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Trackbed Mechanical and Physical Characterization using PANDA®/Geoendoscopy Coupling

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Abstract
Most developed countries in the world have large existing railway networks. Most of which are old and have been maintained and partly renewed to mainly upgrade safety, regularity, speed and load.
The principal issues of the asset manager are how to prioritize maintenance/renewal works and how to provide engineering teams with reliable geotechnical data for track design on revenue service lines. Indeed, if we can master rail and sleeper specifications, railway natural trackbed remain very variable and difficult to characterize.
As a matter of fact, the knowledge of mechanical and physical properties of existing subgrade and sub ballast layers is very important for the future track design. Such data can be acquired through geotechnical tests. However, the majority of classical geotechnical tests can be difficult to carry out on revenue service lines because of existing railway constraints (limited possession times, track access, no destabilization of the track...).
Hence, this article presents a new methodology for railway track characterization using light and cost effective tests, based on the coupled use of the PANDA® dynamic penetration tests and geoendoscopy. The goal of this methodology is to provide to the asset manager key point indicator helping with the optimization of the maintenance and renewal strategy.

Keywords: PANDA®, Geoendoscopy, trackbed

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1 Introduction

Currently, we can witness a global renaissance of rail travel (passenger and freight) leading to construction of new lines and to the traffic increase on existing lines. For existing lines, the challenges is to offer more availability time and to upgrade safety, regularity and train speed in order to be competitive with other transportation means.

To achieve these goals, asset manager must make astute decisions regarding renewal/maintenance strategy. In this process, one of the key input data is the trackbed geotechnical hazard that can highly impact work budget. As a matter of fact, higher speed, heavier rolling stock and new concrete sleepers induce an increase of the dynamic stress to be applied on the trackbed after renewal.

In order to mitigate that risk, it is important to have accurate and ideally continuous geotechnical information on the existing track characteristics (layer thickness, condition, mechanical properties…). However, if classical in situ geotechnical tests (rigs) are relevant prior to construction on new lines, they are seldom compatible with existing revenue service line constraints.

The main constraints we face when working on this existing network are:

- limited possession time: 4-5 hours generally in night shift,
- limitation in equipment height in case of electrified line,
- tests must be as less damaging to the track as possible to allow service next day,
- engine-based equipment not suitable.

This article presents a new methodology designed to help the asset manager with the optimization of the maintenance and renewal strategy by providing geotechnical data with light tools compatible with existing line constraints. This methodology is based on the use of PANDA® dynamic penetrometer and geoendoscopy.

2 Background

In order to design the substructure for track renewal, track engineer mainly need topographical and geotechnical information on the existing line.

The geotechnical survey should provide:

- nature and thickness of existing layers
- cross fall variations
- depth of the platform
- hydric state and fouling index
- track bed indicator (platform classification)

SNCF has written a specific instruction ([1]) regarding the investigations prior to renewal works. This document has lately integrated the presented methodology.

The first methodology used to collect trackbed data for track design consisted in manual soundings (shovel and fork). The layers' condition was assessed visually on site and reported on tables. This kind of test required 2 to 3 people and the sounding was done in the crib, which is not completely representative given that the efforts are concentrated below the sleepers. Moreover, this test is time/money consuming and cannot be carried out during summer. However, such soundings are still used but for very few and specific purposes where other methods are not as accurate as needed.

In the 2000's, the increase of renewal works on the French network made it necessary to have time/cost effective alternative to manual soundings. The solution has been to integrate a coring machine within a work train. This device cores a 250 mm diameter sample to a depth of 1.5m allowing a visual analysis of the nature and thickness of trackbed layers directly on the photograph taken (Figure 1) ([1]). The sample is immediately put back on the track.

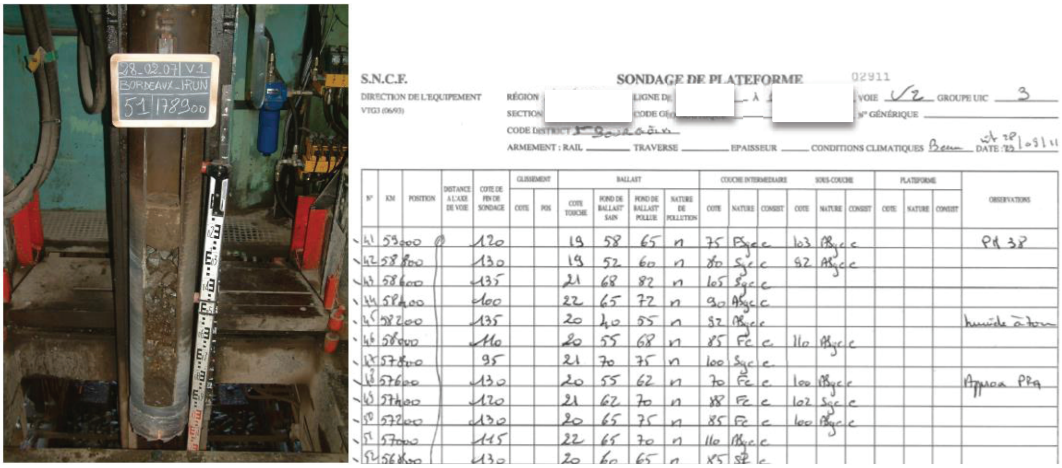

Figure 1: Coring train - results

This device was cost effective, but once again, the use of a work train requires displacement time and a lot of procedures. Moreover, the device had some limitations when coring coarse material (slipping)…and last but not least, it didn't provide any mechanical feature on the soil. Although, this technique was fast, possession time became a big issue for existing lines network and one machine for the whole network wasn't enough to cover the need.

SNCF started looking for a new methodology, not engine based, that would provide at least the layer identification of the coring machine and ideally mechanical characterization of the trackbed.

3 Methodology and Tools

The idea is to replace the engine-based coring machine by manual soundings carried out by a two-people squad using portable devices. This organization allows to increase production during possession time, to simplify access to the track and security procedures.

The proposed geotechnical characterization will be done using PANDA® and Geoendoscopy® that are very light and little intrusive devices.

The dynamic penetration test PANDA® would provide with soil resistance charcteristics, whereas geoendoscopy® would precise the nature and state of the tested soils (thickness of the layers, type of soil, hydric state, gradation...).

This technique will provide:

- detailed characterization for each sounding : mechanical cone resistance of each layer (sound ballast, fouled ballast, interlayer, platform) and nature and condition
- the results will be summarized in a table will the following entries :
    - Line, location of the sounding (longitudinal and lateral)
    - Sounding depth (from Top Of the Rail)
    - Thickness and mean resistance of the sound ballast layer
    - Thickness and mean resistance of the fouled ballast layer
    - Thickness and mean resistance of the intermediate ballast layer

3.1 PANDA®

Principle

The PANDA® test is a variable energy dynamic penetration test that is standardized in France for compaction control ([2], [3]). The use in railway environment has been approved and is commonly accepted in France.

The tests consists in driving a set of steel rods equipped with a conical tip into the soil by hammering (standardized hammer).At each hammer blow, the energy is measured in the anvil with energy gages. Other sensors measure simultaneously the settlement or vertical displacement of the cone. All the data is transmitted to the acquisition unit equipped with a custom software. The cone resistance is directly calculated using the Dutch formula (Figure 2).

The results are given as penetrograms, graphs that show the evolution of cone resistance according to depth.

Equipment

The PANDA® is a versatile equipment with a total weight less than 20 Kg.

Within the framework of the railway use, adaptations have been made to make it even lighter and tougher.

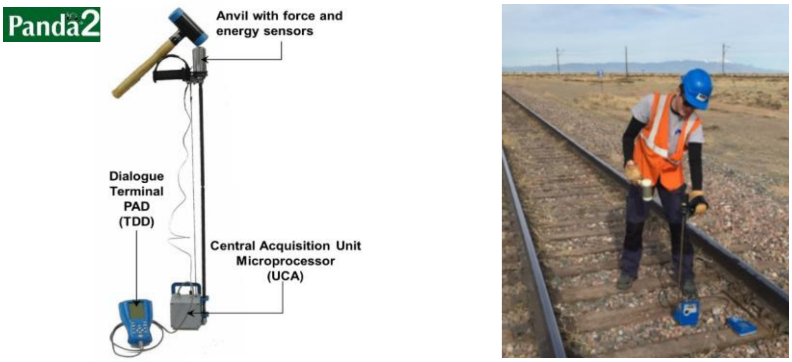

Figure 2: PANDA® principle and photograph

3.2 Geoendoscopy

The geoendoscope is a hardware/software suite designed by the R&D dept. of Sol Solution.

Geondoscopy tests ([4], [5]) consist in introducing a small diameter (8 mm) endoscopic probe into the hole previously made by PANDA® tests or any other boring (Figure 3). A video is then continuously recorded in order to characterize the different soil layers. Images extracted from this video (Figure 4) are then computed using automatic image analysis programs in order to provide information for each layer (thickness, nature, humidity…).

The images are 5 mm wide.

Figure 3: Geoendoscopy principle and photograph.

Figure 4: Examples of geoendoscopic images

4 Results

This methodology has been adapted to the railway environment and issues in order to provide useful information. ([6], [7], [8])

4.1 Subgrade/platform Qualification

Once the pandoscope data has been processed, the results can be presented as follows (Figure 5). The right hand chart shows the evolution of the PANDA® cone resistance according to depth. The left hand window shows the stratigraphy of the track layers (thickness, nature and hydric state).

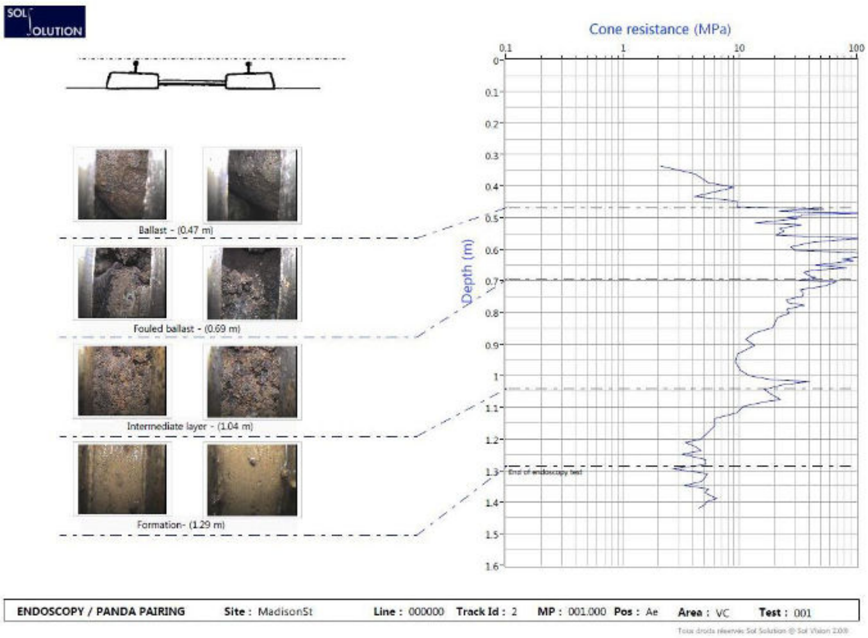

Figure 5: Pandoscope result example

One key feature provided by this test is the platform classification. Each railway network has its own by they are all more or less based on mechanical features.

SNCF has long used a platform classification based only on the soil classification (visual) and to the estimation of compaction state for fine materials (visual). ([1]).

Soil nature are divided in 2 main groups, coarse material and fine material. Many sub-groups are defined.

In order to benefit from the penetrometric cone resistances given by the PANDA® in the classification process, we have used the Highway Research Board (H.R.B.) classification that qualifies bearing capacities according to CBR values and soil classifications (Table1).

CBR	Bearing capacity	USCS soil classification	GTR (French soil classification)
0 to 3	Very poor	CH, MH	A2, A3
3 to 7	Poor to medium	CH, MH	A2, A3
7 to 20	high	CL, ML, SC, SM, SP	A1, A2, B5, B6, D1

Table 1: HRB platform classification ([9])

As CBR values and cone resistances are linked with several correlations ([10]) cone resistance threshold can be calculated for CBR values of 3, 7 and 20 (Figure 6)

- All soils (except CH and CL) $CBR = 1,56 \cdot qd^{1,12}$
- CL soils with CBR<10 $CBR = 0,304 \cdot qd^{2}$
- CH soils $CBR = 3,27 \cdot qd$

q_d en MPa

a

CBR	Estimated Panda Cone resistance (MPa)
3	2
7	5
20	15

b

Figure 6: a. ASTM CBR/cone resistance correlations ([10]) – b. Cone resistance estimation

The final step is to pair soil identification brought by geoendoscopy with panda cone resistance to obtain the formation classification (Figure 7).

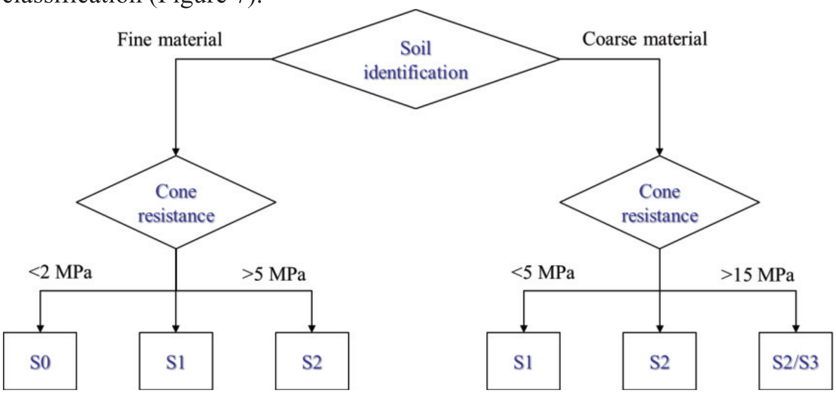

Figure 7: Simplified French railway platform classification ([1])

4.2 Sustainable Ballast Management

Ballast renewal is one of the most important renewal operations and is often very expensive (aggregate and volumes). From both an environmental and an economical perspective, sustainable ballast management is growing in importance.

One of the trend of sustainable ballast management is the partial re-use of ballast during renewal operations thanks to ballast cleaning machines after mechanical sieving.

Within this framework, several studies including panda/geoendoscopy have been led in order to characterize used ballast properties on the one hand, and to estimate ballast "re-usable" volume.

Used Ballast Properties Characterization

A study has been carried out by SNCF several years ago to study ballast degradation process. The work package involved:

- used ballast sampling on high speed line between Paris and Lyon prior to ballast renewal,
- laboratory tests (grain size distribution, Los Angeles test, Micro Deval test),
- fouling assessment with panda/geoendoscopy tests,
- "re-usable" ballast volume estimation.

These tests have been carried out in collaboration with Institut Blaise Pascal.
10 samples of 100 kg of ballast each have been collected from the existing line and the laboratory results are presented below (Table 2). PANDA®/geoendoscopy tests have also been carried out on each location of the sampling.

	Los Angeles	**Micro deval**
Mean value	12	5
Min	11	4
Max	14	6

Table 2: LA, MDe test results

According to ballast standard ([12]), the samples can be classified as LARB12 and MDERB5.
The ballast specifications for HSL in France require a LA value<19, MDE value<=6 and LA+5MDE<=44.
One of the main outcome of this laboratory survey is that, no matter where the ballast samples have been taken (sound or fouled ballast layer), the intrinsic features of ballast grains are not highly modified by the traffic. However, and as expected, grain size distribution have clearly shown a higher fine ratio that put the sample out of the acceptance specs.
Hence, this study has shown that, if an appropriate sieving is done, existing ballast could be re-used at least in the areas least stressed in the track.

Ballast Fouling Profile

To better understand ballast fouling mechanisms and geometrical extension, PANDA®/geoendoscopy technique has been used.
17 tests have been carried out with a 30 cm spacing in one location of high speed line between Paris and Lyon. Geoendoscopic images have been processed and interpreted in order to provide fouling information.
As clearly shown (Figure8), on a HSL cross section with bi-block sleepers, the fouling is concentrated under the blocks and more than 70% of the ballast section can be considered as unfouled. The concentration of fouling under the rail is also encountered for monoblock sleepers maybe with less localized effects.

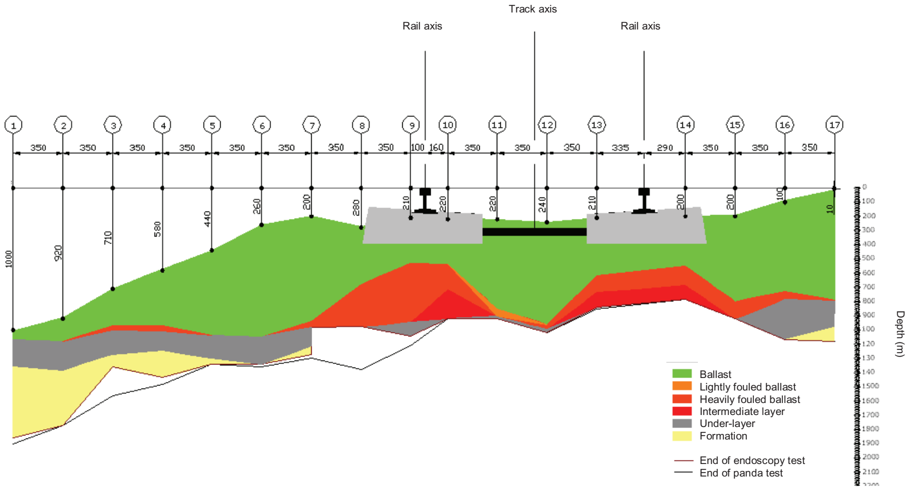

Figure 8: Fouling profile on a HSL cross section

This analysis coupled with the lab tests presented earlier enabled us to estimate up to 80% the ratio of potential ballast recycling on the Paris/Lyon high speed corridor.
The contractor in charge of the ballast renewal using a new undercutting machine reached this recycling ratio allowing a massive environmental and cost economy.

5 Conclusions

To face the new demanding challenges of the railway industry, and particularly concerning track renewal works that have been gaining massively on a lot of countries with ancient railway networks, innovative solutions have to be found to provide to the asset manager tools to help with the maintenance strategy and to insure the best track availability and safety for commercial trains.

To comply with the constraints imposed by the railway in terms of short track possession times, low trauma soundings to enable commercial circulations, we have developed a cost effective geotechnical methodology presented in this paper based on the coupled use of PANDA® and geoendoscopy.
This data is directly used by track designer to find the best fit in terms of ballast thickness, sleeper choice and renewal work to comply with higher speed, higher loads and a better safety and availability.
This methodology is now part of SNCF standard and we have carried out more than 20,000 soundings on the French network.

Further to the first analysis directly useable for track design, some advanced analysis can provide refined outcome helping optimizing renewal works using this data, such as renewal work recommendation, ballast volume estimation, image based grain size distribution...
Moreover, the PANDA equipment has been updated with new sensors (PANDA 3, [14]) making it possible to have access to dynamic parameters of the soil (wave celerity, dynamic stiffness...). Image based grain size distribution of ballast layers is also actually available giving a new asset to monitor ballast condition.

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