Influence of the bituminous layer on temperature and water infiltration in railway structures HSL BPL

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ABSTRACT

The phenomena of packing and wear of the ballast, under dynamic stresses lead to high frequencies and high maintenance costs. Several studies have shown that these settlements were linked to the high accelerations produced in the ballast by the passage of high-speed trains (HST). A layer of asphalt concrete (GB) was made under the ballast layer on the high-speed lane Bretagne-Pays de Loire (BPL HSL). It is intended, among other things, to reduce the amplitude of the accelerations produced at the passage of the HST.

The BPL HSL includes 105 km with a sub-layer of asphalt concrete under ballast, and 77 km with a granular sublayer (UGM). In this article, we present the different sensors of the instrumentation as well as the acquisition system installed to collect all the measurements and the webserver developed to monitor the sensors. We will also reveal the outputs recorded by the sensors, slow and fast measurements.

Keywords: Ballasted railways, bituminous underlayment, asphalt concrete, monitoring, sensors, and data acquisition.

1. INTRODUCTION

In France, the structures of high-speed rail lanes (HSL) are generally made of ballast, resting on a sub-layer of granular materials. Several studies have shown that the ballast settlements were related to high accelerations produced in the ballast due to high-speed trains.[1]–[4] One of the proposed to mitigate this problem was to introduce an asphalt concrete layer under the ballast layer [5]. This has been implemented on the HSL Bretagne-Pays de Loire (BPL), to rigidify the track and verify its influence on the reduction of the amplitude of the accelerations due to passing trains.

Instrumentation BPL is a collaborative project led by IRT Railenium, in partnership with Eiffage, IFSTTAR, SNCF Reseau, SETEC and the University of Lille. The BPL HSL has 105 km of innovative track with asphalt concrete sub-layer under the ballast and 77 km of standard granular layer (see Figure 1). Four sections representing the different types of structures of the new BPL high-speed lane (3 sections with asphalt concrete sub-layer and 1 section with granular sub-layer) have been instrumented with different types of sensors, in order to better understand the mechanical behaviour of the track under dynamic rail stress. The development and installation of the instrumentation on 4 sections of the HSL was carried out by IFSTTAR with the support of Eiffage Infrastructures.

The analysis of the measurements recorded by different sensors aim at determining the responses of the different sections and the variations of the various parameters measured according to climatic conditions (temperature, water conditions), speed of the trains and loads[6]–[9].

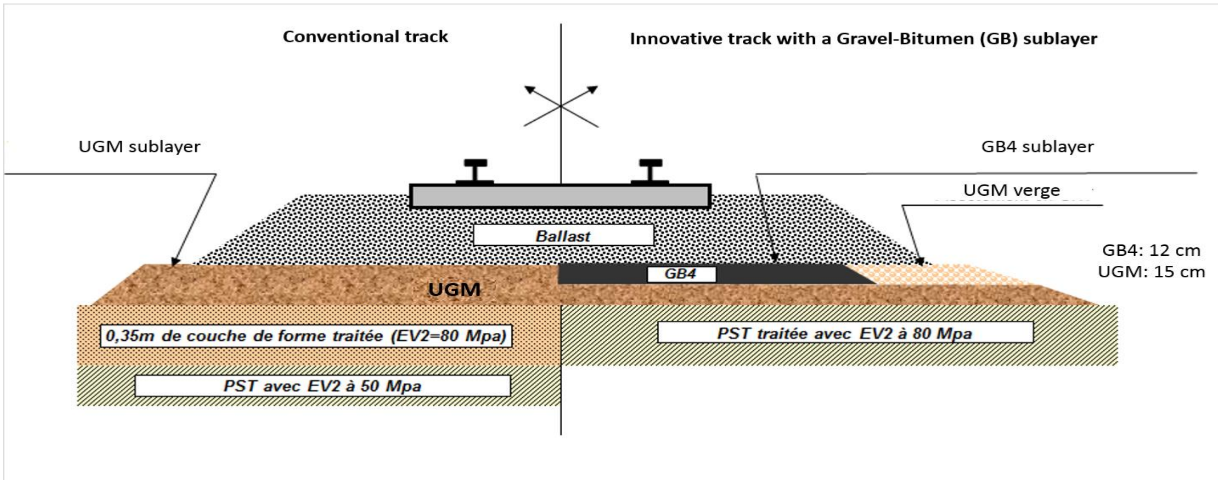

Figure 1- Different structure of the HSL BPL

2. INSTRUMENTATION BPL: SENSORS AND MEASUREMENTS

The objective of this instrumentation is to obtain a database of dynamic and mechanical measurements of the different structures used on the HSL BPL (soil type, granular sub-layer or in GB): accelerations, displacement of the ballast structure, horizontal and vertical deformations in different layers, layers and air temperatures, water content of the layers.

The sensors chosen for the instrumentation of the different sections are a weather station for each section, accelerometers on different levels in the structure and on the sleepers, horizontal extensometers at the base of the asphalt concrete, vertical extensometers in the UGM sublayer, two anchored displacement sensors on each section, moisture probes, and temperature sensors. A detailed description of the instrumentation has been provided in the published papers[10], [11].

At the level of each section, there are two types of measurements: "slow" measurements and "fast" measurements. Slow measurements include temperature sensors, water content probes, weather data, anchored deflection sensors (measurement of the overall settlement of the ballast sub-structure). These are recorded continuously every 15 min. The sampling frequency is adjustable and can vary from few seconds to 15 minutes maximum.

Fast measurements include accelerometers, vertical extensometers, horizontal extensometers and the anchored displacement sensors (measurement of the displacement under a train passage). These measurements are carried out at each train crossing the high-speed fast lane. They are triggered if a threshold value is exceeded (threshold set for an accelerometer placed at the top of the first sublayer). The value of this threshold is very low, which allows the recording of all the trains' passages. A pre-trigger and post-trigger are adjustable from 0.5 to 20 seconds. The signal acquisition frequency is 2000 Hz. Each measurement's start, slow or fast, is dated in GPS time indicated in hour-minute-second-microsecond.

3. ACQUISITION SYSTEM ON HSL BPL: WEB APPLICATION

The mentioned sensors are connected with cables to the measurement acquisition systems. Based on its performance and experience feedback, the acquisition system using Pegase cards, developed by IFSTTAR[8], and marketed by A3IP was chosen. The acquisition boxes containing the Pegase cards connected to its supported sensors are in place at each section. All the data registered on each section is transferred continuously via a 3G network (within a few hours) to a remote server hosted by Power-Lan provider of the remote data server part.

Each system is autonomous in energy and data transmissions. The power supply to the acquisition systems was made by solar panels and batteries for continuous year-round functioning without interruption. Access to the site was forbidden; the acquisition system had to be controlled and programmed remotely and data transmitted via 3G/4G network.

All the data recorded are put into a relational database for a fast and multi-criteria data search. A remote webserver allows management of the various instrumented sites as well as the different measurement systems of each site, including the weather station system, the water content measurements and the configurations of the different acquisition parameters, through a web application.

For each resource (acquisition Pegase cards connected to its sensors), it is possible to visualize in real time the slow and fast measurements associated with each sensor of the resource. For every section, you can choose the Pegase card to access its sensors measurements and visualize their signals and values. We have six acquisition cards on section 2 and 4, seven cards on section 1 and one Pegase card on section 3.

The address of the server is secure https with login and password and different levels of access (all rights, account administrator and system configuration, simple user allowing visualization of the data and export). It allows the different partners of the project to access the data in real time, to view directly the curves of slow and fast measurements and to export and download the needed measurements for any date or train passage. The scheme of the instrumentation with the acquisition system is shown in Figure 2.

4. FAST AND SLOW MEASUREMENTS EXAMPLES

The fast measurements of the sensors, recorded on the web-server are then post-processed using Scilab routines. The treatment and processing data plan and programs developed are detailed in the paper [11].

Unlike the other sensors, the anchored displacement sensor measuring the displacement of the whole structure under the ballast (to 6m depth) takes part in the slow and fast measurements. When a train travels on the HSL, not only are we able to detect the deflection signal of the structure, but also plot the response under traffic in terms of settlement. The sensor in question registers the displacement every 15 minutes.

In Figure 3 and Figure 4, we can easily detect the signals peaks referring to the numerous bogies of the crossing train.

Figure 3 illustrates the deflection signal of a simple 13 bogies train passing on the track of section 2 on May 17, 2017 at a speed of 270 Km/h.

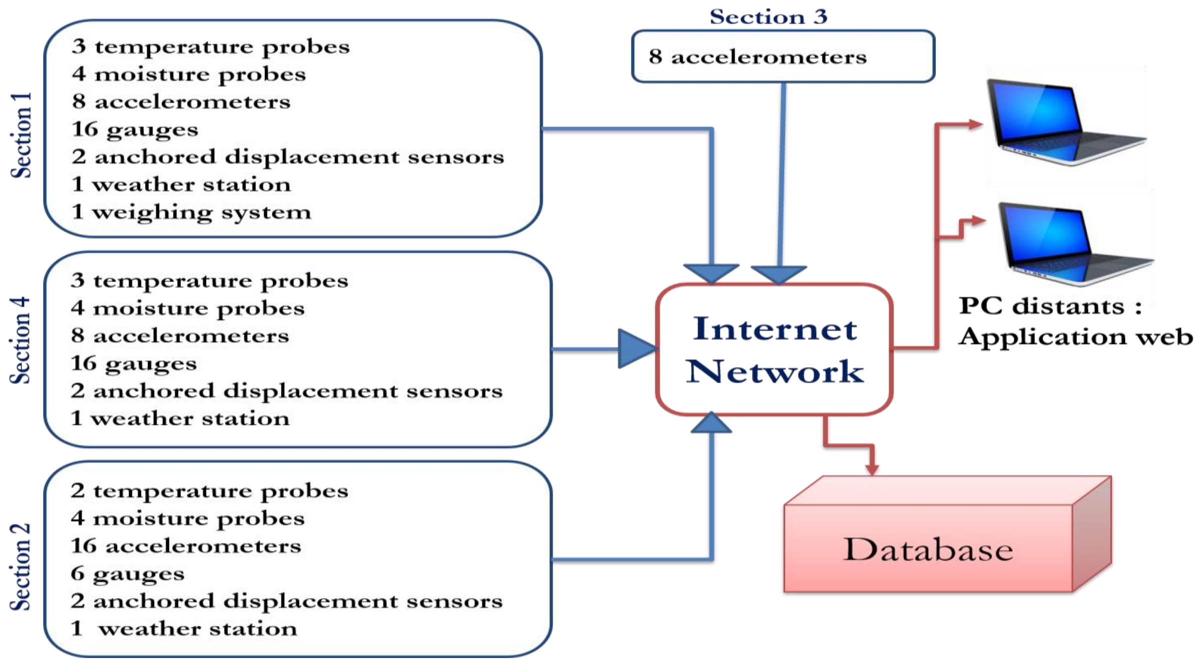

Figure 2 - Overall scheme of the instrumentation and acquisition system

In Figure 4, we plotted the deflection signal of a double train passing in the same day and on the same section but with a speed of 217 Km/h. In this double train signal, the bogies referent peaks are in the number of 26.

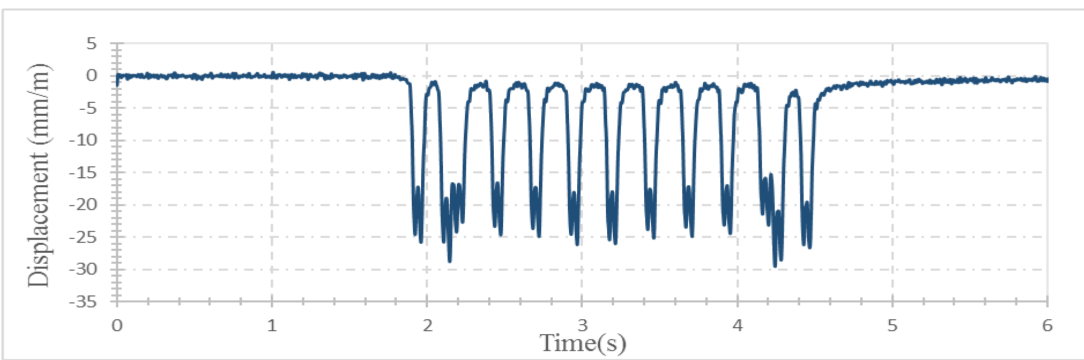

Figure 3 - Deflection signal of a simple train passing on HSL BPL with V=270 Km/h

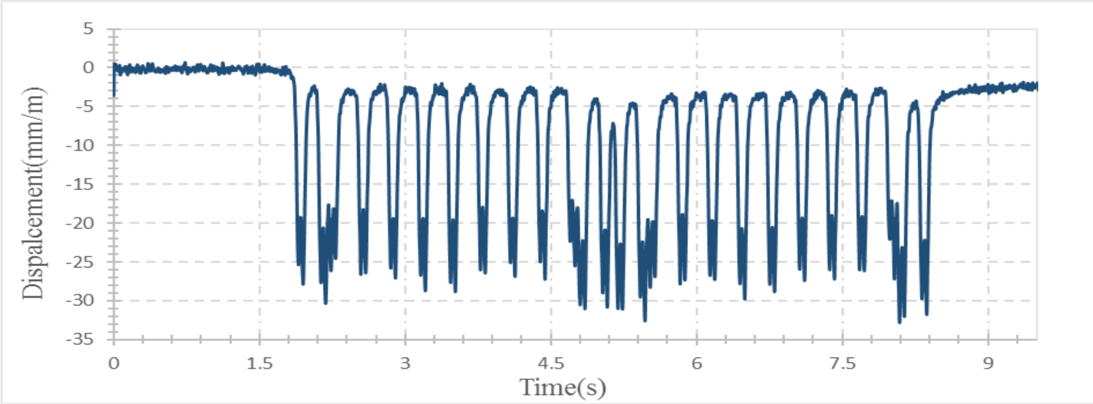

Figure 4 - Deflection signal of a double train passing on HSL BPL with V=217 Km/h

As mentioned earlier, the slow measurements monitored on the BPL HSL include the sublayers' temperature, air temperature, and the water content of the sublayers. In Figure 5 is shown the temperature variation at the top and base of the asphalt concrete layer, the base of the granular layer monitored with temperature probes on various levels and the ambient air temperature monitored with the weather station. It is remarkable that the temperature of the layers is very close but varies with the ambient air temperature without exceeding 23 degrees even when it is 40 degrees in summer months. The lowest temperature registered in winter is 2°C. We can say that the ballast layer limits the temperature variation in the bituminous layer.

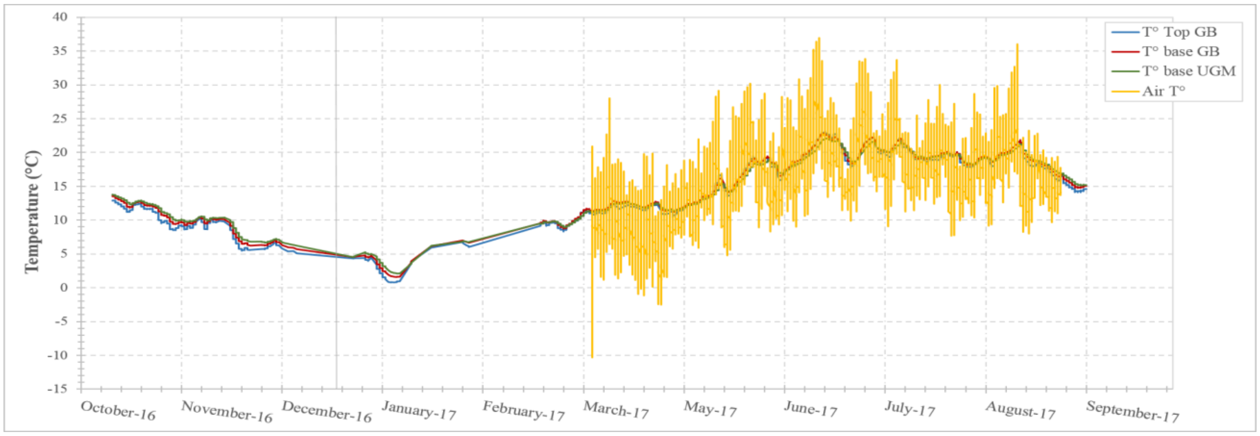

Figure 5 - Variation of sublayers and ambient air temperature in a section for 11 months period

The water content measure is also a slow measurement data registered with humidity probes in different levels of the sections structures. Figure 6 shows the variation of the water content for the period from October 2016 until November 2017. For the two probe installed under the UGM layer, there are many variations of the water content, suggesting important water infiltration.

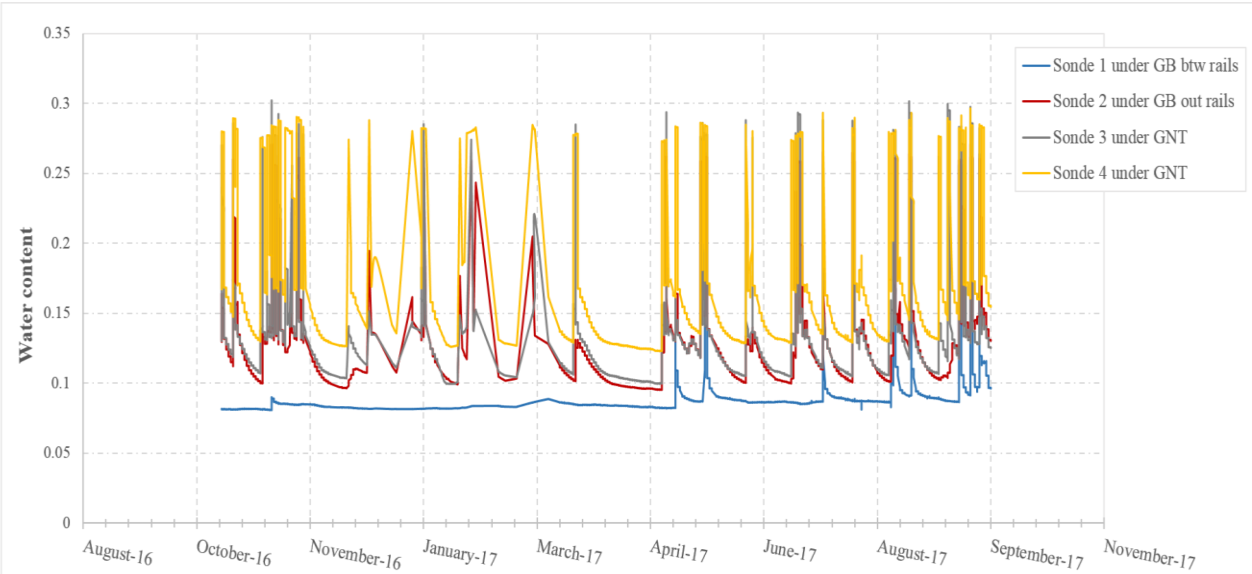

Figure 6 - Water content variation in a section with asphalt concrete for an 11months period

We can easily see in Figure 6 the low water infiltration recorded with the sensor installed under the asphalt concrete layer: for the probe installed under the bituminous layer, between the rails, there are very few water content variations. For the probe installed under the bituminous layer, outside the rail, there are more frequent but less significant variations. It means that the water infiltration under the bituminous layer is minimal. We can conclude and verify that one of the advantages of the bituminous sublayer is to improve storm water drainage.

5. CONCLUSION

In order to alleviate the ballast settlement problems, bituminous layers under ballast have been introduced on the new HSL BPL (Bretagne-Pays de Loire), intended in particular to rigidify the track and reduce the amplitude of the accelerations due to trains' passages. Four different sections representing the different types of structure with and without asphalt concrete have been instrumented with sensors to better understand the mechanical behavior of the track under dynamic traffic. A remote webserver allows the management of the various instrumented sites as well as the different measurement systems of each site. Different slow and fast registered measurements examples are presented. It is possible to conclude that one of the numerous advantages of the bituminous sublayer in high-speed lanes structures is to improve storm water drainage.

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