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USING NATURAL SEISMIC METAMATERIALS TO MITIGATE RAILWAY GROUND-BORNE VIBRATION

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The negative effects caused by the railway traffic to adjacent buildings and humans in the form of ground-borne vibration and noise is one of the weaknesses that could slow down the growth that the railway industry is experiencing due to its sustainability. Therefore, it is of crucial importance to implement mitigation measures that cancel and/or reduce the vibration wave propagation by possibly holding fast to the sustainable aspect that distinguishes this means of transportation. In this direction this paper studies the effects that forests as natural metamaterials have on the attenuation of the induced vibration generated at the wheel-rail interaction. In particular, the resonance behaviour of such metamaterials is investigated with a numerical approach using a validated model based on the two-step approach, followed by an investigation of specific geometrical characteristics and material proprieties that consent to achieve the enhancement of the performance and efficiency in terms of attenuation level of the natural metamaterials.

Keywords: mitigation systems, railway ground vibration, seismic metamaterials, forests.

1. Introduction

The railway system as means of transportation is experiencing a large growth globally because of its sustainability in terms of carbon emission per passenger. One main drawback that could slow down the ongoing extension of the railway traffic is the ground vibration that is generated at wheel-rail interaction and propagates through the transmission path right up to the nearby building's foundations [1 - 3]. Consequently, the generated oscillations and noise (ground-borne vibration and noise) affect negatively the daily life of urban areas, as depicted in Fig. 1.

Ground-borne vibration is not a new issue but the extension of the railway grid highlights the necessity of finding solutions that can stop and/or minimize the level of vibration propagating through the soil. Different mitigation measures already exiting in the railway industry, applicable to the vehicle, track, transmission path (soil or rock) and at the receivers (buildings) as comprehensively presented in [4].

Although, their usage is not very spread these days in the field due to the high cost and/or the limited level of attenuation. To change this trend a promising technology is one of the metamaterials that can be used in the different subdomains of the railway system to implement the existing measures [5].

The metamaterial definition emerged from applications in the nano-scale world (up to 10^{-9} [m]), those can be generally defined as a natural or artificial material designed to obtain one or more propriety that cannot be found in nature [6].

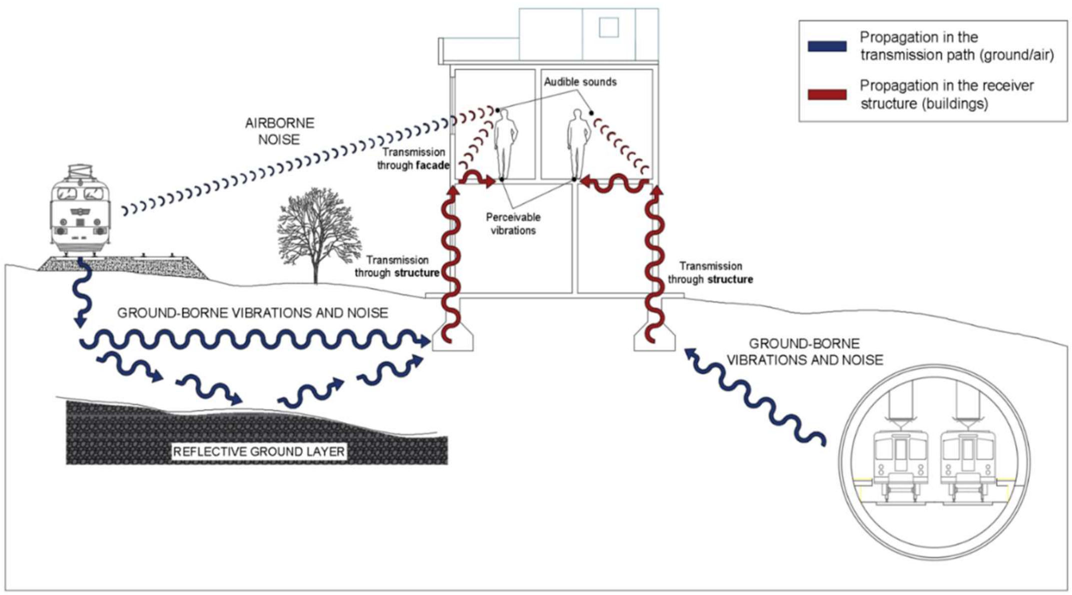


Figure 1: Railway mechanism effects and transmission paths of ground-borne vibration and noise [6].

Their novel concept was afterwards exported to a large scale and applied in different fields of the civil engineering industry, where they were generally referred to as seismic metamaterials. Among the different civil engineering fields where those can exhibit, a huge improvement in terms of waves attenuation is in the mitigation of railway vibrations [7-8]. Seismic metamaterials are periodic arrays based on a repeated primitive unit cell with the lattice constant **'a'**, that interact with the incident waves to mitigate the vibration responses. Fig. 2 shows an example of inclusion piles with circular and generally the soil and inclusion are assumed to be homogenous, linearly elastic, and perfectly bonded conditions [9].

In addition to the man-made seismic metamaterial obtained by the insertion of inclusion in the soil, it is possible to find some examples in nature with the same configuration. An example that has been used in recent research is the one of a forest composed of arrays of trees, seen as natural metamaterials to attenuate the propagation of seismic waves [10-11].

In this study, the aforementioned concept of natural metamaterials is extended to the application of railway to mitigate the ground-borne vibration generated at the wheel-rail interaction. Although the use of *natural metamaterial* may sound inconsistent with the most used definition of metamaterial as a result of an artificial arrangement of its periodicity, the concept can be extended to the existing structure as far as the proprieties of metamaterial are achieved.

Using trees in the railway industry besides the important scope of mitigating the induced vibration will at the same time add an extra value because of its sustainability, which is the crucial feature that made the railway transport the one with the fastest growth. In particular, by considering a previously validated model based on the two-step approach of the T2000 Brussels tram [12-13], a particular determined array of trees will be considered to evaluate which vibration level of attenuation can be reached. In this paper, a particular configuration of trees array will be inserted in the soil finite element model, and the level of attenuation will be compared in terms of vibration time histories with the case of no mitigation measure applied.

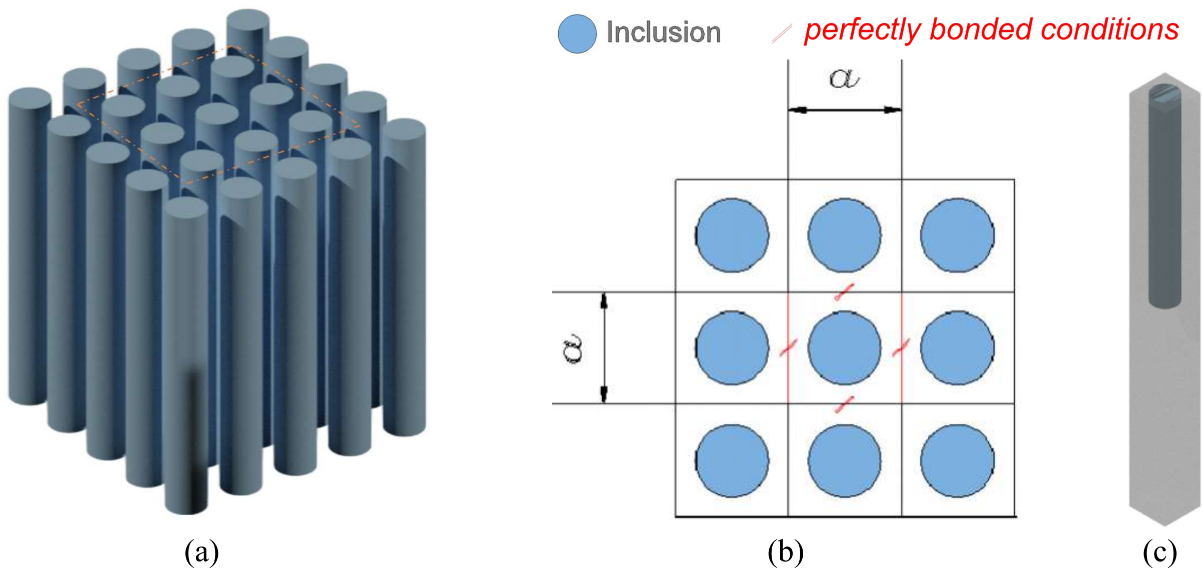


Figure 2: Graphical representation of the seismic metamaterial (a) periodic array of barriers, (b) metamaterial plan view and (c) 3D view of the unit cell.

2. Vehicle-track-soil numerical model

The numerical model used to reproduce the railway environment is the vehicle/track/soil based on the two-step approach. This approach is organized into two separate steps (see Fig.3). During the first one, the vehicle/track subsystems are modelled with the in-house framework Easydyn to compute the forces applied by the track to the soil. Whereas, in the second step the outputs of the first step, which represent the forces acting on the soil, are applied to the soil implemented in the commercial finite element software ABAQUS.

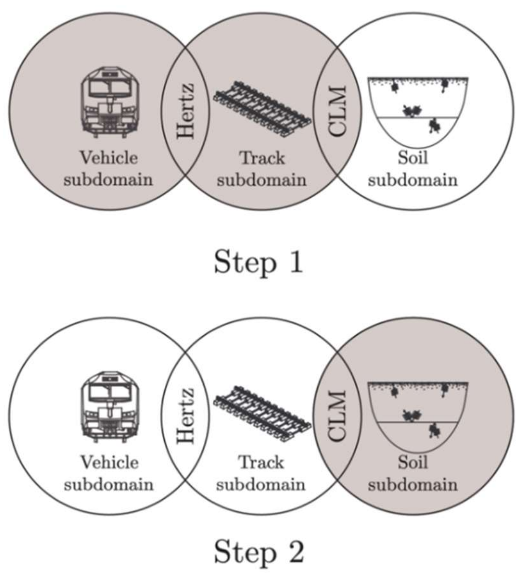


Figure 3: Vehicle/track/soil model, decoupled between the ballast and the soil [14].

Tram T2000 LRV tram operating in Brussels is considered as a case study. The T2000 is a representative vehicle for the investigation of the induced vibration generated by the rail traffic, due to its low floor design with a bogie BA2000 that is characterized by independent rotating wheels and motors mounted inside the wheels which results in a high level of the induced vibrations generated. The dynamic properties of the T2000 and the ballast track are reported in Fig. 4(a-e) with values according to [12].

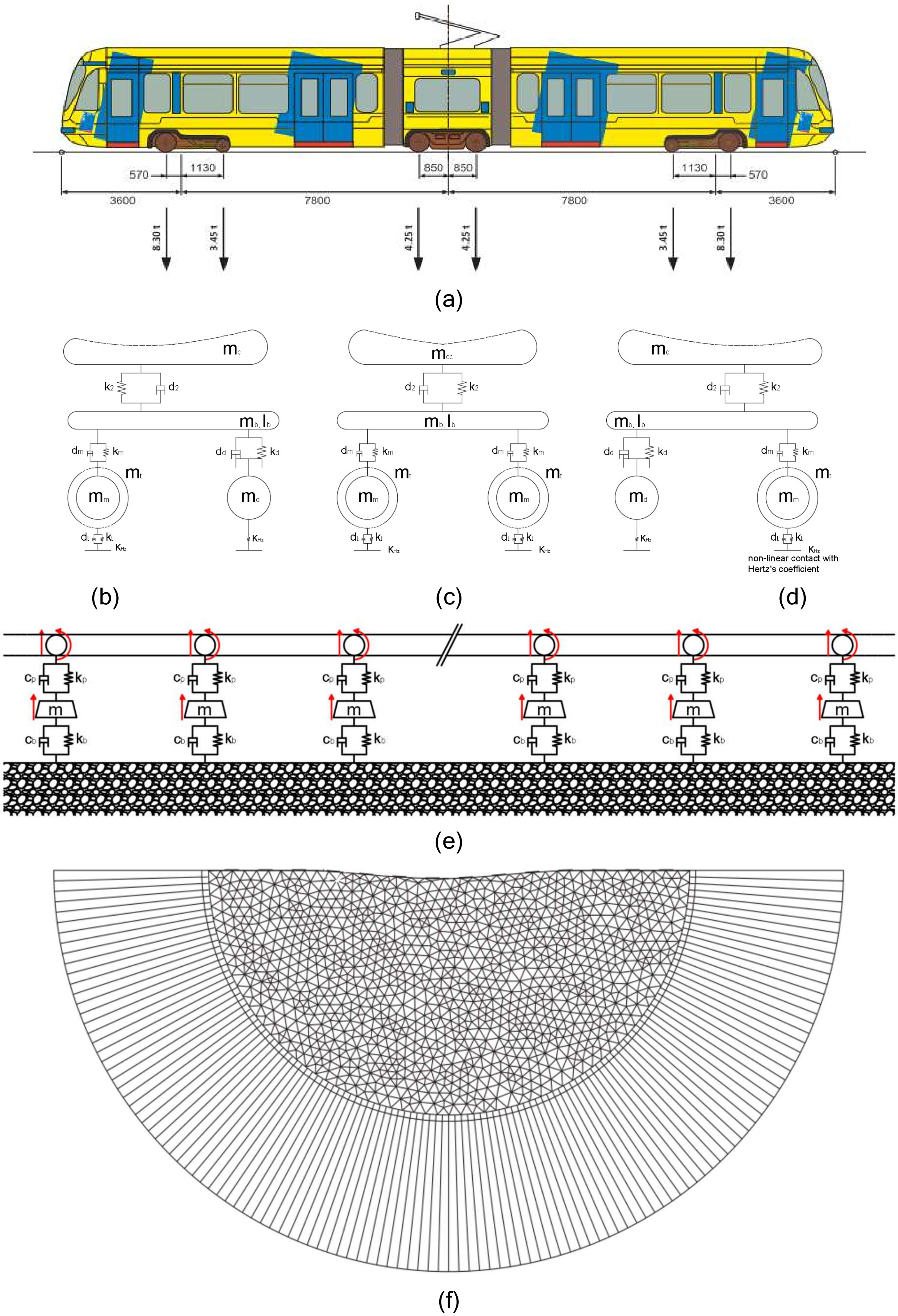


Figure 4: T2000 Brussels tram details: (a) dimensions and axial loads, (b) rear bogie, (c) central bogie "smaller", (d) front bogie, (e) track/foundation coupling and (f) half-sphere finite element model of the soil.

On the other hand for the development of the second step, the soil is represented as homogeneous by a half-sphere made up of classical 3D finite elements, see Fig. 4(f), with the soil characteristics reported in Table 1.

Table 1: Ground and trees proprieties

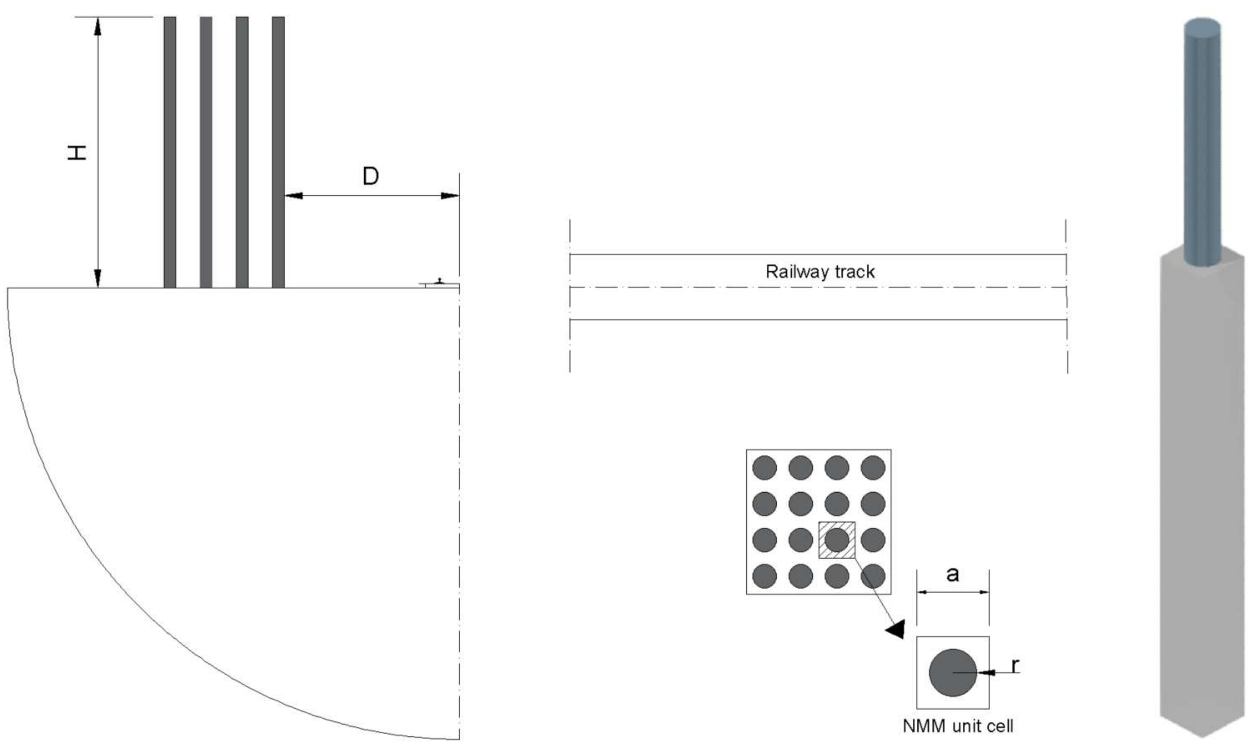
	Soil	Tree
Primary wave velocity: v_p $\left[\frac{m}{s}\right]$	900	2200
Secondary wave velocity: v_s $\left[\frac{m}{s}\right]$	500	1200
Density: ρ $\left[\frac{kg}{m^3}\right]$	1200	800

3. Natural metamaterials

A configuration of the trees array can be considered as previously highlighted as natural metamaterial due to the periodic configuration of its cells that stick with the general definition of the classical metamaterial.

In particular, the natural metamaterial configuration considered is a 4 by 4 periodic array of trees as depicted in Fig. 5 with the respective material properties and geometrical specification reported in Table 1 and Table 2 respectively. In particular, for the investigation conducted in this study the following simplification can be considered within the model, as in the simulations conducted by Colombi et al. [10,15]:

- the soil-roots interaction is neglected,
- the trees are considered as straight trunks, with a constant diameter,
- trees of the same configuration with the same geometrical and material proprieties.



(a) (b)

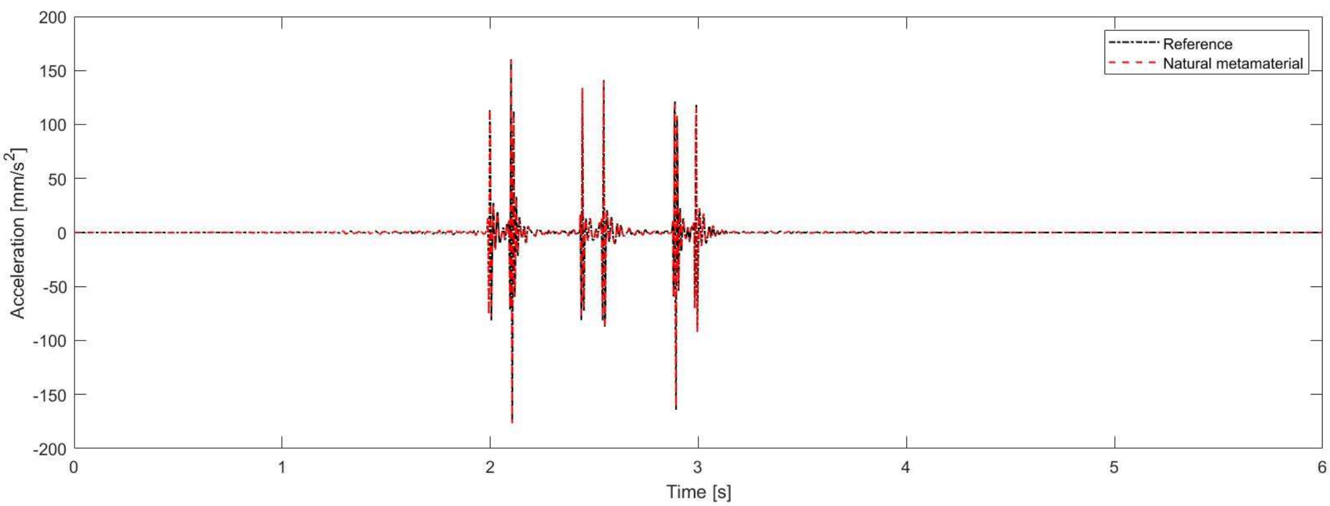
Figure 5: Trees distribution in the model: (a) array configuration and (b) 3D view of the NMM units.

Table 2: Configurations of the investigated natural metamaterial

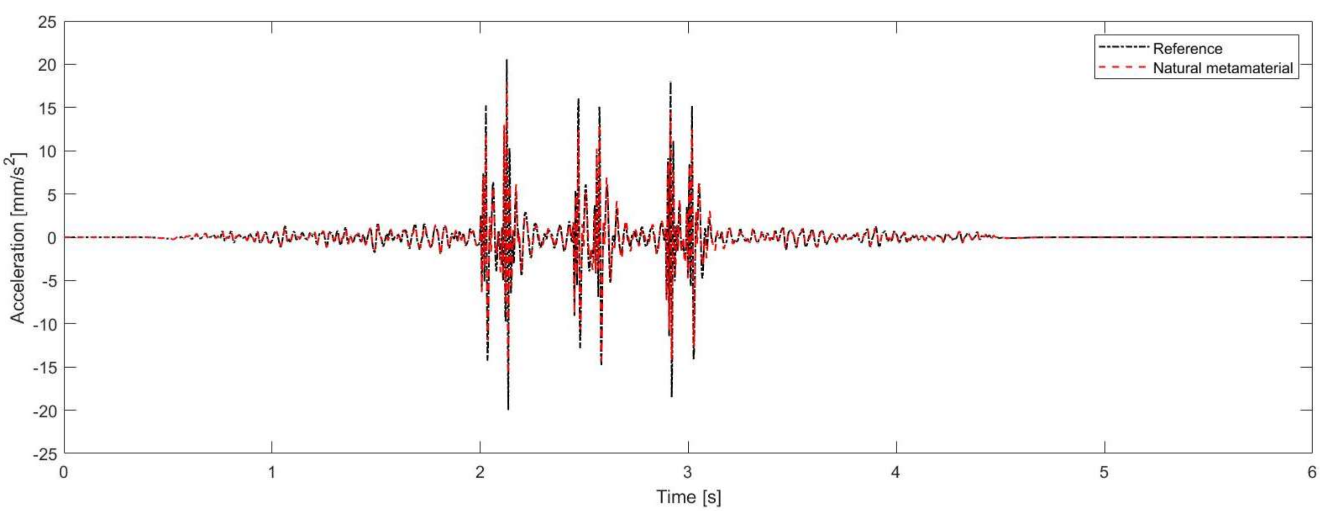
Natural metamaterial	Configuration
Height (H) [m]	14
Distance (D) [m]	10
Period (a) [m]	2
Radius (r) [m]	0.4

4. Numerical results

Results of the configuration considered of trees array are presented in this section compared with the reference case without the consideration of the trees to investigate both the achievement got from the insertion of the trees and how the selected geometrical parameter affect the propagation of the wave in the transmission path.



(a)

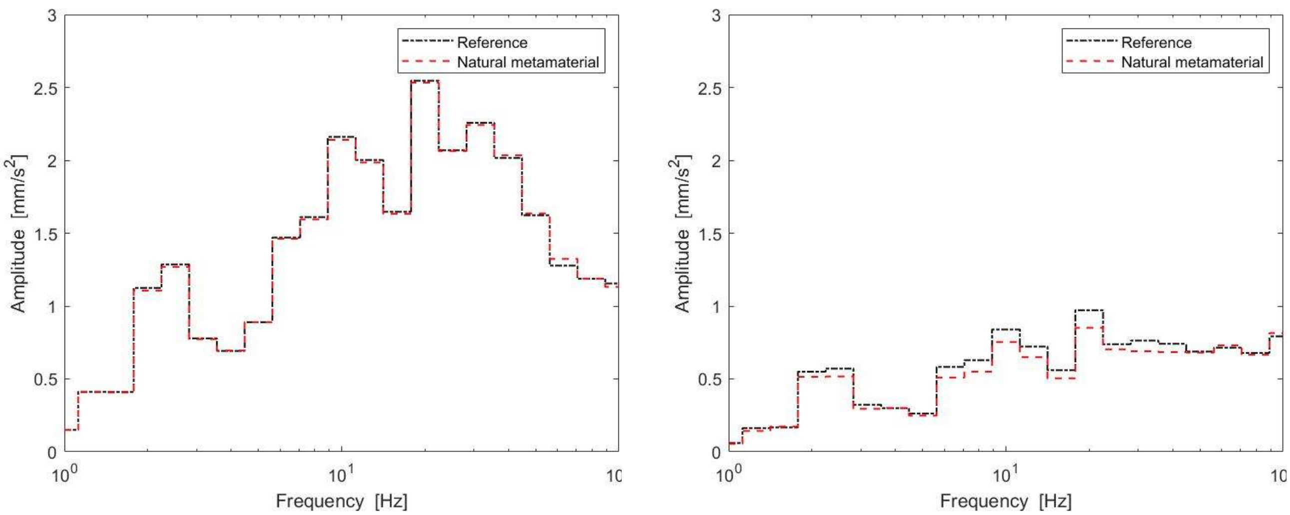


(b)

Figure 6: Soil accelerations with tram velocity of 60 km/h: (a) at 8 [m] and (b) at 20 [m].

Fig. 6 shows the level of vibration attenuation in terms of horizontal acceleration, the results n refer to a travel speed of 60 km/h that is the most representative velocity for the T2000. The results are plotted for two distances from the centre of the track at 8 [m], in Fig. 6 (a), and at 20 [m], in Fig. 6 (b), respectively just before and after the trees array.

The results reported in Fig. 6 (b) show an attenuation of the soil vibration especially at high frequencies when the natural metamaterial is introduced. This observation is further confirmed by comparing the spectral content as illustrated in Fig. 7. The amplitude is dominated by the frequency range between 7 and 100 Hz and the level is affected by the introduction of the array of trees especially at high frequencies.



(a) (b)

Figure 7: One-third octave band of the soil velocity (speed 60 km/h): (a) at 8 [m] and (b) at 20 [m].

5. Summary

Railway vibration is the means of transportation that need to be developed and extended the most in the next years due to its sustainability that can represent a turning point for the global warming the world is facing. Therefore there is the need to attenuate one of its few drawbacks such as the induced vibration generated when the train interacts with the track.

A novel concept like one of the metamaterials can help to achieve new levels of mitigation [5]. The concept of metamaterials is even more attractive when their propriety can be found in nature such as in the case of this study by using an array of trees as natural metamaterial barriers.

Results presented in this paper show a good level of attenuation especially at high frequencies (in the range 15-100 [Hz]). Taking this into account this research represent a promising starting point for future investigation to better investigate the potential that this technology can bring to the railway industry.

In addition, this concept of trees as a mitigation measure can be further investigated in the case of the embankment where in some cases vegetation is already used for the slope stability [16], or even considered in the attenuation of the airborne noise generated by the railway traffic.

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