The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 22.7
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.22.7

Numerical validation of a 2.5D experimental/numerical hybrid methodology for the prediction of railway-induced ground-borne vibration on buildings

P. Soares[1], P. A. Costa[1], R. Arcos[2,3]

[1] CONSTRUCT, Faculty of Engineering (FEUP), University of Porto, Portugal
[2] Serra Húnter Fellow, Universitat Politècnica de Catalunya (UPC), Spain
[3] Acoustical and Mechanical Engineering Laboratory (LEAM). Universitat Politècnica de Catalunya (UPC), Spain

Abstract

In this work, an experimental/numeric hybrid methodology for the assessment of building induced vibrations due to railway traffic is presented. This method has as main advantage the use of measurements of the actual vibration field to the terrain surface as an input parameter. The main application for this method is the study of the vibrations that a given building will be subjected to when built close to a railway line. A set of virtual forces is applied to a sub-model of the ground alone, making this displacement field equal to the one that is measured experimentally, allows obtaining the virtual forces to be applied to the soil-building model and which will give the vibrations to which the same building is subjected. In the present work, this methodology is presented and validated numerically by 2.5D for a case of homogeneous and stratified soil. The proposed hybrid model simplifies the usual numerical procedure as it is no longer necessary to modulate the railway infrastructure and reduces the uncertainty of the prediction due to the use of experimental site measurements.

Keywords: Railway-induced vibration, ground-borne vibration, soil-building interaction, underground railway, propagation path, hybrid methodology.

1 Introduction

Nowadays, railway-induced noise and vibration is a public concern. Many countries all around the world have established regulations for the maximum noise and vibration levels that can be reached in buildings nearby of railway infrastructure. These regulations are set mainly to control the annoyance of the building inhabitants.

One of the most common situations in where a railway-induced noise and vibration assessment is required is the construction of a new building nearby to an existing and operational urban railway line. In such cases, the railway line administration or the city council usually demands a study that certifies that the railway-induced ground-borne noise and vibration levels will comply with the local regulations. Thus, prediction models are required in those situations.

Various theoretical models that account for the comprehensive system, i.e. the railway infrastructure, the soil and the building to be studied, have been developed during the last three decades. One of the first proposals in this regard was presented by Trochides [1] in where a simple method based on statistical energy analysis concepts for predicting ground-borne vibrations levels in buildings near underground railway infrastructure was presented. Chua et al. [2] proposed a two-dimensional (2D) finite element method (FEM) model. Fiala et al. [3] used a decoupled approach to assess the vibration response of the building. This approach considers a weak coupling between the tunnel/soil and the building/soil systems. For the tunnel/soil system, a two-and-a-half-dimensional (2.5D) FEM model for the tunnel coupled with a 2.5D boundary element method (BEM) model for the soil are used [4]. In contrast, for the building/soil model, a 3D FEM-BEM model is considered. A similar approach was presented by Lopes et al. [5].

The uncertainty on the railway-induced ground-borne predictions in buildings due to the imperfect knowledge of the local subsoil conditions is found to be significant in various scientific works. Also, uncertainty related to the parameters of the train, the truck and the tunnel systems affects the accuracy of numerical modeling to predict railway-induced ground-borne vibration.

In this paper, a hybrid methodology to assess the vibration-induced on a building due to a train passage is numerically validated. The proposed method, when it is used for real cases, considers experimental vibration measurements on-site where the building will be constructed as an input that feeds a numerical model of the building and the surrounding soil. In this paper, instead, the real site measurements are also simulated numerically. In the next sections, the dynamic response of a building computed from a comprehensive numerical model of the tunnel-soil-building system is compared with the response obtained from the proposed hybrid method. Both responses are directly compared to determine the reliability of this method.

2 Methods

In this section, a hybrid methodology for the prediction of the railway-induced ground-borne vibration in buildings to be constructed nearby to railway urban lines is described. This is a hybrid method since it combines experimental measurements on the soil surface and a numerical model of the building/soil system.

The measurements on the surface were replaced by a simulated response in order to validate numerically this methodology. This numerical method is formulated to be applied in the 3D domain although in this case it is being formulated in the 2.5D domain. The points where the response is measured in the field, in this case, the points for which the response is calculated due to the passage of a moving load on the railway line are considered in this method the collocation points, (blue markers on Figure 1). This is the "experimental" step of the approach. Since the methodology is formulated on the frequency domain.

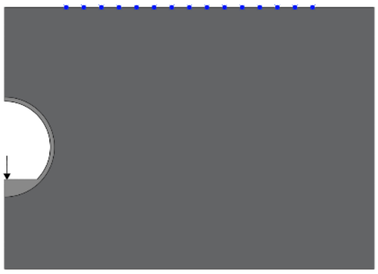


Figure 1: Two-dimensional schematic representation of the source and the colocation points in the ground surface.

The numerical part of this hybrid methodology is based on an approach similar to the method of fundamental solutions (MFS), where it is assumed that a previously known boundary conditions, defined by the so-called collocation points, and a set of virtual sources, as depicted in Figure 2 (a-i), this method is explained by Arcos et al. [6].

The number of colocation points and virtual sources was considered equal, this number and their arrangement will certainly affect the accuracy of the result. future studies will study the influence of these aspects on the accuracy of the result.

The virtual forces are determined by imposing equal displacements between the measured displacements, and the ones originated by the unitary virtual forces relating the displacements on the same colocation points to a set of unitary virtual sources placed over e semicircle, presented on Figure 2 (a-i).

$$F_v = H_{cf}^{-1} U_c \tag{1}$$

(a-i) (a-ii)

Figure 2: Two-dimensional schematic representation of the virtual sources (green marker) and colocation points, (a-i) and the evaluation point on the building, red marker (a-ii).

Then, the response of the building/soil system can be obtained by

$$U_b = H_{bf} F_v \quad (2)$$

where U_b represents the response at the evaluation point placed in the building/soil model and H_{bf} is the receptance matrix that relates the virtual forces and the evaluation points response, considering the building presence see Figure 2 (a-ii).

3 Results

In this section, a 2.5D FEM-PML is used to numerically validate the methodology, using the approach presented by Lopes et al. [5]. Two distinct soil scenarios have been considered in the verification, which is illustrated in Figure 3. The first soil scenario considers a homogeneous half-space as a model of the soil and the second a layered half-space. The ground properties used on the calculations are presented in Table 1. In this system, the railway underground infrastructure considered consists of a tunnel of 8.5 m of inner diameter with a tunnel wall thickness of 0.35 m. The building is made up of 2 floors with 3 m of height and a span between walls of 4 m. The thickness of the walls and the floors is 0.3 m. The depth of the shallow foundations is 1.4 m from the ground surface.

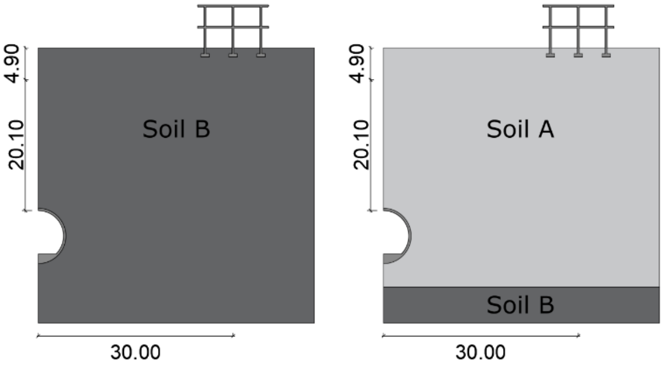
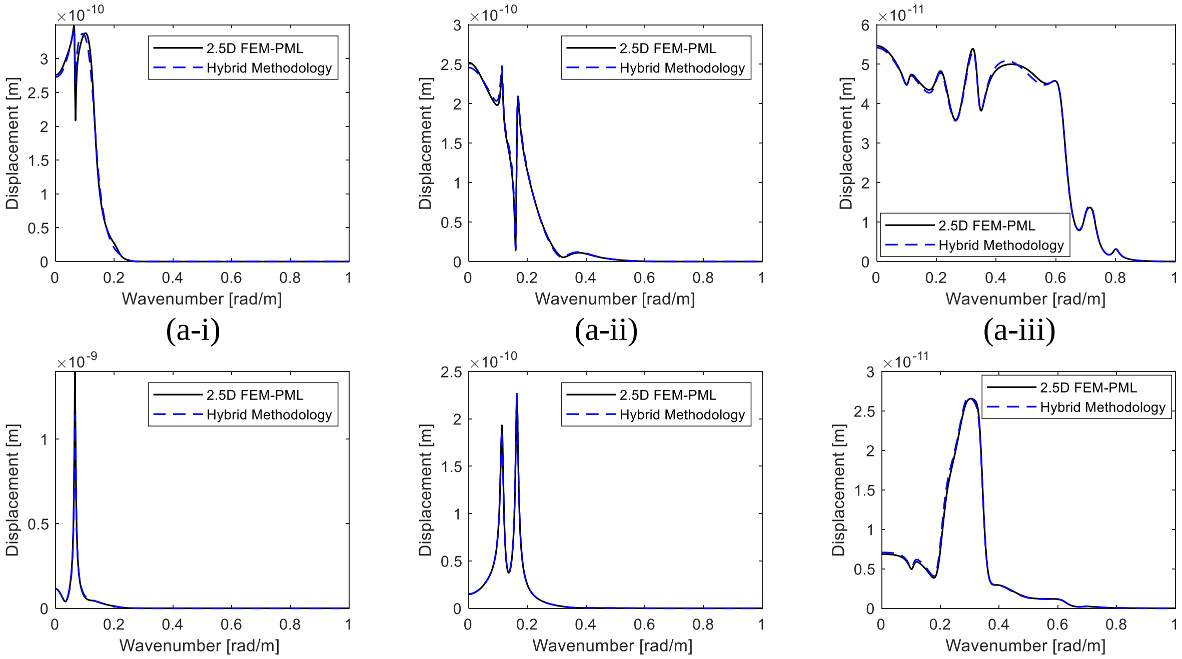


Figure 3: Geometry of the tunnel/soil/building system assumed for the calculations. Distances in meters.

Table 1: Mechanical properties considered for the different materials.

Material	Density [kg/m^3]	Young's modulus [MPa]	Poisson's ratio [-]	Damping [-]
Soil A	2000	195	0.3	0.04
Soil B	2000	350	0.3	0.04
Tunnel	2500	30000	0.2	0.01
Building	2500	30000	0.2	0.01

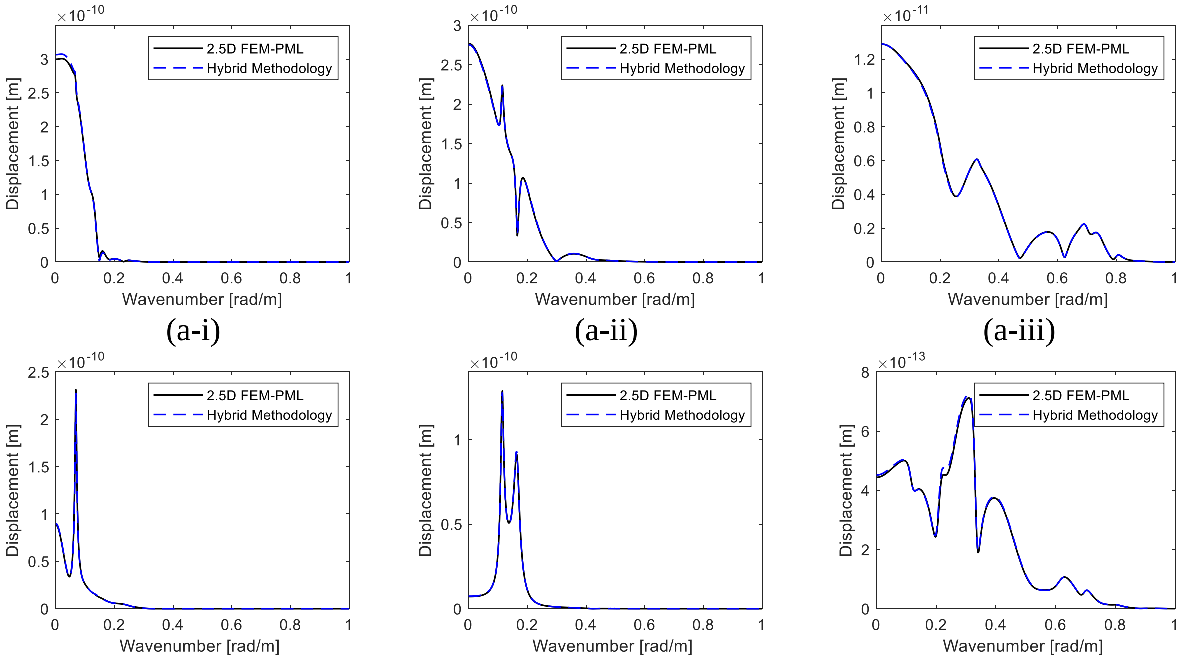
The calculations have been performed at three specific frequencies. To validate this hybrid methodology, the response of the system has been calculated with a 2.5D FEM-PML of the complete system and with the new hybrid methodology. The comparisons between responses obtained by both models at an evaluator located at the middle span of the first floor are shown in Figures 4 and 5, respectively. For this calculation, a set of 16 virtual sources evenly distributed along a semi-circle with radius 7 meters is considered.



(a-i) (a-ii) (a-iii)

(b-i) (b-ii) (b-iii)

Figure 4: Response at the evaluation point, for the first case scenario, for vertical (a) and horizontal (b) displacements and for frequency of 10 Hz (i), 31.5 Hz (ii) and 63 Hz (iii).



(a-i) (a-ii) (a-iii)

(b-i) (b-ii) (b-iii)

Figure 5: Response at the evaluation point, for the second case scenario: for vertical (a) and horizontal (b) displacements and for frequency of 10 Hz (i), 31.5 Hz (ii) and 63 Hz (iii).

The results obtained with this methodology for both case studies presented in Figures 4 and 5 for the wavenumber domain are very close to the results for the same cases obtained with the 2.5D FEM-PML of the complete system, these results verify this methodology in a 2.5D domain. This comparison can be made because the models done for a complete model of tunnel/soil/building and the hybrid method retain a full geometrical and mechanical correspondence.

4 Conclusions and Contributions

A new methodology for the prediction of railway-induced vibration in buildings to be built near an operational railway infrastructure is numerically validated in the present paper. This hybrid methodology is based on a weak coupling between the source of ground-borne vibration, considered in this case a railway infrastructure, and the receiver, a specific building. The main feature of this methodology is that it uses experimental measurements of the railway-induced vibration in the ground surface where the new building will be constructed to obtain the wave incident field. Once the incident field is computed, in the form of a set of virtual forces applied on the soil, a theoretical building/soil model can be used to obtain the vibration response specific building due to the railway infrastructure excitation.

The results presented in this paper formulated in 2.5D show that this hybrid methodology is very precise when compared with a complete 2.5D FEM-PML model calculation. This accuracy of the method is verified for both homogeneous and layered half-space cases. As shown in Figures 4 and 5.

This hybrid model simplifies the usual numerical procedure for these problems since a model of the railway infrastructure is no longer required. Thus, with this approach, it is possible to reduce the domain to be modeled, only considering the building and the surrounding soil, resulting in less computational effort. Moreover, it reduces the uncertainty of the prediction due to the use of experimental measurements of the site to be studied. In addition, it provides higher accuracy and flexibility than empirical models based on experimental transmissibility functions between the ground surface and the building. The results obtained in the verification presented show that the proposed hybrid model is working accurately for both the cases homogeneous and layered half-spaces. The next step to improve the performance of this methodology is to conduct a set of parametric studies to establish some standard rules to efficiently choose the smallest number of colocation points that lead to accurate results.

Acknowledgements

This work was financially supported by: Programmatic funding - UIDP/04708/2020 of the CONSTRUCT - Instituto de I&D em Estruturas e Construções - funded by national funds through the FCT/MCTES (PIDDAC); Project PTDC/ECM-COM/1364/2014 – POCI-01-0145-FEDER-016783 – funded by FEDER funds through COMPETE2020 – Programa Operacional Competitividade e Internacionalização (POCI) and by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P; Project POCI-01-0145-FEDER-029557 – funded by FEDER funds through COMPETE2020 – Programa Operacional Competitividade e Internacionalização (POCI) and by national funds (PIDDAC) through FCT/MCTES; Individual Grant SFRH/BD/148276/2019; Project VIBWAY: Fast computational tool for railway-induced vibrations and re-radiated noise assessment, with reference RTI2018-096819-B-I00, supported by the Ministerio de Ciencia e Innovación, Retos de Investigación 2018.

FCT
Fundação para a Ciência e a Tecnologia

REPÚBLICA
PORTUGUESA

References

[1] A. Trochides, "Ground-borne vibrations in buildings near subways”, Applied Acoustics 32 (1991) 289–296.

[2] K. H. Chua, T. Balendra, K. W. Lo, "Groundborne vibrations due to trains in tunnels", Earthquake Engineering & Structural Dynamics 21 (1992) 445–460.

[3] P. Fiala, G. Degrande, F. Augusztinovicz, " Numerical modelling of ground-borne noise and vibration in buildings due to surface rail traffic", Journal of Sound and Vibration 301 (2007) 718–738.

[4] G. Lombaert, G. Degrande, D. Clouteau, "Numerical modelling of free field traffic-induced vibrations", Soil Dynamics and Earthquake Engineering 19 (2000) 473–488.

[5] P. Lopes, P. A. Costa, M. Ferraz, R. Calçada, A. S. Cardoso, "Numerical modeling of vibrations induced by railway traffic in tunnels: From the source to the nearby buildings", Soil Dynamics and Earthquake Engineering 61-62 (2014) 269–285.

[6] R. Arcos, P. J. Soares, L. Godinho, and P. Alves Costa, "A hybrid methodology for the assessment of railway-induced ground-borne noise and vibration in buildings based on experimental measurement in the ground surface," in INTER-NOISE and NOISE-CON Congress and Conference Proceedings, vol. 259, pp. 5522-5533, Institute of Noise Control Engineering, 2019.