

VARIABILITY ON THE PREDICTION OF VIBRATION LEVELS IN BUILDINGS NEAR RAILWAY LINES USING EXPERIMENTAL MEASUREMENTS AS INPUT PARAMETER

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Abstract

Railway-induced ground-borne vibrations pose significant challenges particularly on highly densified urban areas, where the proximity of noise and vibration sources causes discomfort for the inhabitants, as well as devaluing their property.

Traditional methods of vibration assessment, relying solely on either numerical models or experimental data, often unable to provide comprehensive and accurate predictions of the induced vibrations. In this work a hybrid methodology is used to estimate the vibrations induced on a receiver.

Since the methodology depends on the measurements taken on site, the existence of variability, for example between different measurements and resulting from uncertainty in soil characterisation, could affect the accuracy of the hybrid method's predictions. Sensitivity studies of the method were carried out, taking into account different measurements as input parameters and different soil mechanical properties for the numerical models developed. There were used properties driven from different geotechnical tests, including SASW and Cross-Hole tests.

Results indicate that the hybrid methodology provides reliable predictions of dynamic responses, even when are considered slightly different soil mechanical on the numerical part of the model. The methodology robustness is crucial for practical engineering applications, ensuring accurate vibration predictions, contributing to healthier and more sustainable urban infrastructure development.

Resumo

As vibrações induzidas pelo tráfego ferroviário configuram um grande problema, especialmente em áreas urbanas altamente densificadas. A elevada proximidade entre fonte e recetor agrava a problemática, causando desconforto aos habitantes e ocupantes dos edifícios, bem como a sua desvalorização imobiliária. As metodologias convencionas de avaliação de vibrações, que se baseiam normalmente em modelos numéricos não conseguem, na grande maioria dos casos, prever eficazmente e de forma precisa as vibrações induzidas aos edifícios. Neste trabalho é utilizada uma metodologia híbrida para determinação precisa dos níveis de vibração induzidos num recetor.

Uma vez que a metodologia depende de um conjunto de medições realizadas no local, a existência de variabilidade, por exemplo, entre diferentes medições e resultante das incertezas que advém da caracterização do solo, podem afetar a precisão do método híbrido. Neste sentido, foram realizados alguns estudos de sensibilidade do método, tendo em conta diferentes medições como parâmetros de entrada e diferentes propriedades mecânicas do solo para os modelos numéricos desenvolvidos. Foram utilizadas propriedades obtidas através de diferentes ensaios geotécnicos, incluindo ensaios SASW e *Cross-Hole*.

Os resultados indicam que a metodologia híbrida é capaz de prever a respostas dinâmica do recetor, de forma precisa, mesmo quando são consideradas propriedades mecânicas do solo ligeiramente diferentes em diferentes modelos. A robustez da metodologia é crucial para garantir a sua aplicação prática, garantindo a precisão das previsões do modelo e contribuindo para o desenvolvimento urbano de forma saudável e sustentável.

Keywords: Vibration prediction, Variability Study, Uncertainty Assessment, Railway

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1. Introduction

The acceleration of the energy transition and the decarbonisation of the economy has boosted investment in railways around the world. The desire to meet global environmental targets has led to a real modal transition in railways.

The existence of increasingly consolidated urban environments, with a growing number of inhabitants, has brought the problem of vibrations induced by railway traffic in urban environments to the fore.

If, on the one hand, there is a growing demand for transport, leading to an increase in frequencies, with more vehicles circulating, we have a greater number of buildings in the vicinity of railway lines, with light and heavy traffic.

The problem of propagating vibrations generated by railway traffic to buildings is extremely complex, and its prediction is associated with high levels of uncertainty. Conventional methods have a very deterministic nature and are therefore highly susceptible to the properties considered. For example, one of the sources of uncertainty is related to the correct characterisation of the mechanical properties of the soil[1], and its characterisation throughout the domain of interest, which is often assumed to be invariant.

Recently, new ways of approaching the problem have emerged, with the reduction of uncertainties in the predicted values, as is the case with hybrid methods. A hybrid experimental/numerical methodology, was initially developed by Arcos[2]. This methodology combines experimental measurements, carried out on the site of the building prior to its construction, with numerical models to evaluate railway-induced vibrations. In addition to predictive studies, this type of methodology allows designers to evaluate the performance of different types of mitigation measures, either on the road or in buildings[3], enabling the project owner to make an informed choice with a high cost-benefit ratio.

Along the work, the influence of soil characterization and the initial experimental measurements on the accuracy of the hybrid method is studied, considering the mechanical properties of the soil in the numerical models, which are slightly different for different calculations.

2. Methodology

The determination of vibration levels in structures is achieved using a hybrid experimental/numerical methodology initially developed and introduced by Arcos[4]. The hybrid methodology combines experimental measurements with a numerical model to accurately assess railway-induced ground-borne vibrations.

This methodology is divided into three steps.

Step 1. To perform the experimental measurements of the vibration induced at the ground surface, in a set of collocation points, previously chosen where the building structure will be constructed.

Step 2. To determine the virtual forces, taking into account the measured response at the collocation points, transforming them from space-time domain into displacements in the frequency domain, collected in the vector \mathbf{U}_c . From those displacements, the virtual forces, \mathbf{F}_v , can be computed, according to Eq. (1).

$$\mathbf{F}_v = \mathbf{H}_{cf}^{-1} \mathbf{U}_c \quad (1)$$

The \mathbf{H}_{cf}^{-1} is a square receptance matrix that relates the virtual forces and the collocation points response obtained with a local subsoil model that considers only the ground

Step 3. Computation of the building/soil system response according to Eq. (2).

$$\mathbf{U}_b = \mathbf{H}_{bf} \mathbf{F}_v \quad (2)$$

where \mathbf{U}_b represents the response of a set of evaluation points placed in the building/soil model and \mathbf{H}_{bf} is the receptance matrix that relates the virtual forces and the evaluation points response. The \mathbf{H}_{bf} matrix is obtained using the building-soil theoretical model specifically developed for each case study.

3. Variability study

3.1. Soil Mechanical Properties

The constitution of soils is very diverse and heterogeneous, were they not the result of natural phenomena. For this reason, the mechanical properties of soils vary widely, sometimes even over a short geographical range.

The geotechnical reality is usually relatively complex, and in many cases, there are significant heterogeneities in the massif, which increase the difficulty of correctly characterizing the soil in the area surrounding the building. Discrete or very localised tests characterize the test area well, without providing information on the whole area under study.

Multiple tests of different types and with a certain spatial distribution were carried out in the loaded experimental field, allowing a better understanding of the local variability of the massif's properties. SASW tests were carried out, which provide a more global characterisation of the massif, and Cross-Hole tests, which provide a more localised characterisation. In the basic modelling solution, the mechanical characteristics of the soil corresponding to the Cross-Hole 2 test were used throughout this work, simply because this test was carried out closer to the site under study.

The variability in the numerical prediction of the hybrid method, which comes from the consideration of the different geotechnical profiles determined by the four geophysical tests carried out on site, was studied.

The mechanical properties of the soil, for each one of the different geotechnical profiles are presented on Figure 1.



Figure 1 - Comparison of soil mechanical properties obtained through Cross-hole and SASW tests carried out on site.[5].

The variability in the numerical prediction of the hybrid method, which comes from taking into account the different geotechnical profiles determined by the four geophysical tests carried out on site, was studied. Comparing the different displacement curves with the experimental curves, as well as

comparing the relative difference between the numerical curves, will allow conclusions to be drawn as to the influence that this consideration may have on the dynamic response calculated using the hybrid method.

The global dynamic soil-foundation-structure system considered for this study is presented in Figure 2. The evaluation point considered is located on top of the steel structure.

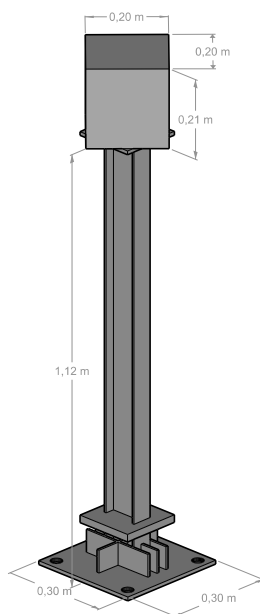


Figure 2 - Three-dimensional schematic representation of the structure.

The numerical dynamic response curves obtained using the hybrid method for each of the geotechnical scenarios mentioned are shown in Figure 3.

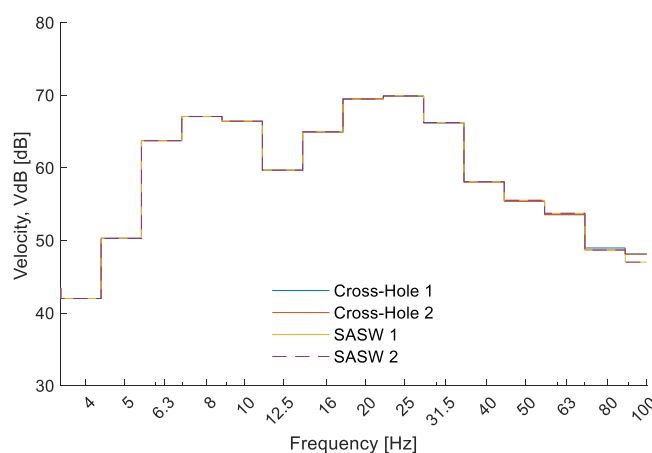


Figure 3 - Prediction curves obtained using the Hybrid Method, considering the four geotechnical profiles.

The comparative analysis between the numerical curves obtained for each geotechnical scenario and the experimental curve in the figure shows the method's ability to provide accurate results, despite the fact that different geotechnical profiles were considered in the soil sub-models. This ability of the method is of great importance, since the accuracy of the results obtained is guaranteed even if there is a variation in the characterization of the soil's mechanical properties in relation to its real properties.

The deterministic nature of conventional numerical approaches is highly sensitive to soil properties, and therefore significantly influenced by their variation; in contrast, the hybrid method allows accurate results to be obtained even with variations in the soil's mechanical properties. This property is due to the fact that the virtual forces are determined for each of the different cases so that the same energy is introduced into the domain of the virtual forces, matching the initial excitation measured at the collocation points.

3.2. Measured Vibration Field

The other variability factor is related to the vibration field measured on site and used as an input parameter in the hybrid method for determining virtual forces. Since the building will be subjected to a wide range of demands, different trains, different loads, different speeds and directions of traffic and different routes, it is important to study induced vibrations for all types of traffic.

The Figure 4 shows the 95% probabilistic confidence interval, the mean curve of the predictions and the reference experimental vertical speed curves.

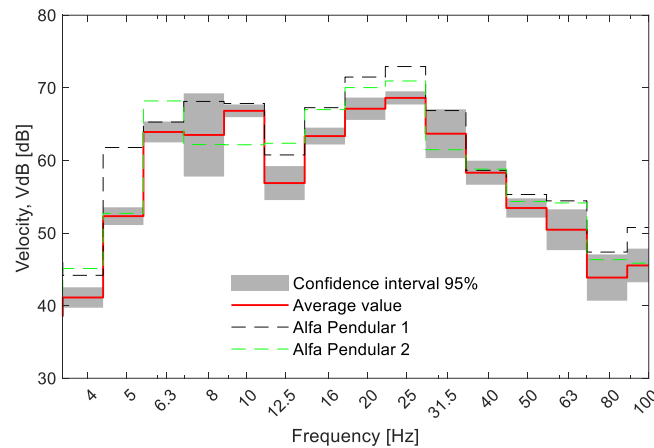


Figure 4 - Representation of the 95% confidence interval and the average numerical curve, as well as the two experimental records evaluated at the top of the structure.

The different numerical curves that give rise to the average curve and the respective confidence interval were calculated considering the five experimental measurements in free-field conditions (before construction), regarding the passage of five Alfa Pendulares with speeds of 212 ± 8 km/h, in the direction of Porto.

Analysing the results obtained allows us to state with a greater degree of certainty the predictive capacity of the hybrid method, with the envelope of the confidence interval providing an additional guarantee of the accuracy of the dynamic response of the structure obtained through the hybrid method. Obtaining multiple curves is a relatively simple numerical process, as it is enough to determine the system's stiffness matrices once, allowing for the rapid determination of the multiple dynamic responses resulting from the different sets of experimental measurements carried out before the structure was built.

4. Conclusions

In this work, there was studied the influence that the consideration of different soil properties used for the soil sub-model and the measurements taken to be used as input for the hybrid method have on the final accuracy of the vibration predictions obtained with the hybrid method.

Since the variability in the vibration levels measured at the ground surface reached a value of around 10 dB, in 1/3 octave bands, for the same type of traffic travelling in the same direction and at similar speeds, minor values of uncertainty related to the mechanical characterization, or similar model inputs could be considered. These levels of experimental variability highlight the need to obtain several prediction curves, taking into account the variation of different properties, since the deterministic nature of prediction is compromised by such variability.

The hybrid method allows several numerical prediction curves to be obtained for different stresses, quickly and with high levels of precision. Obtaining a probabilistic curve of the vibrations induced at the evaluation point, as well as its uncertainty envelope, represents a significant advance for the study of vibrations induced by railway traffic in buildings located near railway infrastructures.

The hybrid experimental/numerical methodology presented in this study offers a significant advancement in assessing and predicting railway-induced ground-borne vibrations in building structures. By integrating experimental measurements with numerical models, the methodology effectively addresses the limitations of traditional approaches, providing a more accurate and reliable analysis.

This approach has the ability to integrate diverse data sets and adapt to varying conditions, making it a valuable contribution to the field of civil engineering. It is available as a tool for the industry and engineering consultants.

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