Optical Fiber Sensors for Asphalt Structures Monitoring

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Abstract: A novel optical fiber installation method was explored for asphalt monitoring. Glass-fiber polymer encapsulated SMF was installed in the intermediate and surface layers in order to study the strain sensitivity with a distributed strain interrogator.

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1. Introduction

Understanding the behavior of asphalt can result in optimized structures designs, thus reducing the rehabilitation costs associated with premature failures or with the long term conservation of roads. Although typical maintenance works of asphalt are focused on the surface course layer, fatigue in the deeper layers produces a continuous deterioration of the whole asphalt platform which entails permanent damages [1].

The principal responsible for the roads deterioration are certainly the overloaded vehicles. Therefore, an overload control system is extremely attractive for the organizations in charge of the roads' maintenance. The concept of Weigh-In-Motion (WIM) was introduced more than fifty years ago. There are several advantages of weighing vehicles while they are in motion rather than at rest [2]. These include savings in time and cost, and that they are safer to operate on busy roads. These systems have been used generally by public agencies for collecting vehicle weights as well as several other statistical traffic data, to aid in the pavement construction, maintenance, highway safety assessment and improvement, and other several transportation and highway related planning and design [3].

During the lasts years, a number of improvements has been carried out in the fiber optic sensor field, showing in laboratories the great potential of this technology as an interface between the environment and the human modern applications as structural health monitoring (SHM), smart structures, biotechnology and others [4]. But it is also important to perform in-field tests to demonstrate the potential of the laboratory prototypes in real applications. Thus, this contribution is devoted to the testing of the fiber optic sensor monitoring technologies in real asphalt structures with two main objectives: the validation of a novel sensing fiber installation method and the sensitivity study in the different parts of the asphalt structure

2. Methodology

In order to achieve the previous objectives, a complete experiment was developed. Thus, a two layers' asphalt pavement structure (Fig. 1.) was designed to install different standard single-mode optical fibers (SMF) encapsulated with glass fiber reinforced polymer by Monitor Optics Systems, at different depths. Therefore, three fibers were installed at one, two and three centimeters into the subbase layer; and four fibers were placed from one to four cm depth at the surface course. The installation method consists of trenches of different depths wherein the fibers were placed and protected with epoxy resin (Megapoxi 265).

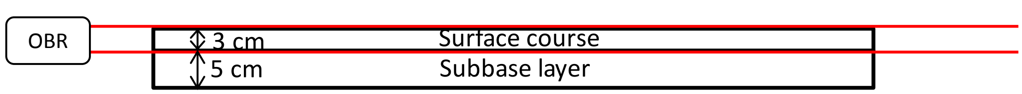

Fig. 1. Schematical layer distribution of the asphalt platform built for the test. Lines in red correspond to the fibers positions and OBR refers to the Optical Backscatter Reflectometer interrogation unit.

So, the fiber installation was carried out in two stages: the subbase layer fiber installation after the first paving procedure and, once the surface course was paved, the surface sensing fibers were installed. It is important to clean correctly each trench in order to avoid fiber damages with little stones and to have the best adhesion of the fiber to the asphalt with epoxy.

Fig. 2. Pictures of the asphalt paving procedure and trenching for the fibers installation.

Previously to the asphalt deployment, the sensing fibers were prepared to endure in this harsh environment. Each sensing fiber consists of a piece of SMF reinforced fiber of 3,5 m, spliced to a PC/APC pigtail and protected with the standard splice heat-shrink protector. This interface was also protected with the heat-shrink protectors used in electrical cables. In the installation process, the fiber was placed in the trench inserting a small part of the pigtail (Fig. 3.) into it in order to preserve the fiber fully protected.

Fig. 3. Pictures of the sensing fibers installation, the second layer paving procedure and resulting interface.

3. Results

Once the sensing fibers were installed, the sensitivity and breakage tests study were performed. Firstly, we confirmed that all fibers overcome the installation process, even when a fully loaded truck (~40 Tons → ~20 per axis) passes over the fibers. Thus, the subbase layer installation process was validated. Afterwards we proceed to check the load sensitivity. In this way, the truck was placed sequentially over the sensing fibers and then, a fiber strain scan was performed with the Optical Backscatter Reflectometer OBR 4600 by Luna INC. Thus, in Fig. 4. the strain results vs. fiber position for fibers installed in the subbase layer and the surface course layer are illustrated. In this figure the strain caused by the load corresponding to the two wheels is seen. It is also visible the strain difference between the fibers depending on the depth. In such a way, this demonstrates the good sensitivity of the optical fiber sensors when installed in asphalt structures.

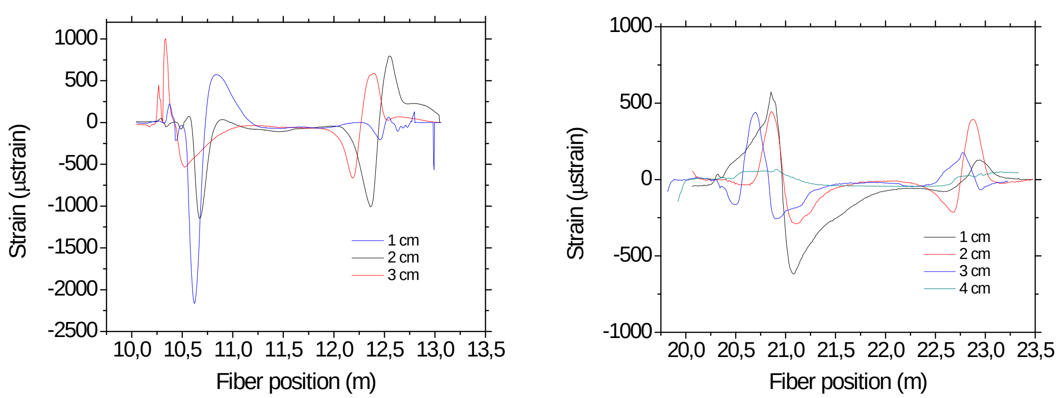

Fig. 4. Left: OBR strain results for the subbase layer sensing fibers placed at different depths. Right: Results for the sensing fibers installed in the surface layer.

Finally, the recovery of the strain state of the sensing fibers due to the small plasticity of the asphalt structure was explored. In Fig. 5 is shown how the truck wheels were placed over the fibers and in the right graphic the fiber recovery after 1 minute of the load point. This plot demonstrates the elasticity of the asphalt structures but it should be studied in deep using a dynamic sensor system such as FBG sensors technology.

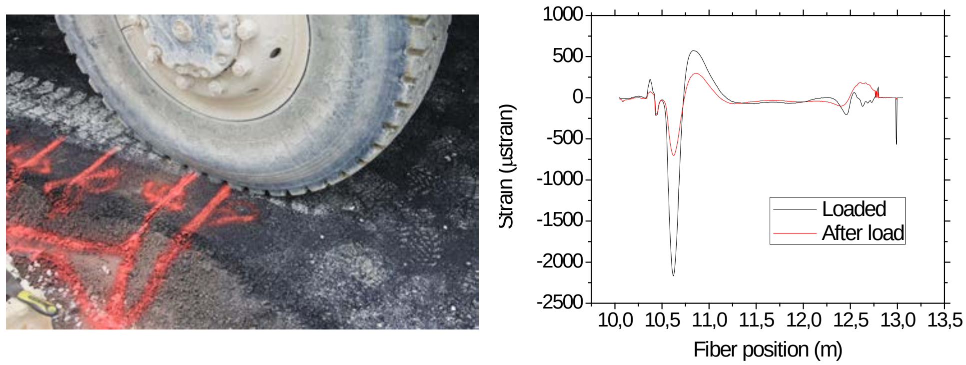

Fig. 5. Truck placed over the sensing fiber, and the OBR strain measurement when a truck is over the sensing fiber and when this is gone.

4. Conclusions

This contribution demonstrates the viability of the installation method proposed and the sensitivity achieved, enough to propose new OFS monitoring applications in asphalt structures. Besides, this method demonstrates the possibility of using distributed or punctual fiber optic sensor systems.

All installed fibers passed the process of paving and measure without breaks. The load tests were made with a fully loaded truck. As expected, the fibers installed at 1 cm of depth were the most sensitive in the subbase and surface course layers. It was also analyzed the plasticity of the asphalt in order to assure repeatability in the measurements. Although the result showed in this first stage a slow recovery time, it could be related with the sensing procedure based on the OBR and also because the results were obtained few days after the paving process. Thus further measurements will be carried out to analyze the asphalt structure’s elasticity on the sensing system.

Taking into account the strain values obtained, the installation method seems to be enough in order to propose new systems for predictive maintenance, traffic flow monitoring, speed measurements and, even, weigh in motion applications.

5. Acknowledgements

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