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SAPEM 2014 - Stockholm

In-situ sound absorption measurement

New methods beyond ISO standards

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Agenda

Agenda

Context – From where we start…

- Many situations call for *in-situ* sound absorption assessment
  - City soundscape
    (noise barriers, **road absorption**…)

  - Buildings insulation
    (walls, panels...)

  - Pass-By Noise ISO testing
    (**road absorption**) [ISO 10844:2011]

Context – From where we start…

- Measurement standard: ISO 13472-2:2010
  - Impedance tube measurement
  - Based on ISO 10534-2 (2 microphones)
  - Range: 250Hz - 1600Hz (1/3 octave)
  - Uncertainties corrections to apply

9.6 The general expression for the calculation of the corrected absorption coefficient, $\alpha(f)$, is:

$$\alpha(f) = \alpha_m(f) - \alpha_{system}(f) + \delta_1 + \delta_2 + \delta_3 + \delta_4$$

where

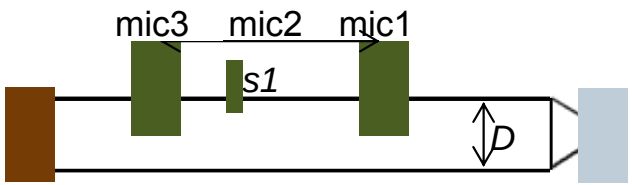
$\alpha_m(f)$	is the measured absorption;
$\alpha_{system}(f)$	is the internal damping measured with the reference test object;
δ_i	is an input quantity to allow for any uncertainty i

Let's ask ourselves some questions!

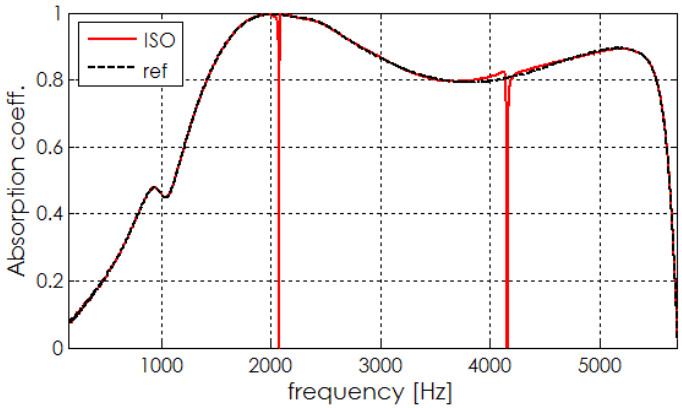
1. How reliable are ISO standards?

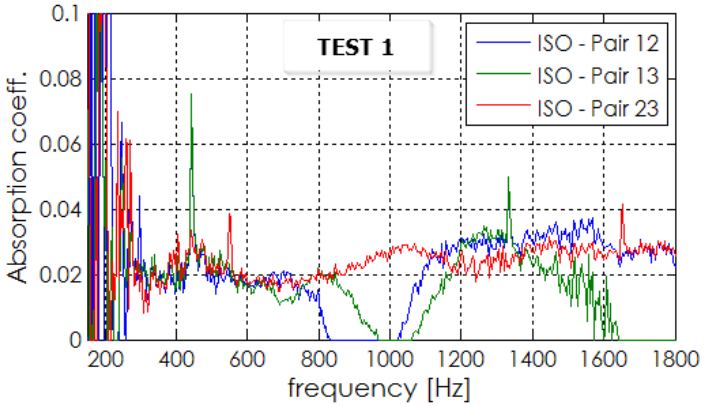
- High frequency limit (microphones spacing)
- High frequency limit (tube geometry)
- Low frequency limit (devices' quality)

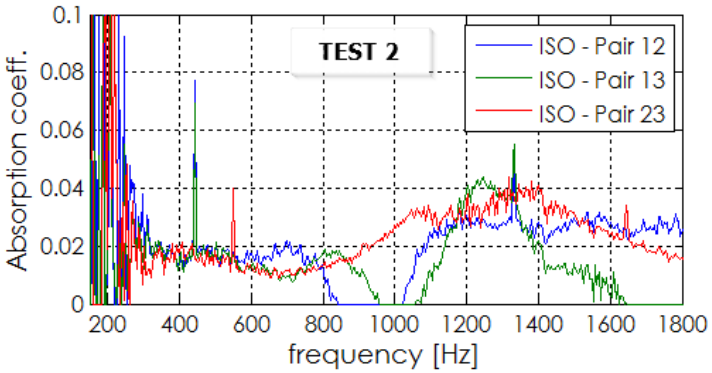
- Uncertainties?
- Repeatability?
- Accuracy?



ISO case: D large enough →
No cutoffs from each microphones pair
But different results per pair!







Answers? … Aims of the present work

1. Develop methods taking advantages of N microphones:
   a) Per pair: $\frac{N(N-1)}{2}$ pairs in identical sound field;
   b) gobal (no pairs);

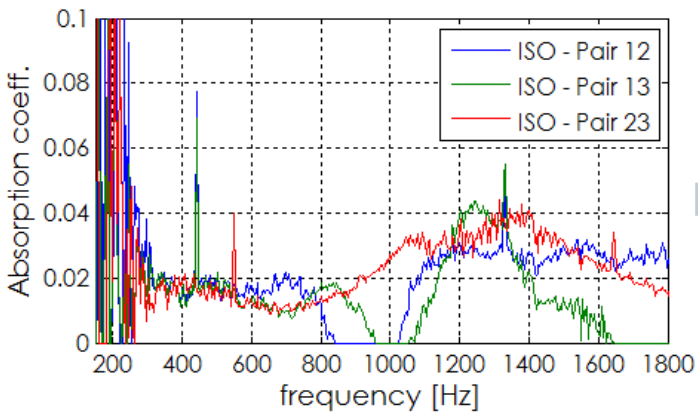
2. Increase stability and robustness
   - Sensitivity analysis of uncertainties (simulations)
   - Optimal spread of microphones

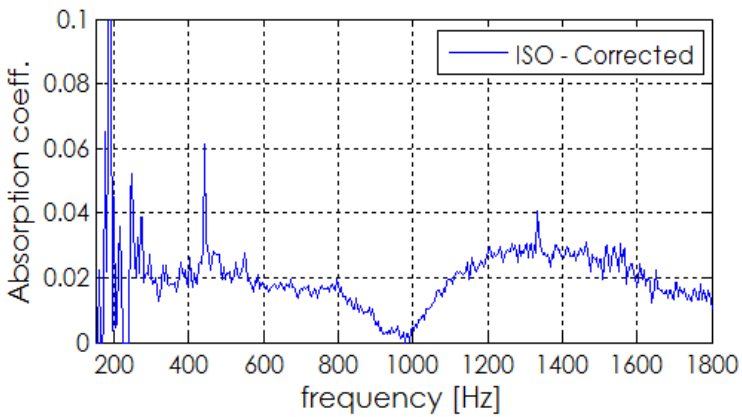
3. Test and validate for N = 3 microphones

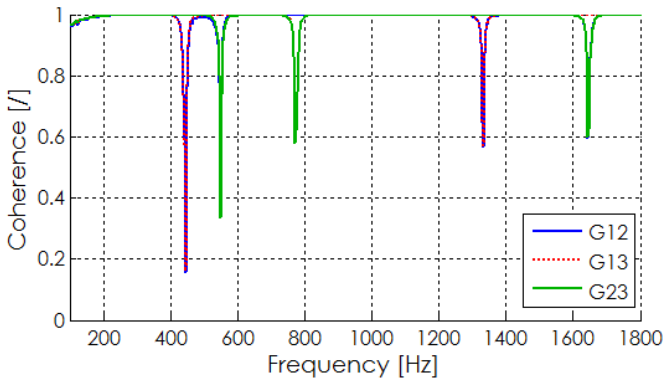
Agenda

Methods per pair of microphones

1. Equivalent to measuring simultaneously many impedance tubes
   - Follows ISO 10534-2 and ISO 13472-2 procedures
   - Average the $N(N-1)/2$ sound absorption results







Problem:

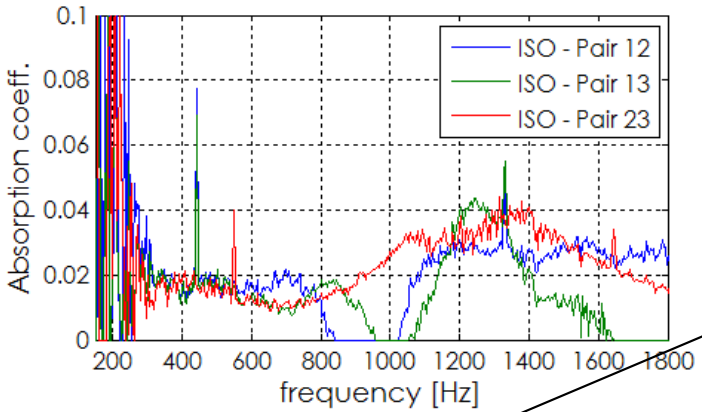
Each pair shows drops of coherence

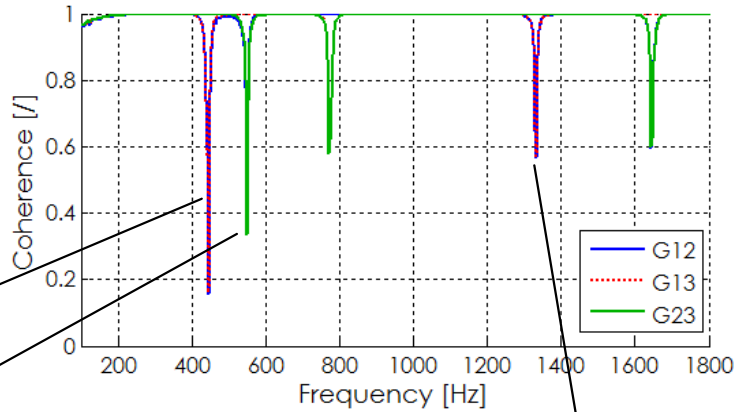
Methods per pair of microphones

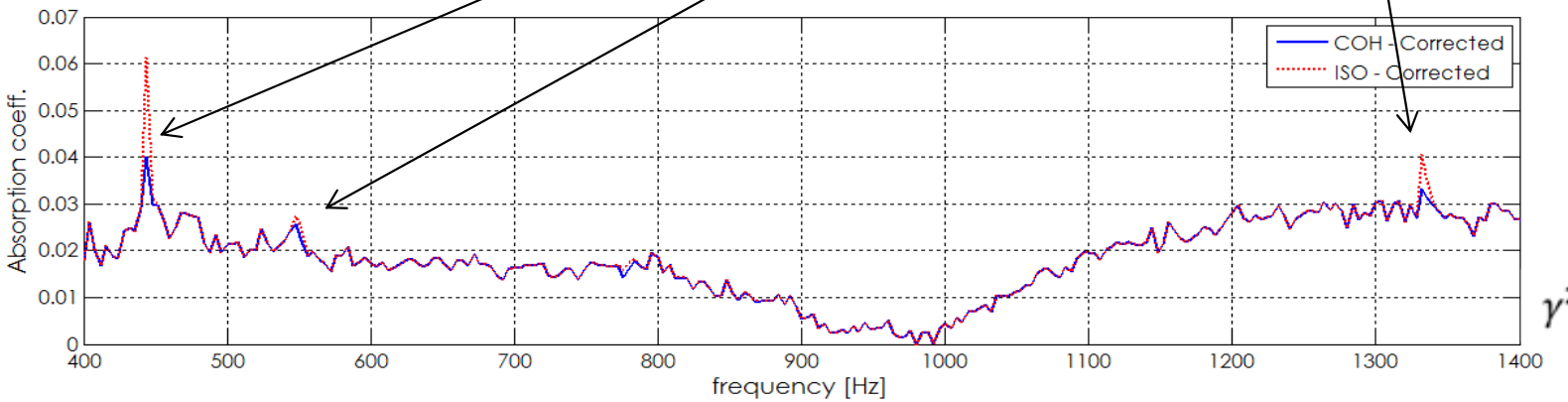
2. Improvement: Weighted average by each pair's coherence

$$\alpha(\omega) = \frac{\sum_{i=1}^{n} \alpha_i(\omega) * \gamma_i(\omega)}{\sum_{i=1}^{n} \gamma_i(\omega)}$$

α : Sound absorption
γ : Coherence
i : Pair index
n : total pair number of microphone



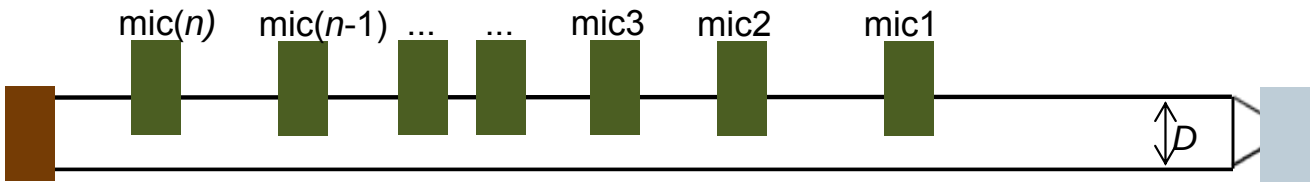




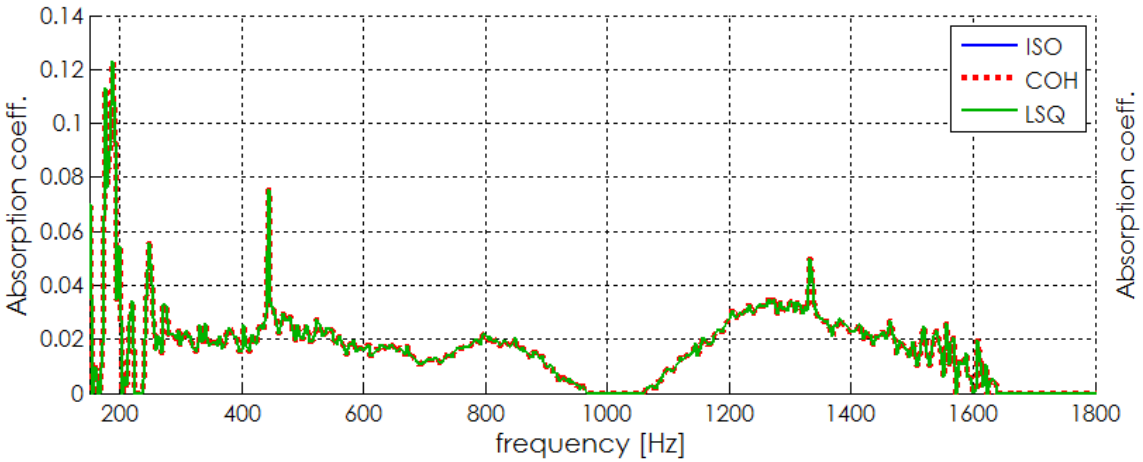
γ^2-weighted absoption

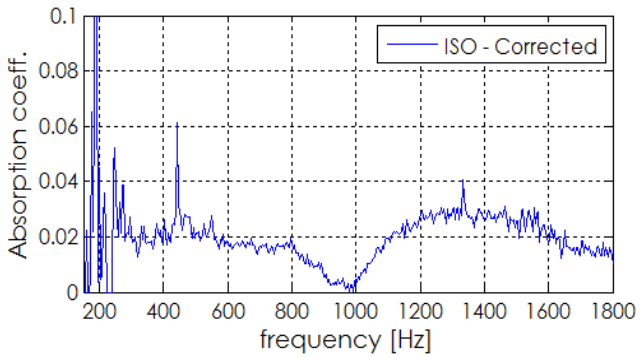
Global method

- Single operation to get the absorption coefficient
  - Spatial sampling (each microphone position)
  - Over-determined (more microphones than wave components)
  - Solution obtained in Least-square sense



- Generalize the ISO method: Formally identical for 2 microphones



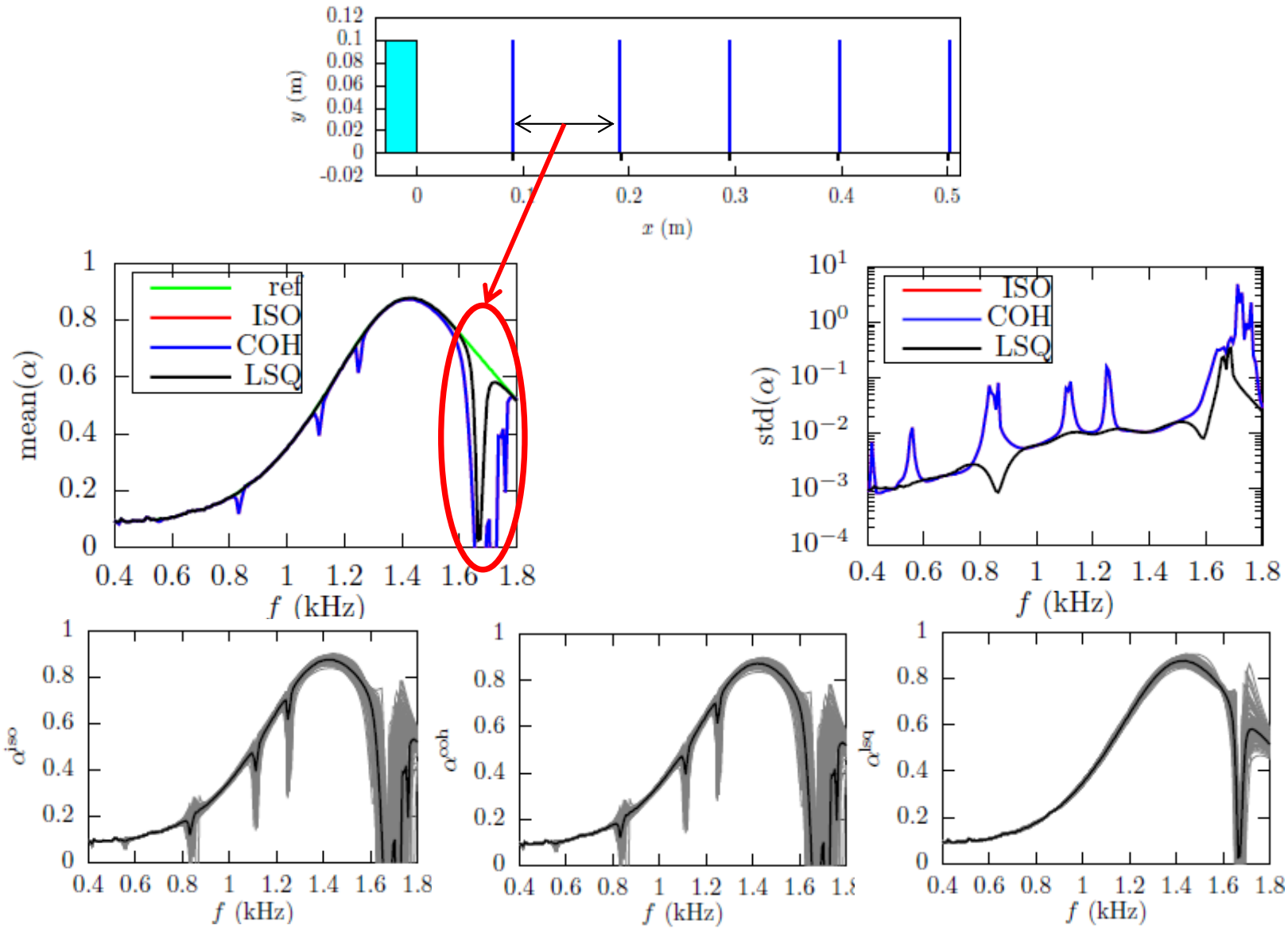


Sensitivity analysis - simulations

- Sources of uncertainties:
  - Errors on microphones' positions (= phase errors)
  - Uncorrelated random noise on each microphones' amplitudes
  - Errors on microphones' sensitivity
- Methods of testing:
  - Normal distribution of errors
    - Position standard deviation (std = 2mm)
    - Additive Gaussian noise (std = 10% of max pressure)
  - 50 averages with errors
- Add more microphones with different spread
  - Linear
  - logarithmic

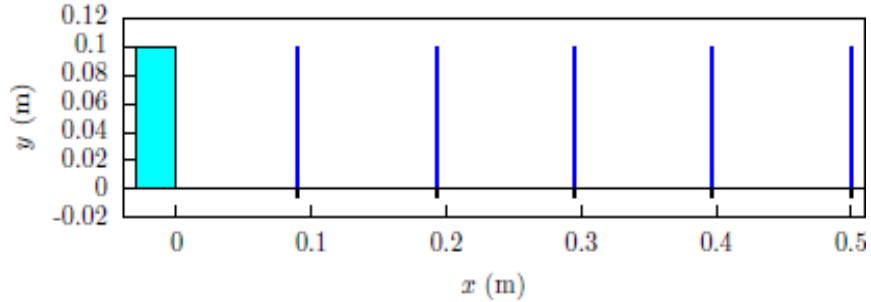
Absorption from foam – Uncertainties on position

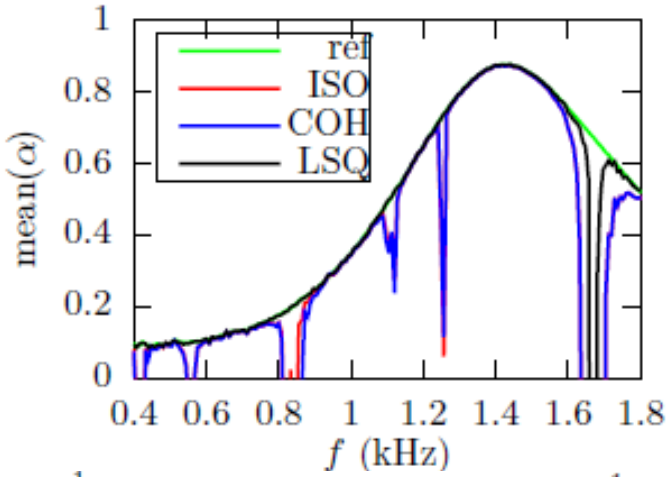
5 microphones - 50 shots - linear spacing - $\gamma = 1$

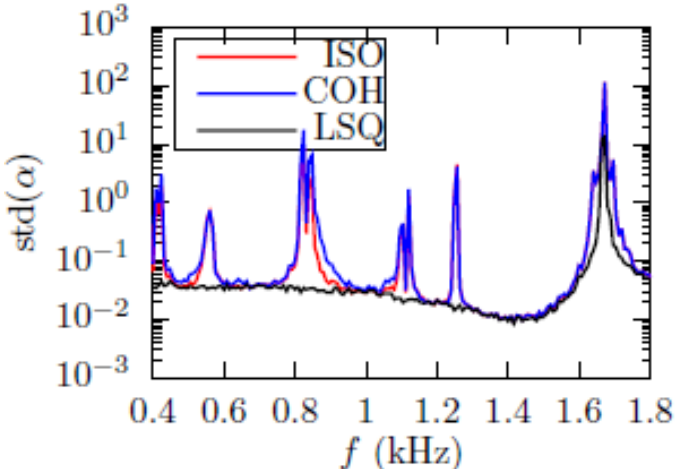


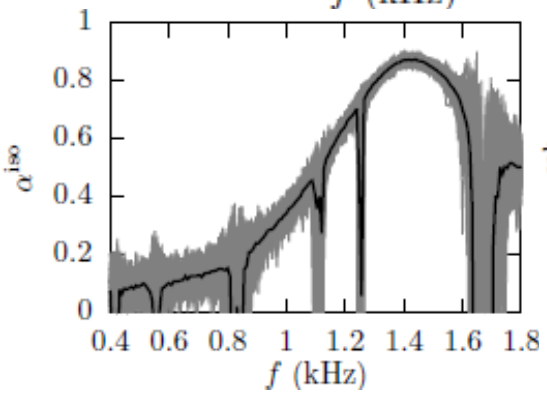
Absorption from foam – Random noise on signals

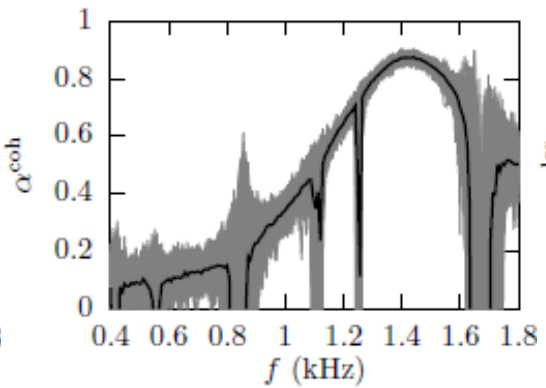
5 microphones - 50 shots - linear spacing - $\gamma \in [0.2 - 1]$

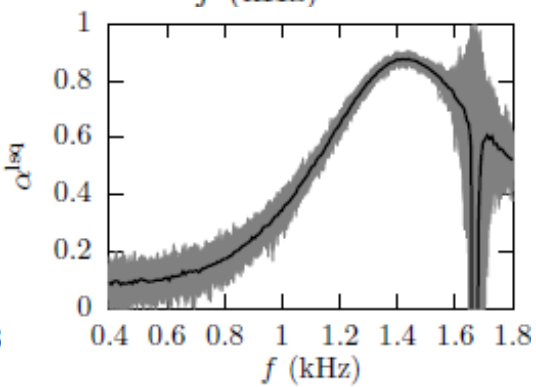






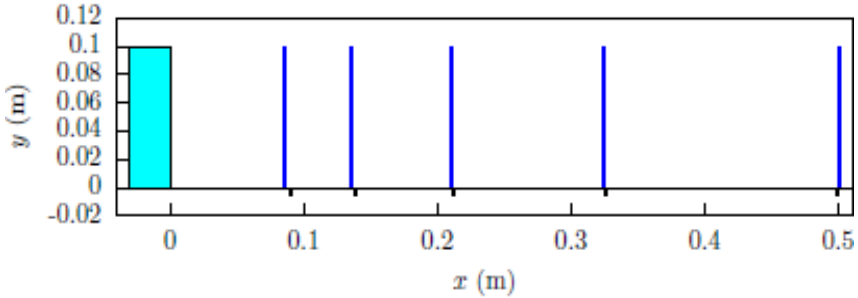


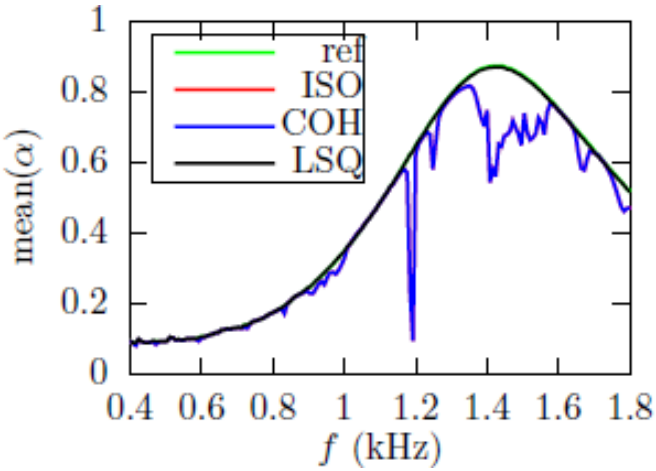


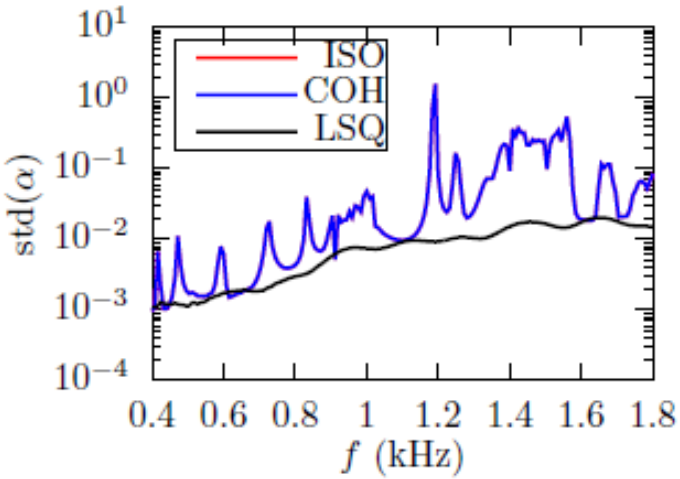


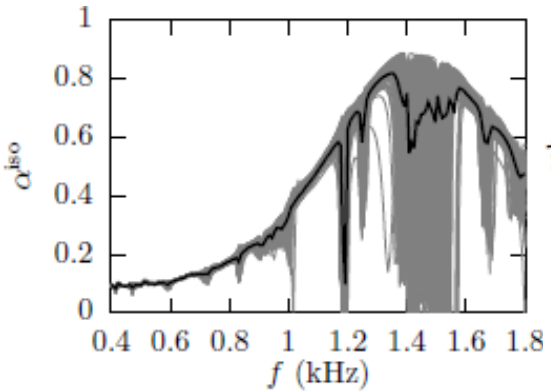
Absorption from foam – Uncertainties on position

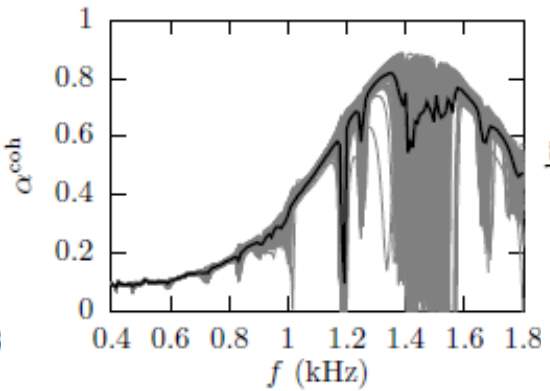
5 microphones - 50 shots - log spacing - $\gamma = 1$

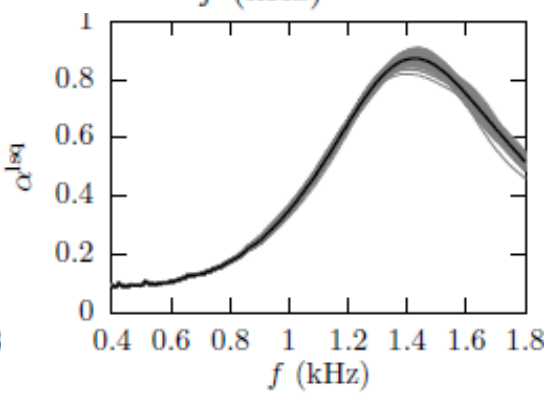






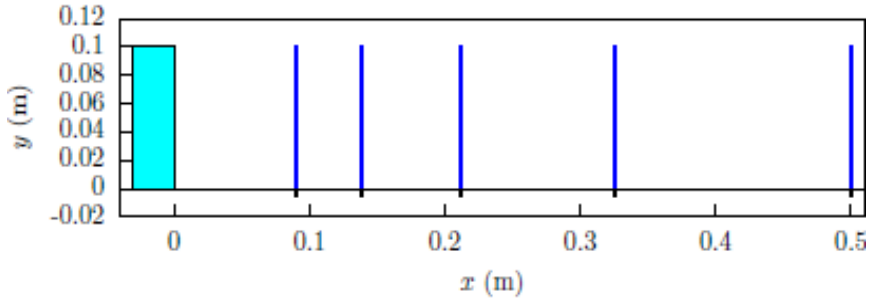


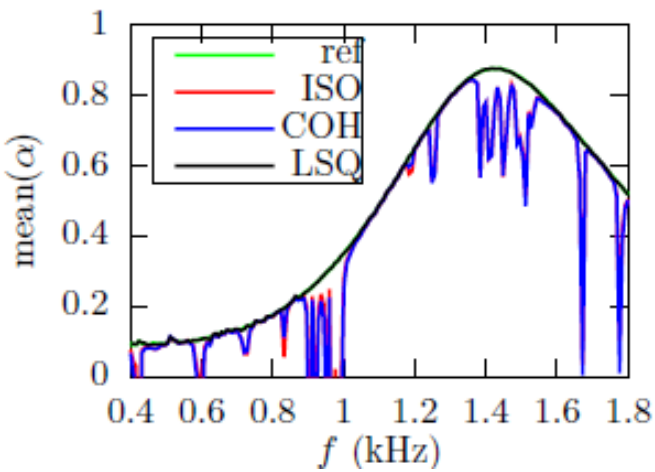


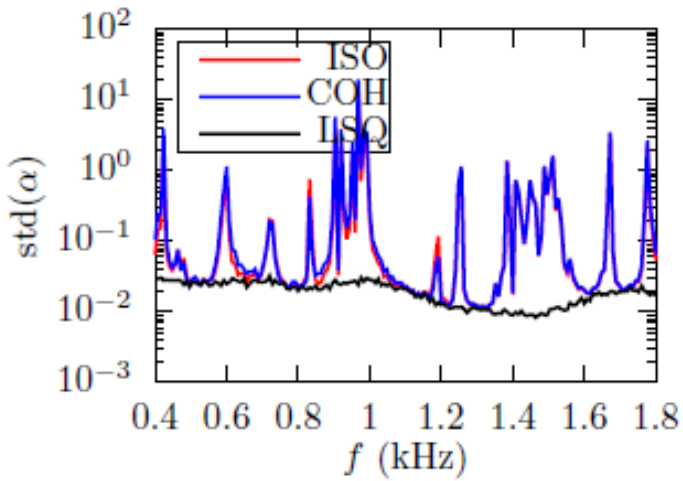


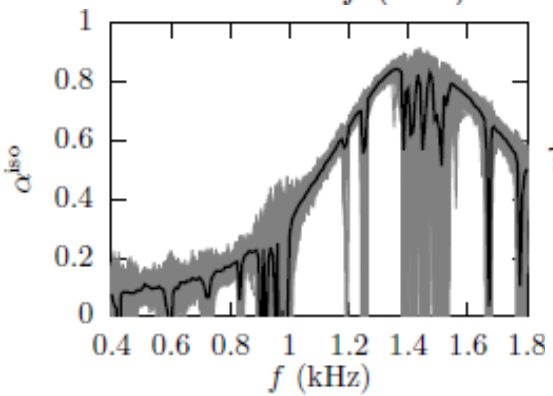
Absorption from foam – Random noise on signals

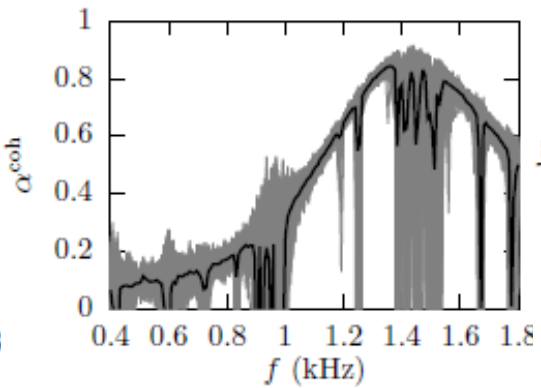
5 microphones - 50 shots - log spacing - $\gamma \in [0.2 - 1]$

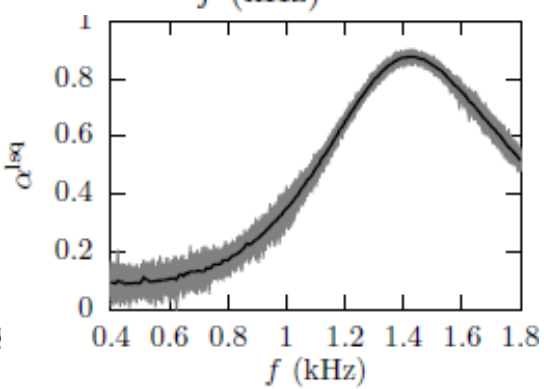






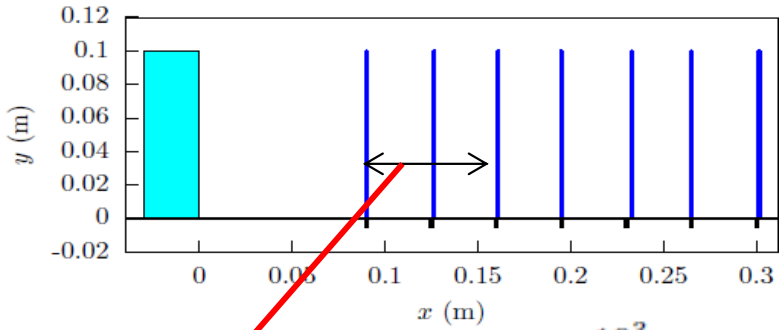


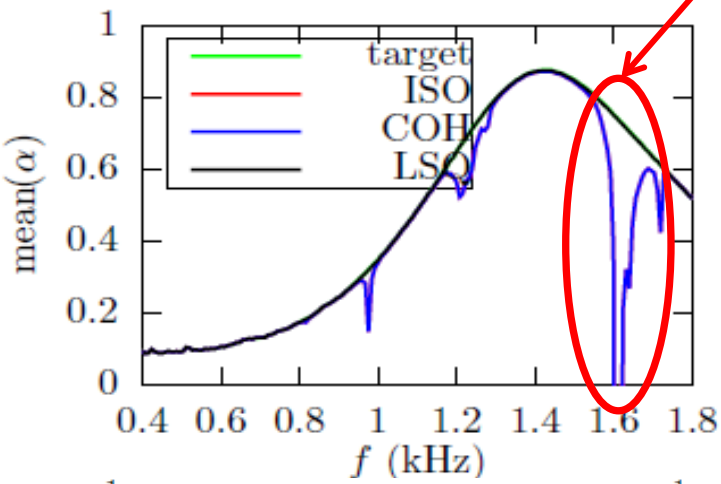


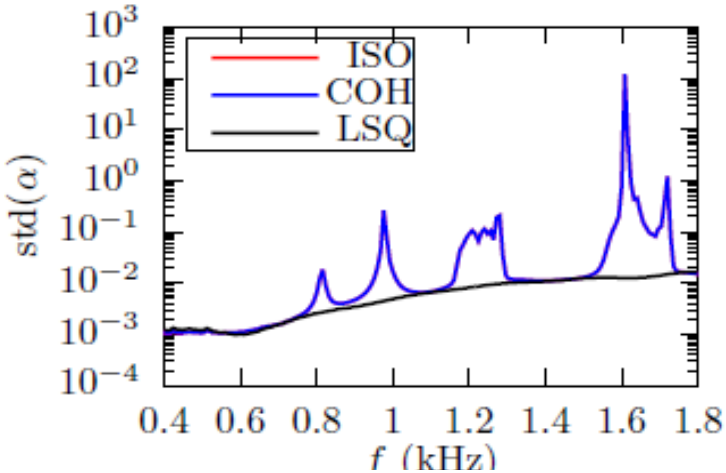


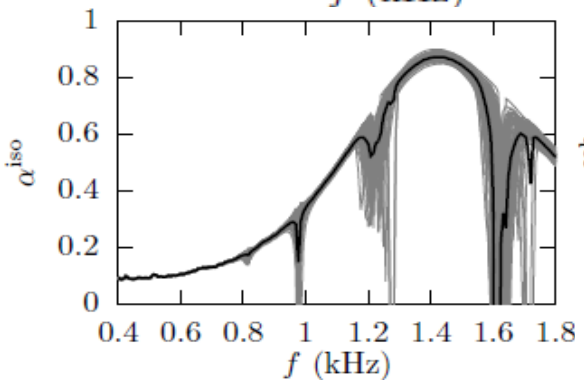
Absorption from foam – Uncertainties on position

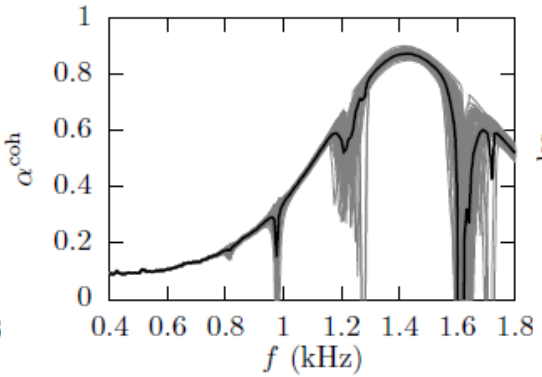
7 microphones - 50 shots - linear spacing - $\gamma = 1$

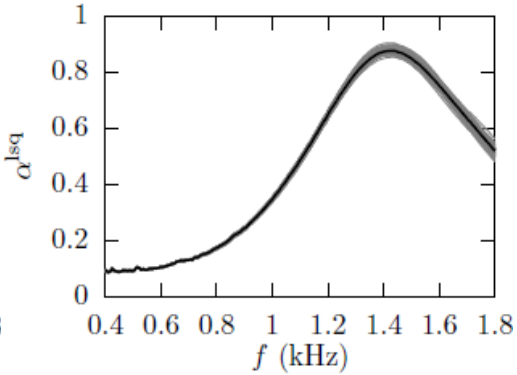






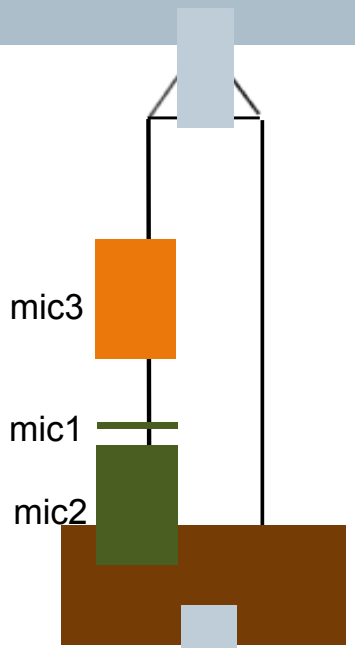




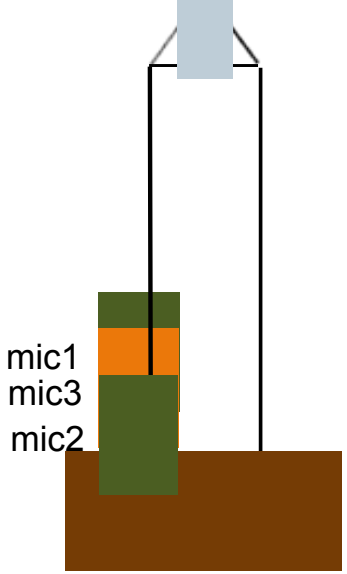


Agenda

3 microphones' tube

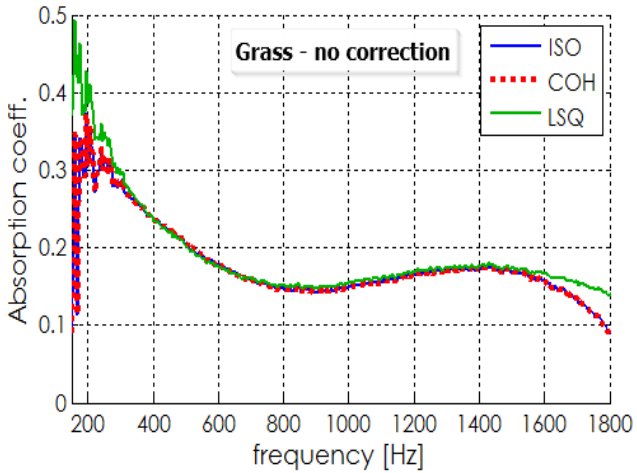


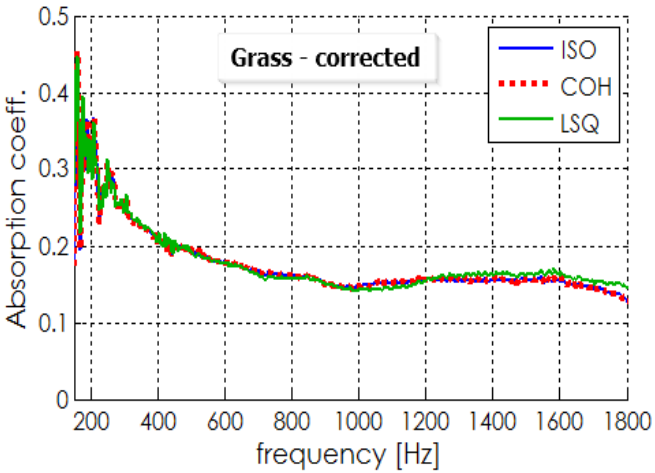
- Ideal test setup to validate LSQ method:
  - 3rd microphone beyond existing ones
  - Respect minimum distances from (cf. ISO 13472-2):
    1. Source
    2. Test ground



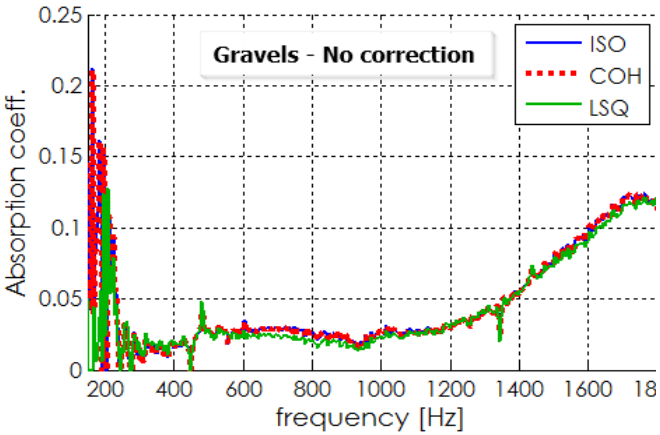
- Available test setup:
  - 3rd microphone placed between the 2 existing ones
  - Optimal positioning with regards to each coherence
  - Designed to test COH method with reflective grounds

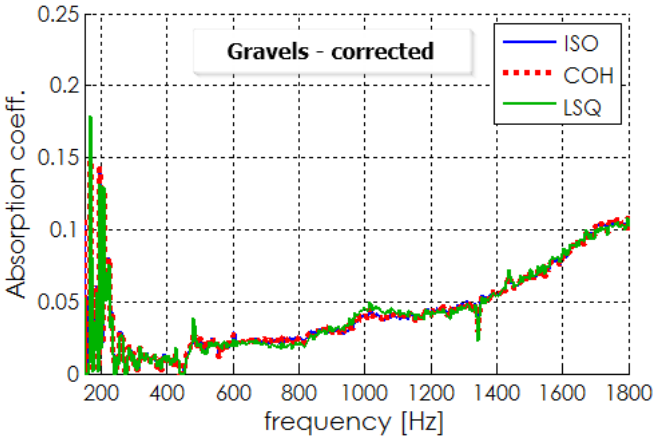
Grass ground and rigidly-backed gravels



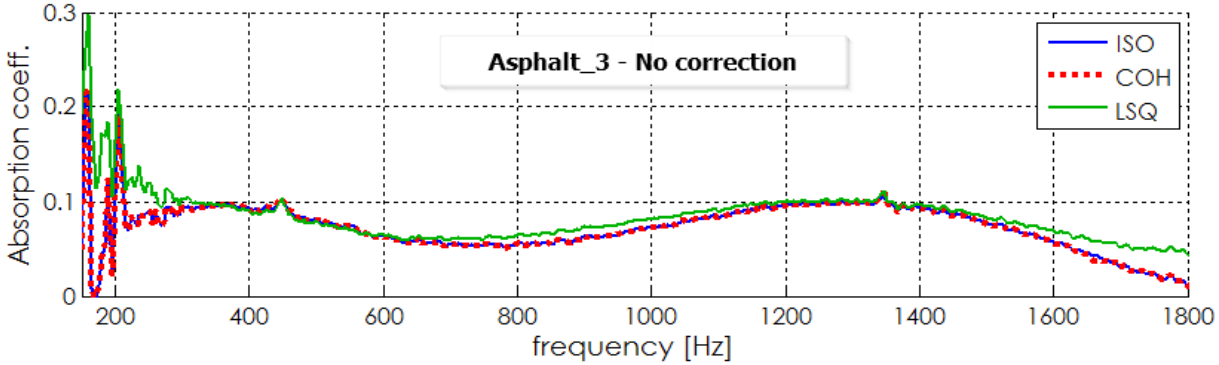


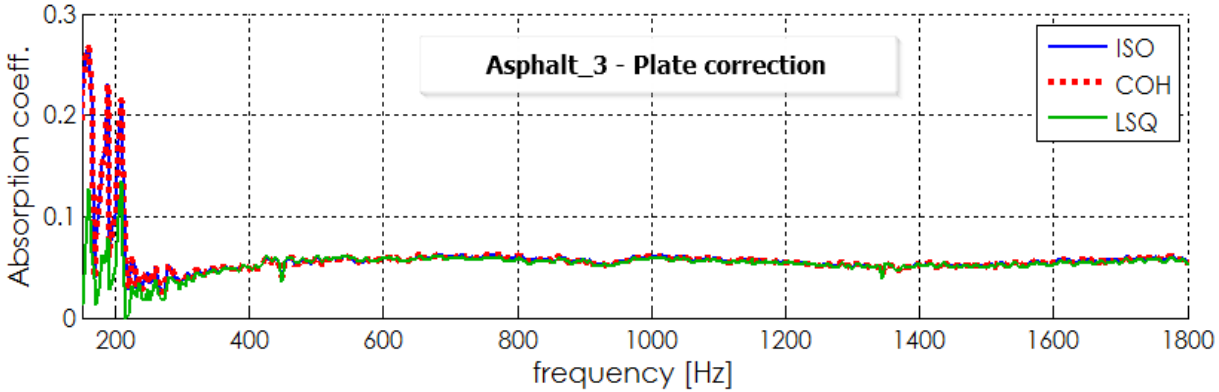
Gravels h=25mm

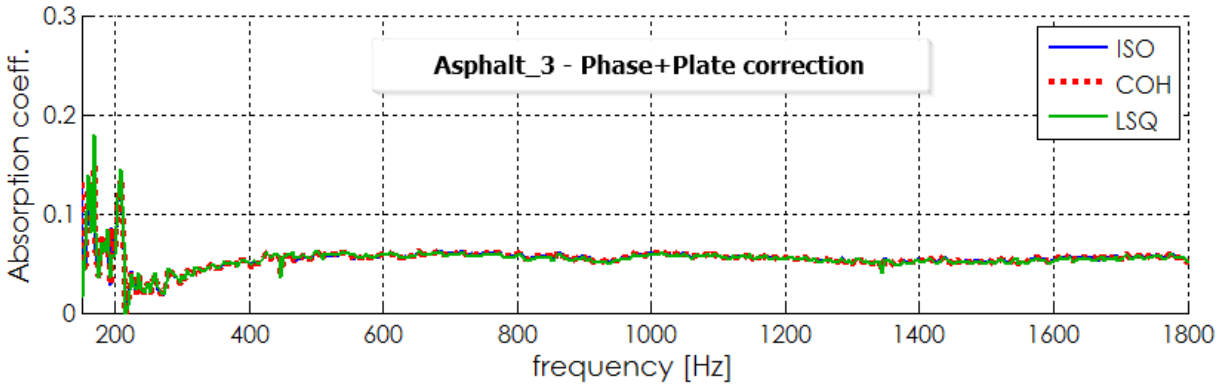




Asphalt ground







Agenda

Conclusions

- LSQ method: Single operation to get the absorption coefficient
  - No average of absorption coefficients per pair (*potentially quite different*)
  - More stable, reliable and flexible:
    1. Less uncertainties (more information)
       - Largely spaced microphones ➔ Increase low frequency accuracy
    2. Less sensitivity to microphones' spacings / phase errors
    3. The method allows enlarged designs for impedance tubes
- COH & LSQ methods: Identical to ISO methods for 2 microphones
- COH method: Reduce artifacts due to coherence loss

Next steps

- Build a new test impedance tube with largely spaced microphones
- Improve calibration procedure
- Plane-wave approximation: tube cross-section remains a limit!
  - Do some tricks:

What's the link to the impedance tube?

Try the LSQ method removing the tube!

POSTER @ SAPEM2014

sapem 2014
Symposium on the Acoustics of Poro-Elastic Materials
2014/12/16-18, Stockholm

Inverse estimation of the properties of porous ground surfaces from in-situ sound absorption measurements

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Summary

- A method is proposed for extracting a set of properties of porous ground surfaces from acoustic impedance measurements performed in situ.
- The ground is modelled as a layer of rigid-frame porous material using a model by Hamet and Bérengier, which consists of four parameters: the porosity, the tortuosity, the flow resistivity and the thickness of the material layer.
- The parameters are estimated as the underlying set of values which provide a best fit of model predictions onto experimental data.
- The model fitting process is formulated as an optimisation problem and the parameter search is automated using an optimisation algorithm.

Model

Porous ground surfaces can be modelled as rigid porous solids and approximated by an equivalent fluid where a single compressional wave exists.

Phenomenological model (Hamet and Bérengier [1])

$$\begin{cases} \text{Specific impedance: } Z_0(\omega) = \dfrac{\rho c A(\omega)}{\phi\, B(\omega)} \\ \text{Wavenumber: } k(\omega) = \dfrac{\omega}{c} A(\omega) B(\omega) \end{cases}$$

$$A(\omega) = \sqrt{K\left(1 - i\frac{\omega_\mu}{\omega}\right)} \qquad B(\omega) = \sqrt{\gamma\left(1 - \frac{1-1/\gamma}{1 - i\omega_\theta/\omega}\right)}$$

$\omega_\mu = \dfrac{\sigma\phi}{\rho K}$ and $\omega_\theta = \dfrac{\sigma}{\rho \mathrm{Pr}}$: viscous and thermal characteristic frequencies

Model parameters

- ϕ = porosity
- K = shape factor
- σ = flow resistivity
- h = thickness of the material layer

Properties of air

- $\rho = 1.2\,\mathrm{kg{\cdot}m^{-3}}$ (density)
- $c = 344\,\mathrm{m{\cdot}s^{-1}}$ (speed of sound)
- $\gamma = 1.4$ (ratio of specific heats)
- $\mathrm{Pr} = 0.71$ (Prandtl number)

Normal impedance of the ground

- Ground material backed by a rigid wall: $Z(\omega) = -iZ_0(\omega)\cot(k(\omega)h)$
- Ground material backed by a soft wall: $Z(\omega) = iZ_0(\omega)\tan(k(\omega)h)$
- Infinite material thickness: $Z(\omega) = Z_0(\omega)$

Reflection coefficient: $R(\omega) = \dfrac{Z(\omega) - \rho c}{Z(\omega) + \rho c}$

Sound absorption coefficient: $\alpha(\omega) = 1 - |R(\omega)|^2$

[1] J.F. Hamet and M. Bérengier. Acoustical characteristics of porous pavements: A new phenomenological model. In *Internoise 93*, pages 641–646, Leuven, 1993.

[2] J. Cuenca, C. Van der Kelen, and P. Göransson. A general methodology for inverse estimation of the elastic and anelastic properties of anisotropic open-cell porous materials—with application to a melamine foam. *J. Appl. Phys.*, 115(8):–, 2014.

[3] L. De Ryck, J. Cuenca, and K. Menino. Innovative estimation methods of in-situ sound absorption : Beyond the iso standards. In *SAPEM 2014*, Stockholm, 2014.

[4] K. Svanberg. A class of globally convergent optimization methods based on conservative convex separable approximations. *SIAM Journal on Optimization*, 12(2):555, 2002.

Inverse estimation method

The properties (ϕ, K, σ, h) of a porous ground surface are obtained as the set providing the best fit of the model onto on-site measurements of the sound absorption coefficient, following the methodology in Ref. [2]. The measurements may be performed using a standard two-microphone impedance tube, or more advanced methods [3].

Model curve-fitting formulated as an optimisation problem

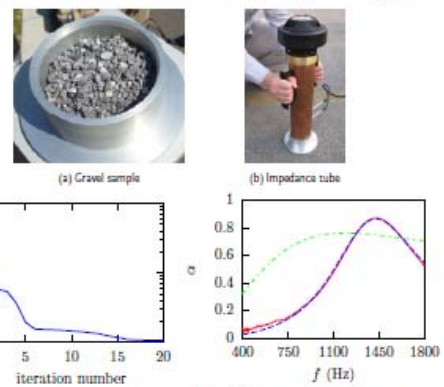
$$\min f_{\mathrm{obj}}(\mathbf{x}) = 1 + \sum_n |\alpha(\mathbf{x}, \omega_n) - \alpha_0(\omega_n)|^2$$

- $\alpha_0(\omega_n)$: measured absorption coefficient
- $\alpha(\mathbf{x}, \omega_n)$: absorption coefficient predicted by the model at frequency ω_n for a given set of parameters $\mathbf{x} = \{\phi, K, \sigma, h\}$

The problem is solved using an optimisation algorithm [4].

Validation on a rigid-backed gravel sample

The method is here validated on a 41 mm-thick sample of rigid-backed gravel.



(a) Gravel sample (b) Impedance tube (c) Evolution of the objective function (d) Sound absorption coefficient (full line: experiment; dashed-dotted line: arbitrary initial guess; dashed line: fitted model)

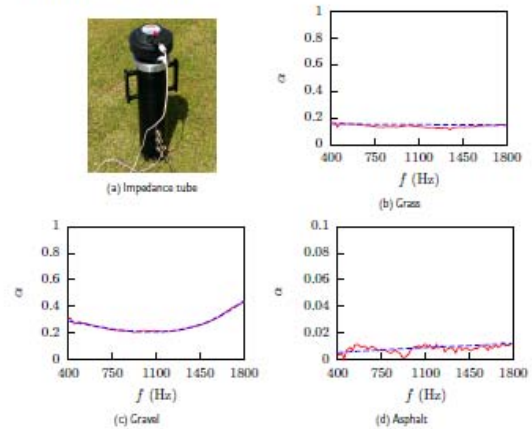
Figure 1: Rigid-backed gravel sample and curve fit.

Parameter	Symbol	Estimated value
Porosity	ϕ	0.155
Shape factor	K	1.54
Flow resistivity	σ	36824 N·s·m^{-4}
Thickness	h	0.0414 m

Table 1: Estimated parameters for a rigid-backed sample of gravel.

Application to in-situ ground measurements

The method is applied to the estimation of the properties of outdoor ground surfaces. On-site measurements of the sound absorption coefficient are performed on grass, gravel and asphalt.



(a) Impedance tube (b) Grass (c) Gravel (d) Asphalt

Figure 2: Sound absorption coefficient for different ground surfaces. (Same key as Fig. 1(d).)

Parameter	Symbol	Estimated value			unit
		Grass	Gravel	Asphalt	
Porosity	ϕ	0.1055	0.317	0.015	-
Shape factor	K	8.79	7.89	6.47	-
Flow resistivity	σ	10982	167503	19407172	N·s·m^{-4}
Thickness	h	-	0.024	-	m
Boundary condition		∞	F	∞	

Table 2: Estimated parameters for grass, gravel and asphalt.

Observations and conclusions

- A simple methodology has been developed for measuring a set of properties of the upper layer of a ground surface.
- The method is applicable to a homogeneous porous ground layer under the rigid-frame approximation.
- The simplified model does not capture the full complexity of the ground, such as its stratified nature or its inhomogeneity. In particular, a more detailed description of the boundary conditions at the interface between the tested layer and the soil underneath is required.

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Thank you!

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