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Combining geotechnics and geophysics for a thorough railway embankment auscultation on high speed lines

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Abstract

The renewal of existent railway lines requires an accurate characterization of the nature, mechanical and moisture properties of the Railway Embankment (RE) layers to select appropriate maintenance and/or renewal actions, especially concerning local disorders.

A specific zone of the Northern Europe high speed line is the subject of frequent maintenance effort probably due to strong variations in soils properties or to bad drainage conditions. A specific geological, geotechnical and geophysical investigations mission was carried out along the line to understand the origin of the observed phenomenon.

Classical geotechnical measurements are not able to determine the source of the disorder except for VS obtained from BE tests that indicate strong changes in a specific layer. However, these conventional geotechnical measurements still remain local, destructive and with low yields in terms of auscultate linear. Thus surface-wave methods, were deployed along the line. 1D VS models obtained along the line clearly show strong contrasts in mechanical properties at depth. Such method can be considered to develop a control criterion of the RE state.

Keywords: High speed line, Railway Embankment, Geotechnics, Surface wave methods

1 Introduction

The renewal of existent railway lines requires an accurate characterization of the nature, mechanical and moisture properties of the Railway Embankment (RE) layers to select appropriate maintenance and/or renewal actions, especially concerning local disorders.

The required data (e.g., bearing capacity, cone resistance) mainly depend on the mechanical properties of the materials constituting these structures and the soil supporting the RE. Yet, their accessibility is difficult due to operational constraints. Furthermore, conventional geotechnical techniques remain local, destructive and with low yields. The use of non-destructive investigation techniques for local diagnosis and monitoring is of great interest for enhancing the control of RE. Ground penetrating radar is for instance widely used for the auscultation of the surface layers [1] but suffers from its great sensitivity to metal components, conductive media, 3D-effects due to local geometry. Micro-gravimetry is also used to locate cavities and/or poorly compacted areas. However, these techniques do not assess the mechanical properties of the RE. In this study, we suggest seismic methods and more precisely surface-wave analysis as a complement for geotechnical issue approach through this presentation of a case study [2].

A specific zone of the Northern Europe high speed line (LGV) is the subject of frequent maintenance effort. This issue can be due to strong variations in soils properties or to bad drainage conditions. In order to precisely determine the origin of the phenomenon, a specific geological, geotechnical and geophysical investigations mission was carried out: geotechnical characterization, bender elements (BE) tests and seismic surface waves. First results clearly show good correlations between BE tests and seismic models [3].

2 Methods

A deformation issue was observed over few meters in the track of the LGV. This phenomenon involves frequent maintenance works. An appropriate treatment of this zone suggests a good knowledge of its origin. Disorders are probably due to the large variations in the nature and the behaviour of the soils and drainage deficiency. To determine the exact cause of this phenomenon, geological and geotechnical surveys have been proposed [3].

Geological studies show the typical railway structure, defined by the LGV standards (see Figure 1), overlaying: (i) backfilled loess, 70 to 80cm thick, coming from the creation of the railway platform; (ii) loess, 4 to 5m thick and; (iii) Campanian chalk.

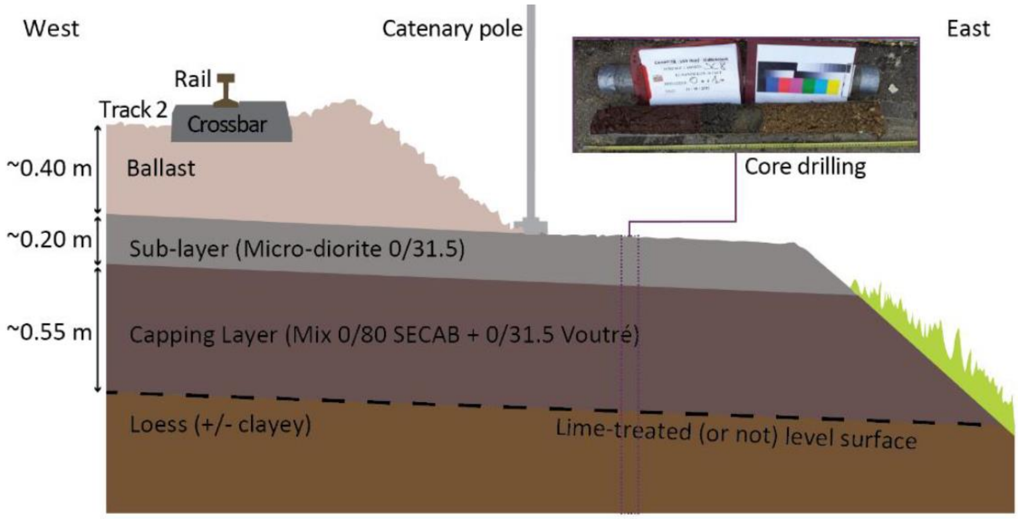

Figure 1. Section of the studied RE corresponding to the LGV standards. The inset photo shows a core drilling located on the side-path. After [6].

Geotechnical studies consisted in 8 core drillings reaching 3 to 12m deep (Figure 2 and inset in Figure 1), and cone penetrometer tests down to 12-m depth, along the line. Core drilling 8 is representative of the healthy zone and core drillings 3 and 5 are in the disturbed area (white lines). Water content, Atterberg limits, methylene blue test, density and compressive strength were performed on soil samples. To have a whole description of the materials constituting the RE and to complete the results, BE tests were also performed on loess samples at different depths.

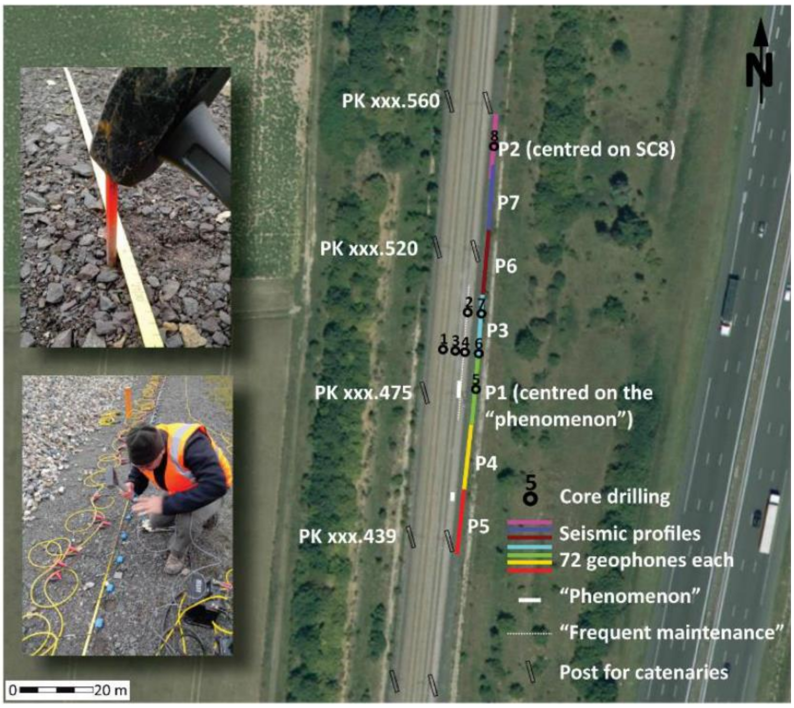

Figure 2. Schematic layout of the seismic profiles (P#). The approximate positions of core drilling are in black circles. White lines indicate the locations of the phenomena. After [6].

Geotechnical tests indicate typical good properties of the materials used for the RE according to the LGV standards: sub-ballast and capping layers appear more compact than the underlying loess; and the latter is less compact than the chalk located about 7m deeper.

Water contents and density values of the loess layers do not vary along the line and in depths. Using these classical tests, we are not able to identify the origin of the phenomenon as there is no significant variability.

The BE results are interpreted using both density and water content measurements [5]. VS determined using this method are clearly lower in the loess located in the affected area. It goes from about 300m/s in the healthy zone to 150m/s in the disturbed area. Moreover, shear moduli vary from 50MPa in the disturbed zone to 200MPa in the healthy area. It clearly shows that variations in VS, and thus in shear-moduli, in loess are correlated with the presence of phenomenon along the line [3].

3 Results

Such laboratory studies cannot be deployed to diagnose large distances. As shear-modulus and VS appear to be good indicators of the quality of the RE layers and the soils, near-surface seismic has been proposed to estimate their *in situ* mechanical properties with sufficient resolution and high yields [6]. Because of the specific railway context, surface-waves methods are suggested as these waves are less sensitive to the strong 3D character of the structures.

Seismic surveys consisted of 7 identical profiles (P# in Figure 2) with 72 vertical component geophones. The profiles were implanted on the side path to ensure good geophone coupling with the medium and to overcome specific acquisition conditions on ballast. P1 was carried out at the base of the core drilling 5 in the disturbed area, while P2 was centered on the core drilling 8 in the healthy area. Five other profiles (P3 to P7) helped to complete the survey between these two profiles and slightly south of the maintenance area where the phenomenon was spotted during the campaign (Figure 2).

For each profile, surface-wave dispersion curves were extracted and inverted [7]. For each profile, dispersion data were inverted generating a total of 753,000 models. The results are presented in Figure 3. Models are represented with a colour-scale depending on the misfit value (best models according to the misfit values are in red). Results show that VS are not well defined for the two first layers, at a depth of less than 1m, and do not suggest strong interface for the chalk. With these models we can clearly distinguish the loess layer between 1 and 4m depth. However, they show that in the healthy zone, VS in the loess is about 300m/s (e.g., P2) and about 190m/s in the disturbed area (e.g., P1). The resulting contrast corresponds to the lateral mechanical property variations observed along the line and confirmed by the BE tests. Moreover, the thicknesses obtained using surface-waves corresponded to the geotechnical data of both core drillings and cone resistance. It is about 4m for P1 and 6m for P2. These support the relevant results of the inversions.

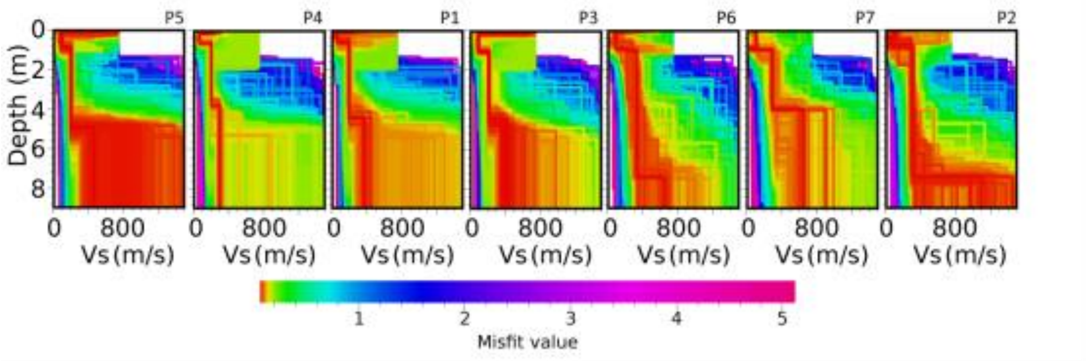

Figure 3. Vs models obtained from surface-waves dispersion data for profiles P1 to P7. Colour bar corresponds to the misfit value of each model. After [5].

4 Conclusions and Contributions

Following the discovery of a disturbed area on the Northern Europe speed line, geological, geotechnical and geophysical surveys were carried out in order to determine the origins of this issue.

Classical geotechnical measurements as water content, density measurements or Atterberg limits do not show specific variations due to the presence of the phenomena. However, it appears that VS from BE tests on loess samples clearly indicate changes between the affected and the healthy zones. Thus, considering constant water content, shear-modulus is a good indicator of the layer quality. Moreover, Qd show a strong decrease in the loess layer of the disturbed area.

These conventional geotechnical measurements still remain local, destructive and with low yields in terms of auscultate linear. They cannot be used to explore large linear. In this sense, non-destructive investigation techniques as geophysics, and more precisely surface-wave methods, are of great interest. 1D VS models obtained along the line clearly show strong contrast in mechanical properties in the loess layer. These contrasts are representative of the ones obtained using BE tests in the core drilling but also of the cone resistance measured on field. The proposed inversions were able to produce relevant results only thanks to strong available *a priori*. These results show that the measured dispersion can be considered as a control criterion of the RE state.

These results are encouraging even if they need to be demonstrated in different railway contexts before being generalized. In order to be used in an operational workflow, as a decision support tool, the parameter space needs to be displayed in terms of probability with Bayesian formalism [8]. However, this kind of acquisition and the associated processing still remain cumbersome to manage highlighting the need to create a specific toolbox adapted to this railway environment (equipment and workflow development). New tests are also necessary particularly concerning the inclusion of ballast and the inclusion of higher propagation modes from dispersion data to better describe the first meter of the embankment.

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