Metamaterial concepts for ground-vibration isolation in railway systems

ABSTRACT

The importance of railway transportation in modern societies is ever-increasing due to its efficiency and sustainability. However, the dynamic interaction between the moving load and the track infrastructure can lead to the generation of significant vibrations which represents the principal drawback of this means of transport, and one which poses a challenge to the structural integrity of the railway infrastructure and adversely impacts the quality of life for nearby communities. As a consequence, the assessment of ground-borne vibrations and noise, as well as the development of different mitigation measures and their application at different levels of the railway systems (vehicle, track, transmission path, and receiver), have been a key concern in the railway industry.

Although there has been the advancement of different strategies and mitigation measures in the literature, these do not fulfil the optimal requirements in order to permit the positive expansion of the railway grid. This is because often the proposed techniques have limitations in terms of installation and maintenance costs or their carbon footprint impact. At the same time, the application of the notion of metamaterial (i.e. artificial and/or natural periodic elastic structures of scattering inclusions located in a structure or material) is having great success in attenuating the propagation of vibration waves in different applications.

In this regard, this doctoral thesis, through the use of validated numerical models, focuses on the development of a new type of mitigation measure based on the novel concept of mechanical metamaterials. The combined vehicle/track/soil prediction numerical model, based on the two-step approach developed at the University of Mons, is used to reproduce the railway environment. Considering that the implementation of mitigation measures in the soil subdomain allows their use in new and existing grids, and, at the same time, does not require any intervention in the other railway subsystems (vehicle, track, and receivers). In particular, the thesis considers two main configurations of metamaterials, seismic and resonant (natural) metamaterials, which are characterised by artificial embedded inclusions, and inclusions placed at the surface acting as resonators respectively. The latter is also referred to as "natural metamaterials" when the inclusions are made out of trees, as presented in this research.

The main findings contribute to the advancement in the field of railway vibration mitigation. This represents the first comprehensive evaluation, within a digital twin, of the attenuation of the vibrations generated by rail traffic using mitigation measures based on the novel concept of metamaterial. It has shown that significant levels of attenuation are obtained in the order of several [dBs] in terms of Insertion Loss (IL) for both configurations. The two configurations have been analyzed under multiple parametric investigations, varying the different material and geometrical parameters, in order to calibrate the metamaterials to the main frequency of the generated vibrations of each considered vehicle/track/soil configuration. Although the attenuation levels obtained using this new concept in the implementation of new mitigation measures do not represent the peak values, they achieve ample levels of attenuation which combined with their straightforward application and sustainability (as in the case of natural metamaterials) make them a valuable alternative to the existing mitigation system for the railway industry to minimize the adverse effects on surrounding communities. The developed strategies improve the sustainability and efficiency of railway transportation, and furthermore, this research contributes to the development of a more environmentally friendly and socially responsible network.

In addition, to these important results, this PhD research introduces a new form of seismic metamaterial where just a part of the inclusion is embedded in the hosting material (i.e. soil) and gives some insights into the possible advantage of using this new technology. At the same time, an important quantification of the existing measures based on the same numerical model is conducted to quantify and compare the transmissibility of different strategies and the presented added value of the new mitigation measures based on metamaterials.