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New mitigation solution by waves deviation, numerical experiments

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Abstract
Railway vibration are transmitted into buildings as low frequency noise, called ground-borne noise. It is an hard task to diminish this sound and classical mitigation solutions are disposed on the track (floating slab, resilient material...). Nevertheless, many constraints are already imposed to the structure of the track and efficient solutions are often costly. A new approach which consist in deviating waves instead of attenuating them [1] is here investigate. This new mitigation solution is disposed at the foundation slab of the building to isolate. In this document, we propose a prototype applied to a 2D model of a transfer mobility function between a surface slab to a neighbouring crossbar.

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1. Introduction

In dense urban areas, railway structures are increasingly close to residential and public buildings (laboratories, hospitals, theaters, etc.). The risks of annoyance and vibratory impact on sensitive instruments are then seriously reinforced.

Among the nuisances generated by rail traffic, ground-borne noise is more and more observed.

This noise results from the radiation of the walls and slabs of a room under the effect of vibrations emitted by the train traffic and transmitted to the building via the ground through the foundations. Its amplitude is a function of the bending movements of the walls, the reverberation time in the room as well as the radiation factors of the walls of the room [2, 3].

A simple relation is given in the RIVAS project for a standard room ($Tr = 0.5$) which connects the ground-borne noise level (Lp) to the vibratory level observed at the centre of the floor (Lv): $Lp = Lv + 7$.

This noise has the peculiarity of being felt while the source of noise is not visible. As a result, it represents a gene that is sometimes very poorly accepted by residents of neighbouring rail infrastructure buildings.

This noise is generated at the characteristic frequencies of the excitation of the rail. The vibratory emission has a significant component around 60-80Hz [4, 5] and is generally included in the low frequency band [40-160Hz]. In addition, transmitted vibrations are rarely observed at high frequency (high limit 250 Hz and low limit 10 Hz), mainly because of the dissipation in soils and the reflection that occurs at the interface between solids (ISS, stratification , etc.). On the other hand, the perception of this sound is limited in the low frequencies by the response curve of the human ear, represented by the weighting A.

The evaluation of the noise and vibration impact is systematically included in any new railway infrastructure project. It appears that often the ground-borne noise dominates the risk of discomfort, and sizes the mitigation recommendations. Thus, for the development of the cities to come, innovative solutions must be found to eliminate this pollution.

1.1. Actual context of ground-borne sound mitigation solution

Only few type of solution are available: resilient material on track, floating slab, rigid or open trench between railway and building [6, 7, 8, 9]. The most common used solution (resilient material under sleeper) is often limited on low frequency and are efficient generally up to 30 or 40Hz. Floating slab may be a very efficient solution at lower frequency (efficient up to 10-20Hz), but hard difficulties appears in construction and maintenance. Trench are less used and are not always very efficient. In addition, trench is hard to construct for depth infrastructure. All these solutions are designed to create a barrier between tracks and building.

1.2. A new idea: deviation instead of mitigation

Architectured materials, i.e. materials having a large inner structure, offer many new possibilities for conceiving innovating materials. By exploiting their dynamic properties, new seismic mitigation systems have recently been designed [10]. Further, recent studies on invariant based description of elasticity offer useful relationship between material symmetries and the overall behaviour of structured materials [13, 14]. The centre idea of the present study aims at combining the previous observations and can be summed up in a simple question: "*Can we beam elastic waves in structured material by controlling the orientation of its "periodic" lattice?*" If the answer is yes, then we are able to propose a new route for mitigating vibration and, hence, for limiting ground borne noise in buildings.

For instance, consider and isotropic material organise into a square lattice. Waves propagate in this structured material in all directions, but not with the same velocity. More importantly, the energy flows towards preferred directions. This example is at the core of this preliminary work.

In the following we shall describe the principle of material symmetry and geometric symmetry interaction. Then, a two-dimensional finite elements computation is performed to show efficiency of this idea. Finally, remarks and perspectives will be proposed.

2. Principle of wave propagation in structured material

When a wave propagates inside an architectured material, the propagation constants (e.g. phase velocity, group velocity, energy velocity) are influenced by the geometry of the heterogeneities. This effect becomes more and more prominent as the frequency increases and the wavelength approaches to the size of the unit cell of the mesostructure.

In order to avoid diffraction, i.e. reflections at the heterogeneities, the ratio between the wavelength λ and the size of a unit cell of the mesostructure L must be kept higher than $\lambda/L \simeq 10$.

If this constraint is fulfilled, the material can be replaced by an homogeneous elastic material. Up to $\lambda/L \simeq 6$ an overall homogeneous description is still possible, but the elasticity model has to be enriched to take architectural effects into account in the continuous description[11]. In this work we will remain in the validity range of classic elasticity. These concepts are summed up in table I

Table I. Modelling strategies in function of the wavelength/ scale separation ratio $S = \lambda/L$

Scale separation ratio	$S < 6$	$6 < S < 10$	$10 < S$
Overall description	No	Yes	Yes
Nature of the continuum	Explicit microstructure	Generalized elasticity	Classic elasticity

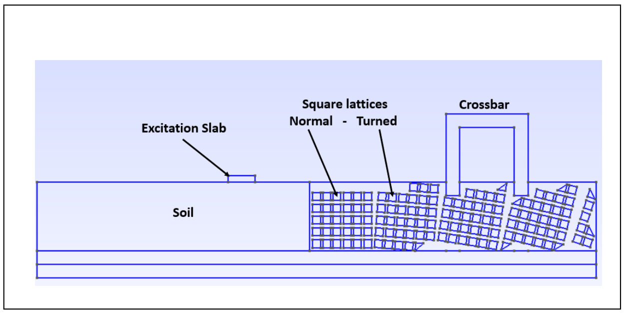

Figure 1. 2D geometry and example of rotated lattices.

3. Application on vibrations emitted by railway

In this section, we construct a 2D numerical prototype to show how this type of solution may be designed to mitigate a building to a railway in activity.

3.1. The 2D finite elements demonstrator

We consider the 2D situation depicted on Figure 1. The model is defined by a track (rigid rectangle) on the soil surface, and a crossbar (three rigid beams) located on a architectured slab. The soil is bounded by a layer designed to enforce Sommerfeld conditions and hence to avoid non-physical spurious reflections at boundaries.

The excitation is modelled by a unit point force F applied on the slab. Material properties for surface soil are standard (E = 50MPa, ν = 0.4 and ρ = 2000kg/m^3). The material for the excitation slab, the crossbar and structured lattice is concrete with its classical properties (E = 27GPA, ν = 0.25 and ρ = 2500kg/m^3).

3.2. Meshing of structured slab

Structured lattices are built by a square tessellation.The unit cell of this tiling is a square hollowed-out at its centre. As a consequence the symmetry class

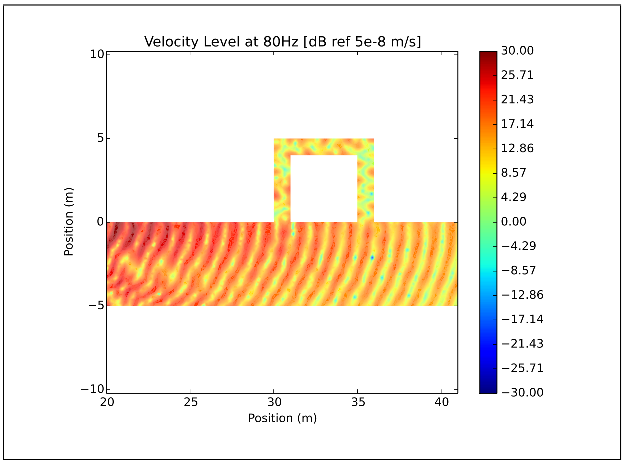

Figure 2. Velocity maps on structured slab and crossbar without lattices (Case 0).

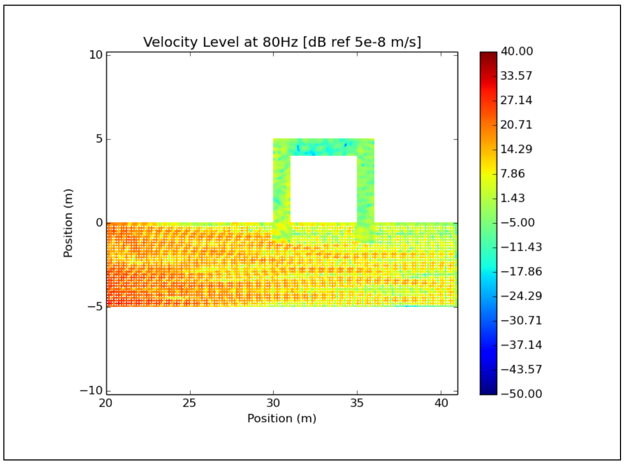

Figure 3. Velocity maps on structured slab and crossbar with lattices (Case 1).

of the homogenized elastic material corresponding to this structure is tetragonal [12].

The tessellation is generated along two orthogonal directions x_i and y_i which define the orientation of the edges of the squares. These directions may be constant in the domain (case 1) or rotated to ensure wave beaming (case 2). In this case, directions are gradually rotated to avoid reflections generated by brutal modification in domain (see Figure 1).

4. Results

First, velocity maps of domain close to the crossbar are presented for the three following cases: crossbar based on a full slab (Case 0, Figure 2), crossbar based on a structured slab with square tessellation in constant direction (Case 1, Figure 2) and crossbar based on structured slab where lattices are gradually turned to 0 at $\pi/4$ (Case 2, Figure 3).

These three maps show that a structured slab deviates naturally waves. In addition, the rotation of lattices increases the deviation.

Secondly, quantitative results on mitigation are given in the frequency domain for the velocity on the crossbar. Spectrum of velocity level at centre of the crossbar are shown in Figures 5.

These curves show a large effect of the lattices and their rotation. Even if this results are not realistic, this observation is promising. Same comparison must be performed on 3D realistic cases in order to attest to the efficiency of the concept proposed here.

5. Perspectives

Study presented in this work is the starting point for forthcoming development. To have a complete proof-of-concept of our approach, real 3D cases have to be investigated with multisource excitations.

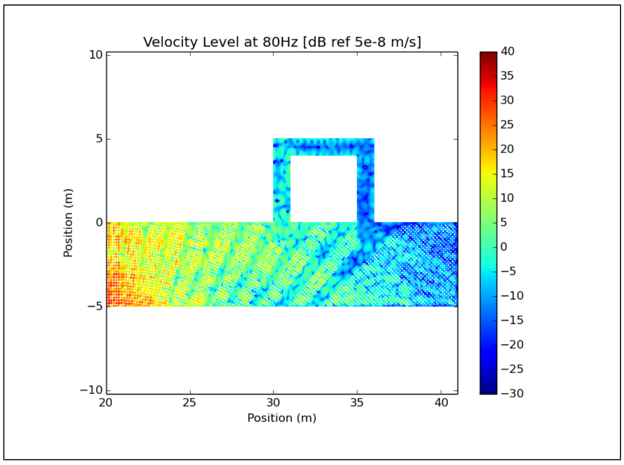

Figure 4. Velocity maps on structured slab and crossbar with gradually turned lattices (Case 2).

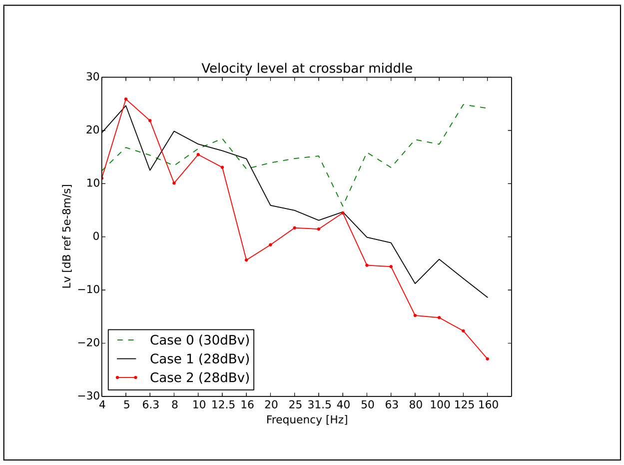

Figure 5. Velocity level at the middle of the crossbar.

Lattices have to be optimized, both in shape and size, to obtain realistic dimensions applicable to real buildings. This implies, in particular, to variate the types of soil, excitation, direction of in coming forces, etc. In this task, homogenized model have to be used in order to perform some topological optimization processes [16].

6. Conclusions

This work presents a prototype of waves deviator for mitigate building from vibration disturbance produced by railway traffic This deviator is proposed as a structured foundation slab which is composed of square lattices. These lattices may be oriented to increase the effect of deviation for wave around 80Hz. Numerical results observed on a cross-bar system show a significant reduction of transmitted waves. Future investigations will be conducted on more realistic configurations. The ultimate objective is to optimize the inner structure of the lattice in order to beam waves along a complex path.

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