Workshop ELADYN

17[th] – 18[th] October 2019
École des Ponts ParisTech
Champs sur Marne

Study of a new mitigation system for railway vibrations

18 October 2019 ; Champs sur Marne

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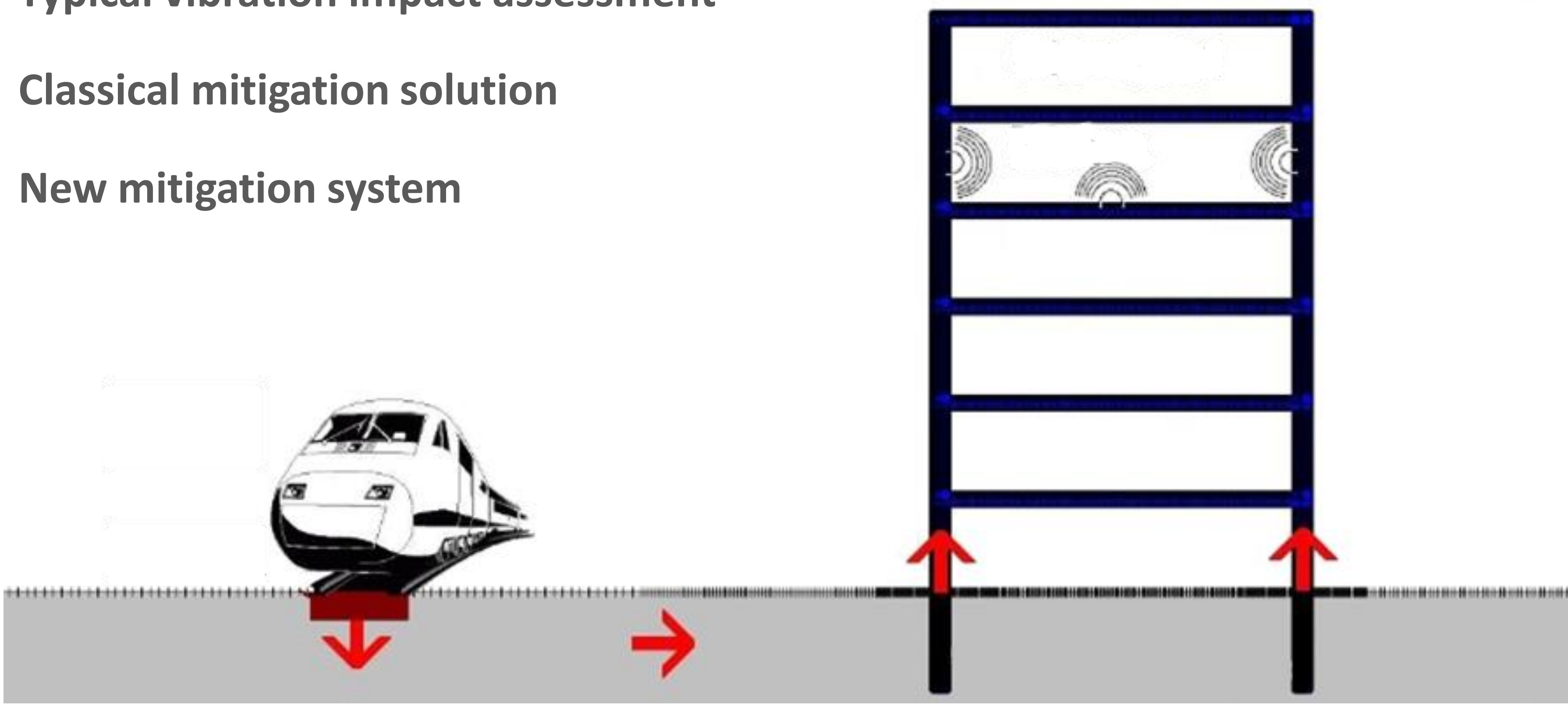
SYSTRA

Summary

- ❑ **Context**
- ❑ **Typical vibration impact assessment**
- ❑ **Classical mitigation solution**
- ❑ **New mitigation system**



SYSTRA

Context

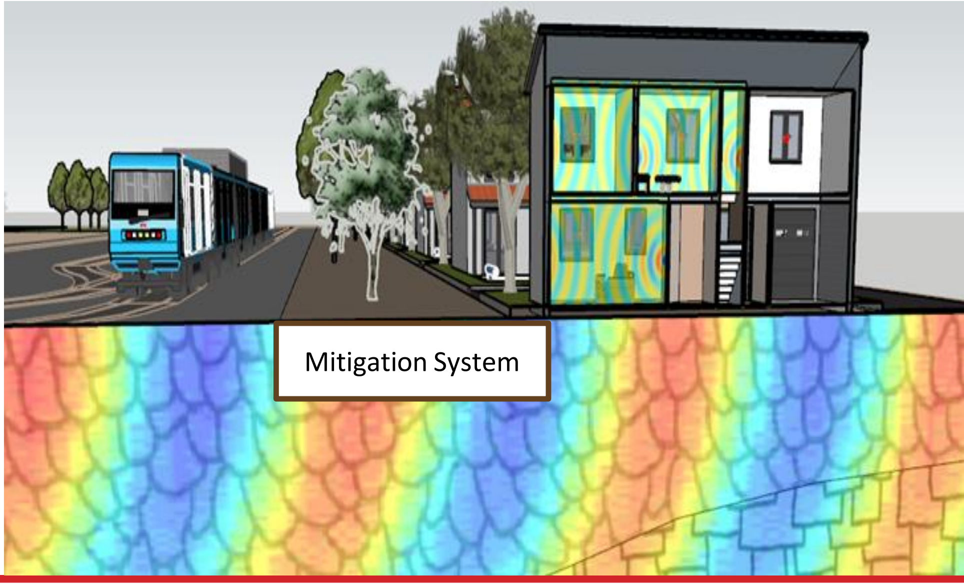
With recent advances in computation of microstructured media, new solutions are looking for mitigation system devoted of railway vibrations.

Today, such a system are available through the 3D concrete printer.

A first collaboration was made with N. Auffray et G. Rosi (Euronoise 2018).

In summer, S. El Ouafa made an internship on the topic:

<u>Optimisation of a microstructured slab to design railway vibrations mitigation system</u>



Vibration impact study – Typical Issues

<u>Study in 3 steps:</u>

- Characterization of transfer
- Characterisation of excitation
- Characterisation of sensitivity

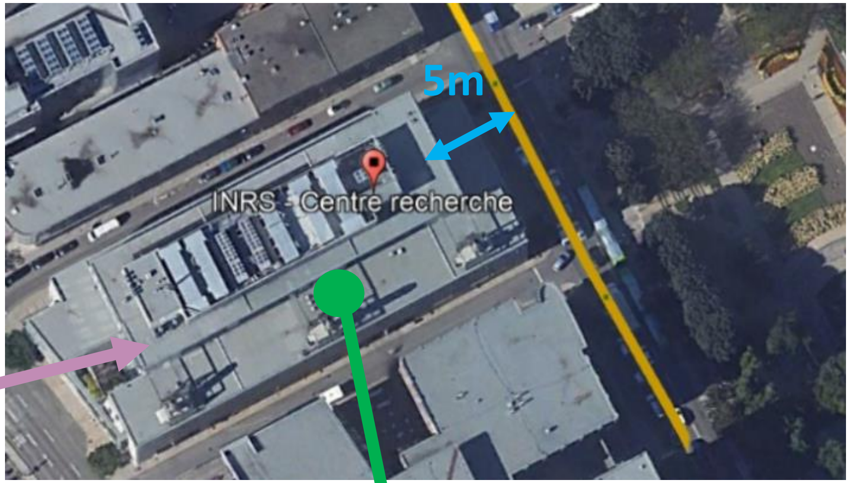
On a metro line there are always

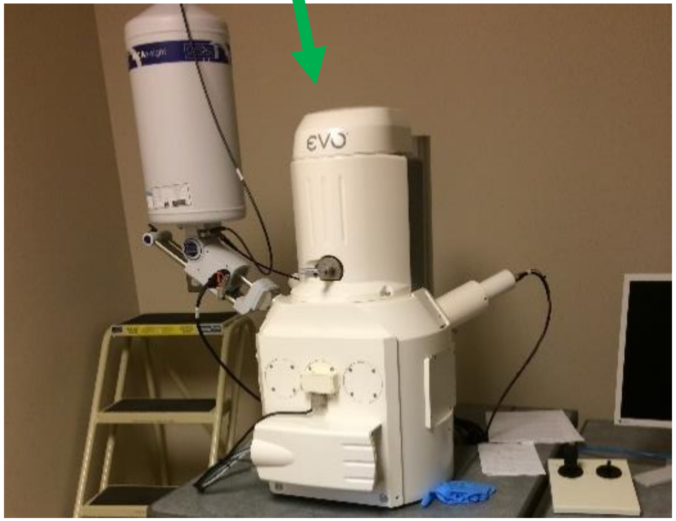
<u>Specific sites with</u>:

- Small distance from the track
- Sensitive equipment
- Strategic site

<u>Specific studies with</u> :

- Large predictive models
- In situ measurements
- Control of mitigation system

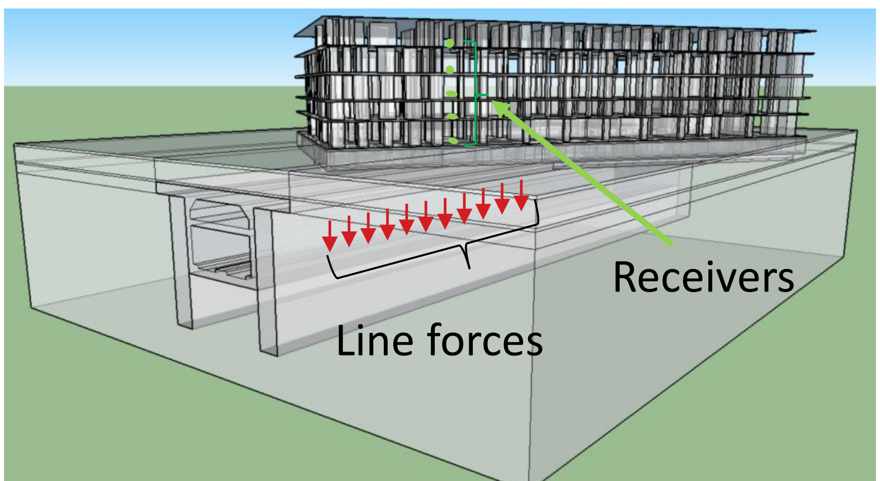


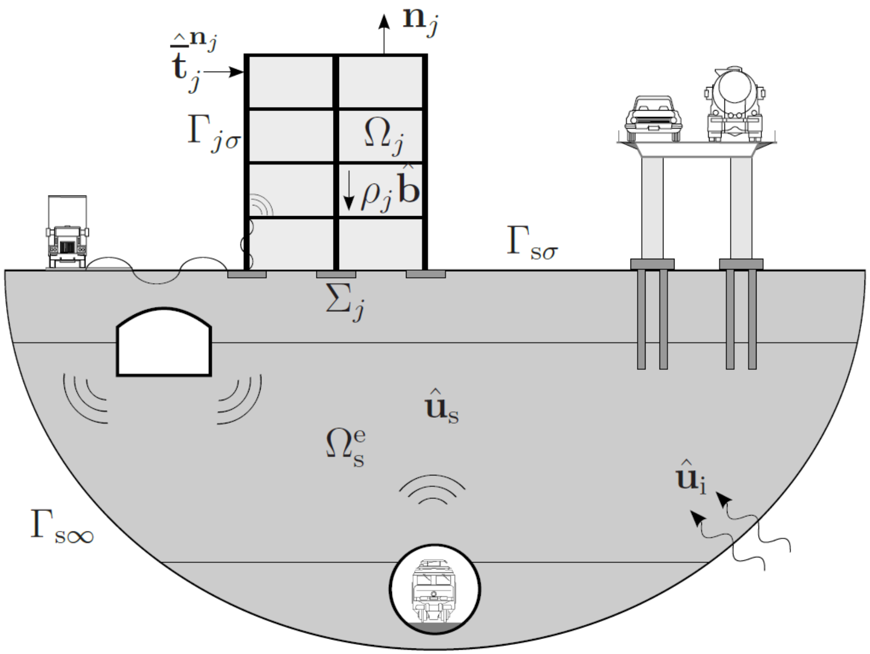


Vibration impact study – Track-Building Mobility transfer function

The track-building mobility transfer function must take into account:

- Sommerfeld conditions (Soil boundaries)
- Propagation into the soil
- Soil-structure interaction
- Frequency response of building
- Line forces
- Mitigation systems available

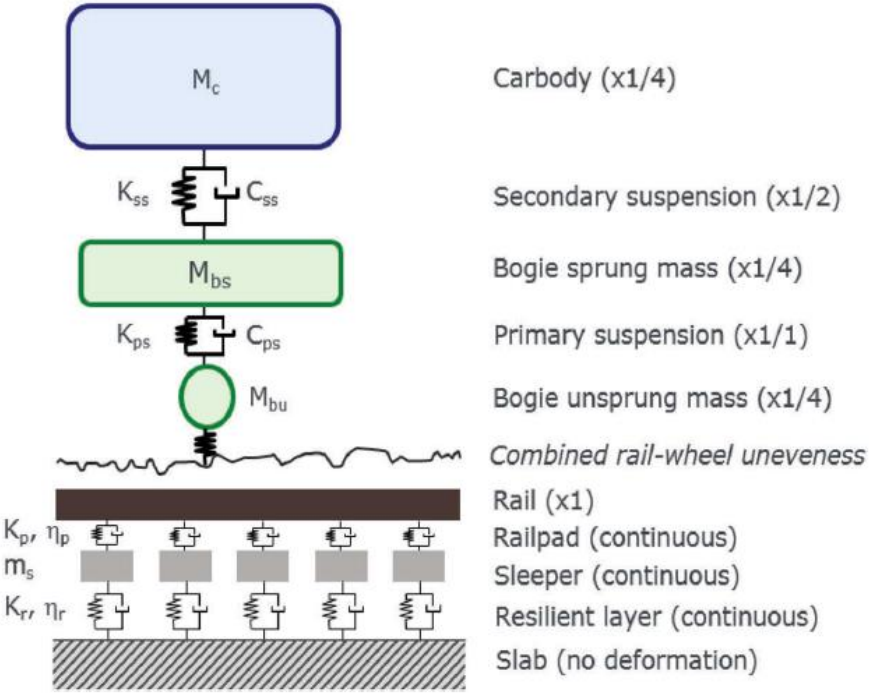


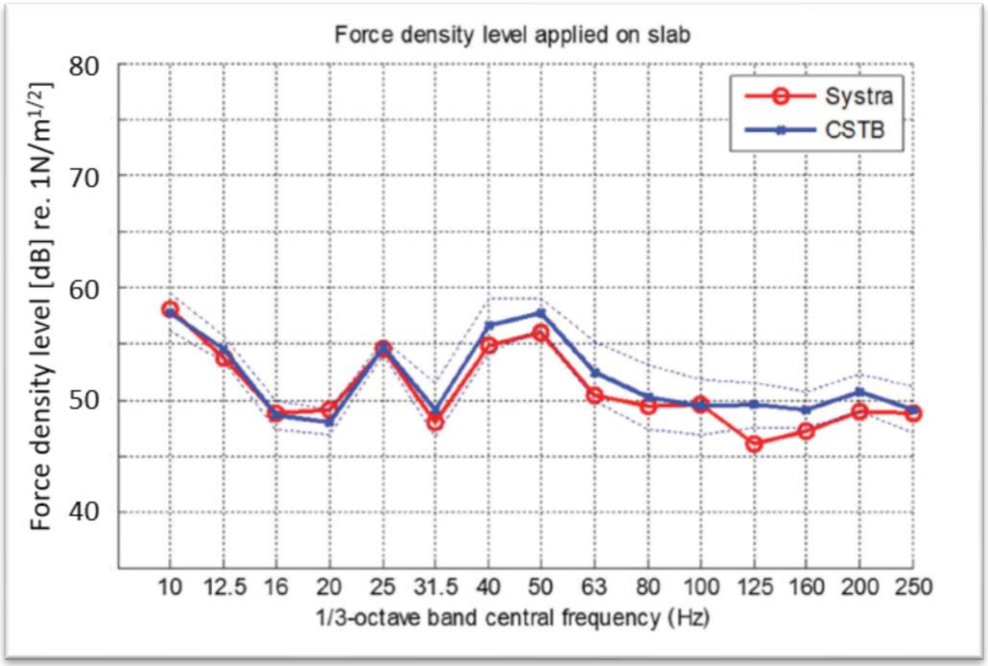


SYSTRA

Vibration impact study – Excitation & Frequency band of interest

M. Villot, E. Augis *et al.;* Vibration emission from railway lines in tunnel characterization and prediction; IJRT 2016



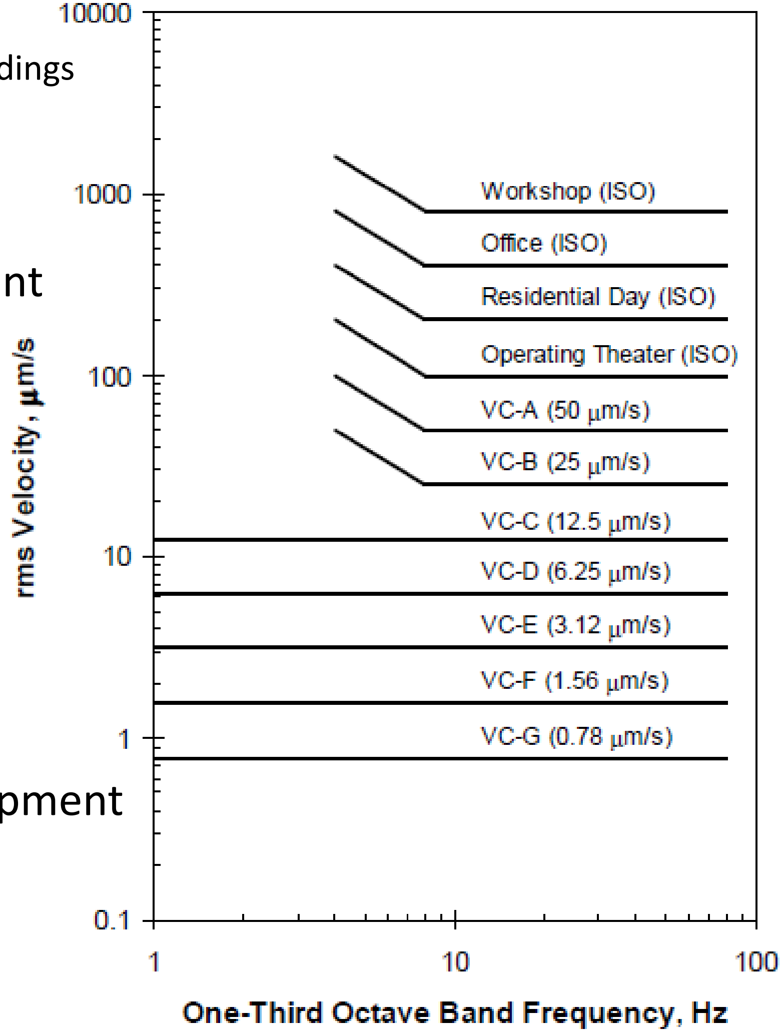


Vibration impact study – Typical values of sensitivities

C. Gordon, Generic Criteria for Vibration-Sensitive Equipment. Proceedings of International Society for Optical Engineering (SPIE), Vol. 1619, 1991

Criteriums commonly used in vibration impact assessment

- Defined the maximum velocity acceptable in floor
- Give a first estimation for most common receivers
- Must be used with to defined ambient vibrations measurements
- Old criteriums, not available for recent sensitive equipment
- Not sufficient for human receivers (ground borne sound must be considered in place)



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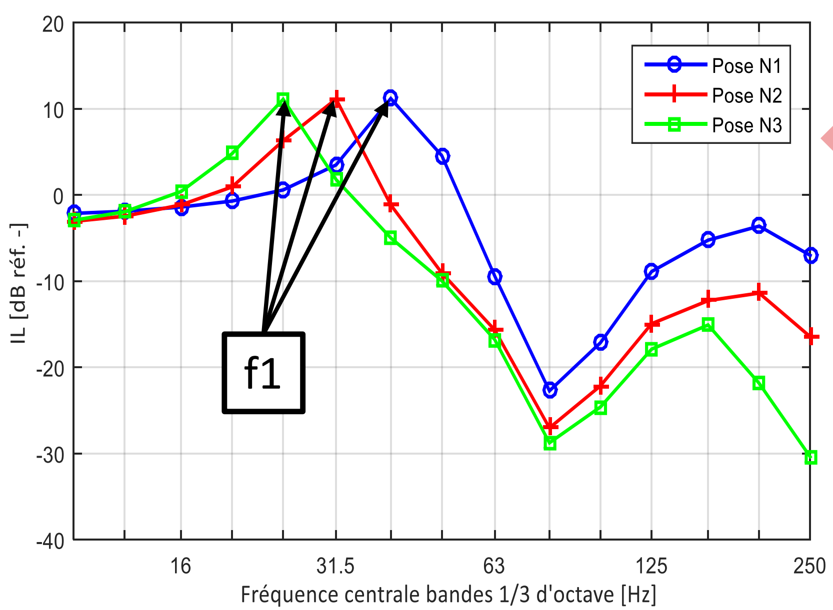
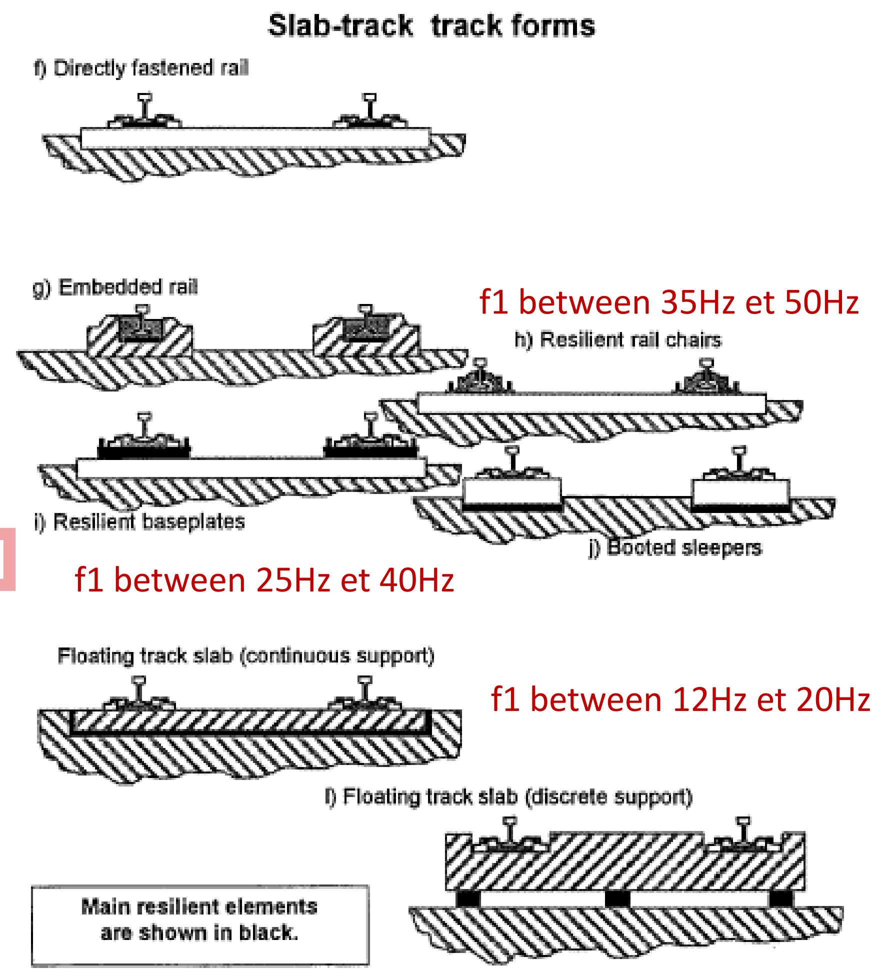
Classical mitigation system – Typical Insertion Loss

Insertion Loss :
Loss of vibration level between track with and without mitigation system

There is always a coupling frequency f1
Attenuation for $f > \sqrt{2} \times f1$





f1 between 35Hz et 50Hz

f1 between 25Hz et 40Hz

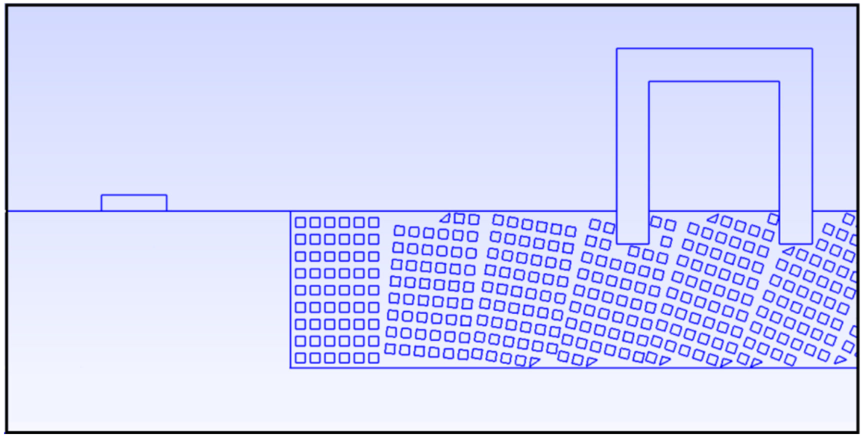
f1 between 12Hz et 20Hz

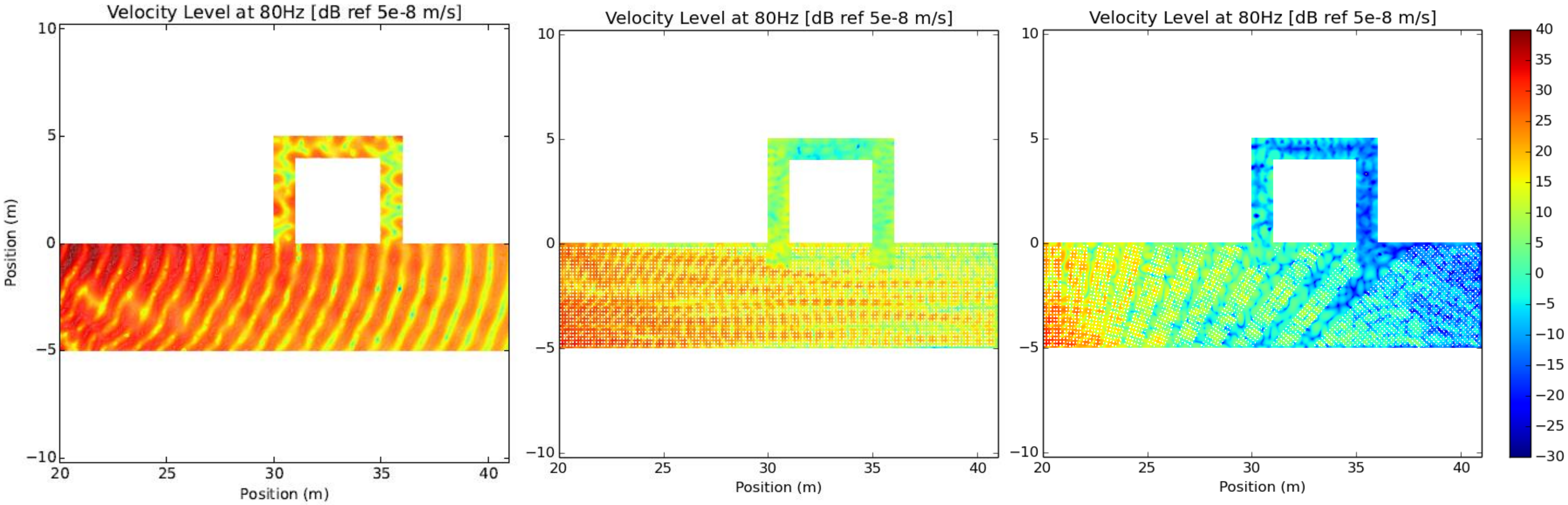
f1 between 5Hz et 12Hz

SYSTRA

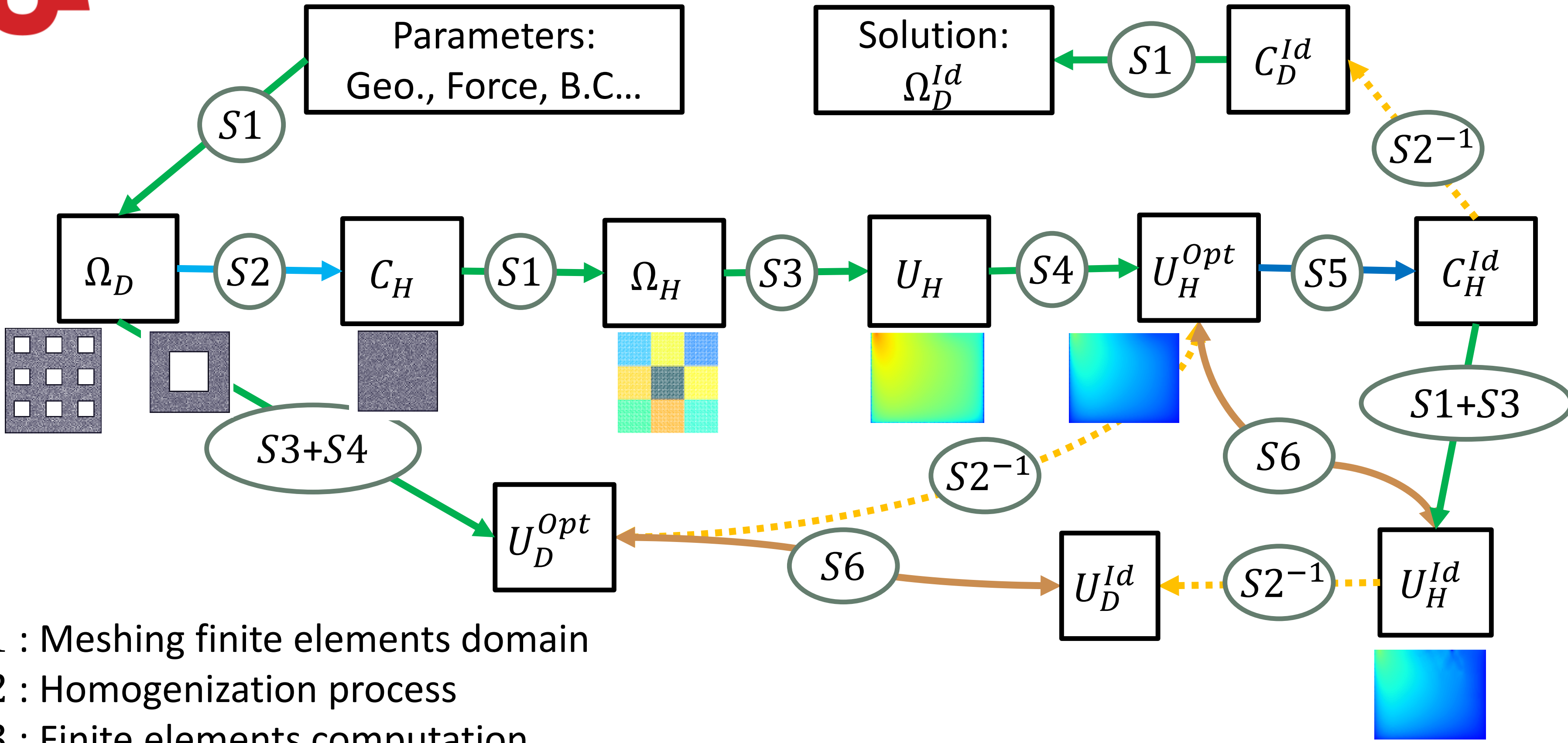
New mitigation System – Proof of concept

New mitigation solution by waves deviation
Numerical Experiments





New mitigation System – Optimisation process



- $S1$: Meshing finite elements domain
- $S2$: Homogenization process
- $S3$: Finite elements computation
- $S4$: Determination of an arbitrary "optimal" solution
- $S5$: Identification process
- $S6$: Comparison

New mitigation System – Identification Process

Considering a finite elements model composed of a force f a stiffness matrix $[K]$ and an optimal displacement vector u

$$\mathbf{f} = [\mathbf{K}]\,\mathbf{u} = \left(\sum_{e=1}^{N_e} [\mathbf{K}_e]\right)\mathbf{u}$$

Where $[\mathbf{K}]$ can be written as

$$\begin{aligned}
[\mathbf{K}] &= \sum_{e=1}^{N_e}\left(\int_{\Omega(e)} [\mathbf{B}_e]^{\mathrm{T}}\,[\mathbb{C}_e]\,[\mathbf{B}_e]\,\mathrm{dV}_e\right)\\
&= \sum_{e=1}^{N_e}\left(\int_{\Omega(e)} [\mathbf{B}_e]^{\mathrm{T}}\left[\sum_{I=1}^{9} \mathrm{c}_I[\mathbb{1}]_I\right][\mathbf{B}_e]\,\mathrm{dV}_e\right)\\
&= \sum_{e=1}^{N_e}\left(\sum_{I=1}^{9} \mathrm{c}_I\left[\int_{\Omega(e)} [\mathbf{B}_e]^{\mathrm{T}}\,[\mathbb{1}]_I\,[\mathbf{B}_e]\,\mathrm{dV}_e\right]\right)\\
&= \sum_{I=1}^{9} \mathrm{c}_I\,[\mathbf{K}_u]_I
\end{aligned}$$

With the following base:

$$\mathcal{B}_\mathrm{b} = \{\mathbf{b}_I = [\mathbf{K}_u]_I\,\mathbf{u}\} \qquad \mathbf{b}_I = \sum_{J=1}^{9} \gamma_J^I\,\widetilde{\mathbf{b}}_J$$

The first relation can be rewritten as:

$$\mathbf{f} = \sum_{I=1}^{9} \mathrm{c}_I\,\mathbf{b}_I = \sum_{J=1}^{9}\left(\sum_{I=1}^{9} \gamma_J^I \mathrm{c}_I\right)\widetilde{\mathbf{b}}_J$$

$[\gamma]$ is identified by projection

$$\langle \mathbf{f}, \widetilde{\mathbf{b}}_J\rangle = \sum_{I=1}^{9} \gamma_J^I \mathrm{c}_I = p_J$$

The coefficient of the elasticity tensor decomposition are then identified by :

$$\mathbf{c} = [\gamma]^{-1}\,\mathbf{p}$$

SYSTRA

New mitigation System – Some precisions

In the above identification process, the solution depend to:

- Constraint given (exp: symmetries of the elasticity tensor)
- Number of coefficient in the elasticity decomposition
- The “optimal” solution, arbitrary given
- The norm used in the identification process

No mathematical restriction on the elasticity tensor decomposition

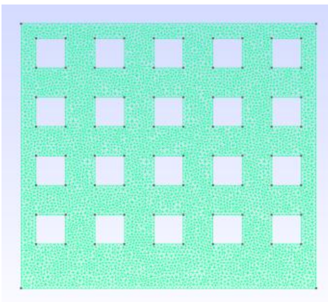
In the optimisation process, the coefficient of the elasticity tensor are look for described the orientation of the inclusions.

No mathematical restriction on the optimal solution. An ideal solution could be used.

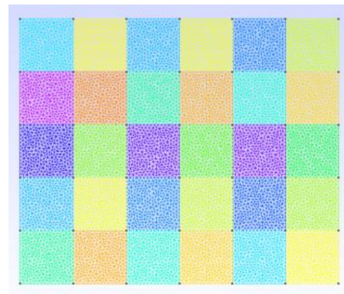
The norm allows to take into account the frequency range of interest. It could be used to focalize the solution on a part of the FE domain.

New mitigation System – First results (in dB ref 1)

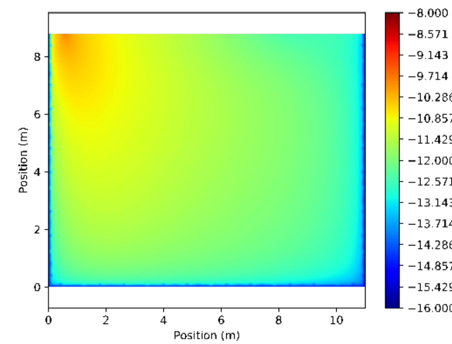
Ω_D



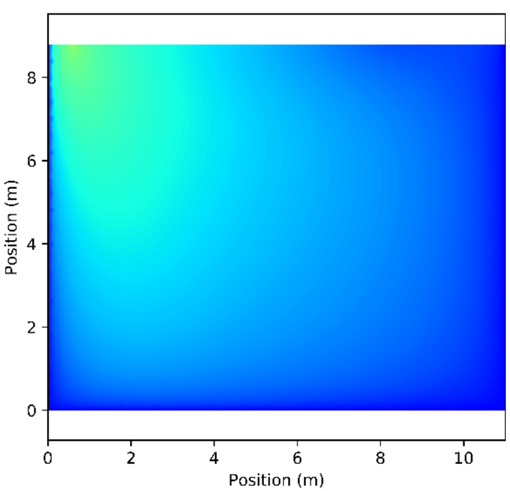
Ω_H



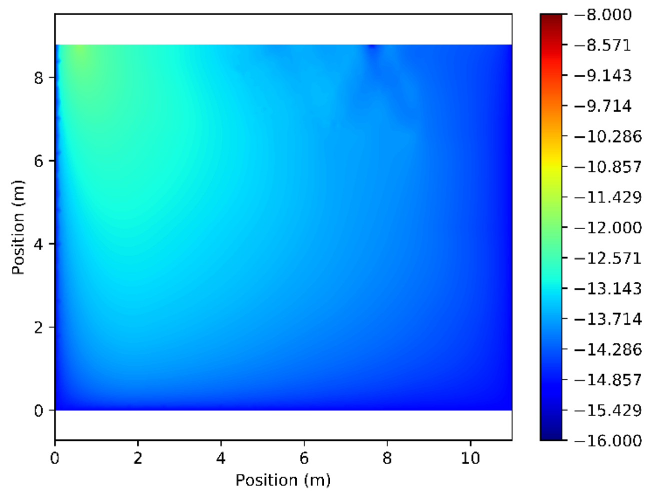
U_H



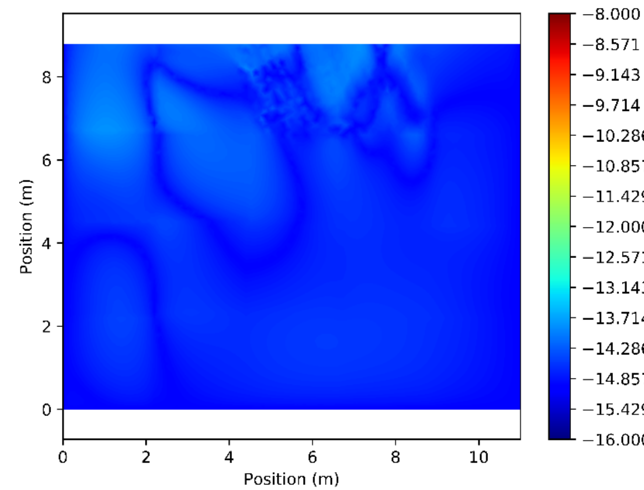
U_H^{Opt}



U_H^{Id}



$||U_H^{Opt} - U_H^{Id}||$



SYSTRA

New mitigation System – Perspectives and Future works

Most important future steps

- Compute the inverse of the homogenisation process to obtain the result $\Omega_{\mathrm{D}}^{\mathrm{Id}}$
- Extend the methodology for semi-infinite domains

To allow the prescription of this type of solution

- Measurements on a real system
- Optimisation of the dimensions of system
- Find how to include this kind of system in a urban context

LA CONFIANCE TRANSPORTE LE MONDE

SYSTRA