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# Monitoring of railway structures of high-speed line BPL with bituminous and granular sublayers

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**Abstract.** The phenomena of packing and wear of ballast, under dynamic stresses lead to high frequencies and high costs of maintenance. To mitigate this problem, an innovative track structure, with an asphalt concrete layer under the ballast was built on the Bretagne-Pays de la Loire high-speed line (BPL HSL). It is intended, among other things, to reduce the amplitude of the accelerations produced at the passage of High-Speed Trains (HST), major cause of ballast settlements.

BPL HSL includes 105 km with an asphalt concrete sub-layer under the ballast, and 77 km with a granular sub-layer. In order to study the dynamic responses of these different structures, four track sections were instrumented using, among others, accelerometers, strain gauges, temperature probes, etc. In this paper, we present the tracks' instrumentation, the acquisition system installed to collect all the measurements, as well as comparative results of dynamic and mechanical behavior between structures since July 2017, the inauguration of the BPL HSL to commercial traffic.

**Keywords:** Ballasted track, asphalt concrete, monitoring, sensors, data acquisition.

## 1 High-speed line BPL

The phenomena of packing and wear of the ballast, under dynamic stresses, lead to high frequencies of maintenance, and high costs, on high-speed lines. It has been demonstrated that the settlements in the ballast are 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 a first test on the East European HSL,

which led to satisfactory behavior, structures with an asphalt concrete sublayer under the ballast were built on a high scale lane, the Bretagne-Pays de la Loire (BPL) high-speed lane. This solution is intended, among other things, to reduce the amplitude of the accelerations produced at the passage of the HST. On HSL BPL, 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 / 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 a 15 cm thick unbound granular layer (UGM) and a 12cm thick bituminous layer. The standard structures include a 37 cm thick granular layer under the ballast with a treated PST layer as well.

Instrumenting several sections of the BPL line appeared to be an opportunity to study the behavior of different sections with granular underlayment and with bituminous layers and to compare their behavior. Accelerometers, weather stations, anchored displacement sensors, horizontal and vertical strain gauges, moisture probes and temperature sensors were installed on each section. The instrumentation is detailed in [1-2]. The sensors are connected by cables to the data acquisition systems. The acquisition systems are based on PEGASE boards, developed by IFSTTAR [3]. In this article, only the measurements made with accelerometers and anchored displacement sensors are presented.

All the measurement systems are powered by batteries and solar panels, for continuous year-round operation without interruption. All the data collected on each section is transferred continuously via a 4G network (within a few hours maximum) to a remote server. Thus, each system is autonomous in energy and data transmissions.

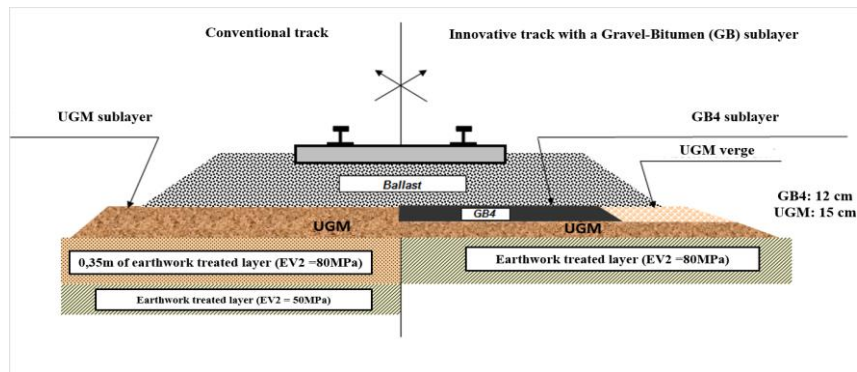
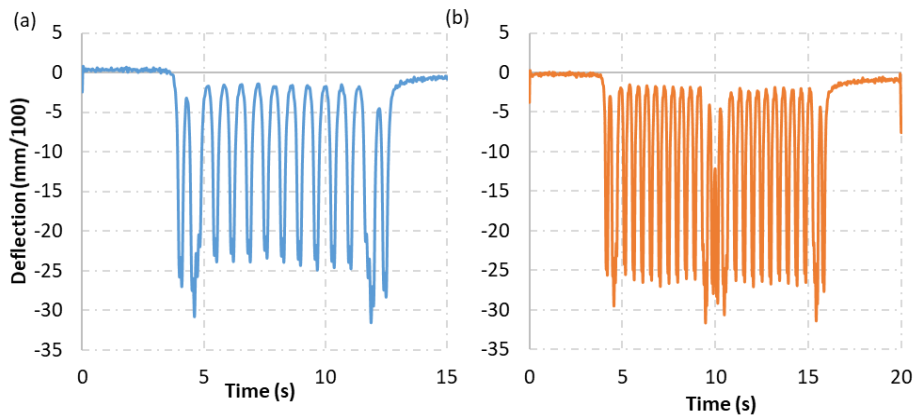


Fig. 1. Two structures of the BPL high-speed line

## 2 Data processing

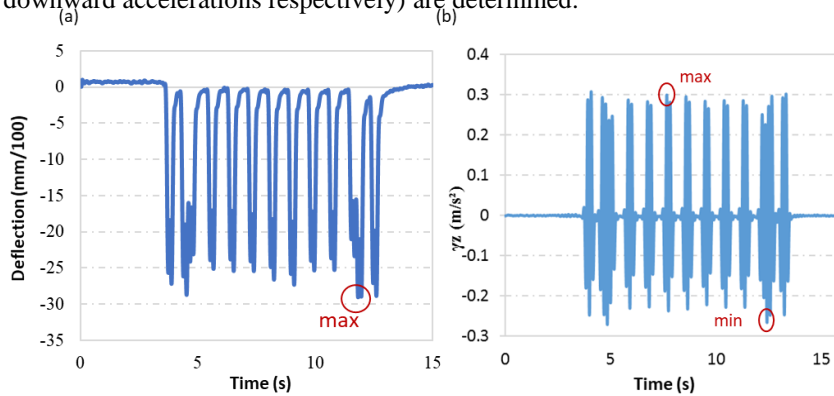
The BPL track was first circulated, at increasing speed, during a test phase that began in November 2016 and lasted until January 2017. Different routines and functions

were developed using the Scilab software, to analyze the measurements made during these tests. The train speed is calculated first, by calculating the time difference between signals of two accelerometers placed at different longitudinal positions, at the top of the sub-ballast layer. Then, the program performs low-pass filtering of the measurements, function of train speed, to eliminate dynamic effects [4-5]. The adjusted filter allows to extract the peaks of all sensor signals. Once signals are filtered, the number of bogies can be determined. 4 types of high-speed trains have been identified: simple trains with 13 and 15 bogies, and double trains with 26 and 30 bogies (Fig. 2)



**Fig. 2.** Example of temporal deflection signals of single and double trains with (a) 15 bogies (b) and 30 bogies, having circulated on section 4 in July 2017.

The developed processing routines make it possible in particular to calculate the maximum and minimum values of the sensor signals (Fig. 3), which can then be used to compare the responses obtained on different sections, or for different speeds. The highest peak of deflection is determined for each train passage on each section. For accelerometer signals, a positive and a negative peak (corresponding to upward and downward accelerations respectively) are determined.



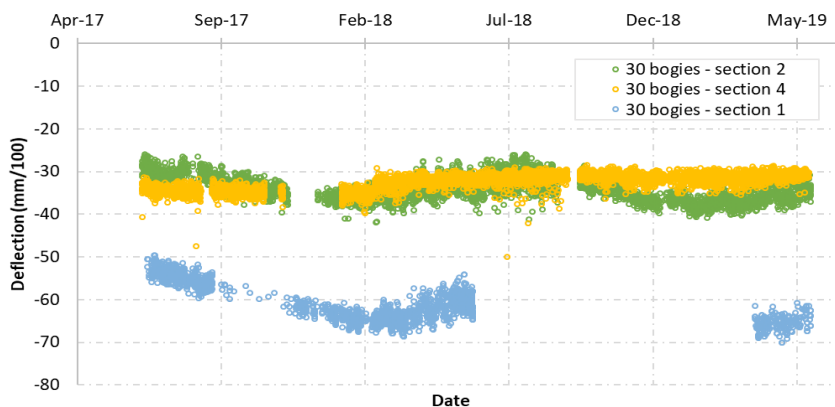
**Fig. 3.** Retained peaks from (a) deflection signals (b) acceleration signals

### 3 Comparison of response of granular and bituminous structures

#### 3.1 Deflection measurements

The different signal treatment procedures were applied to the sensor signal recorded during a period of 23 months, after the opening of the line to commercial traffic. More than 16,000 HST passes were recorded during this period. All these passages were exploited and the maximum deflection values recorded by the anchored deflection sensors were determined. Measurements obtained on section 2 with granular sub-layer and on sections 1 and 4 with bituminous sub-layers, presenting different soils were compared. Soil on Section 1 is composed of yellowish fine sand with water inflow detected at 4.5 m depth. Section 4 is built on a yellowish clay soil with sand and scattered blocks. No water was detected on this site. Figure 4 compares the maximum deflection values recorded for all double 30-bogie trains that circulated on the three mentioned sections starting from the track opening to commercial traffic (July 2017) up to May 2019. It can be seen that sections 2 and 4 have similar maximum deflection values, ranging between 25 and 42 mm/100, but with different evolutions in time: on the granular section, deflection peaks present seasonal variations, values increasing between September and May and decreasing during the summer months. On bituminous section 4, the deflection evolution is quite different: a decrease in values during the first 7 months of track service is observed, followed by a stabilization of deflection values, regardless of the season.

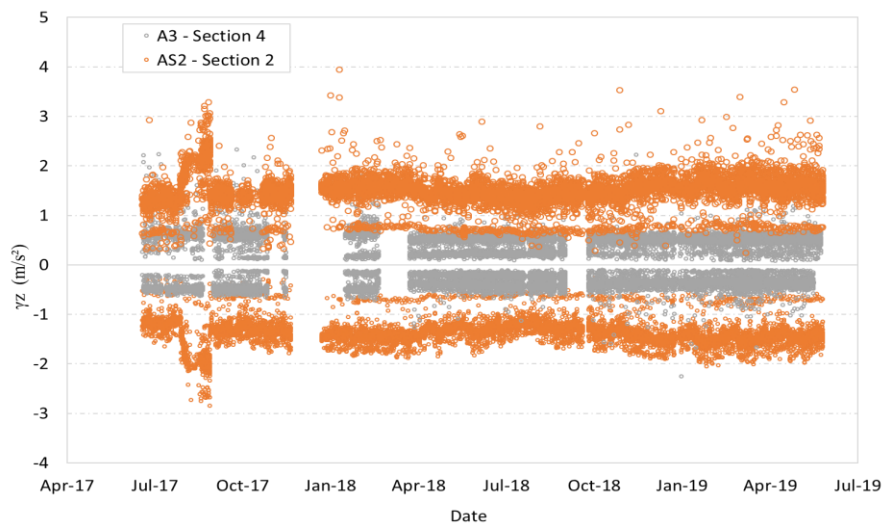
On section 1 with bituminous sublayer and sandy soil with water infiltrations, unlike on sections 2 and 4 with clay soil, the maximum deflection values are significantly higher, of the order of 48 to 70 mm/100 (for double trains). Seasonal variations during the first 7 months of service are also more pronounced on this section.



**Fig. 4.** Comparison between the maximum deflection values measured on section 2 with granular sublayer and sections 4 and 1 with bituminous sublayer

### 3.2 Acceleration measurements

In a second step, we compare accelerometers measurements obtained on section 2 with granular sub-layer and on section 4 with bituminous sub-layer, during the commercial phase. Figure 5 shows a comparison of the minimum and maximum accelerations for two accelerometers installed below the rail axis at the top of the sub-layer: AS2 on section 2 with granular sub-layer and A3 on section 4 with an asphalt concrete sublayer. The results clearly show that acceleration peaks at the top of the GB sublayer are much lower than those measured at the top of the granular sublayer, both for upward and downward accelerations. It can be concluded that, during the commercial phase, the presence of the GB layer reduces by a factor of about 2 the accelerations measured under the ballast.



**Fig. 5.** Comparison of positive and negative vertical accelerations peaks measured by accelerometer AS2 on section 2 with granular sub-layer and accelerometer A3 on section 4 with bituminous sub-layer, during the commercial phase

## 4 Conclusion

High-speed line BPL consists of two different structures, with granular and bituminous sublayers. It was instrumented with more than 100 sensors during construction, to monitor the response of the two types of structures. The commercial phase started on July 1, 2017, and was followed during nearly 2 years, until May 2019. Traffic during this phase averages 23 HST per day, and consists of 4 HST types, single trains with 13 and 15 bogies, and double trains with 26 and 30 bogies. The analysis of this phase therefore required the processing of a large number of measurement files. These data have been processed only partially in this paper, focusing on the evolution of

maximum deflections and maximum and minimum accelerations over the duration of the observation period.

The deflection analysis showed deflection levels higher on section 1 than on sections 2 and 4, probably due to differences in soil type and water intervention. Deflections seasonal variations were also highlighted, on sections 1 and 2, but not on section 4. This confirms the large influence of the subgrade soil on the track deflections. No change in the average level of deflection (which may reflect a degradation of the track) was observed during the 2 years follow-up.

The analysis of accelerations measured at the top of the sub-layers indicated a very significant reduction of accelerations on the bituminous section, in comparison with the UGM section, by a factor of about 2. As for the deflection, no evolution of accelerations was observed during the 2-year period, indicating a stable behaviour of the track.

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