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Monitoring of railway structures HSL BPL with bituminous layer

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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. It has been demonstrated that the settlements in the ballast were linked to the high accelerations produced in this layer by the passage of high-speed trains. The solution with bituminous underlay was used since the 1980s in several countries like the United States, Italy, Spain, especially on high-traffic and high-speed lines (HSL). In France, the interest in this technique is recent. Following the satisfactory behavior of the East European HSL, a layer of asphalt concrete was made under the ballast layer on a high scale lane, the Bretagne-Pays de la Loire (BPL) fast lane. It is intended, among other things, to reduce the amplitude of the accelerations produced at the passage of the HST.

The HSL BPL has 105 km of innovative track with an asphalt concrete (GB) sublayer under the ballast, and 77 km with a granular under layer. In order to study the dynamic responses of these different structures and to understand the effect of the different layers on the dynamic response, four sections were instrumented (3 with asphalt concrete, and one on a standard granular structure) using, among others, accelerometers, strain gauges, temperature probes, etc. More than 100 sensors have been installed on the structure in different positions and depths. The acquisition of the data is made during the speed up test phase under controlled conditions with the same train passing with speeds going up from 160 to 352 Km/h. In a later phase, measurements of all the sensors will be treated under actual traffic. The BPL lane is subjected to commercial traffic since July 2017.

The main idea of the project and the expected results for the first phase are to analyze the measurements in the database created and determine the responses of the different sections and the variations of the various parameters measured: Vertical displacements, accelerations at different levels, horizontal deformations in the bituminous layer, etc.
In this paper, a description of the railway track "Bretagne pays De la Loire", the instrumentation of the different sections and the acquisition system are detailed. The processing and treatment method used for the registered data is explained. The variation of the speed of the trains is also expected to be carried out in this paper to evaluate the behavior of the structures in section 4 with bituminous underlayment in terms of vertical acceleration.

Keywords: monitoring, railway track, bituminous layer, sensors, acquisition system, data processing.

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1. Introduction

The design of modern railway platforms has to cope with the changing loads, the increased traffic and train speeds. In the case of conventional structures with ballast and granular underlayment, the dynamic effects are significant, resulting in a high necessity of regular maintenance to restore the track geometry and maintain a high level of service (Suiker, 2002;Saussine, 2004; Pita et al., 2004; Quezada, 2012;). Even though the ballast settlements were studied, there is no definite criterion for ballast modelling, to reduce this phenomenon of settlement. Likewise, the relations between the characteristics of the railways substructure (stiffness of different layers, in particular) and settlement are not clearly established. Research were conducted on this subject at IFSTTAR in the thesis of (Martin, 2014), who developed a method for calculating the dynamic response of ballasted structures. This work has also demonstrated that the ballast settlement is strongly related to the maximum acceleration downwards in the ballast layer.

In recent years, new types of railway structures have been developed: either rigid (concrete) or using bituminous under layers. The solution with bituminous undercoat has been used since the 1970s in several countries such as the United States, Italy, Spain, and recently in France (LGV East European line) especially on high-traffic and high-speed lanes (HSL). It offers several advantages such as improvement of the rigidity of the platform supporting the ballast, improving soil moisture protection, improving drainage, and reducing the thickness of the under layers.

The thicknesses of the bituminous layers are typically of the order of 12 to 15 cm. Experience feedback indicates a good behavior and durability of the asphalt concrete in railway structures(Robinet and Cuccaroni, 2012). The asphalt concrete layer had shown satisfactory behavior, with low tensile stresses and deformations, and moderate temperature variations, due to the thermal protection provided by the ballast.

Following this first experience in France, the High-speed lane “Bretagne Pays de la Loire” (HSL BPL) is the first large-scale application of this new technique, with varying platform conditions. It is a collaborative project, led by Railenium, whose partners are Eiffage Infrastructures, IFSTTAR, SNCF Réseau, SETEC and the University of Lille.

A detailed instrumentation on several sections thus seemed to be an opportunity to check the behavior of different sections with granular under layer and with bituminous layers(Chupin and Piau, 2011a, 2011b; Le Cam et al., 2010; Martin, 2014); and to compare the two behaviors in real values.

2. HSL BPL description

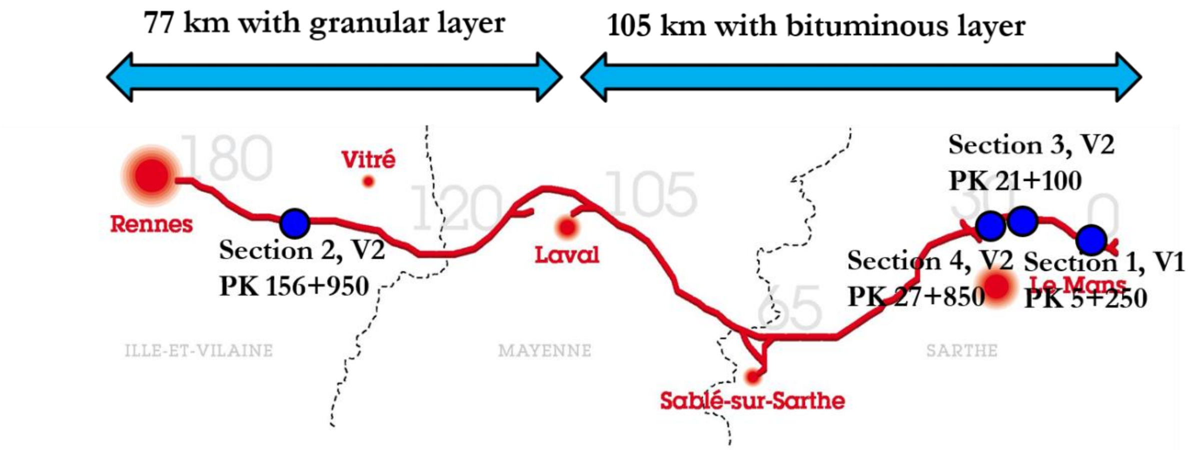

Figure 1 - High speed Lane BPL

On the HSL, the railway underlayment is made of granular materials on 77 km west of the route and with asphalt concrete on 105 km east of the route as shown on Figure 1. The asphalt concrete (GB) is a class 4 (GB4) according to the NF EN 13-108-1 standard and the unbound granular material (UGM) is of UGM A type with particle size

0 / D (with D ≤ 31.5 mm).

In the innovative track structure, the upper part of the earthworks (PST) is treated with lime and hydraulic binders and is surmounted by 15 cm untreated granular layer (GNT) on which relies a 12cm bituminous layer. The standard structures are made with 37 cm granular layer under the ballast with a treated PST layer as well.

3. Sections Instrumentation

The aim of the instrumentation is to have dynamic responses of the four different structures in different locations (indicated in Figure 1 as 4 different sections), and thus to better understand the effect of the different layers (soil type, granular under layer and asphalt concrete) on the dynamic response and durability of the track. The sensors were chosen by IFSTTAR, drawing on its experience in the field of road instrumentation. More than 100 sensors were used for this objective.

Accelerometers, weather stations, anchored displacement sensors, horizontal and vertical strain gauges, moisture probes and temperature sensors were used for the instrumentation of the sections.

The accelerometers allow tracking measurements on the rails, at the top of the asphalt concrete layer and at the top and bottom of the granular under layer for the classical structure. With these acceleration measurements on several levels of the structure, comparisons of the dynamic response of a section with/without asphalt concrete are possible.

The weather station placed on each of the four sections allows measurement of the variation of the environmental conditions (temperature, heat, precipitation ...). The anchored displacement sensors (two on each section) allows measurement of the total displacement of the structure located under the ballast (between the top of the bituminous layer and a reference point located at 6 m depth).

The horizontal strain gauges serve to measure the longitudinal and transverse tensile deformations at the bottom of the bituminous layer and furthermore to estimate the fatigue life of the bituminous layer. The instrumentation of the granular under layer with vertical strain gauges is to measure the deformation levels of the layer.

In addition to the extensometers, moisture and temperature probes were installed. With the moisture probes, not only the variations of water content can be measured but the variations of the deformation measurements with the seasonal variations of water content. Temperature sensors (top and bottom of the GB layer) were also installed.

The various sensors and their implementation in section 4 are shown in Figure 2. Section 2 being the traditional standard section with granular under layer and section 1, 3 and 4 are the innovative tracks with bituminous layer. 16 accelerometers, 6 vertical gauges, 4 moisture probes, 2 temperature sensors, 2 anchored displacement sensors and 1 weather station are used for the instrumentation of section 2. Whereas 7 accelerometers, 6 vertical gauges, 7 horizontal gauges, 4 moisture probes, 3 temperature sensors, 2 anchored displacement sensors and one weather station are in place in section 4. In section 1, additionally to the sensors added on section 4, a weighing system was installed. It is important to mention that the sections 1, 2 and 4 have linear structures unlike the section 3 that has curved structure. This section was instrumented only with 8 accelerometers.

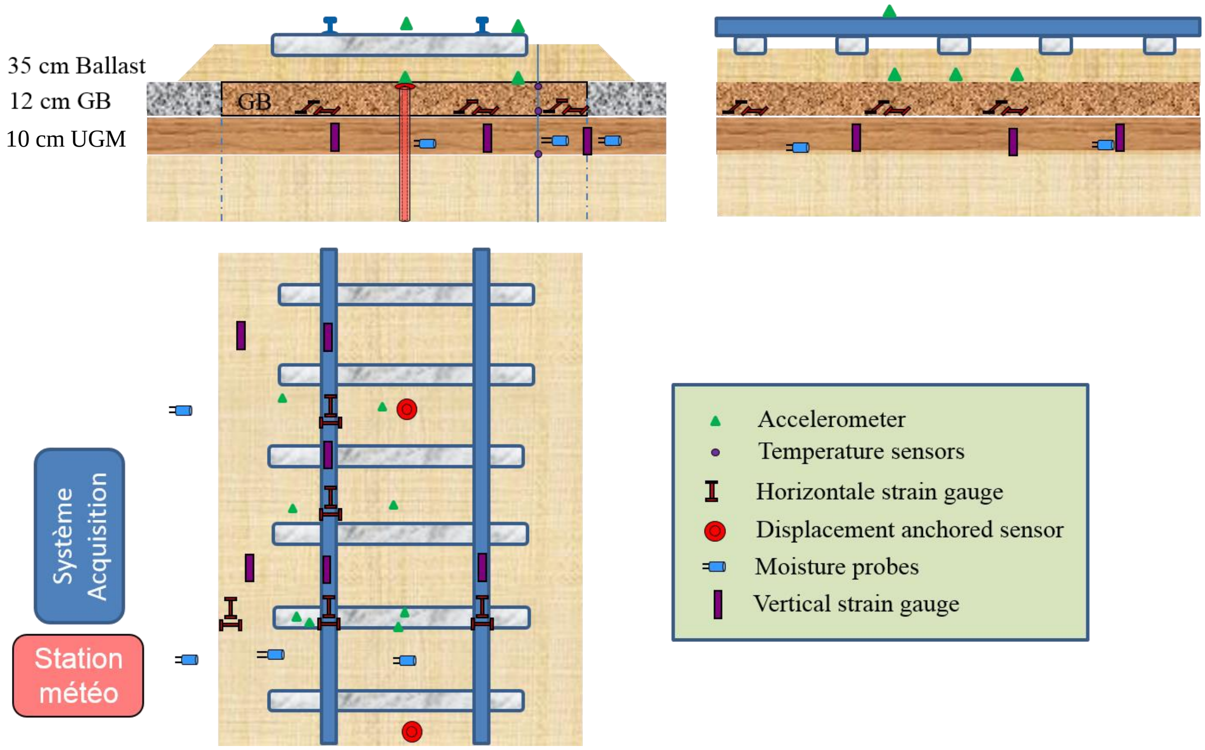

Figure 2 - Section 4 instrumentation planning

4. Acquisition system

The sensors are connected by cables to the data acquisition systems.

Based on its performance and experience feedback, the acquisition system using PEGASE cards, developed by IFSTTAR's "Measurement, Auscultation and Scientific Computing" department. (Le Cam et al., 2010), and marketed by A3IP was chosen.

Figure 3 - Monitoring system diagram and PEGASE boards of section 4

Generic Experts Platform for Embedded Wireless Applications (PEGASE) is a concept derived from intelligent and wireless instrumentation. This system has been designed to support the needs of instrumentation such as wireless communication, dating, signal processing. Figure 3 shows the box containing the set of Pegasus cards installed in section 4 (with bituminous under layer). At this site, there are two Pegase 0-10V for the 16 accelerometers, a Pegase bridge of gauges for 6 vertical gauges and two temperature sensors, one Pegasus RS232 for the 4 moisture probes, a Pegasus bridge gauge for the two anchored displacement sensors.

The 100% wireless solution can be obtained by supplying PEGASE with a battery and a solar panel. This is what has been done for the 4 acquisition systems set up on the HSL BPL. The cabinets are powered by a stand-alone system (solar panels + batteries) for continuous year-round operation without interruption. Each system supports the sensors connected to it. All the data collected on each section is transferred continuously via a 3G link (within a few hours maximum) to a remote server hosted by Power-Lan provider of the remote data server part. Each system is autonomous in energy and data transmissions. For each of the acquisition cards, one can visualize in real time the slow and fast measurements associated with each sensor of the resource. Slow measurements include the temperature's variation, the water content and weather data. The fast measurements are triggered by the passage of a train. A pre and post trigger is adjustable for a storage window from 0.5 to 20 seconds.
The acquisition systems installed at the sites 2 and 4 are shown in Figure 4.

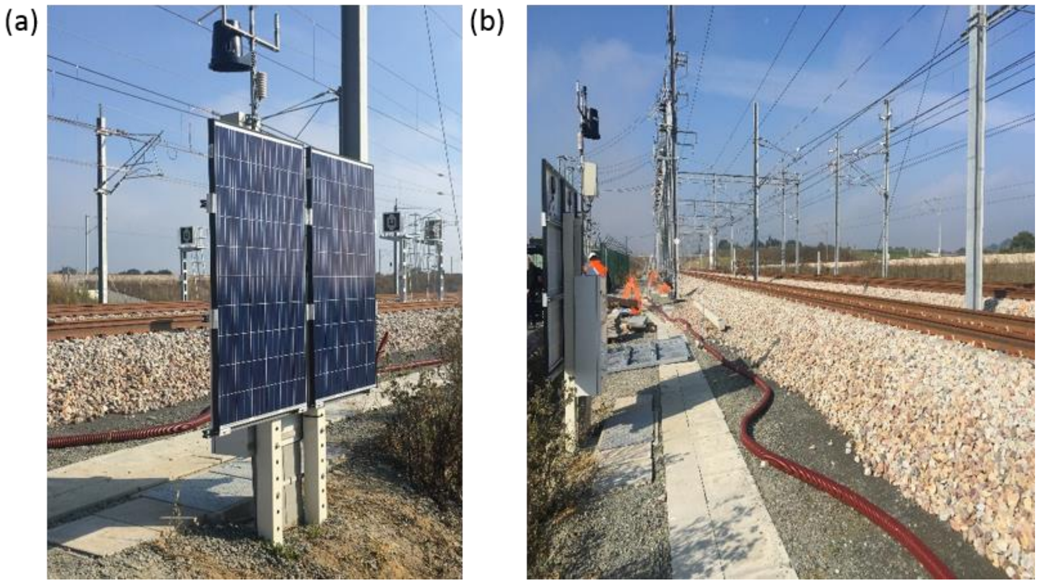

Figure 4 - Acquisition systems installed on (a) section 2 (b) section 4

5. Data processing

As mentioned earlier, the registered data, slow and fast measurements, are transmitted via 3G network. These data are downloaded from a web application, with which the measurements signals can also be visualized.
For a train passage on each section, the measurements can be downloaded as well as the signal files of each sensor registered at the time of the passage. The date and time of the passage measured in the number of seconds that have elapsed since January 1, 1970 (midnight UTC/GMT) can also be gotten.

The BPL track operated first for a speed increasing test phase that began in November 2016 and lasted until January 2017. During this phase, the speed of the passing trains variated from 160 Km/h to 352 Km/h. It is important to note that the HST train used during this phase test is the same for all the registered passages. In other terms, the load on railway is known and comparisons of other parameters can be carried. Along with registered data of HST train, maintenance machines and trains have crossed the lane and triggered the fast measurements of the acquisition system. These triggers are filtered and deleted once the data are downloaded (but are always saved on the web application).
A train passage on BPL track railway generates more than 50 files referring to all the sensors installed that need to be treated and visualized. Scilab that is a numerically oriented programming language and be used for signal processing was chosen for the automation and data processing.

Programming and developing different routines and functions using Scilab language have permitted to complete the following steps when it comes to visualization of the signals:

1. Get the exact date and time of the train passage(s) from the number of seconds that have elapsed since 1970 with a Scilab function called “getdate”.
2. Scale the various sensors installed.
3. Calculate the speed of the passing HST train at this date.
4. Filter the registered sensor signals using a low pass filter for this same passage.
5. Chose the desired sensor(s) for which you can draw the signal(s).
6. Visualize the needed time signals.

These steps were programed for the 4 instrumented sections. The wanted section(s) can be chosen at the beginning of the program. The program retrieves the data and parameters of the sensors, PEGASE cards and the scaling coefficients of the measurements from a detailed Excel file that groups together the 4 sections (one sheet / section) and allows to launch several functions of computation, read data file, scaling, filtering, calculation of speeds, processing and drawing of graphs. As mentioned in the sensors description paragraph, two displacement-anchored sensors are installed in the sections 1 and 4 separated by a 6m distance. On section 2, the two sensors are 7m far apart. Since these sensors are triggered when the train is passing, we can pull the time between the trigger of the first displacement anchored sensor and the second. The speed is calculated by the ratio of the distance separated the two sensors and the time interval drawn.

Once the velocity of the train passage is calculated, the program performs low-pass filtering of the measurements adjusted to train speed to eliminate dynamic effects. The filter thus adjusted allows to extract the peaks and / or valleys of the different signals. This treatment makes it possible in particular to clearly detect the peaks of the displacement and acceleration sensors in the graphs referring to the commercial high-speed train bogies.

These measures are then dealt with by the so-called "cumulative of carrier bogies" method. On the basis of the recordings made for a given sensor at HST passages traveling at a known speed, the procedure consists in tracing, from the same time origin, the signals originating from the passages of carrying bogies wagons (by omitting the bogies of locomotive engines) by sequencing and temporal translation of the complete signal. The experimental measurements can then be analyzed statistically, for a given sensor, from the calculation of the mean curve and of the curves located at more or less one standard deviation.

For each sensor signal thus filtered, the cumulative method of the carrier bogies is then applied to the seven

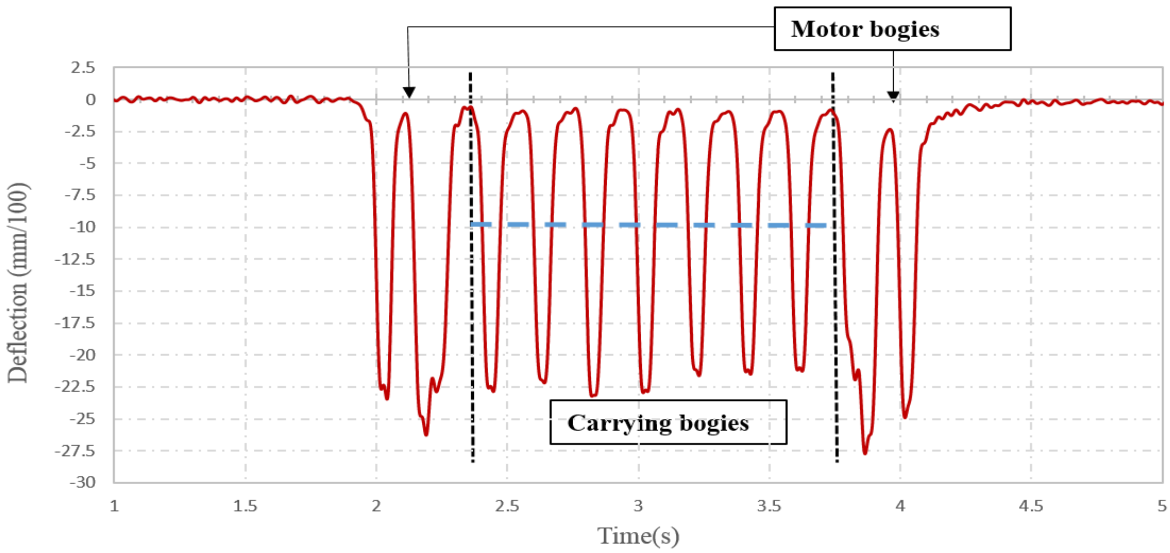

Figure 5 - Filtered deformation signal for a train passage

carrying bogies constituting the high-speed train as shown in Figure 5 on the deformation signal.

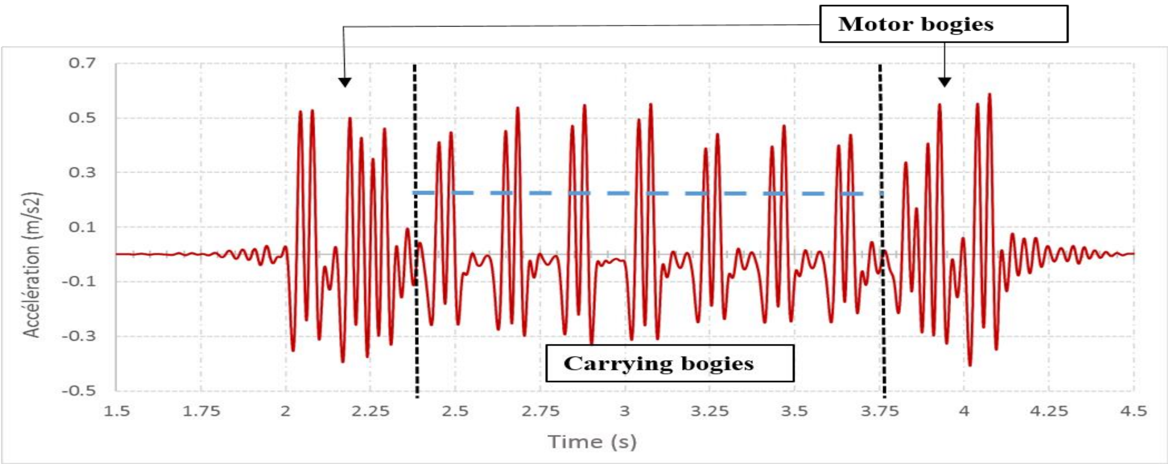

Figure 6 – Filtered acceleration signal for a train passage

In Figure 6, the filtered signal of an accelerometer is cut off to isolate the sequences in connection with the passage of the seven carrier bogies. For this matter, to withdraw the peak for every bogie signal, we subject the signal to a low filter to remove the peaks (below the blue line in Figure 6 shows the average signal extent that we keep). We now can get the interval of time for each bogie signal by calculating the number of points removed relatives to the erased peaks without forgetting to enlarge later on this interval in order not to miss a part from the bogie signal.

The normal axle load of the motor bogies is 17t/axle while the load of the intermediate carrier bogies varies between 14.5t and 15.5t per axle. It was necessary to adjust the acceleration peaks by weighting the masses of the bogies with the normal axle load. The average value was reduced to 15t per axle.
These signals are then plotted as a function of a product abscissa between train velocity and time (Vt), which represents at a constant the distance between the wheel and the sensor under consideration. They are plotted in Figure 7 from the same time origin, looking for the maximum likelihood between measurement sequences. The "average response" of the considered sensor is then calculated point by point.

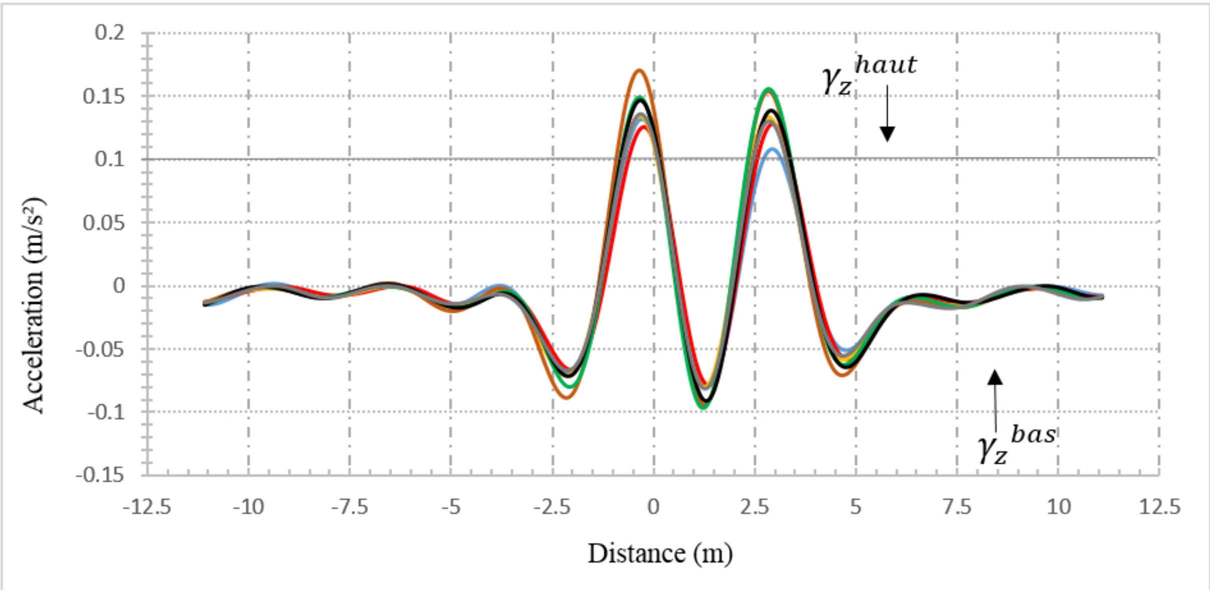

Figure 7 – Superposition of the seven bogies acceleration signals

As illustrated in Figure 7, it can be noted here that the signal obtained, for a given sensor, preserves largely the shape of the filtered bogie signals. This method of treatment serves later on to analyze the influence of different parameters such as the velocity of circulation on the vertical accelerations; and to compare later on the experimental results with the modeling graphs.

6. Velocity influence on vertical accelerations:

Below is shown an example of the acceleration signals recorded on section 4, with an accelerometer placed at the top of the bituminous layer, when high-speed trains with different velocities has passed on the railway track on December 2016. Three mean acceleration signals referring to three different train speed passages calculated with the above-explained technique (160 Km/h, 300 Km/h and 350 Km/h) are drawn in Figure 8. Those 3 examples were chosen with similar temperature at the base and top of the asphalt concrete layer. Otherwise, the comparison would not be possible.

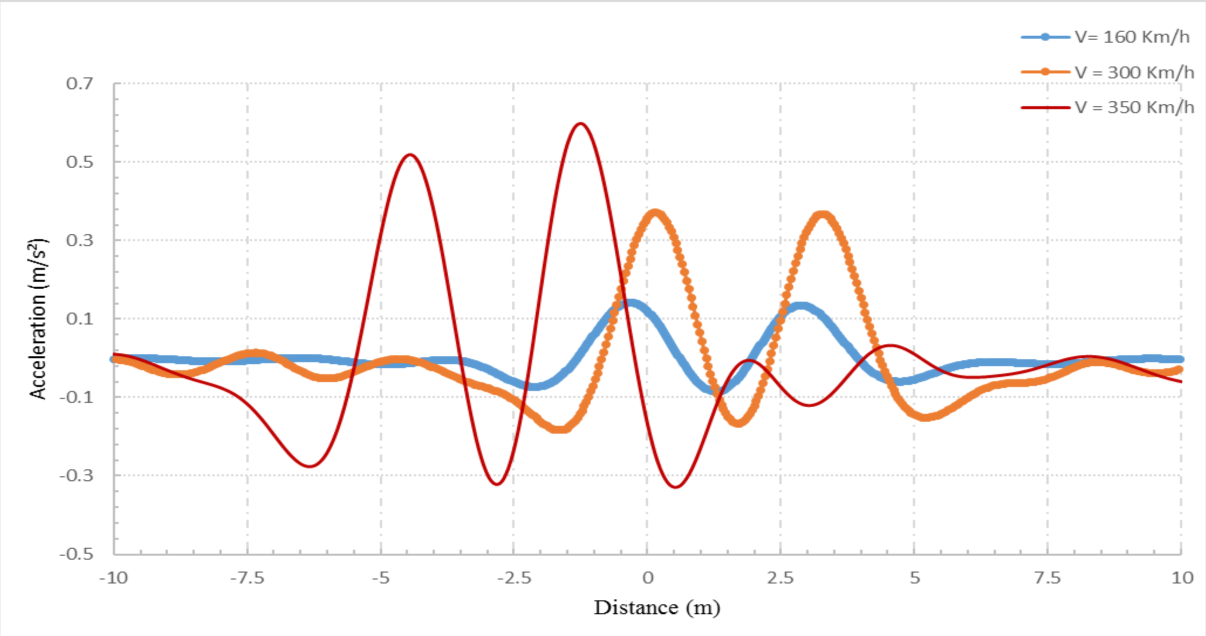

Figure 8 - Variation of the acceleration in function of the train velocity

The influence of the increased train velocity is neatly visible and can be considered as an important factor for the evolution and rise of the acceleration signal peaks. The maximum acceleration value recorded for the low train speed has been multiplied by almost 3 for the maximum train speed.

7. Conclusion

Four sections representative of the different types of structures were instrumented with more than 100 sensors in the Bretagne Pays de la Loire railway track. The sensors installed are connected to fully autonomous energy acquisition systems working with PEGASE cards and powered by solar panels and batteries. Data transmission is via 3G / 4G network. The systems are fully remotely controllable.

This powerful and autonomous instrumentation should make it possible to validate the performance of this innovative solution. The acquisition of the data has already been successfully carried out during the entire speed test phase (HST of known loads, speeds up to 350 km/h).

In order to study the influence of the asphalt concrete layer, and the dynamic responses of the different structures (with or without bituminous under layer), Scilab routines and functions were developed to process and visualize the data and signals of the recorded measurements once the trains are passing.
After the explanation and the detailed presentation of the data processing and treatment were presented in this paper, we can now start the comparisons of the different measurements with the variation of the different parameters other than the train velocity (climatic conditions, temperature, moisture and with/without GB).

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