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Bayesian inversion of MASW data for the characterization of railway embankments

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Abstract

The renewal of railway embankments (RE) requires the characterization of their mechanical properties. Techniques classically used to study RE are mainly local, destructive, expensive and of low yields (geotechnical in situ tests, core-drillings). There is a great need in the development and deployment of non-destructive methods, allowing quick and efficient diagnosis of the RE state. Surface wave method has been deployed in a test site to determine the shear modulus along the line. The development of a surface-wave dispersion inversion algorithm according to a probabilistic approach, enables to switch from qualitative to quantitative results. Such Bayesian implementation should help the results interpretation and constrain end-users decisions.

Keywords: High Speed Line, Railway Embankment, Surface wave methods, Bayesian inversion.

1 Introduction

The renewal of railway embankments (RE) or the selection of appropriate maintenance actions require the characterisation of their mechanical properties. Techniques classically used to study RE are mainly local, destructive, expensive and of low yields (geotechnical in situ tests, core-drillings). There is a great need in the development and deployment of non-destructive `on-the-fly' methods, allowing quick and efficient diagnosis of the RE state. An unusually frequent and local need for maintenance (in particular `clogging operations') was observed along the Northern

Europe high speed line (LGV-Nord). The area has been chosen as a test site, on which geotechnical and geophysical surveys were performed to understand the phenomenon at the origin of the observed disorders [1]. Samples collected along this site were analysed with the Bender Element (BE) technique [2]. The study showed that shear-wave velocity (Vs) was an acceptable criterion to differentiate materials within this RE. Therefore surface-wave seismic method has been suggested as an alternative tool to describe mechanical properties of the RE (as already proposed in such context, e.g. [3] since the technique makes it possible to retrieve Vs of soil and near-surface anthropic structures, e.g. [4]). The seismic surveys and extracted data have been presented in detail in [1]. Preliminary inversions along the seismic line confirmed a decrease of Vs in the disturbed zone. In the present study, to provide a more quantitative assessment of these encouraging results, the Bayesian formalism was used to interpret the surface-wave dispersion data and help build a decision tool for the RE monitoring.

2 Methods

The area selected is a structurally well constrained site. The typical structure of the RE is describe in the inset of Figure 1 and detailed in [1]. 7 seismic surface-wave profiles were performed along the side path (Figure 1). Southern profiles were deployed along the disorder zone when Northern profiles were along the intact area.

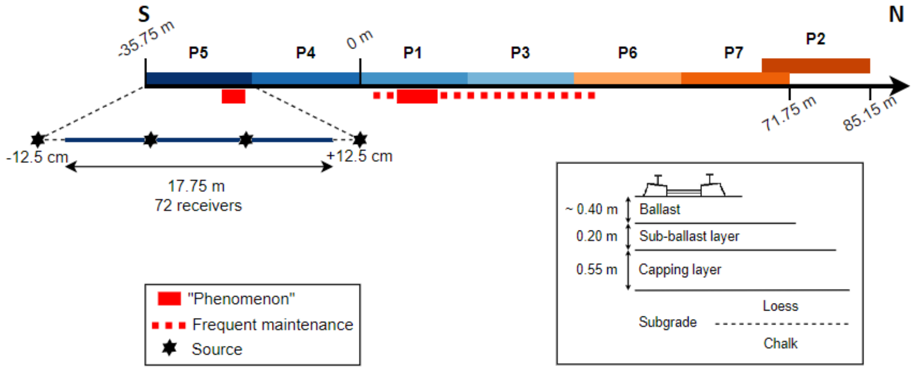

Figure 1: Schematic layout of the seismic profiles (P1 to P7) along the trackside. The schematic structure of the RE is shown in the inset on the right.

The processing and surface-wave dispersion data picking were carried out by [1]. For each profile, the data vector d, involved Nd phase velocity (V_ϕ) measurements depending on frequency (f_i, i = 1, …, N_d), **d** = [V_ϕ^1, V_ϕ^2, …, V_ϕ^i, …, V_ϕ^{Nd}]. Two distinct zones are clearly highlighted (see Figure 2): lower phase velocities (blue) on the south; and higher phase velocities (orange) on the north.

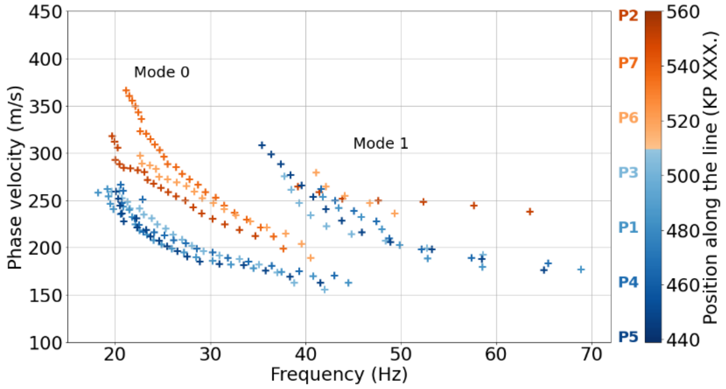

Figure 2: Figure 2 : Dispersion curves plotted for every profile (P1 to P7). The color scale represents the location of profiles along the line.

The inversions of the 7 profiles were performed thanks to a grid search algorithm, using the parameterization summarized in the Table 1 and constrained according to strong *a priori* information available about this RE. The model vector is then defined as $\mathbf{m} = [Vs_1, Vs_2, Vs_3, Vs_4, H_3]$. The Thomson-Haskell forward operator [5, 6] has been used to compute dispersion curves for all possible model of the parameter space (413,712). For each model, the difference between the calculated dispersion (V_{calc}^i) and the picked dispersion (V_{obs}^i) at every frequency (f_i) was computed with the following *misfit*: $misfit(\mathbf{m}) = \sqrt{\sum (V_{calc}^i - V_{obs}^i)^2 / N_f \, \sigma^2_i}$.

Parameter	Min	Max
Vs_1 [m/s]	50	300
Vs_2 [m/s]	50	300
Vs_3 [m/s]	50	400
Vs_4 [m/s]	200	600
H_3 [m]	3	7

Table 1: Parameter space

According to [7], formulate the inverse problem involve the information and probability theories. This has been suggested as first step to help quantifying the grid search outputs and initiate the development of a decision support tool for the RE monitoring. The parameterization and *a priori* information helped define the *a priori* probability density function (*pdf*) $\rho(\mathbf{m})$, homogeneous throughout the model space. The grid search and misfit computation for each profile provided with a likelihood function: $\Theta(\mathbf{d}|\mathbf{m}) = e^{-1/2 misfit(\mathbf{m})}$. According to the possible Bayesian formulation of the inverse problem, Vs models of the RE along the line were inferred from each profiles' *a posteriori pdf*: $\sigma(\mathbf{m}|\mathbf{d}) = \rho(\mathbf{m})\, \Theta(\mathbf{d}|\mathbf{m}) / \int \rho(\mathbf{m})\, \Theta(\mathbf{d}|\mathbf{m})\, d\mathbf{m}$.

3 Results

Only the a posteriori pdf for the parameter Vs3 are presented in Figure 3a. As expected, they show a significant variation along the line which is coherent with the phenomenon observed on the surface. The profiles further south (P3, P1, P4 and P5) have lower velocities in the loess layer than in the north (P2, P7 and P6).

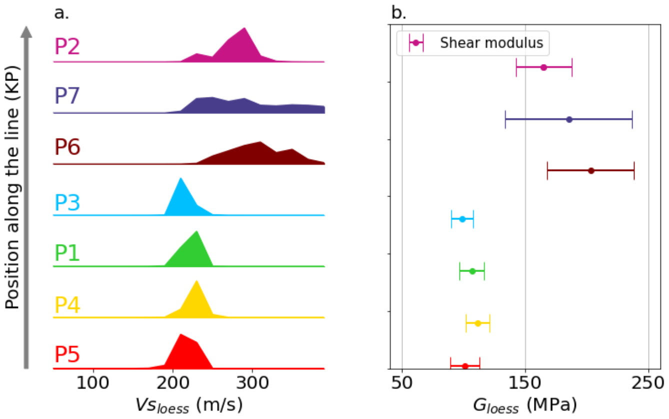

Figure 3: Synthetic representation of the Bayesian inversions performed along the line for the parameter Vs3, target of this study. The profiles are ordered according to their position along the line (see figure 1). a) A posteriori marginal probability densities of Vs3. b) Shear modulus of the loess layer with its error bars.

As mechanical moduli are used as a criterion for characterization of the RE, we suggested, for each profile, to consider a fixed soil density in the loess layer, to calculate the mathematical expectation of each probability density from Vs3 and then, to estimate the shear modulus $G_3 = \rho Vs_3^2$. Error bars were expressed from the standard deviation of the probability density. The results of these statistical estimates are presented in the figure 3b. Likewise to Vs, shear moduli of the northern profiles are higher than the southern profiles. The errors are directly related to the resolution of the parameter and to dispersion measurements uncertainties (calculated according to the relation of [8]).

4 Conclusions and Contributions

From the dispersion curves collected along the profiles, the developed method detect Vs variations linked to a “disorder” in depth (particularly localized in the loess layer). The development of a surface-wave dispersion inversion algorithm according to a probabilistic approach, enables to switch from qualitative to quantitative results. It allows uncertainty to be extracted from the results. Shear moduli are also expressed with their uncertainties. Such Bayesian implementation should help the results interpretation and constrain following end-users decisions. Future works will allow to combine surface-wave dispersion data with other geophysical (GPR, ERT, etc.) and geotechnical measurements (Pandoscopes®, surveys, lab tests, etc.) in order to increase a priori information available on the RE and better constrain the inversions.

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