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Experimental analysis of track-ground vibrations on a stretch of the Portuguese railway network

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ABSTRACT

This paper presents a comprehensive experimental campaign developed on a stretch of the Portuguese railway network. The experimental work includes three fundamental and complementary components: the characterization of the ground, the characterization of the track and the measurement of the vibrations generated by railway traffic. The characterization of the ground was performed using a combination of conventional and geophysical tests (cross-hole and SASW). The mechanical characterization of the track was performed through receptance tests and the rail unevenness profile was accurately measured. The vibrations due to the passage of more than 20 trains were measured. First, a selection of the results is presented and analysed in detail; later, the variability of the responses is briefly discussed. The presented data may be used by other researchers (e.g. in the validation of their prediction models), since it can be downloaded from www.fe.up.pt/~csf/DataCarregado.zip.

1. Introduction

The growing of world population expected during the present century will bring new challenges to societies and demands to the engineering. Moreover, it is expected that in 2050 about 66% of the world population lives in cities and metropolitan areas [1]. This incredible growing and concentration of population will demand for the development of new and efficient mass transportation systems, where the railways present a relevant role. Actually, railway systems are one of the most efficient transportation systems in highly populated areas, allowing the fast mobility of people, avoiding traffic jams and contributing for a more sustainable use of the natural resources [2]. In spite of the benefits associated to this transportation system, their implementation in urban environment is particularly demanding in what concerns to noise and vibration. The noise and vibration elicited by railway traffic are drawbacks usually pointed out to the railway transport, for whose mitigation engineering solutions are needed.

Having in mind the concerns expressed above, considerable efforts have been allocated by the technical and scientific communities on the development of prediction models of ground-borne vibrations. These models, with different degrees of accuracy and complexity, ranging from empirical and scoping approaches [3–6] up to detailed and complex numerical formulations [7–10], have been applied for achieving a better understanding of the problem and for the assessment of the efficiency of some mitigation countermeasures. Despite the advances recognized on the prediction tools, the experimental characterization of the problem did not receive the same attention during latter years. Actually, the experimental characterization and analysis of the complex problem of ground-borne vibrations due to traffic has undeniable value, since they allow observing the main trends of the problem, to establish behaviour patterns and to identify the main sources of uncertainty. Moreover, reliable experimental data is always required for the validation of prediction models, which justifies the value of this kind of research.

As an attempt to contribute for the development of an experimental data base of vibrations induced by railway traffic, Connolly et al. [11] collected experimental results from different sites along Europe. Despite the insights proceeding from that kind of approach, it is notorious the difficulty inherent to the development of comprehensive test fields attending all the relevant components. Actually, specific aspects as the geotechnical characterization of the ground, the mechanical characterization of the track (together with the measurement of its unevenness) and the description of the trains involved in the tests are fundamental for an adequate understanding of the dynamic behaviour of the system [12–15]. By those reasons, the challenge of comprising a deeply characterized experimental field, where several tests are performed in order to obtain redundant data, should be pursued in order to obtain reliable data that can be used by other researchers.

The objective of the present paper is twofold: i) to contribute for a deeper understanding of the problem of ground-borne

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vibrations due to railway traffic; ii) to present and provide reliable experimental data, obtained on a comprehensive test site, that can be used for experimental validation of prediction models.

The selected test site corresponds to a stretch of the main railway line of the Portuguese network. During the latter years, this test site has been explored by the authors and partial results have been also published in previous papers [7,11]. The present paper presents the whole range of study developed up to now, namely:

i) The geotechnical and geophysical ground characterization, comprising cross-hole tests and SASW tests. These tests allowed to define the ground profiles of elastic wave velocities and damping;
ii) An extensive mechanical characterization of the railway track based on receptance tests, where 20 cross-sections (along a railway length of 40 m) where tested. These tests allowed not only to obtain a picture of the dynamic behaviour of the track, but also to deliver an overview of its variability;
iii) The measurement of the railway track unevenness;
iv) The measurement of vibrations on the track-ground system induced by the passage of more than 20 of trains. Accelerations and displacements of the track were measured for each passage as well as the acceleration at the free field, for distances to the track up to 45 m.

Once several passages of trains of the same type were recorded, a critical analysis about the dispersion of results is performed.

The presentation of the tests and results is accompanied with some discussion and the main conclusions are summarized. Since the presented data can be valuable for further analysis by other researchers, they are available for download.

2. General description of the test site

The experimental test site was implemented in a renovated stretch of the Portuguese railway network (Linha do Norte), near Carregado. Fig. 1 shows its location in the Portuguese territory, accompanied by an aerial photograph.

According to the geotechnical characterization campaign conducted during the renovation of the railway track, the ground is characterized by the existence of an embankment consisting of clay-sandy material with a thickness of about 2.0 m. This formation is overlying clay and clay-sandy alluvial formations with variable thickness.

Fig. 2 shows the railway track at the test site. It corresponds to a double ballasted track with a straight alignment along a considerable distance. The analysis of the renovation project, accompanied by the results of some on-site tests, enabled the identification of ballast and subballast layers with a thickness of 0.35 m and 0.30 m, respectively. It was also possible to identify a layer of granular material beneath the subballast, with a thickness of about 0.25 m. The prestressed concrete sleepers are spaced 0.60 m and support continuous welded rails (UIC60).

Due to its proximity to the region of Lisbon, the studied site has a very significant traffic volume, with the passage of several types of passenger trains (Fig. 3) as well as freight trains. The Alfa Pendular train (the fastest train operating in the Portuguese railway network) circulates on this site and reaches speeds up to 220 km/h.

The experimental campaign included three fundamental and complementary components: the characterization of the ground, the characterization of the track and the measurement of the vibrations generated by railway traffic.

3. Characterization of the ground

3.1. General description

The assessment of the dynamic properties of the ground was performed using conventional tests (CPT and SPT) and geophysical characterization tests (cross-hole and SASW). These tests were developed in the vicinity of the track, near to the reference section, defined at km 41+625. Figs. 4 and 5 present the layouts of the site under study, including the location of the tests.

The information provided by the first group of tests was used

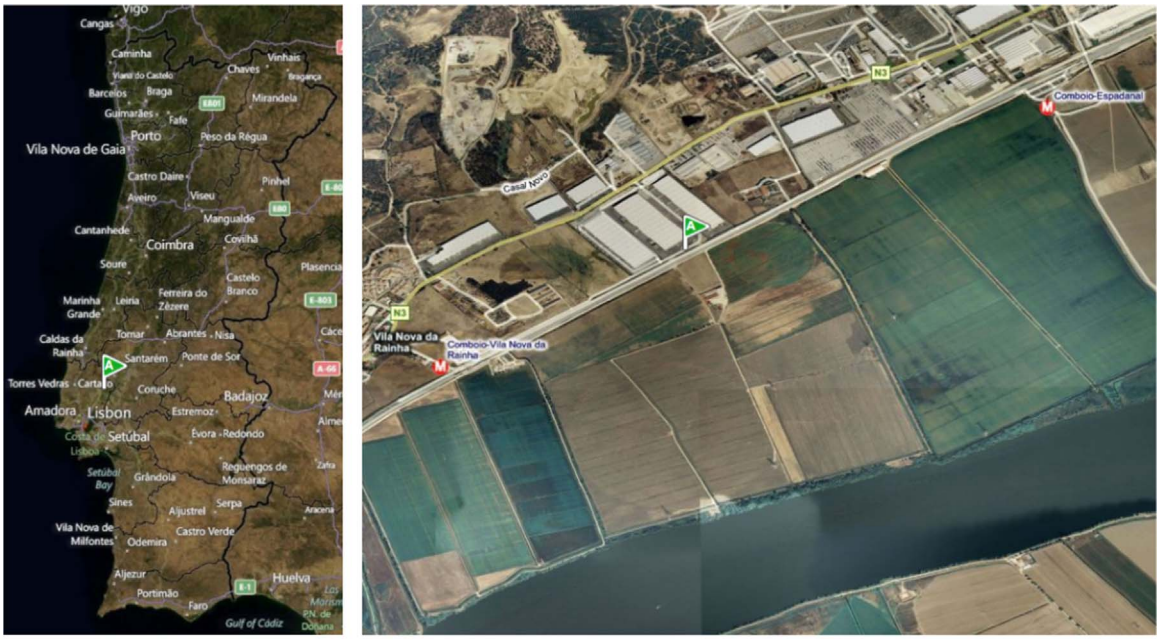

Fig. 1. Location of the test site: a) in the Portuguese territory; b) aerial photograph [16].