this type of monitoring is seldom used in APT experiments.

1.1 Objectives

The objective of this work is to develop a technique that allows monitoring rapidly and easily the crack development on pavement surface during APT experiments. For this purpose, an original imaging procedure, named Rapid and Continuous Imaging (RCI) technique, has been developed and tested at IFSTTAR.

The paper presents firstly the APT facility at IFSTTAR, describing the heavy traffic simulator and the test track configurations. The development of the RCI technique is then outlined following a chronological approach from preparation, image recording, cleaning, to crack mapping steps. Finally, a real case study is used for application of this technique.

2 Presentation of the APT facility at IFSTTAR

The center of Nantes of IFSTTAR has a large scale circular accelerated pavement testing (APT) facility, also called the pavement fatigue carousel (Figure 2). By its characteristics (40 m in diameter, maximum loading speed of 15 rounds/min corresponding to a linear speed of 100 km/h at the radius of 19 m), it is one of the largest accelerated pavement testing facilities in the world. The APT facility can simulate in a few months the heavy traffic supported by a pavement during its whole service life. Its maximum loading rate is approximately 500 000 heavy loads per month. With this facility, it is possible to reproduce, in a few months, the deterioration mechanisms of real pavements, and to overcome the long durations necessary to observe significant deteriorations on real roads.

The carousel consists of a central tower and four arms (each 20 m long) equipped with wheels, running on a circular test track. The positions of the loading modules can be adjusted for different radii on each arm, for instance to test simultaneously the effect of different load configurations. During loading, a lateral wandering of the loads (up to 1.6 m wide) can be applied to simulate the lateral distribution of loads of real traffic. The moving speed of the loading module and its lateral position are controlled while the loading level is maintained, whatever the degree of deterioration of the experimental pavements.

The circular test track has a mean radius of 17.5 m and a width of up to 6 m, and thus a total length of approximately 110 m. Experimental pavements are built at full-scale by standard construction equipment.



Fig. 2 The Accelerated Pavement Testing (APT) facility at IFSTTAR

3 Development of the RCI technique for crack monitoring

This development is based on the characteristics of the IFSTTAR's APT facility. The principle of this technique consists in taking images of the experimental pavement surface continuously along the test track, at intervals depending on the moving speed of the traffic simulator. By assembling isolated images taken from a digital camera mounted on a loading module of the simulator while running, it is possible to generate rapidly and easily a full pavement surface image.

The process consists of four main steps, namely preparing the equipment, recording image data, image processing and crack mapping (Figure 3).

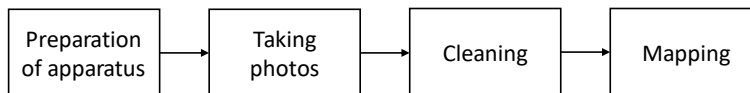


Fig. 3 Main structure of the crack mapping process

3.1 Preparing

Before taking photos of the pavement surface, it is necessary to calibrate the equipment to guarantee the uniform quality of all photos. First, a digital camera is installed on a dedicated fixing system attached to one of the APT loading modules. It is essential to check that this loading module will run exactly on the monitored test

track at the corresponding radius following a fixed lateral position (without wandering), to obtain the desired pictures of the pavement surface. In parallel, the camera needs to be installed at an appropriate height to be able to capture the whole width of the loading path, for each picture.

3.2 Registering images data

In order to take high quality pictures of cracks on the pavement surface, the APT machine needs to run at low and constant speed (1 m/s at the radius of 19 m of the loading module). A specific program is used to control the camera, to take a picture every 0.1 to 0.3 second during running of the traffic simulator. With such synchronization of the moving speed of the APT machine and image recording frequency of the camera, all the pavement surface can be covered homogeneously (Figure 4).

However after analysis of the first pictures, it appeared very difficult to detect cracking on the asphalt pavement, especially for fine cracks. Therefore, to facilitate crack detection, it was decided to mark the cracks with white paint, as soon as they appeared on the pavement surface, before taking the images. This survey needs to be performed by experienced operators, to guarantee that positions and directions of the cracks are marked properly.

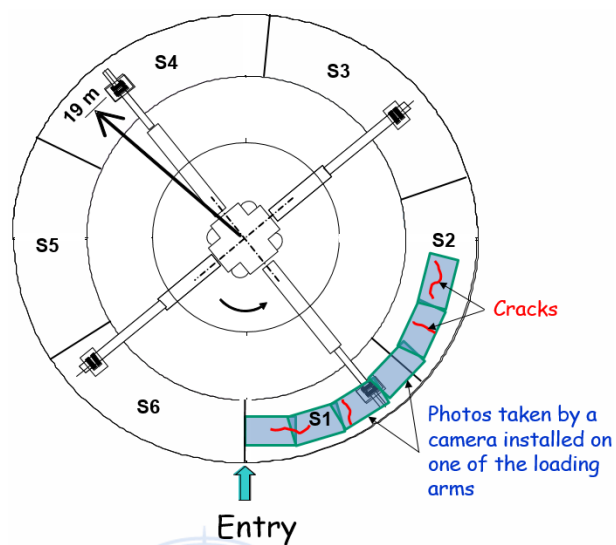


Fig. 4 Procedure for recording images of pavement surface in APT experiments

3.3 *Image processing*

At this stage, the recorded images are checked to ensure that they all have uniform characteristics in terms of dimension and lighting condition. They are then filtered to keep only a sufficient number of images per section for use in the next step..

3.4 *Crack mapping*

To observe the propagation or the evolution of cracks during an APT experiment with isolated images is quite difficult. An algorithm was developed for connecting individual photos of the pavement surface into a map that could show all the test track surface condition at a particular time corresponding to a given number of load cycles. Thanks to a code developed with the Matlab software, continuous images along the test track can be generated, and used to help visualize the cracks on a unique map after a given number of load cycles. The development of cracks can also be followed by means of several consecutive crack maps, corresponding to successive loading periods in an APT experiment.

Figure 5 illustrates the state of cracking in a pavement section after two different loading periods. These maps clearly show the development of the cracks, and can be stored in digital version for further research.

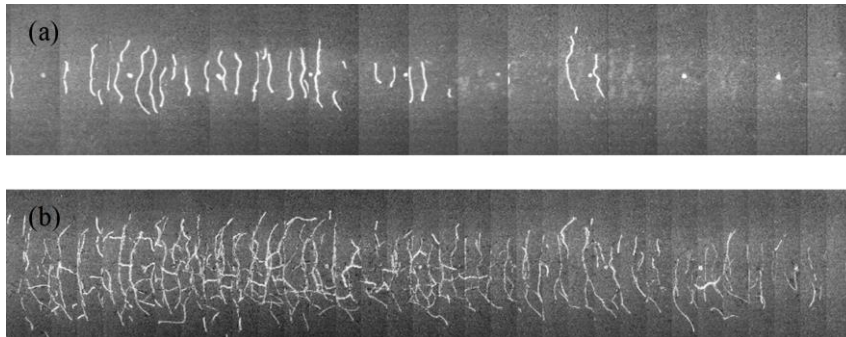


Fig. 5 Crack maps of section 6b after: a) 1 million load cycles, b) 2.2 million load cycles

4 Case study

This part presents a study carried out on a test track of the IFSTTAR APT facility. This test track was divided into 6 sections (S1 to S6 – Figure 4) with different structures and materials. 2.2 million loads were applied in this experiment, with dual wheels loaded at 65 kN. During this APT experiment, fatigue cracks appeared and developed progressively with the number of applied load cycles.

By applying the RCI technique, a series of crack maps was created all across the loading period, to monitor the development of the cracks on the experimental pavement surface (Figure 5).

Additionally, by exploiting these crack maps, indicators defining the orientation or the severity of the cracks can be calculated. In the example presented here, the objective was to determine the percentage of the length of the pavement affected by cracks, which can be related with the level of fatigue damage of the pavement. For that purpose, the length of each crack was measured, and the following approach was used to determine the cracked length :

- For longitudinal cracks, the “cracked length” L_f was considered equal to the measured length of the cracks.
- For transversal cracks, a length L_f of 25 cm was conventionally attributed to each crack, representing the longitudinal distance affected by the crack.
- The percentage of cracking of the pavement section was then calculated, as the ratio between the cumulative length of the cracks and the total length L of that section (Eq. 1).

$$\text{Percentage of cracking} = \frac{\sum L_{fi}}{L} \quad (1)$$

where L_{fi} is the equivalent length of each crack with its conventional evaluation given in Figure 6, and L is the length of the pavement section.

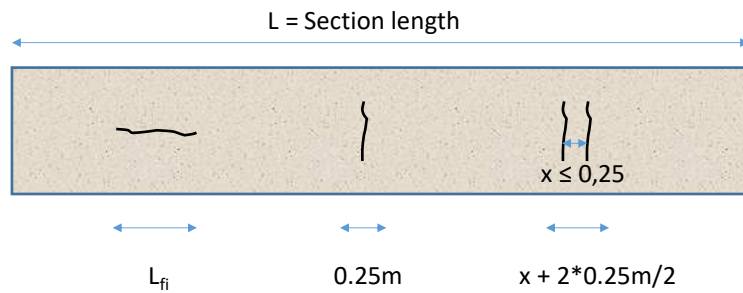


Fig. 6 Evaluation of the cracking of the pavement section along the longitudinal direction

Figure 7 presents the evolution of the percentage of cracking of the six different experimental pavement sections with applied traffic, calculated with the approach

described previously. On the IFSTTAR APT facility, it is generally considered that the failure of the pavement is attained when the level of cracking is equal to 50 %. (This limit is represented by the dotted line on figure 7). The results indicate that :

Sections 1 and 5 present the best fatigue behaviour, with levels of cracking of 10 % and 35 % respectively, at the end of the experiment.

Section 4 presents an intermediate behaviour, reaching a level of cracking of 50 % (corresponding to failure) after approximately 2 million loads.

Sections 2, 3 and 6 present the worst behaviour, reaching failure (50 % of cracking) after between 1.2 and 1.4 million load cycles.

The simplified approach for the evaluation of the percentage of cracking described on figure 6 could possibly be improved by determining a cracked area in place of a cracked length. This area could be determined as the product of the length of the crack by a width of 0.25 m, representing the distance affected by the crack.

Obviously, the crack maps generated by the RCI technique are useful to evaluate more precisely and more objectively pavement condition, and damage mechanisms. The same type of simple automated crack mapping approach could be used on pavement networks, to evaluate pavement condition for road network management and maintenance applications,.

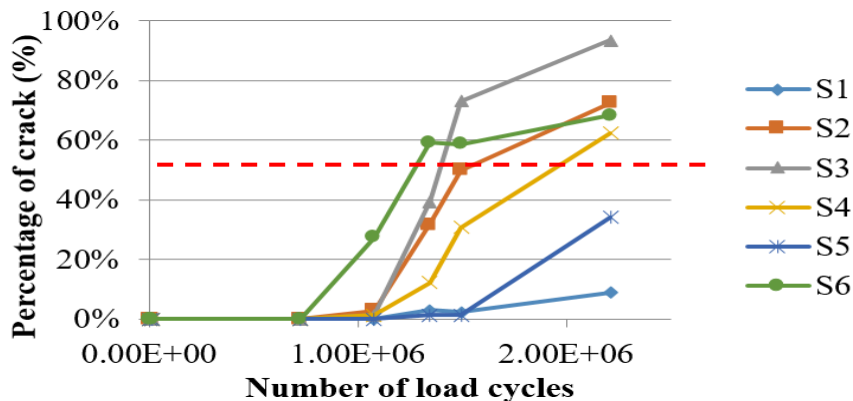


Fig. 7 Crack evolution on the 6 sections tested in the APT experiment, determined from the crack mapping process

5 Conclusions and perspectives

This paper presents the development of the Rapid and Continuous Imaging (RCI) technique for crack monitoring during APT experiments. This technique is developed based on the characteristics of the IFSTTAR APT facility. The application of

this technique to a case study shows that it can produce precise maps of surface cracking at different stages of the experiment. These maps can then be used to calculate a percentage of cracking (and thus a level of damage) of the pavement. Clearly, this crack-mapping approach offers interesting perspectives for improving the monitoring of full-scale accelerated pavement experiments, and analysis of pavement damage.

However, as part of the development, several points remain to be improved :

- In the present case study, the images were taken at low speed (1m/s). If the technique is to be used at traffic speed, it will be necessary to control the quality of the images, and if necessary improve the recording process. For instance, an image stabilization system may be needed for mapping at traffic speed.
- At present, the methodology requires to mark the positions of the cracks to ensure their visibility. The objective is to improve image quality and image processing to enable detection of fine cracks without paint marking, in order to fully automate the crack mapping process.
- Crack maps generated in the study from a single digital camera are in 2D. However, using multiple cameras placed at different angles on the running module, it could be possible to make 3D measurements, to detect rutting or raveling phenomena.

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