Smart Geosynthetics For Strain Measurements In Asphalt Pavements

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ABSTRACT

A special pit pavement has just been built in the civil engineering department of the University of Limoges. The main aim of this pit pavement, 8 x 3 m^2 in size and 2 m deep, is to do full scale pavement testing in usual laboratory testing conditions (controlled temperature and loading). The Texinov company is specialized in innovative technical textiles, with a strong experience in the use of optical fibers that can, for example, monitor strain signals along a pavement lifetime. So, this paper presents this new pavement device with its first application to validate new smart geosynthetics for strain measurements.

The pavement was composed of two layers: a 8-cm thick Hot Mix Asphalt (HMA) base layer and a 5-cm thick surface layer. Sensors were located at the base layer/platform interface and base layer/surface layer interface.

Two types of smart geosynthetics were tested: a low-strength one, positioned at the base layer/platform interface together with traditional strain gauges, and a high-strength reinforcement geogrid, positioned at the base layer/surface layer interface, providing mechanical reinforcement in addition to strain measurements. Both textiles were equipped with optical fiber sensors. Such smart geosynthetics enable reliable pavement monitoring and will therefore make it possible for the road owner to use the corresponding information to program maintenance operations.

The paper presents first the pit pavement and asphalt pavement construction. Then, the signals obtained from the sensors are presented. They were measured once a truck, loaded at various weights, was circulated over the structure. Calculations using pavement design software allowed computing the expected strains in the pavement. The comparison between theoretical and experimental data from both smart geosynthetic and standard strain gauges, clearly shows the superiority of this new generation of sensors over traditional ones.

Clearly, this new technology for strain measurements in pavements can replace traditional strain gages in a very simple way. Apart from obvious pavement monitoring, these devices can also be used for many other potential applications such as weigh-in-motion (WIM) system.

Keywords: geosynthetic; pavement monitoring; strain measurement; optical fiber; weigh-in-motion

1. INTRODUCTION

A special pit pavement has just been built in the civil engineering department of the University of Limoges. The pit pavement is located inside a building in order to control external conditions (temperature, humidity…). It consists of a 8 x 3 m^2 rectangular area, 2-m deep, that is large enough to build a real pavement with usual construction methods. Therefore, it makes it possible to do full scale pavement testing in usual laboratory testing conditions (controlled temperature and loading).

Optical fibers have been used for a long-time in order to monitor pavements [1] or to build weigh-in-motion (WIM) systems [2]. However, the current technologies are either very intrusive [3] or not so efficient. For example, obtaining nice strain signals from single optical fibers in pavements is not easy because it is difficult to have a good mechanical transmission of the loads/deformations to the sensors in pavement materials. Thus, the obtained signals are not so well-defined and their relevance is therefore questionable [4].

The Texinov company is specialized in innovative technical textiles, with a strong experience in the use of optical fibers [5-6]. Here, a new application of smart geosynthetic was tried in order to monitor strain signals along a pavement lifetime. This way, the sensors are fully connected to the textiles are follow the same movements as the textile. Thanks to Texinov's experience in the field of reinforcement geosynthetics for pavements (Notex® Glass product range), and in the field of smart geosynthetics (Geowarning® range), it was natural to experiment a combination of those products.

The paper presents first the pit pavement and asphalt pavement construction, including a description of the structure and sensors. Then, the signals obtained from the sensors are presented. They were measured once a truck, loaded at various weights, was circulated over the structure. Calculations using pavement design software allowed computing the expected strains in the pavement.

The comparison between theoretical and experimental data from both smart geosynthetic and standard strain gauges is finally discussed.

2. MATERIALS AND METHODS

2.1 Pavement Materials and Design

An experimental full scale pavement was built in the newly constructed pit of the University of Limoges, located in Egletons in the "Massif Central" mountain range of Southern France. The pit is a 8 x 3 m^2 rectangular area, 2-m deep. It was built from the bottom to the top by superposing the following layers:

- 20 cm of a 20/40 gravel were laid on the bottom in order to insure proper drainage. This draining layer is connected to a water circuit in order to control the water table inside the structure. In this experiment, the layer was maintained essentially dried
- 140 cm of decomposed granite were used in order to act as the subgrade
- 30 cm of untreated gravel of maximum diameter 31.5 mm (Grave Non-Traitée GNT 2 according to NF EN 13-285) were then laid as the subbase. After compaction, it was tested with the plate load apparatus and a plate modulus EV2 of 17 MPa was measured. Prior to the laying of the next course, a first set of sensors was placed as detailed in the next section.
- 9 cm of an Asphalt Concrete for base course (AC 14 base in current European nomenclature EN 13108-1 or Grave Bitume GB 3 0/14 in old French nomenclature) were then laid on the subbase. The GB 3 was obtained from the nearby asphalt plant of SIORAT at Brive (France).
- A tack coat was applied on the GB 3 with a dotation of 300 g/m2. An excess amount of 200 g/m2, hence a total dosage of 500 g/m2, was laid on a 4 x 1 m^2 area to be covered by the second smart geosynthetic, as described in the next section. Placement was performed using the recommended procedure for geogrids and related products: The textile was

placed directly in the fresh emulsion right after spreading. The presence of the light veil in the Notex® Glass product allows the emulsion to readily soak the textile through capillary rise (FIGURE 1).

- Once the tack coat emulsion had fully cured, as observed by the colour change from brown to black, a final layer of 5 cm of an Asphalt Concrete for surface course was placed (AC 10 surf in current European nomenclature EN 13108-1 or BBSG 3 0/10 in old French nomenclature).

FIGURE 1 The second geosynthetic right after placement using the usual method for reinforcement geosynthetics: the product is laid in the fresh tack coat emulsion.

2.2 Geosynthetics

Two types of smart geosynthetics were tested. They were both produced by Texinov using a complete integration of the optical fiber in the textile, allowing for a perfect strain transfer from the geosynthetics to the fiber, therefore from the support to the fiber if the textile is well connected to it. More precisely, the testing was based on the following sensors:

- A low-strength geosynthetic GeoWarning® positioned at the base layer/platform interface. It was equipped with a longitudinal optical fiber containing two Fiber Bragg Grating (FBG) sensors 3-m apart (FBG1 and 2 - FIGURE 2). These two FBG have a different wave length so that the deformation on each one can be separated.
- FBG1 and 2 were placed ~20 cm away from two traditional H pavement strain gauges,
- A high-strength geosynthetic Notex® Glass 100x100 GeoWarning® positioned at the GB/BBSG interface. It was equipped with a longitudinal optical fiber containing one FBG sensor (FBG3 - FIGURE 2). FBG3 was positioned just above FBG2, so that they were only separated by 9-cm of GB.
- Two thermocouples were positioned respectively on top of the GNT and on top of the GB. The temperature recorded on both devices during the loading test was 19°C.
- In this first study, monitoring of strain gages sensors have not been analyzed.

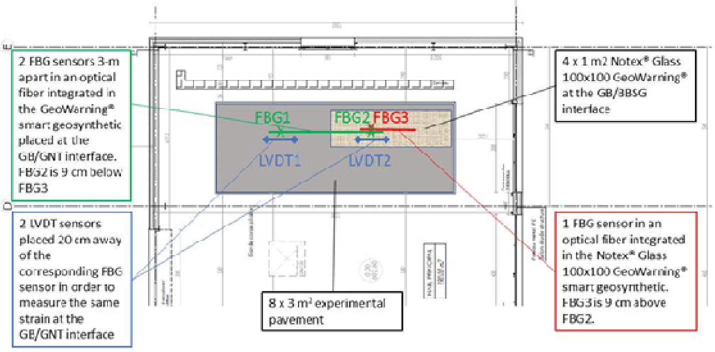

FIGURE 2 The position of the different sensors in the experimental pavement.

2.3 Loading

For the sake of demonstrating the potential of the sensors, a direct loading was organized on the pavement in July 2017. This was down using a Renault S130 truck with unladen weight of 4.7 t. The distance between axles is 3.24 m. The load on the rear dual wheel was measured to be 11,2 kN. The truck was carefully positioned in order to have its rear dual wheel pass just above sensors FBG1, 2 and 3 (FIGURE 3).

Initial measurements were acquired with the unladen truck. Then, the truck was loaded with two 10 kN concrete blocks positioned right above the rear axle. The total load on the dual rear wheel was then 21,2 kN. Finally, the truck was loaded with yet another concrete block positioned on top of the two previous ones. The total load on the dual rear wheel was then 27,2 kN.

For each of these loading conditions, the truck travelled at a low speed of ~1 m/s.

FIGURE 3 The loading experiment with the truck.

3. RESULTS AND DISCUSSION

3.1 Results

The results obtained on FBG2 for the various passes of the truck are shown on FIGURE 4. First, it must be highlighted that the quality of all signals was very good, with the sensor detecting both compression and tension.

The signal had the expected two peaks corresponding to the passing of first the front wheel and then the rear wheel. Given that the driver was directed to have the middle of the rear dual wheel on top of the sensor, we are confident that the rear wheel really passed on top of the sensor while the front wheel was probably in most cases a few cm away from the exact position of the sensor. Therefore, the second peak was preferred for all further analysis. Still, taking the 3.24-m distance between axles for the truck, the speed of the truck could be easily calculated for each loading. The resulting values are given in TABLE 1, showing that the driver was pretty efficient in controlling the target speed of 1 m/s.

Then, the maximum tension recorded for all loads was of order of a few hundreds of microdef, as expected for a small load on a flexible pavement. More precisely, the 11,2 kN load gave a maximum tensile strain of 112 microdef (TABLE 1). It increase to 207 and 260 microdef respectively for the 21,2 kN and 27,2 kN loads (TABLE 1). The linearity with loading level is well checked.

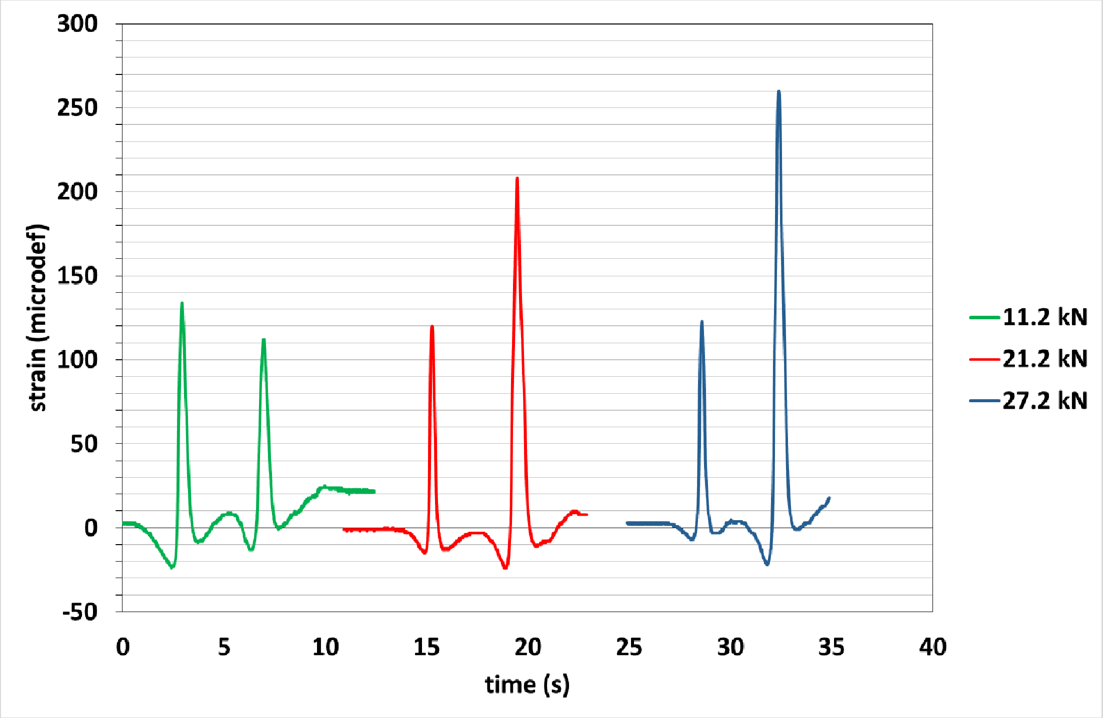

FIGURE 4 The signals obtained from FBG2 upon passing of the truck circulating at ~1 m/s with rear dual wheel loads of 11,2kN, 21,2 kN and 27,2kN. The time scale of all signals have been shifted horizontally arbitrarily in order to better separate the signals. The first peak corresponds to the front wheel and the second, to the rear wheel.

	Load (kN)	11,2	21,2	27,2
calculated speed	m/s	0,94	0,90	1,00
max. tensile strain from FBG2	microdef	112	207	260
calculated max. tensile strain (Alize)	microdef	129	244	313

TABLE 1 Truck speed and maximum strain recorded for the different loadings compared to calculated values. See text for details.

3.2 Calculated strains

The peak strain values given in TABLE 1 were compared to values computed from a pavement design software (Alizé-LCPC version 1.3.0). In order to calculate the design maximum tensile strain at the GNT/GB interface, the following materials properties were used.:

- Platform of 17 MPa
- 9 cm of GB3 with Young's modulus of 5580 MPa at 22°C, 10Hz (the same 18°C, 1Hz)
- 5 cm of BBSG2 with modulus of 3140 MPa at 22°C.

Temperature measurement was 18°C, when the loading rate is average 1Hz frequency. The time superposition principle enable us to convert 10 Hz properties to 1 Hz properties by shift factor adding 4°C

The corresponding calculated peak strain values are given in TABLE 1. Clearly, the match with the data obtained from FBG2 is excellent. The deviation between measured and calculated values (average 15%), probably comes from the uncertainties coming from platform modulus, horizontal boundary conditions given by the pit geometry, and also the true HMA properties. For example, 20 MPa instead 17 MPa as 1°C temperature variation, give 4% strain variation each. Therefore, it can be concluded that the values measured by FBG2 match the calculated values

4. CONCLUSIONS

A special pit pavement has been built in the civil engineering department of the University of Limoges. The main aim of this pit is to perform full scale pavement testing in usual laboratory testing conditions (controlled temperature and loading).

In this paper, the first experiment realized on this facility was presented. Together with Texinov, the University of Limoges tested new smart geosynthetics for strain measurements. A flexible pavement was constructed and two optical fiber sensors integrated in a geosynthetics were positioned at the base layer/platform interface and at the base layer/surface layer interface.

The pavement was loaded and the recorded strains from the smart geosynthetics were close to design calculated values. In addition, speed measurement is made very easy, making it potentially useful for traffic monitoring and many other potential applications such as weigh-in-motion (WIM) system. Next, it will be a validation with the actual HMA material properties and viscoelastic modelling (ViscoRoute 2.0) associated with standard strain gage measurements.

5. REFERENCES

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