Mitigation solutions for low frequency structure borne noise

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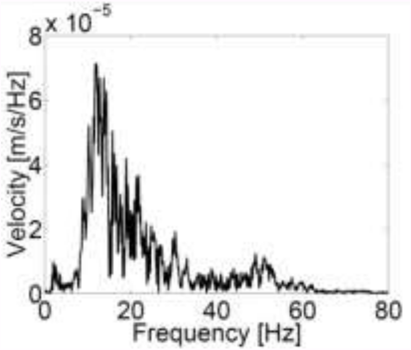
SEVENTH FRAMEWORK PROGRAMME

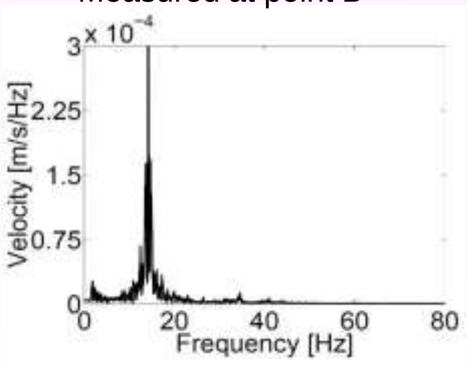
Introduction

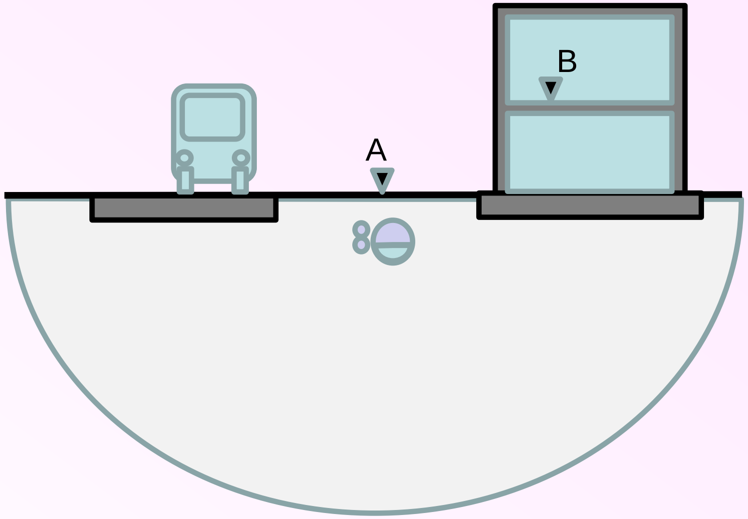
- Traffic generates vibrations:
  - In the ground at 10 to 40 Hz
  - Slab natural frequencies at 12 to 16 Hz
  - Results in a vibration amplification by a factor of 10

Measured at point A



Measured at point B





Passage of a truck at a speed v = 50 km/h, (after Pyl et al. 2004)

Structure-borne noise

- Simplified equation (conservative):
  - $L_p = L_{v5} - 22$ [dB]
    - Vibration level at floor or wall

      $L_{v5} = 20 \log_{10}(v/v_0)$ ($v_0 = 1E\text{-}9$ m/s)
    - Sound pressure

      $L_p = 20 \log_{10}(p/p_0)$ ($p_0 = 2E\text{-}5$ Pa)

L_{pA} = (A-weighted L_p) < $L_{A,max}$ = 40 [dB] residential area

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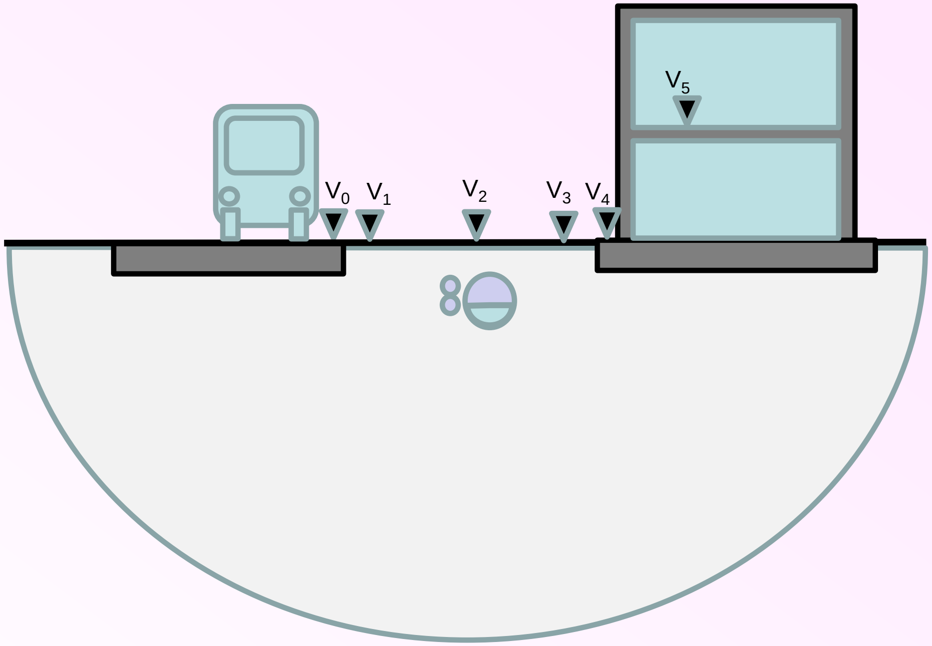
Vibration transmission mechanism

- The main problem is decomposed to:

1. Road-Ground interaction:
    - Road type
    - Ground type
    - Vehicle type
2. Transmissibility:
    - Ground type
3. Ground-foundation interaction:
    - Ground type
    - Foundation type
4. Building response:
    - Wall/floor type



Vibration transmission mechanism

- Road-Ground transfer function

  $TF_{RG} = L_{v1} - L_{v0}$
- Transmissibility in the ground

  $TF_{GG} = L_{v3} - L_{v1}$
- Ground-foundation transfer function

  $TF_{GF} = L_{v4} - L_{v3}$
- Transmissibility in the building

  $TF_{FB} = L_{v5} - L_{v4}$

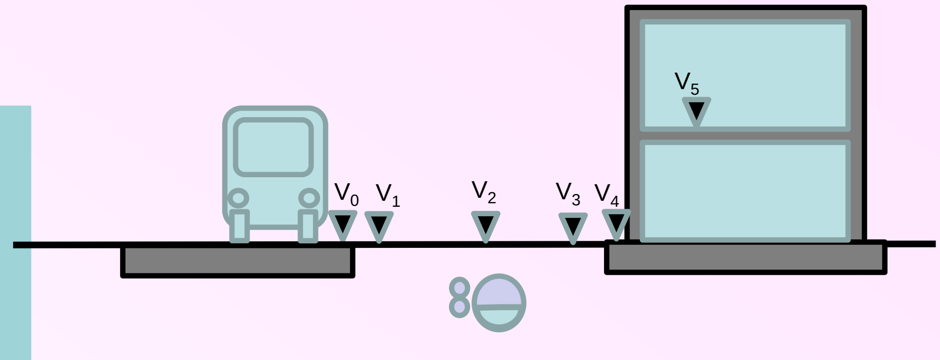
$L_{v5} = L_{v0} + TF_{RG} + TF_{GG} + TF_{GF} + TF_{FB}$

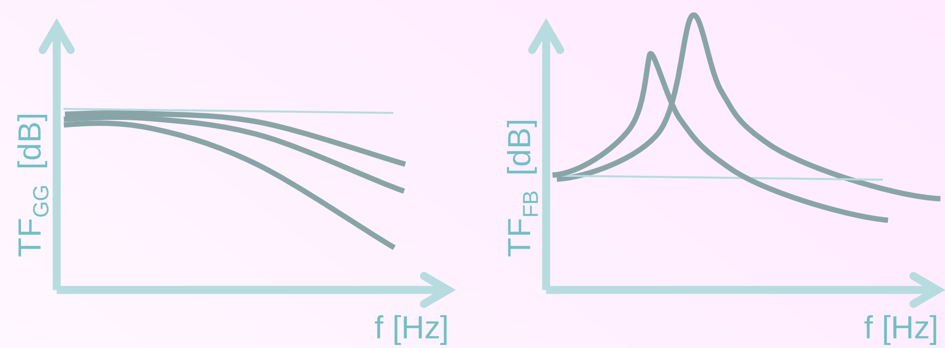
Or

$L_{v5} = L_{v1} + TF_{GG} + TF_{GF} + TF_{FB}$

Vibration level L_v [dB] = $20 \log_{10} (v/v_0)$

(v_0 = 1E-9 m/s)



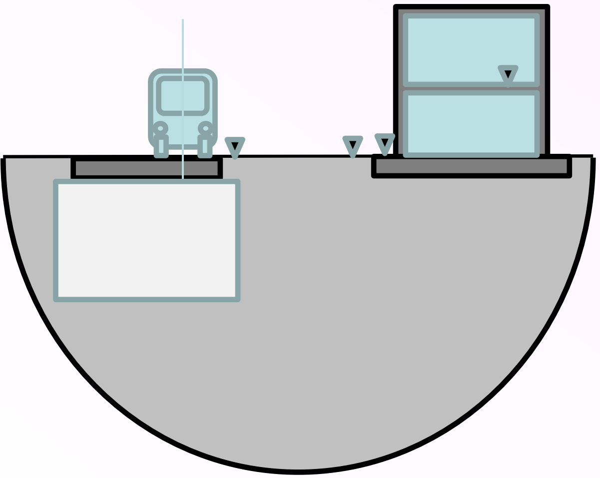


Traffic-induced vibration mitigation

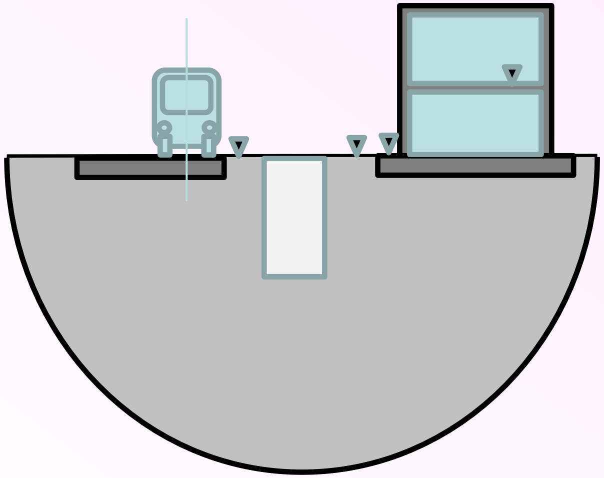
- Vibrations at a frequency range from 10 to 30 Hz
- The mitigation system :
  - (1) reducing the vibration amplitude by improving the soil around the vibration source, and diffracting the generated waves by trenches and barrier,
  - (2) shifting the frequency content of the induced vibrations and, reducing the energy of the transmitted wave by isolating barrier.

Vibration mitigation systems

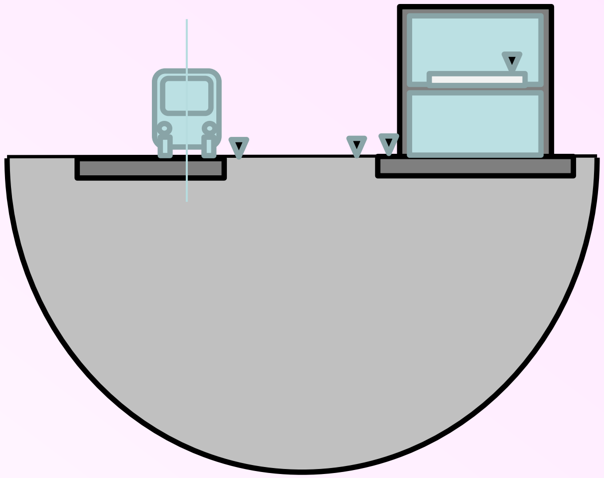
- The mitigation system :
  - reducing the vibration amplitude
  - reducing the energy of the transmitted wave
  - shifting the frequency content of the induced vibrations



Active isolation
by soil improving



Isolation in transmission path
by barriers

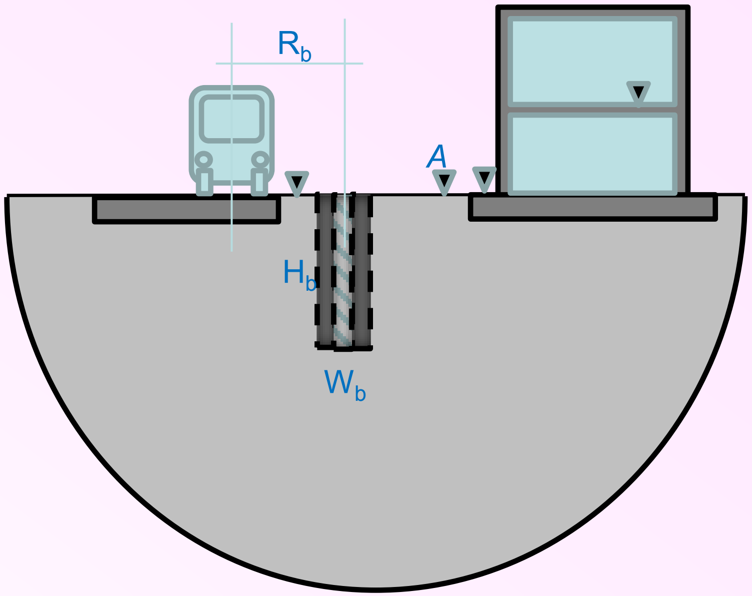


Passive isolation
by isolating panel

Vibration mitigation by isolating barrier

- Efficiency parameters:
  - The height ratio H_b / λ_R
  - The width ratio W_b / λ_R
  - The distance ratio R_b / λ_R

where, $\lambda_R = C_R / f$



$H_b / \lambda_R > 2{,}0$

$W_b / \lambda_R > 0{,}2$

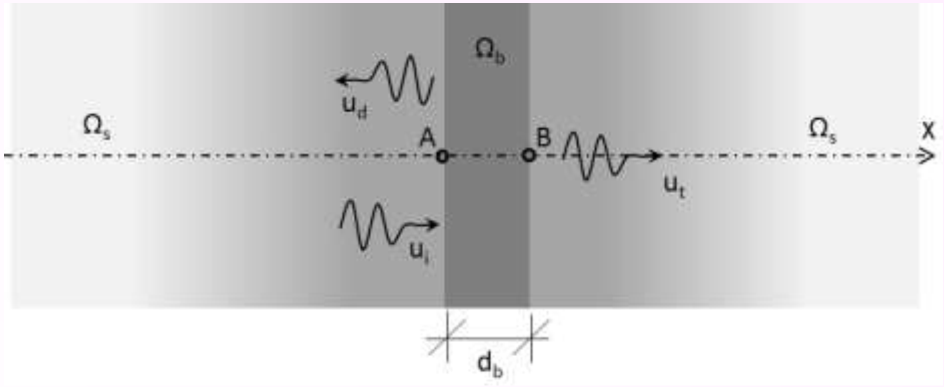
$R_b / \lambda_R < 1{,}5$

$\Rightarrow$

$A_r = u_{A\text{-after}} / u_{A\text{-before}} \leq 0{,}25$

Isolating barrier mechanism

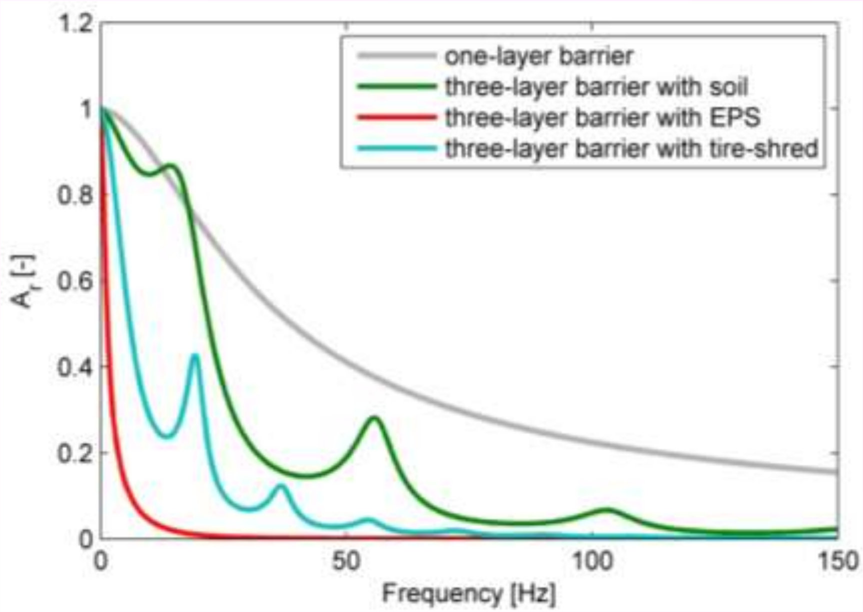
- Reduction factor: $A_r = u_t / u_i$
  - The impedance ratio: $\alpha = \rho_b C_b \big/ \rho_s C_s$ $\quad A_r \propto \dfrac{1}{(\alpha + \frac{1}{\alpha})}$
  - The travelling time: $t_b = d_b \big/ C_b$ $\quad A_r \propto \dfrac{1}{t_b}$



1-D bar element model

as:

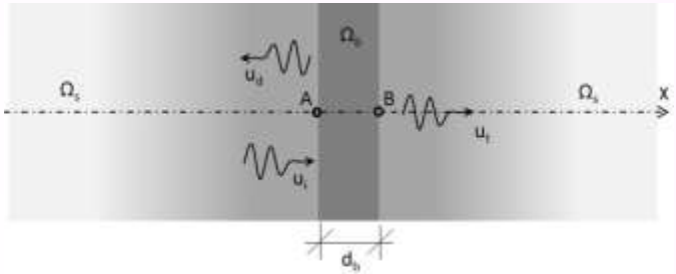
1-D modeling of isolating mechanism



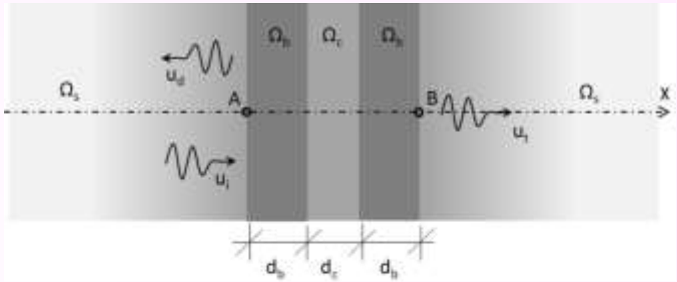
$$Z_{concrete} / Z_{EPS} = 3200$$

$$Z_{concrete} / Z_{tire-shred} = 105$$

$$Z_{concrete} / Z_{soil} = 30$$



One-layer barrier



Multi-layer barrier

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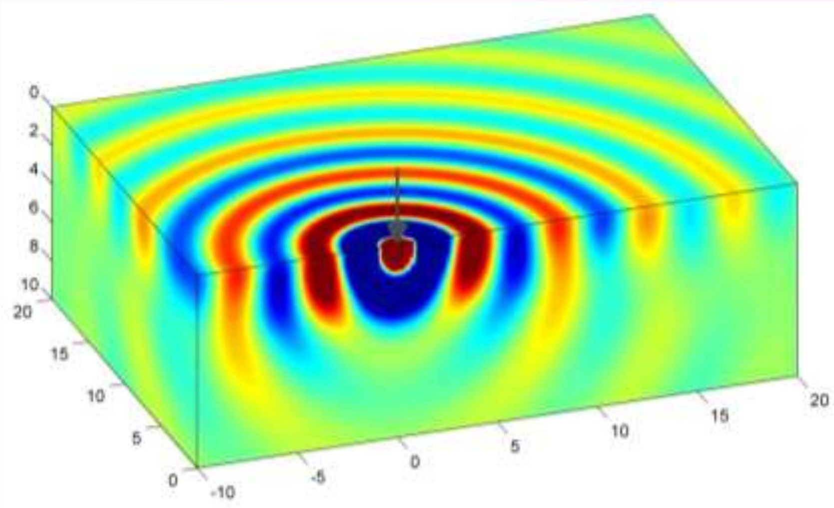
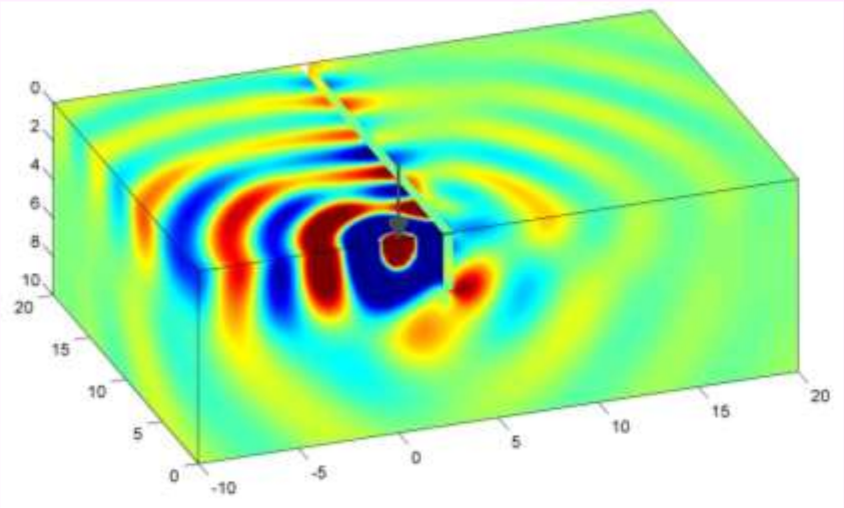
Numerical modeling of isolating barrier

Before isolating barrier installation



After isolating barrier installation



$$ILoss\ [dB] = 20 \times Log_{10}\left(\frac{PPV_{iso}}{PPV_{non-iso}}\right)$$

Description of work

- **Validation of mitigation solutions for low frequency structure borne noise**
  - Selecting a reference site and in-situ measurement
  - Numerical modeling for pre-dimensioning
  - Validation of prediction model by means of
    - Scaled test bench measurement with different barrier type will be examined:
      - Concrete barrier
      - Concrete-EPS-Concrete barrier

Vibration mitigation by isolating barrier

In-situ measurement
L_{v0} or L_{v1} and L_{v3}

Building response
$L_{v5} > L_{v}$ (admissible)

Ground transmissibility before isolating
$TF_{GG} = L_{v3} - L_{v1}$

Ground properties
C_s, ρ_s

Target frequency band

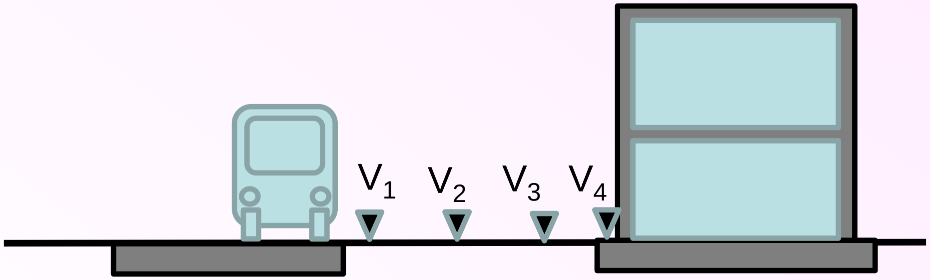
Pre-dimensioning of isolating barrier
H_b, W_b, R_b
By numerical simulation

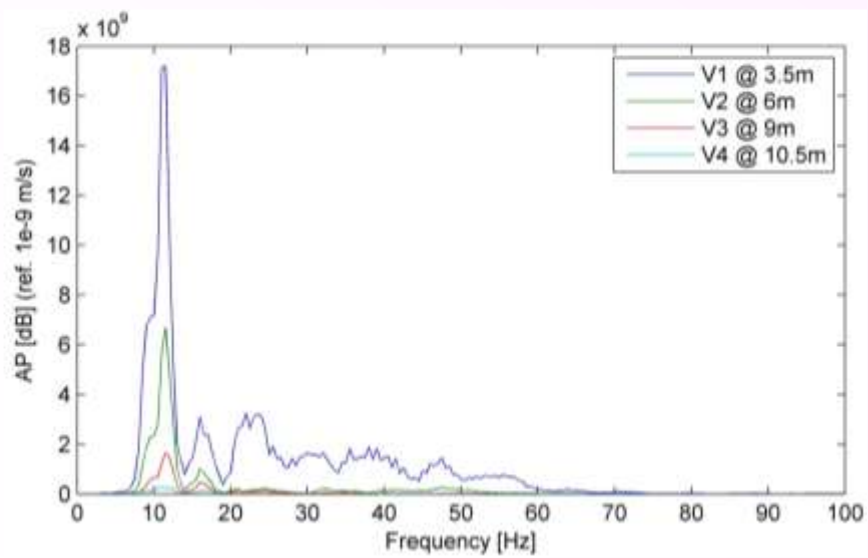
Validation of the proposed model by small-scale test
And tuning the numerical modeling

Selection of barrier dimensions
H_b, W_b, R_b

Measurement at the selected site

- Location A: bus over a speed table





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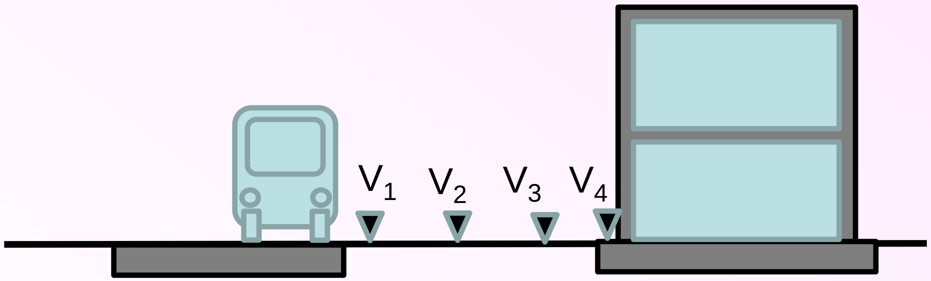
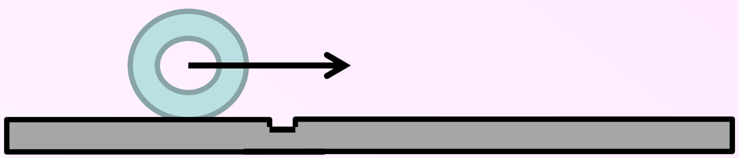
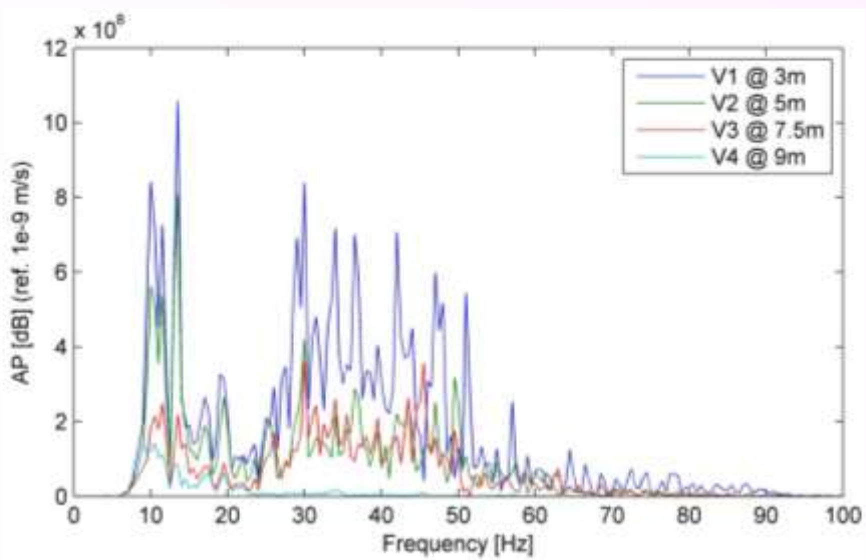
Measurement at the selected site

- Location B: bus over a road joint

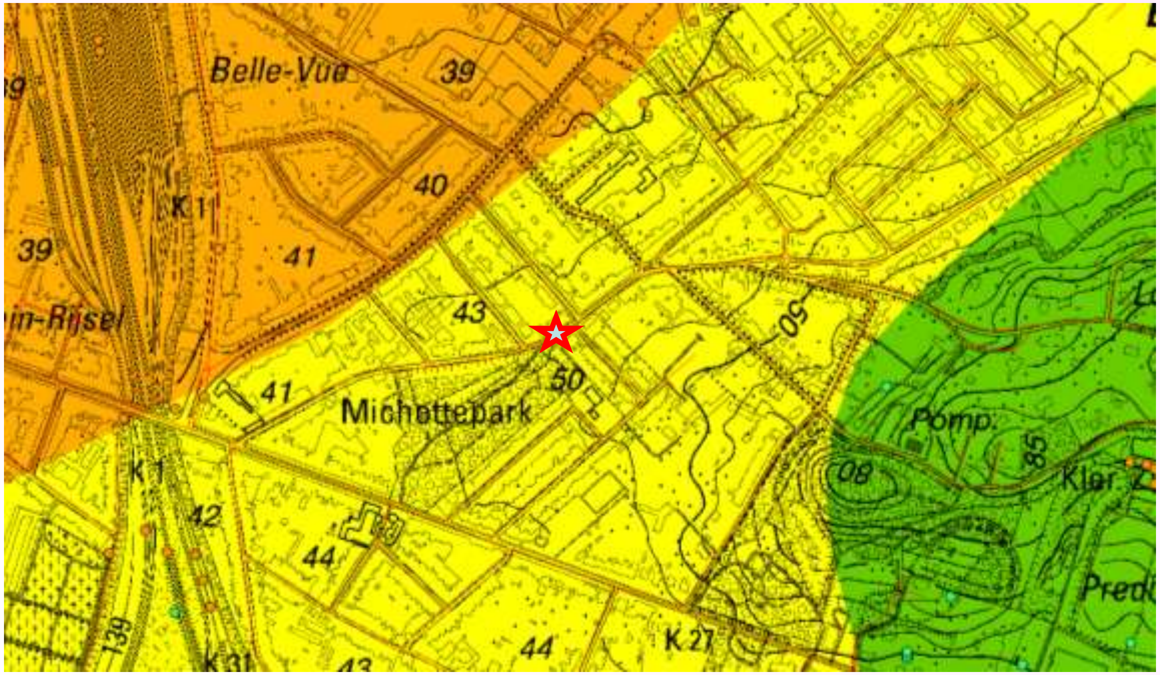






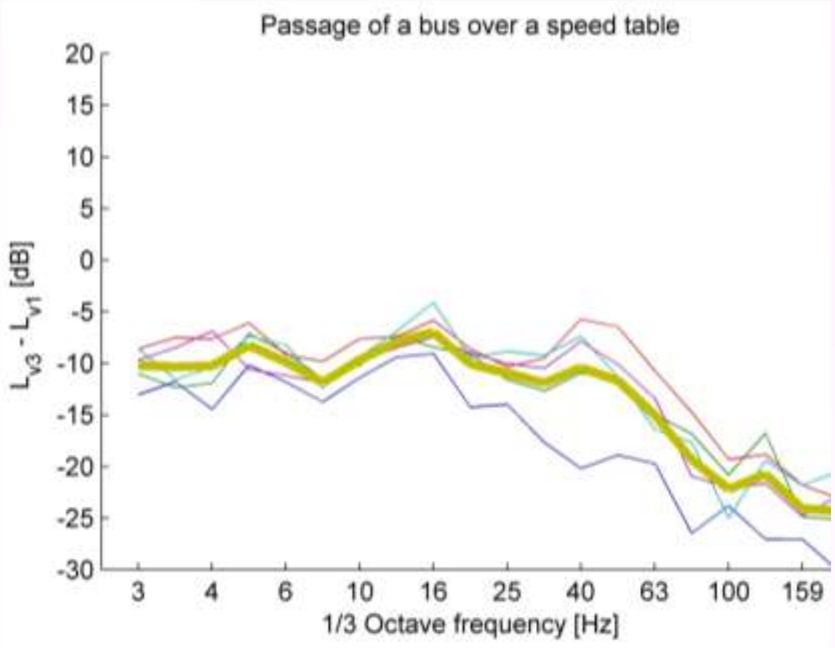
Reference site

- The soil has a Brussels formation with gray fine sand, lime, and lime sandstone.

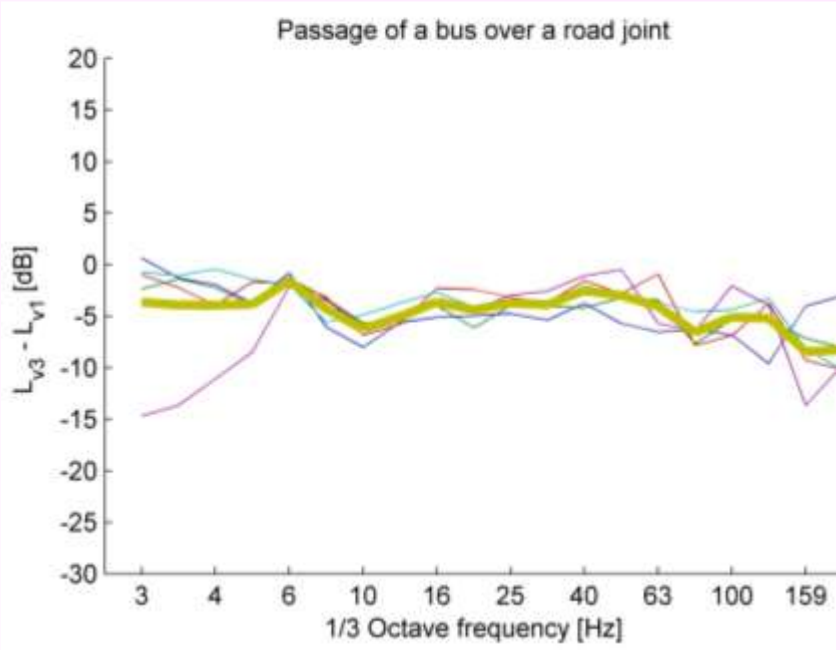


Measurement at the selected site

- Transmissibility through the propagation path ($TF_{GG} = L_{v3} - L_{v1}$)
  Ground conditions : inhomogeneity; pipes; sewers; obstacles



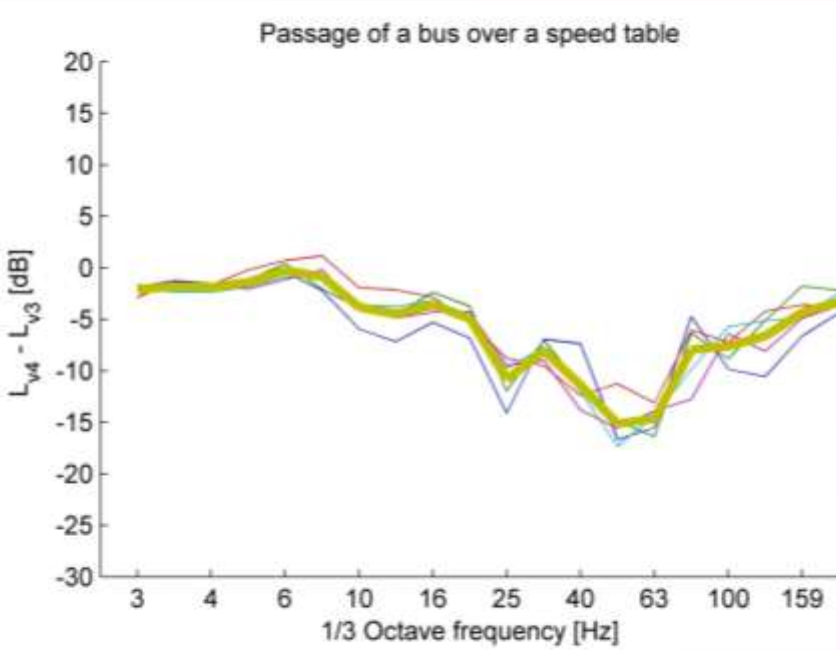
Location A



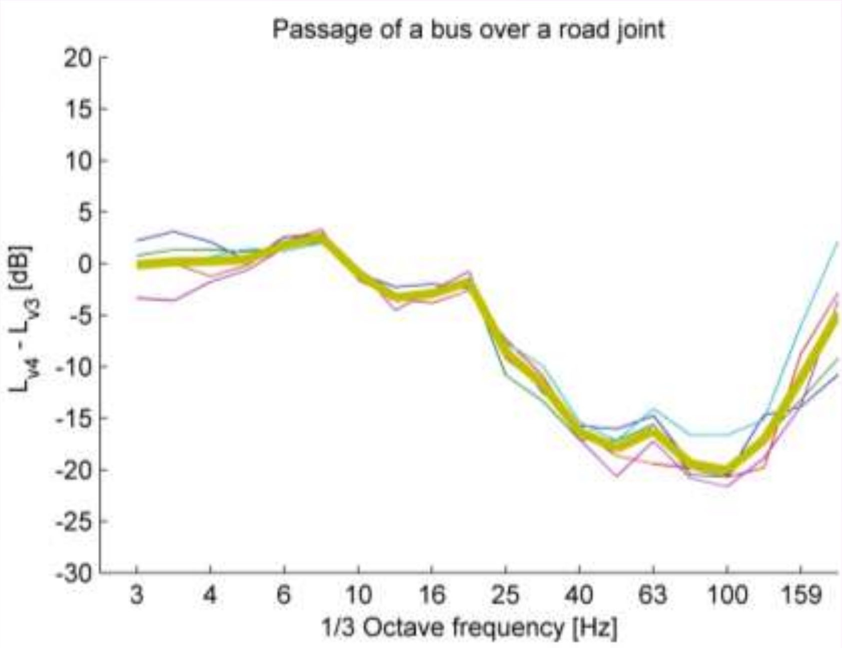
Location B

Measurement at the selected site

- Ground-foundation interaction
  - Soil properties
  - Foundation type



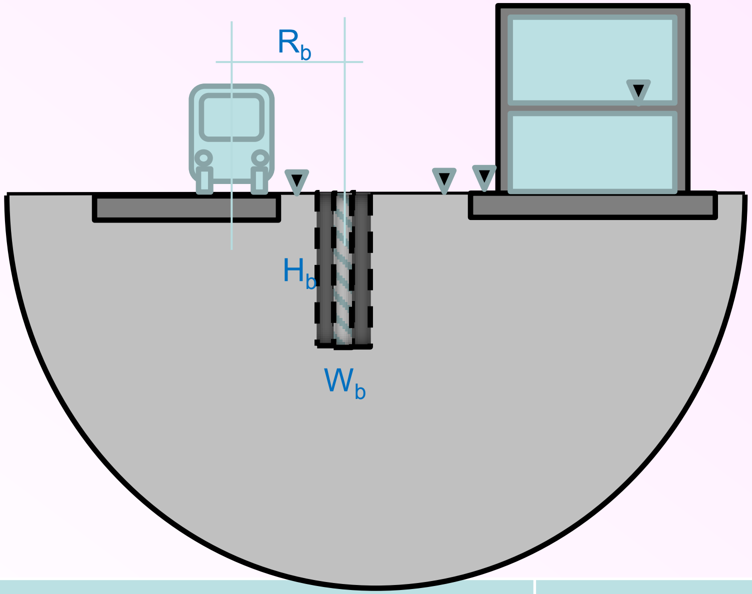
Location A



Location B

Predimensioning

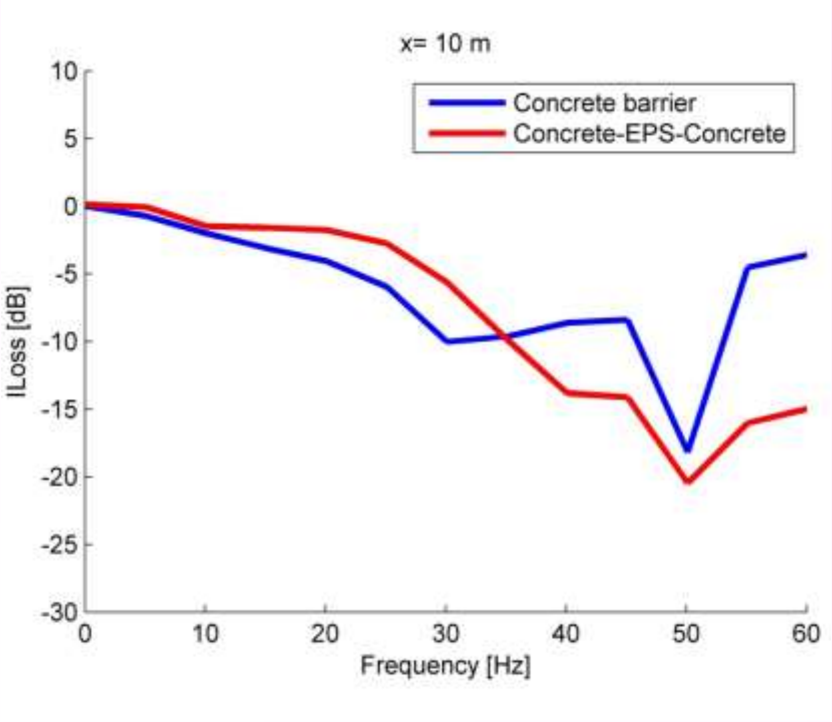
- Using a coupled FEM-BEM model

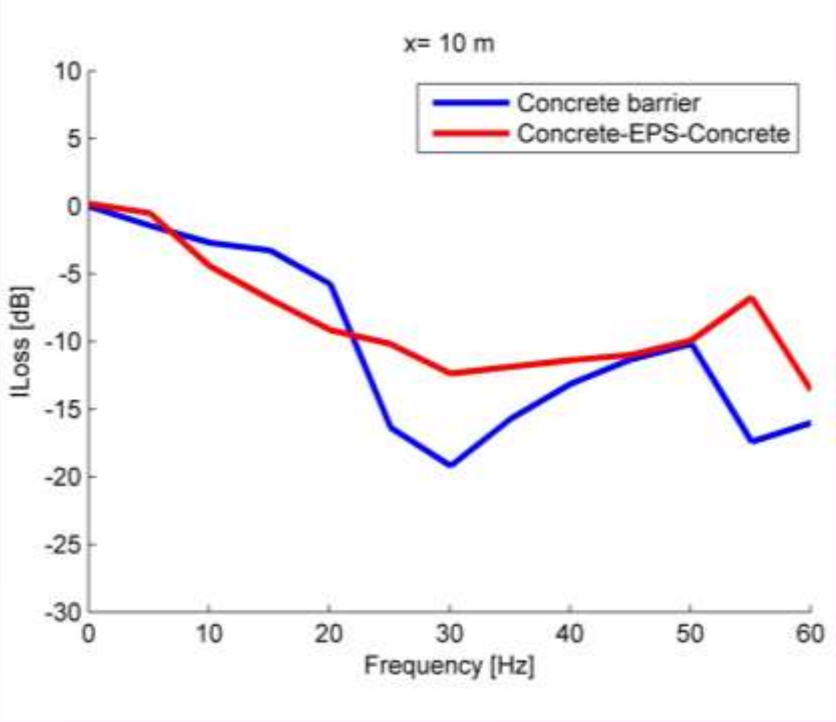


	Concrete barrier			Concrete-EPS-Concrete barrier		
Case 1	W_p = 0,60 m	H_p = 9,0 m	R_p = 2,25 m	W_p = 3x0,6 m	H_p = 6,0 m	R_p = 2,25 m
Case 2	W_p = 0,80 m	H_p = 12,0 m	R_p = 3,0 m	W_p = 3x0,8 m	H_p = 8,0 m	R_p = 3,0 m

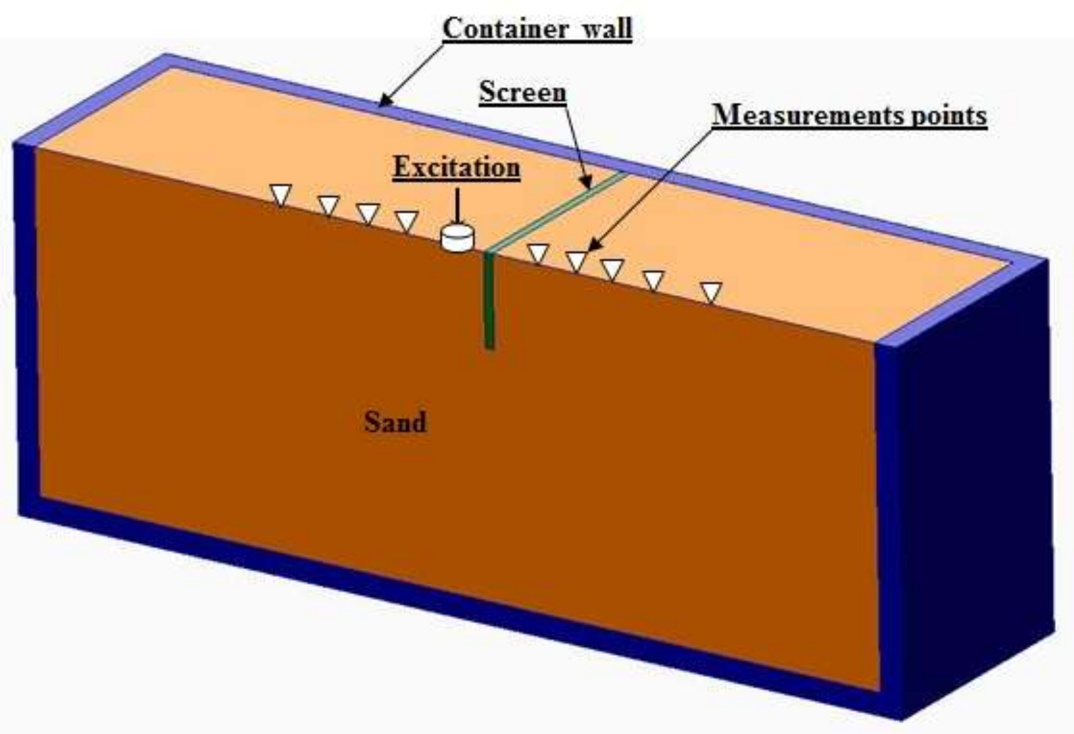
Pre-dimensioning

- Using a coupled FEM-BEM model



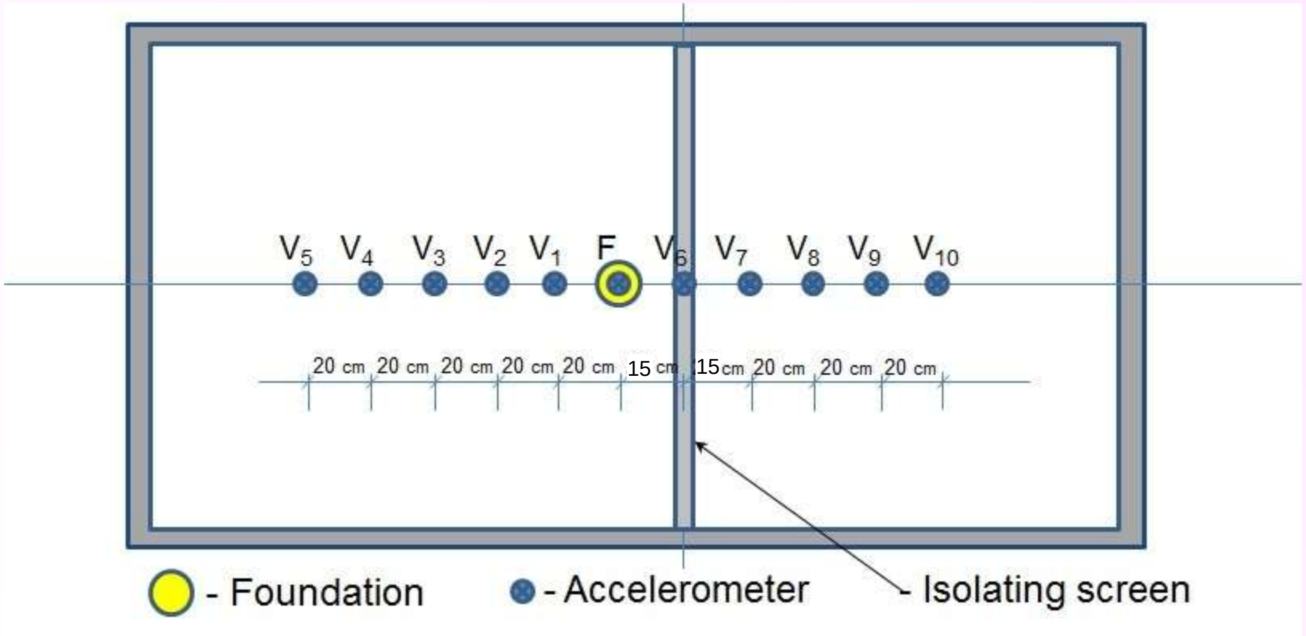


Experimental test bench



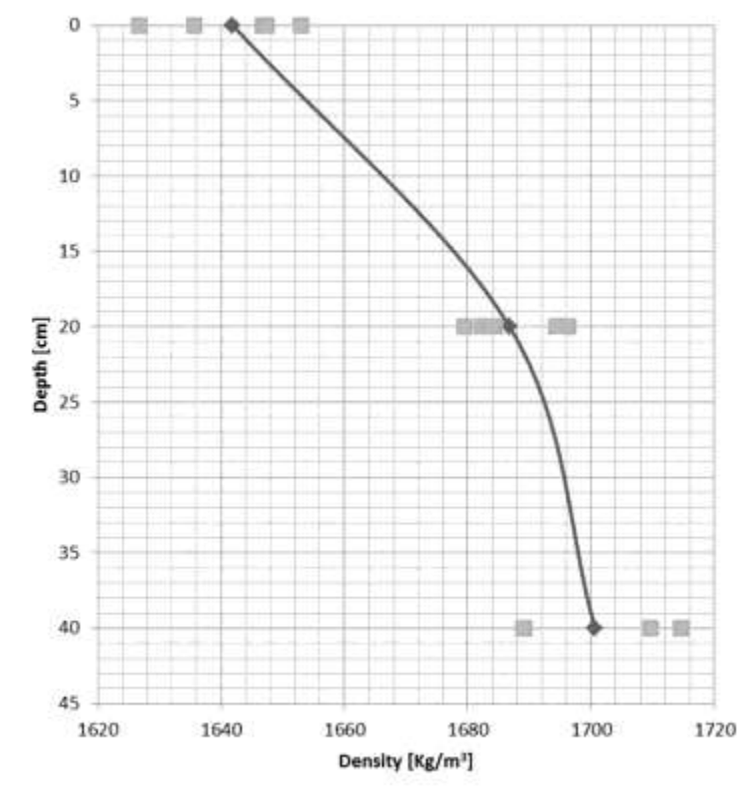
Experimental test bench

- Measurement setup



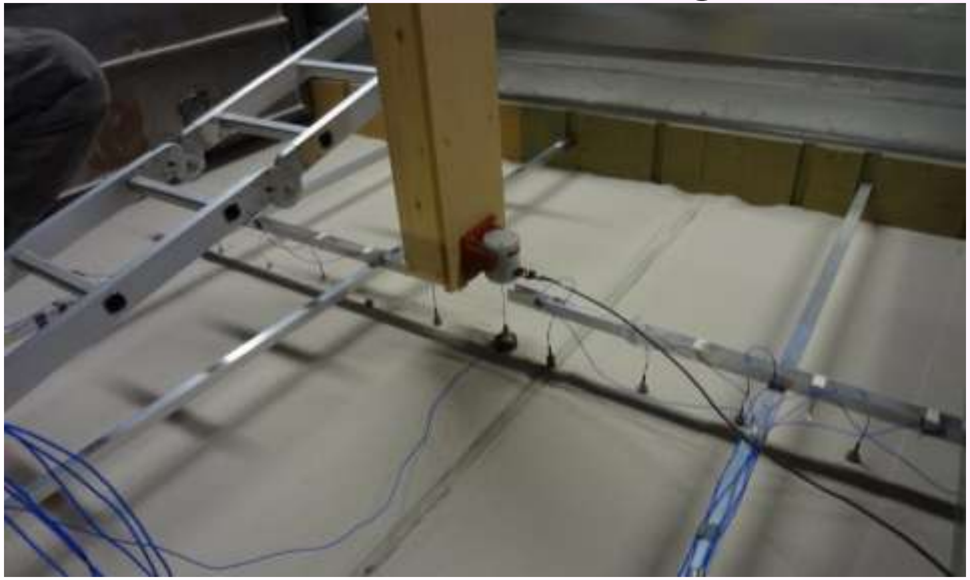
Experimental test bench

- Soil treatment
  - Sand pluviation
    - Density test
    - Impedance test
    - SASW test



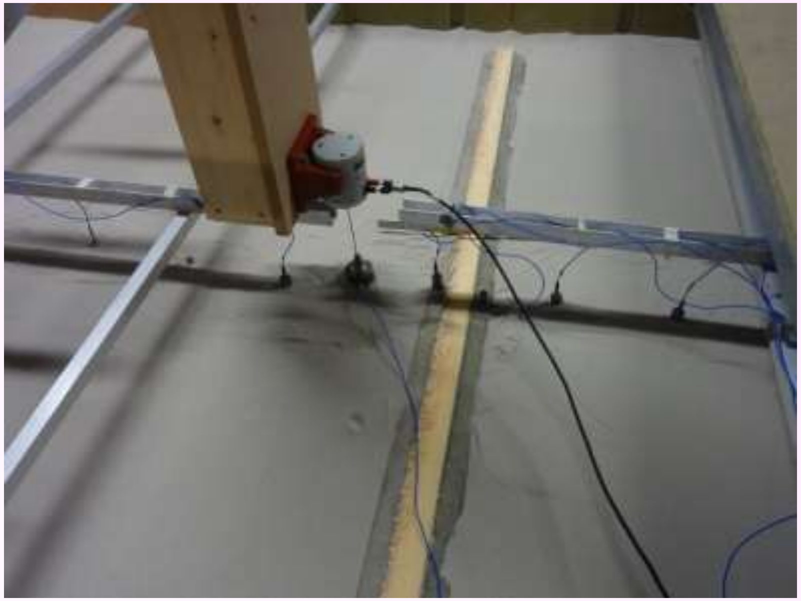
Experimental test bench

- Measurement setup
  - Excitation with a shaker
    - A random harmonic vibration
    - Frequency range from 100 to 900 Hz
  - Acceleration 100 mv/g



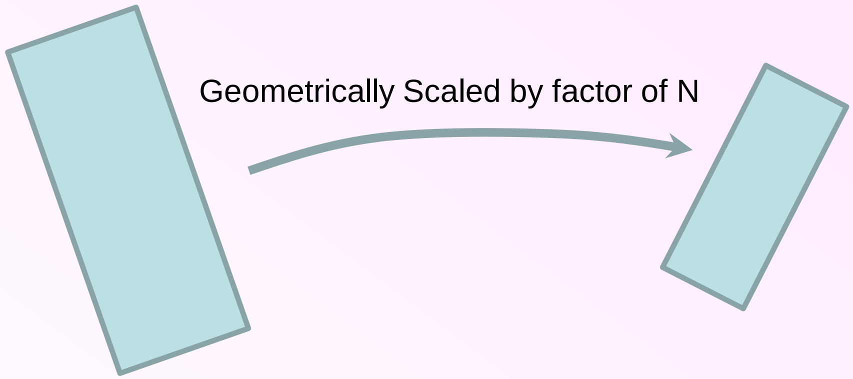
Experimental test bench

Concrete barrier



Concrete-EPS-Concrete barrier

Experimental validation by small-scale test



	Frequency band	Concrete barrier			Concrete-EPS-Concrete barrier		
Small-scale model	f_m = 100 -1100 Hz	W_m = 0,04 m	H_m = 0,60 m	R_m = 0,15 m	W_m = 0,12 m	H_m = 0,4 m	R_m = 0,15 m
Full-scale N = 15	f_p = 6,7 – 73 Hz	W_p = 0,60 m	H_p = 9,0 m	R_p = 2,25 m	W_p = 3x0,6 m	H_p = 6,0 m	R_p = 2,25 m
Full-scale N = 20	f_p = 5,0 – 55 Hz	W_p = 0,80 m	H_p = 12,0 m	R_p = 3,0 m	W_p = 3x0,8 m	H_p = 8,0 m	R_p = 3,0 m

- “m” denotes to “small-scale model”
- “p” denotes to “full-scale prototype”
- N is the geometrical scale factor

Experimental validation by small-scale test

Small-scale test		concrete barrier		concrete-EPS-concrete barrier	
		H_b = 0,60 [m]	W_b = 0,04 [m]	H_b = 0,40 [m]	W_b = 0,12 [m]
Frequency band f_m [Hz]	Wavelength λ_R [m]	Depth ratio $\frac{H_b}{\lambda_R}$ [-]	Width ratio $\frac{W_b}{\lambda_R}$ [-]	Depth ratio $\frac{H_b}{\lambda_R}$ [-]	Width ratio $\frac{W_b}{\lambda_R}$ [-]
100-300	0,5	1,2	0,08	0,80	0,24
300-500	0,25	2,4	0,16	1,60	0,48
500-700	0,167	3,6	0,24	2,40	0,72
700-900	0,125	4,8	0,32	3,20	0,96
900-1100	0,1	6,0	0,40	4,0	1,20

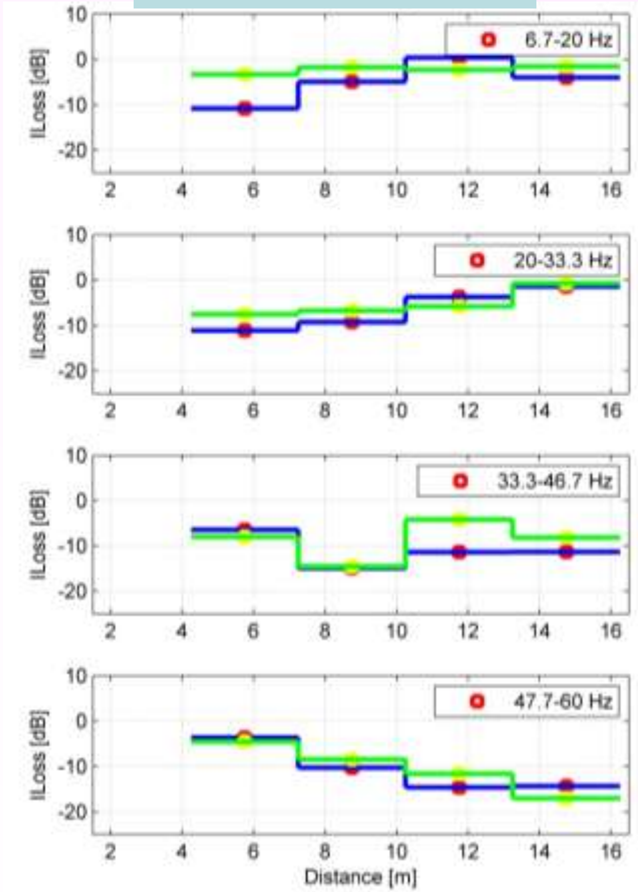
Experimental validation by small-scale test

Small-scale test	Full-scale test N=15	Full-scale test N=20
Frequency band f_m [Hz]	Frequency band f_p [Hz]	Frequency band f_p [Hz]
100-300	6,7-20	5-15
300-500	20-33,3	15-25
500-700	33,3-46,7	25-35
700-900	46,7-60	35-45
900-1100	60-73,3	45-55

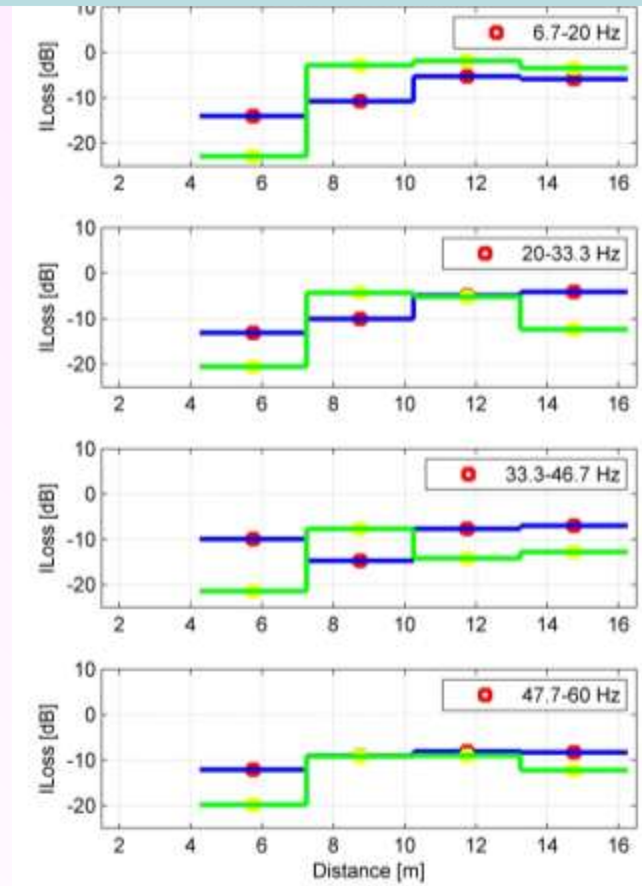
Experimental validation by small-scale test

Numerical
Experimental

Concrete barrier



Concrete-EPS-Concrete barrier



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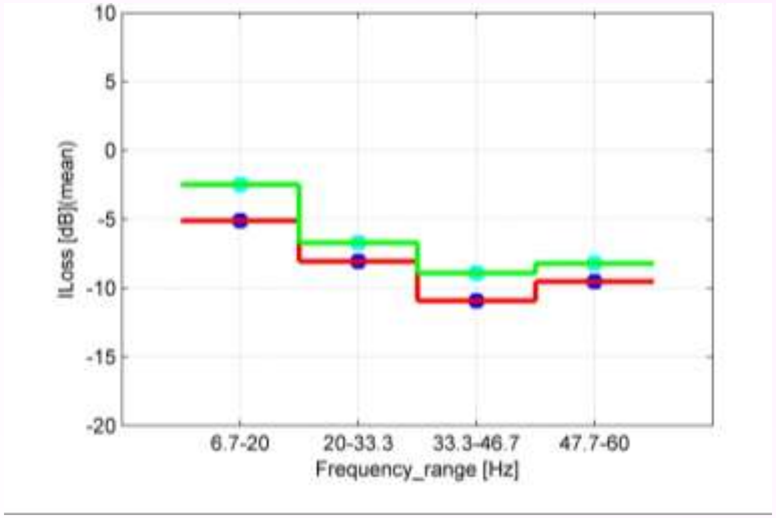
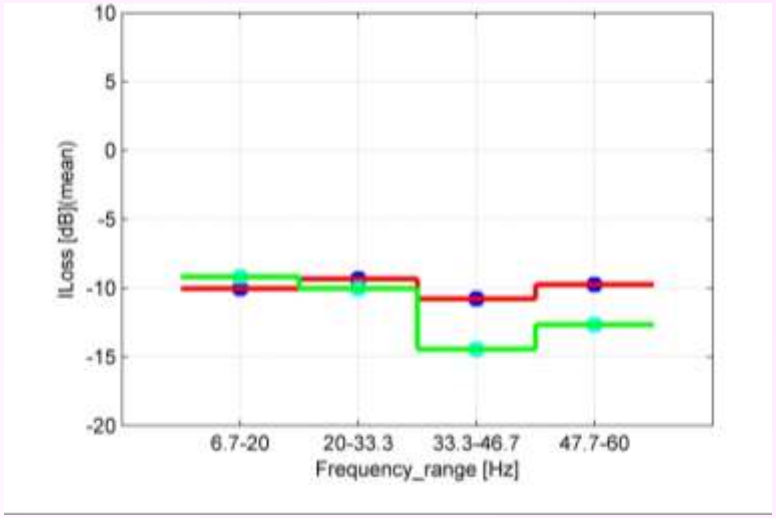
Experimental validation by small-scale test

Mean value of insertion loss over the points behind the barrier:

$$ILoss\ [dB] = 1/(x_2 - x_1)\int_{x_1}^{x_2} ILoss\ dx$$



Concrete barrier



Concrete-EPS-concrete barrier

Conclusion

- Isolating barriers are introduced as a solution for traffic-induced vibration mitigation.
- A practical solution has been proposed for reducing the structure-borne noise in building.
- A numerical simulation is proposed for barrier design and evaluation of their efficiencies.
- Results of numerical simulation have been successfully validated by means of experimental small-scale test.