Smartvia concept : a 5 years feedback on standalone pavement structure monitoring

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ABSTRACT

During the last decade, we notice changes in paving technologies, such as the use of RAP, warm mixes. To design these innovative technologies, engineers first used laboratory and modeling ressources. Then field experiments are required. Gathering feedback from onsite experiment is a real challenge.

Since 2010, Eurovia Research Center developed the Smartvia concept to support onsite feedback for innovative pavement products. This concept is based on the use of sensors fully integrated to the pavement structure during road works, programmable electronics with real time data acquisition software. This enable to trigger acquisition on demand or on event and to push the data through wireless networks towards specific data servers.

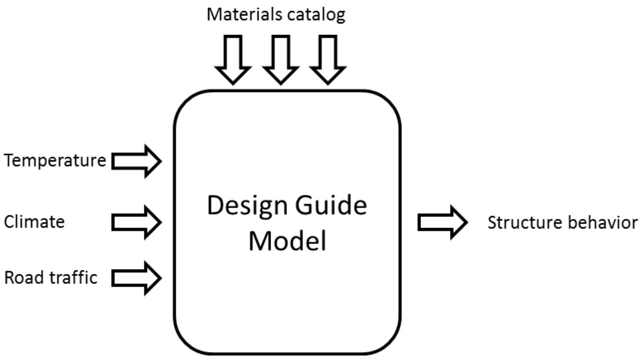
This paper provide a 5 years feedback on standalone pavement structure monitoring based on 6 experimental jobsites. We describe two specific projects: a one scale experiment on the impact of trenches on the durability of pavement (performed in partnership with Lille Metropole Communauté Urbaine) and the Novatherm demonstrator that enable deicing of road surface using geothermal energy.

The authors focus on sensors selection (temperature, humidity, pressure, strain), their integration to the structure, their durability and data management. A vision of future challenges towards a real smart and intelligent road will be discussed.

Keywords: Rheology, Structural fatigue, Thermal Cracking

1. INTRODUCTION

The pavement structure design theory is based in France on the Alizé [Référence] method where it is based on the MEPDN [Réference] method in the US. Both of these methods use an empirical calculation code. Each code uses as inputs asphalt mixes characteristics. According to these theoretical mechanics parameters, the winter's strength in the region and the expected road traffic, the computer code predicts a mechanical behavior and an estimated pavement lifetime of the pavement structure.



Knowing that an under sized structure even of one centimeter can result in a loss of durability of several years, using a new formula that is not in the material catalog is risky. Each type of product has to be tested on representative experimental job sites in order to get enough feedback to become confident on the structure behavior over time. The time to market of a new formula can reach more than a year due to the need of collecting feedback

This paper introduces the premises of a fully automated real time monitoring system in the road industry that allow to drastically reduce the time to market of new products by integrating sensors directly in the structure during the pavement construction.

Monitoring systems are well known in the bridges field for example. Many constructions in the world have been monitored for many years like the Normandie Bridge in France or the Bosphore bridge inTurkey . Those technologies are well known but not used in the pavement field.

The purpose of this paper is to present a five year feedback on pavement monitoring systems. This field is very large so we will focus on specific topics such as the temperature and the strain monitoring. The last part of this paper presents two fully instrumented jobsites.

2. OUR DEVELOPMENT APPROACH

In order to support the innovation and to implement new asphalt formulas, three different technics are used on experimental job sites:

- Surface auscultation
- Samples analyses in laboratory
- Sensor measurement

The chart below compares the advantages of each technics and their limits.

	Advantages	Limits
Auscultation	Large surface control	Only the surface is accessible
Sample analyses	Deep analyze of the structure	Need to collect many samples. Only static parameters are analyzed
Sensor measurement	Dynamic response analyses of the structure	Small part of the road is monitored

Thanks to the development of sensors technologies, high speed cellular network and data acquisition electronics, developing a high speed fully automated monitoring speed is possible.

We choose to develop the sensor measurement technic by adding the real time on event data recording. This enable to monitor over time the main mechanical and physical parameters of the structure like the strain, the temperature, the moisture level, the mechanical pressure… This way the feedback data collection is faster and the evolution of the behavior over time can be monitored.

3. OUR DEVELOPMENTS

3.1 The five steps to a self-monitoring system

We choose to illustrate the Smartvia® concept with the Magie® cycle.

The first step is the sensors selection. Many technologies were tested in laboratory to assess the mechanical resistance, the temperature cycles resistance, the measure precision and the dynamic response.

After the sensors selection, each one has to be studied to make the right integration de the structure. Many tests were conducted to define for each one the installation procedure after an onsite calibration test.

To power all the sensors and the data acquisitions systems and according to the power need, the monitoring system can be powered using renewable energy like solar energy. For small monitoring system Vinci Energie selected lithium battery that can reach 1 month of battery life à high frequency data acquisition of many years for simple low frequency temperature monitoring.

At a high frequency, the data management is a key to ensure long term structure monitoring. Indeed, for example 20 strain sensors at 1 kHz frequency can reach 10 gigabytes per month of unprocessed data. In order to drastically reduce the data amount, a programmable electronics with real time data acquisition software is used. This enables to trigger acquisition on demand or on event and to directly push the data through wireless networks to a specific data server.

The server runs a software 24/7 which analyses the data as it comes. The processed data is stored in a MySQL Database that allows plotting specific period of the structure behavior. This auto diagnosis process can also trigger alarms if high stresses are detected in the structure.

In this paper we will only present the results of the temperature sensor and the strain sensor work.

3.2 Sensor selection

After five years of sensors resistance feedback, the selected temperature sensor is a stainless steel embedded PT100 that is 8 cm long with 1 cm part that is sensitive to the temperature changes. The sensor cable is made with Teflon in order to resist to the high temperature induced by the hot bituminous asphalt mix application.

The strain measure is made with a fully embedded gage that provide suitable waterproofness and an elastic modulus adapted for measuring internal stress in bituminous asphalt mix. Whereas the temperature sensor cable can resist to very high temperature, the strain gage cable needs to be protected.

3.3 Sensor integration to the structure

3.3.1 Temperature sensor

To integrate to the structure the temperature sensor, we use a core drilling machines to make a hole in the structure. Then many holes are made in the circumference of the coring and filled with thermal paste to ensure the thermal coupling. The sensor is then put within the thermal paste. The following picture illustrates the process of temperature sensor integration.

Fig 1 : Temperature sensor integration process

3.3.2 Strain sensor

The strain sensor integration is achieved by adding two stainless steel parts to the sensor in order to ensure the mechanical coupling. The sensor is placed upside down on the surface of the first material layer. The hot asphalt mix paving is done on top of the sensor. That way, the sensor is fully integrated in the bituminous asphalt layer and can measure the strain at the bottom of the layer. The following pictures show the preparation and the strain sensor positioning.

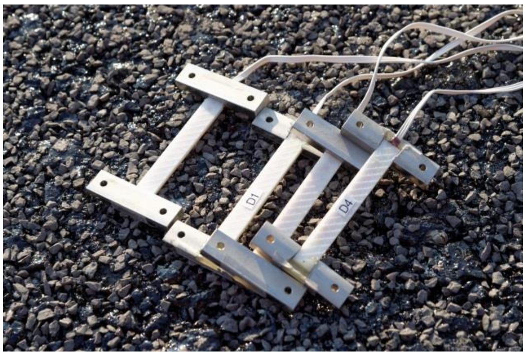


Fig 2 : Strain sensor positioning

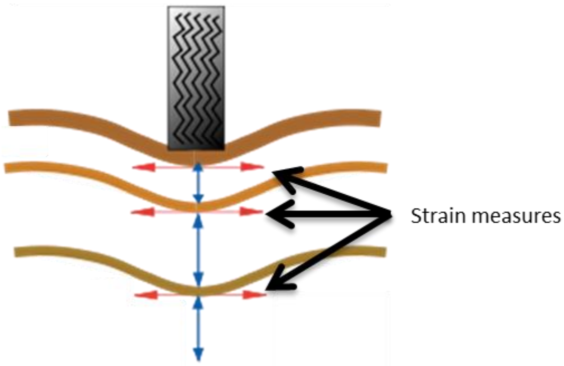


Fig 3 : Strain sensor

3.4 In situ behavior

3.4.1 Temperature

In order simplify the temperature integration; a body equipped with at least four temperature sensors was designed. It is integrated in the structure after making a 22 mm hole with a drill.

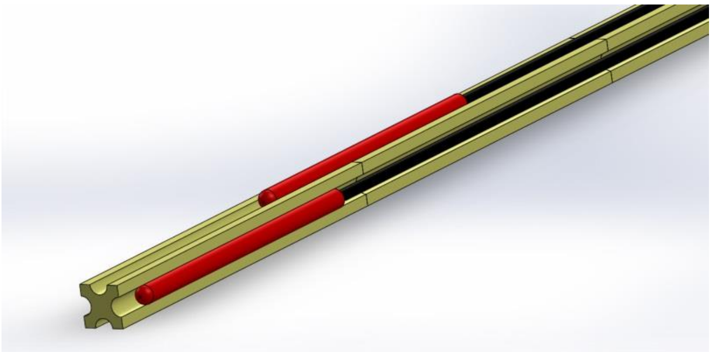
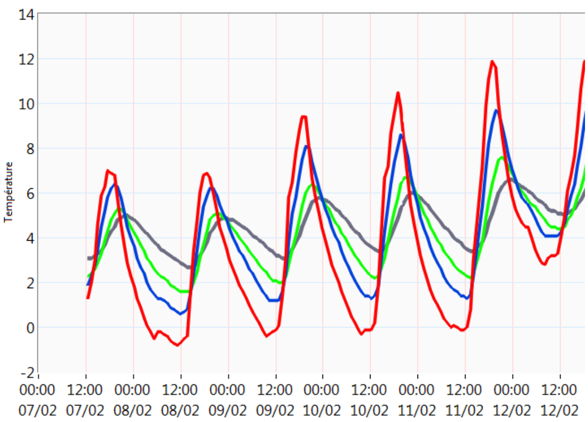


Figure 4 : temperature sensor body

In order to validate the measurement made with this particular sensor, a comparison was achieved between the traditional method and this one. Four temperature sensors were integrated to a structure next to four temperature sensors that use the designed body.

The graphs below show the temperature using the two methods. First, we can notice that the temperature gradient is well represented. Secondly, the two methods show very close results except for the sensor on the surface (Red curve) where there is a 1°C difference.



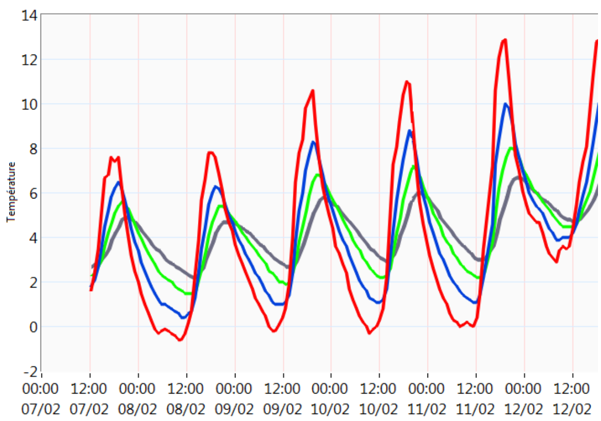


Fig 5 : Temperature measurement using the traditional method

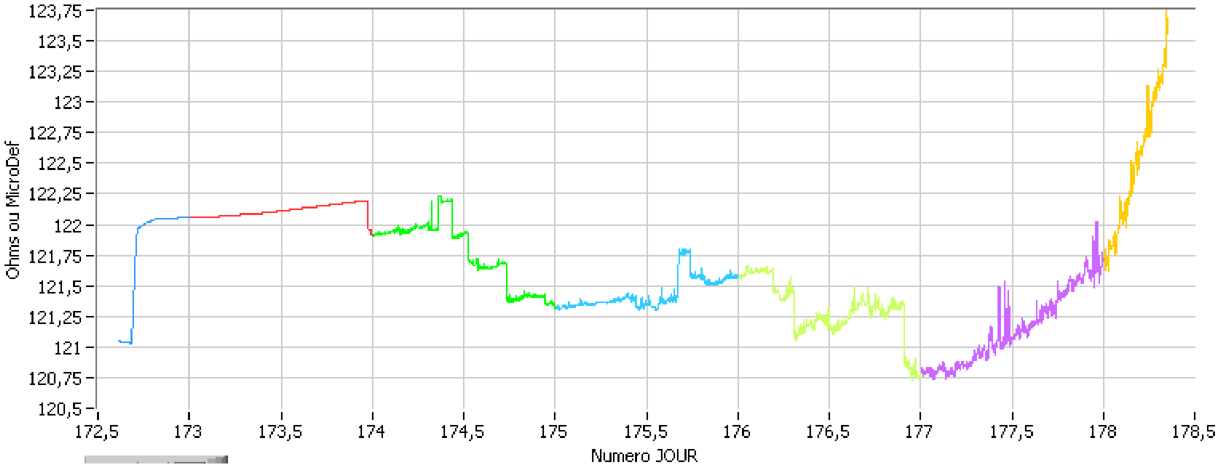
3.4.2 Strain

The strain sensors used for road monitoring system are embedded in a waterproofing materiel wish is compatible with strain measure within asphalt mixes structures.

Even with this waterproofing process, the resistive strain sensors face a phenomenon after 8 to 10 months.

Indeed, we observed an increase of the reference value of each sensor and tried to reproduce the phenomenon is the laboratory.

After many temperature cycle and hygrometric cycle we observed the same increase of the reference value along with the apparition of corrosion. The chart below illustrate this phenomenon.



4. EXAMPLE OF EXPERIMENTAL JOB SITES

4.1 CCLEAR project

In 2012, the IFSTTAR (The French institute of science and technology for transport, development and networks) and the Eurovia Research Center worked together on an instrumented road project. The goal was to assess the climate impact on the durability of a highway structure.

4.1.1 General description

The project takes place in the A75 highway in the south of France.

Figure 6 : Job site location

The structure is equipped with 14 strain sensors and 2 temperature sensors.

4.1.2 Data acquisition

The data acquisition systems are based on Pegase. This is DAG developed by the IFSTTAR. It has embedded software that runs on a custom Linux OS. The resolution of each channel is 12 bits.

Those two Pegases are linked to 3G modem, so that every data collected is transferred to a remote server.

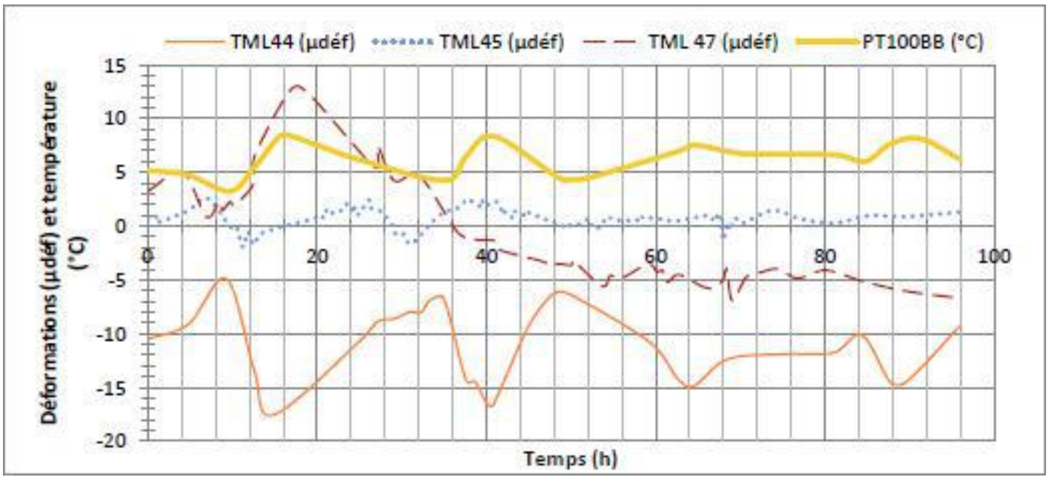
4.1.3 Road works

Here are some pictures of the road works.

Figure 7 : Strain sensor integration

4.1.4 Preliminary results

The chart below shows the strain levels and the temperature in the structure. The 12 bits resolution of the DAQ does not permit de get clean strain signals.



4.2 Smartvia® project

In 2014, the Lille metropolis organization asked Eurovia to design an instrumented road to assess the impact of trenches on new roads. This part of this document presents a fully 24/7 instrumented job sites.

4.2.1 General description

The job site takes place in Villeneuve d'Ascq in the north of France.

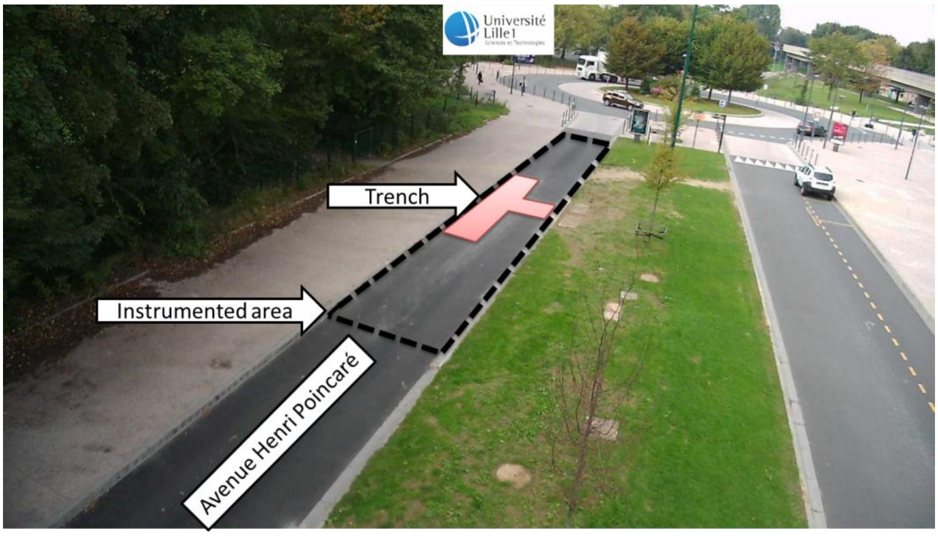


Fig 8 : Project location

In order, to quantify the durability loss due to the trench, 7 instrumented nodes are implemented.

The P0 node is the farther node and consists of a reference.

The P1 and P2 nodes are close to the trench and allow us to see if there is more strain to the structure due to the trench opening.

The P3 and P4 nodes are from either side of the trench and allow us to see the horizontal influence.

P5 and P5' nodes are integrated directly in the trench.

Finally, the P6 and P7 nodes are from either side of a transversal trench.

The tested structure is as follows:

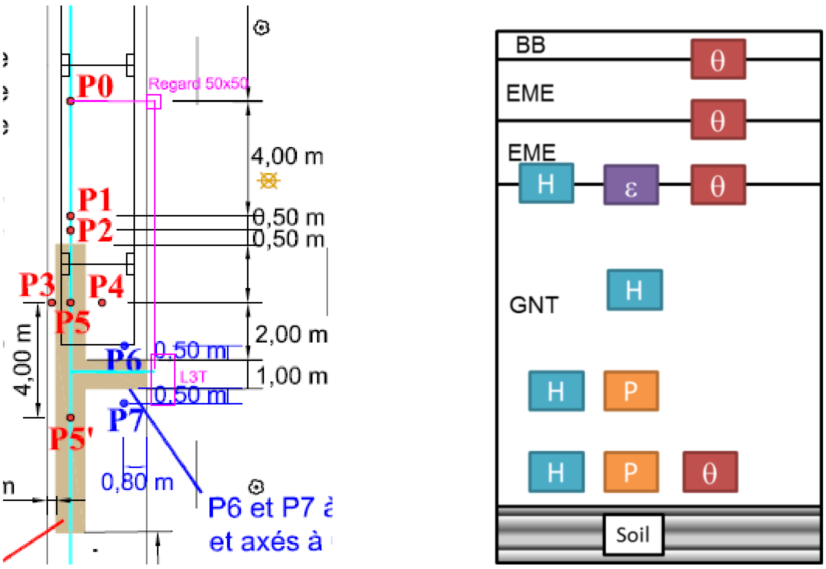


Fig 9 : Global description

The main sensors are:

- Temperature
- Strain
- Moisture level
- Vertical load
- **Experimental** : Bragg Fiber Optic for strain and temperature measurement

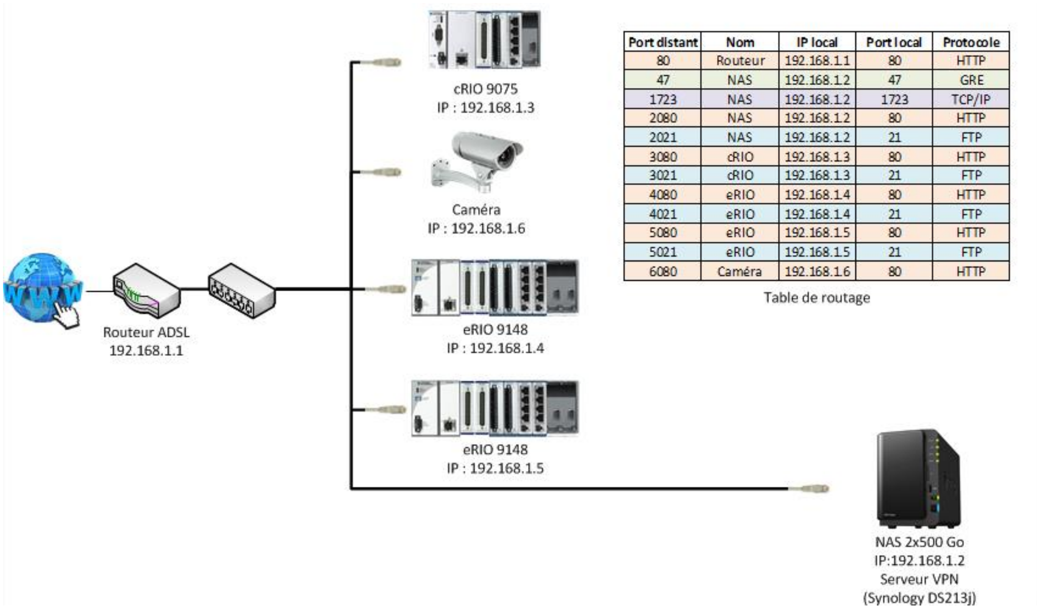
4.2.2 Data acquisition

The data acquisition systems are based on a National Instrument® Compact RIO. Three data acquisition controllers are used to monitor the 98 sensors in the structure. A digital camera is linked to the system to take pictures of every truck that rolls on the sensors. Finally, a backup hard drive is added to the data acquisition system in case of a cellular network loss.

In order, to reduce the 3G transferred data, an on event trigger is implemented in the embedded acquisition software. That way, only valid data are uploaded to the online server.

The data acquisition rate for the strain and pressure sensor has been set to 1 kHz in order to get enough point based on a truck rolling at 90 km/h.

To permit the data processing we recommend using at least a 24 bits data acquisition system for strain monitoring.



Port distant	Nom	IP local	Port local	Protocole
80	Routeur	192.168.1.1	80	HTTP
47	NAS	192.168.1.2	47	GRE
1723	NAS	192.168.1.2	1723	TCP/IP
2080	NAS	192.168.1.2	80	HTTP
2021	NAS	192.168.1.2	21	FTP
3080	cRIO	192.168.1.3	80	HTTP
3021	cRIO	192.168.1.3	21	FTP
4080	eRIO	192.168.1.4	80	HTTP
4021	eRIO	192.168.1.4	21	FTP
5080	eRIO	192.168.1.5	80	HTTP
5021	eRIO	192.168.1.5	21	FTP
6080	Caméra	192.168.1.6	80	HTTP

Fig 10 : Global architecture

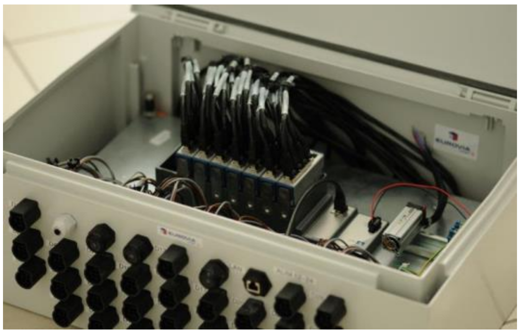
 

Fig 11 : Electronics boxes

4.2.3 Road works

Here are some pictures of the road works during the sensors integration.

Fig 12 : Moisture sensor

Fig 13 : Vertical load sensor

Fig 14 : Compaction

Fig 15 : Trench's sensors

4.2.4 Preliminary results

The graph below shows the strain level (udef) during a truck crossing in P0 and in P5.

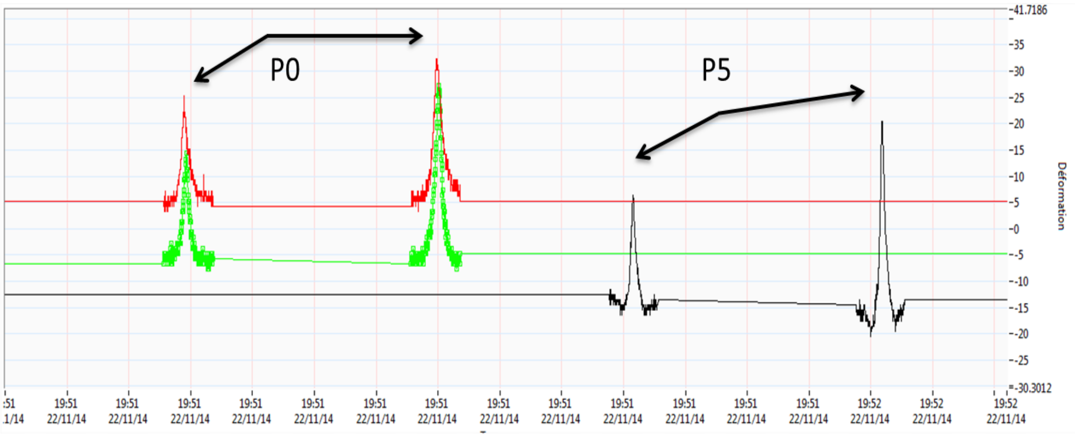


Fig 16 : Strain level

Even at the beginning of the monitoring, we can already detect small increase of the longitudinal deformation level between P0 and P5.

This project aims to monitor this difference over time to link it with the remaining lifetime. The temperature and water level monitoring will permit to compare the strain level in the structure during very close climate conditions.

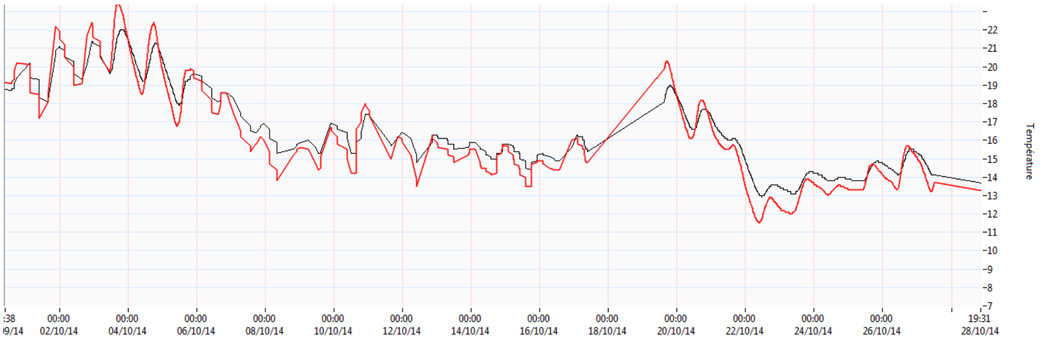


Fig 17 : Surface temperature

As expected, after 8 months most of the resistive strain sensor stopped working. The major part of those sensors experienced the corrosion phenomena. This can be seen by an increase of the reference value of each sensor.

Unlike the resistive sensors, the Bragg Fiber Optic still works after 8 months. The chart below shows the strain during a 13T truck crossing.

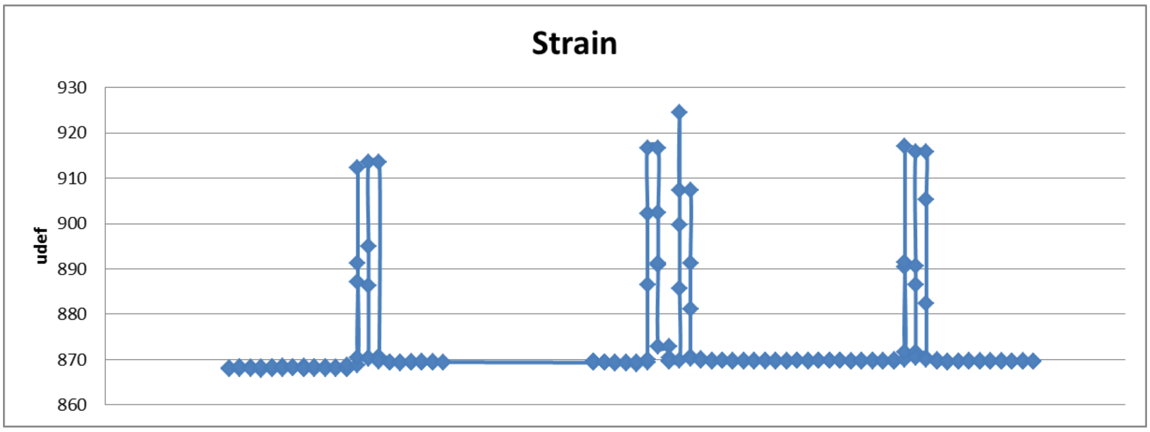


Fig 18 : Fiber optic strain mesurement

5. CONCLUSION

It appears that through the development of the Smartvia® concept, Eurovia provides a complete solution for monitoring innovative pavement structures. The necessary time to collect feedback on the behavior is reduced as for the time to market of a new structure design.

There is still much work to achieve in the strain sensor integration and durability but thanks to recent development it appears that Bragg Fiber Optic last longer in asphalt mixes. Now that this technology can reach more than 1 kHz, it is compatible with road monitoring.

Finally, the importance of the temperature has led us to develop a fully embedded battery powered and wireless temperature sensor that allow us to monitor the temperature at several depths. The Smartvia®-Cryo will be launched in October 2015.

6. REFERENCES

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