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Geotechnical auscultation of a French conventional railway track-bed for maintenance purposes

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Abstract

Prior to renewal or maintenance works on a railway track it is required to perform a proper investigation of the stiffness and thickness of each material constituting the track-bed. In practice, different techniques are used for this purpose. In this study, a comparison of two methods of determining the stiffness of track-bed materials (dynamic penetration and dynamic plate load) is made for a representative French conventional railway line, aiming at optimising the use of different geotechnical auscultation techniques for the railway applications. Firstly, results from geo-endoscopic tests are analysed to define the thickness and nature of the different materials found in the track. Then, dynamic penetration tests (PANDA tests) are performed to evaluate the stiffness of the different layers. Statistical distribution of soil stiffness is analysed for each layer. In addition, the elastic moduli of different materials are estimated from their stiffness using empirical equations. Secondly, dynamic plate load tests using a light weight deflectometer device (LWD) are carried out on surfaces (on tracks and service paths) in order to estimate the dynamic and static moduli of ballast and subgrade. A statistical analysis of the obtained results shows a low dispersion rate and a satisfactory repeatability. The static moduli estimated from LWD tests are found to be consistent with the elastic modulus estimated from PANDA tests, showing that different auscultation methods give complementary information about the mechanical properties of the materials constituting the conventional tracks.

Keywords: Conventional track; Geo-endoscopic test; Dynamic penetration test; Light-weight deflectometer; Statistical analysis; Modulus

1. Introduction

Railway tracks need regular maintenance or renewal, and the corresponding economic issue is in general of great importance. This is particularly the case for the conventional network (Cui et al., 2014). For instance, in France conventional tracks represent 94% of the whole railway network (Duong et al., 2014), and more than 2 billion Euros are spent each year in maintenance operations for these tracks. This situation is related to their history – most of them being constructed at the end of XIXth or the beginning of XXth century. Till the 1970s, the ballast used still did not follow any standards as we know today and was set directly on the subgrade soil (Trinh et al., 2012). As a result, a heterogeneous layer of coarse soil mixed with subgrade soil was formed over time, namely Interlayer (ITL) (Duong et al., 2013), mainly by interpenetration of ballast grains and subgrade soils. The spatial variability of the mechanical properties of ITL and other constitutive materials of railway track-bed as well as its

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influence on the track degradation were reported by several authors (Alves Fernandes et al., 2014; Dahlberg, 2010; Popescu et al., 2005; Rhayma et al., 2011; Steenbergen, 2013). Thus, there is a need to define a prospection method to determine the mechanical properties of these constitutive materials of track-bed (Connolly et al., 2013; Paixão et al., 2014). Obviously, this kind of information from mechanical prospection can help optimise the renewal or maintenance operations.

Different methods have been used in railway auscultations. They can be divided into geophysical and geotechnical categories. The commonly used geophysical techniques are the multichannel analysis of surface waves (MASW), the ground penetrating radar or down-hole tests. MASW is used to analyse the propagation wave velocities in soil and the thicknesses of different layers of soil (Araujo, 2010; Degrande and Schillemans, 2001). Ground penetrating radar (GPR) defines the thicknesses of different layers of substructure (Su et al., 2011, 2010; Sussmann et al., 2003; Vorster and Gräbe, 2013). The down-hole seismic test is suitable for estimating the shear wave velocities of different track-bed materials (Hunter et al., 2002). On the other hand, most of the geophysical methods present some difficulties in track-bed investigations. For instance, the MASW is not easy to apply on the track surface with ballast because common geophone pins cannot be installed into large grains as ballast due to contact failure (Jacqueline, 2014). Other geophysical methods, as GPR, are more suitable for the qualitative auscultation of track-bed layers and for estimating the thicknesses of track layers.

Among the geotechnical techniques, the most commonly used ones are the dynamic penetration test (as PANDA tests) (Benz, 2009) and the dynamic plate loading test (as the light weight deflectometer, LWD) (Staatsministerium, 2012; Shafiee et al., 2011; Tompai, 2008; Woodward et al., 2014). These tests can help define the quality of a track-bed and the required thickness for different layers. The LWD test estimates the dynamic modulus of a soil, and at each construction stage of a track-bed it help the quality control. The PANDA dynamic penetration test has become a common technique in France (Alves Fernandes et al., 2014) since it allows prospecting the stiffness of existing tracks. The PANDA test measures the tip resistance of different materials. The elastic modulus of materials can be further estimated from their tip resistances using empirical equations (Amini, 2003; Cassan, 1988; Chai and Roslie, 1998; Chua, 1988; Lunne et al., 1997).

Even though different techniques have been successfully employed in railway applications, to the authors' knowledge, there is still no comparison in literature between the elastic modulus obtained from LWD and the modulus estimated from PANDA for ballast (track surface) and subgrade (service path). When the values of modulus of ballast and subgrade are estimated, they can be used to further assess the coherence of modulus estimations for the embedded materials as the ITL, not accessible for the LWD. Thus, a combined analysis using both geotechnical auscultation methods is necessary for a proper investigation of a railway site.

In this study, a conventional track investigation was conducted. A representative site was selected among the 30,000 km French conventional lines for this purpose. Three different geotechnical prospecting methods were used: Geo-endoscopic tests, PANDA tests and LWD. The results were analysed in terms of moduli of different constitutive materials.

2. Experimentation site

A representative experimentation site in a conventional line was required to study the impact of train speed on the behaviour of track-bed materials. Different criteria were imposed to the selection. For instance, track components as rail and sleepers should not have more than 10 years since their last renewal. In addition, the maximum service speed should be comprised between 200 and 220 km/h. A site with tracks in an alignment was also required to obtain the same solicitation at each side of each track. Only 3 sites in France satisfied the imposed criteria: Vierzon, Angouleme and Strasbourg. The site in Vierzon, near Kilometric Point (KP) 187+165 of the 590000 line (from Orléans to Montauban) was finally chosen. This site is located in a zone of cutting of 2 m; it has an UIC class 4 and is composed of two tracks: track 1 going from Orléans to Montauban and vice versa for track 2. Prior to the installation of the sensors, a site investigation was performed. The tests were carried out along 30 m, using as reference the catenary post at KP 187+165. Six auscultation points were defined (see Fig. 1). The geo-endoscopic, PANDA and dynamic loading plate tests performed can be identified in this figure.

3. Prospection methods

3.1. Light dynamic penetrometer PANDA

Like other dynamic cone penetrometers (DCP), the key concept of a PANDA test is to drive a cone (of 2, 4 or 10 cm^2) fixed at the end of a set of rods into the soil using a hammer. Its originality relies in the use variable energy after each hit of hammer, which is measured in an indirect way from the sensors of PANDA. For each hammer hit, the depth of rod insertion and the tip dynamic resistance q_d are recorded automatically. This dynamic tip resistance is obtained from Eq. (1):

$$q_d = \frac{MgH}{(1+a)}\frac{1}{e} \tag{1}$$

where M the hammer mass, H its falling height, a the ratio of masses ($a = P/M$, the rod-system penetrated mass, P, over the hammer mass, M), g the gravity ($g = 9.8$ m/s^2), and e the penetration of the rod after impact.

The propagation of a mechanic wave through an elastic material, as the rod, is done through energy transfer. The total energy transported by a wave is divided into two parts (Fairhurst, 1961): kinetic energy $E_K(x,t)$ and potential energy of deformation $E_U(x,t)$. The total energy transferred by the rod