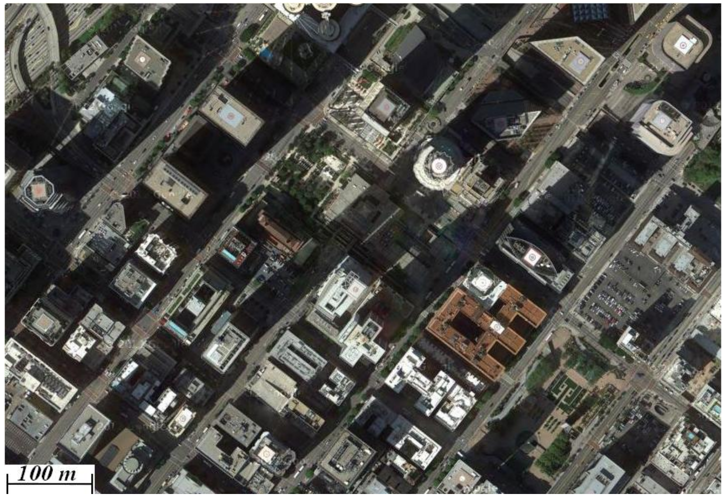
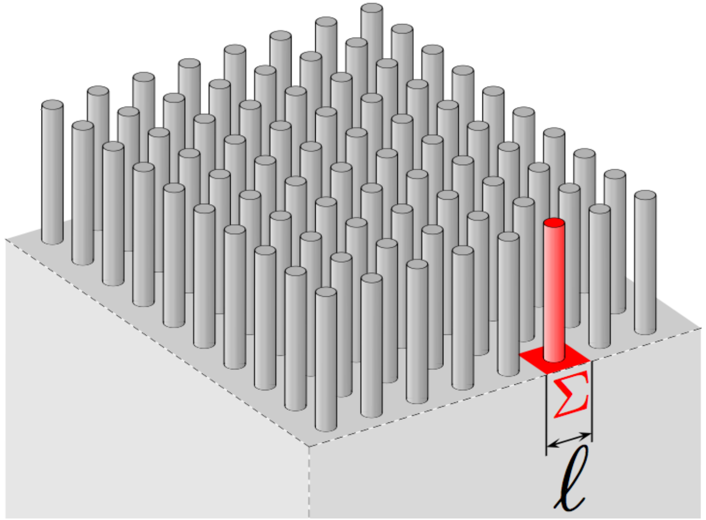
Content

Modeling the city as a resonating surface





Boutin C., Roussillon P. BSSA 2004 ; I.J.E.S. 2006

Schwan et al G.J.I. 2016

Basic ideas

Scale separation

MicroRepresentative Quarter / Γ		$\Sigma_0 = O(l^2)$
Periodic oscillators distribution		Forces : t / Γ
Macro	Incident wavelength	$L = \lambda/2\pi$
Separation	Low frequencies	$\varepsilon = l/L = 2\pi\, l/\lambda << 1$

Homogenisation

2 Space variables	$x \leftrightarrow \lambda/2\pi$	$y \leftrightarrow l$	$y = x/\varepsilon$
Asymptotic expansions	$u = \Sigma\, \varepsilon^i u^i \quad \sigma = \Sigma\, \varepsilon^i \sigma^i$	….	
Micro perturbations / Γ	**Boundary layer**		

Macroscopic Description

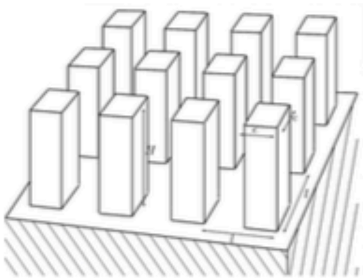
Leading Order

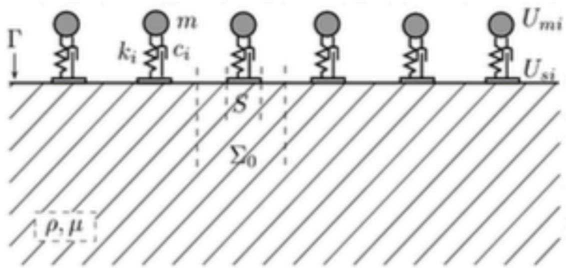
Dynamic balance $\quad div_x (C:e_x(u^0)) = -\rho\omega^2 u^0$

Boundary condition / Γ $\quad [C:e_x(u^0)].n_\Gamma = <t^0>_{\Sigma 0}$ ➔ Mean stress^0

BL field* $\approx \Gamma$ $\quad u^{*1}(x_\Gamma, y) = A(y). <t^0>_{\Sigma 0}$

Distribution of Oscillators





Surface forces

$t = F(\omega)/S = [Z]/S\, i\omega\, U_b \qquad U_b = < u + u^* >_S = u^0 + \varepsilon <u^1 + u^{*1}>_S + \varepsilon^2 \ldots$

[Z] Impedance Matrix

Experimental evidence of the boundary layer

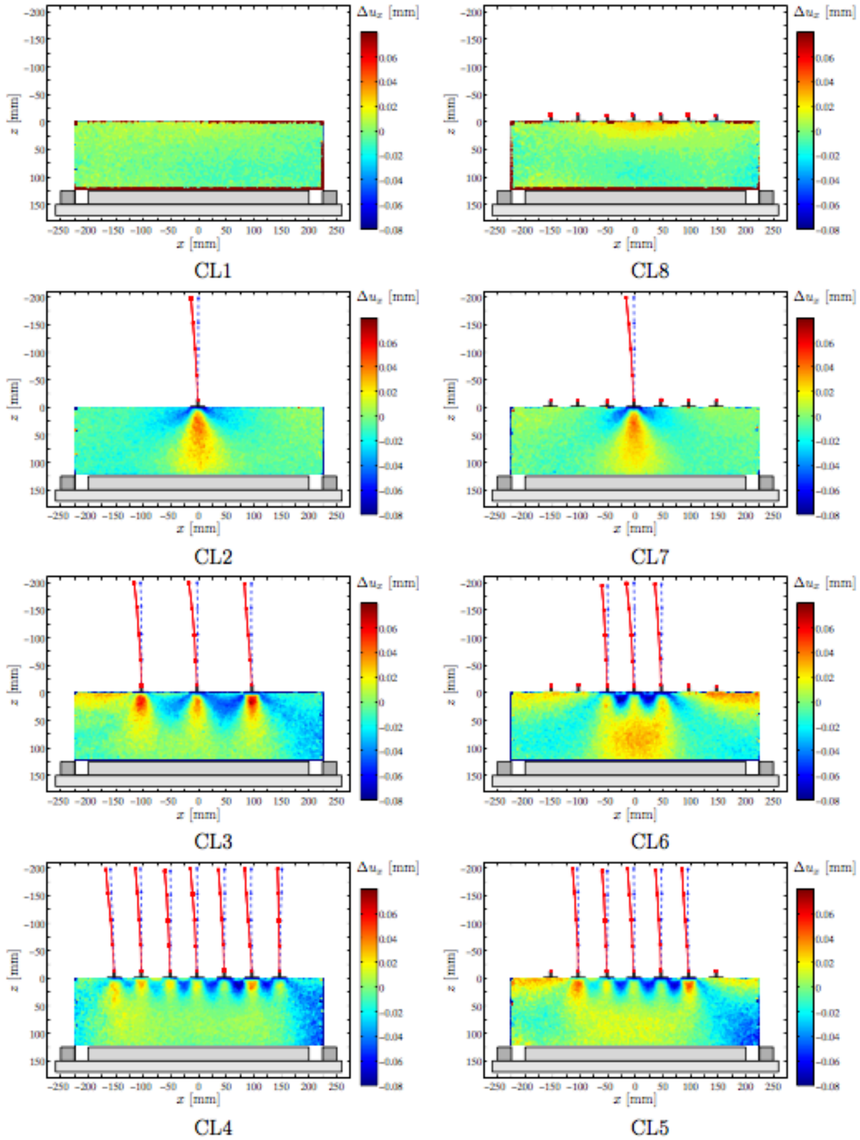


Figure 5.11 : *Mesure par corrélation du déplacement horizontal dans la couche élastique pour les différentes configurations de métasurface résonante. Représentation de la différence $\Delta u_x = u_x - \overline{u_x}$ entre le déplacement total $u_x(t_0, x, z)$ mesuré et*

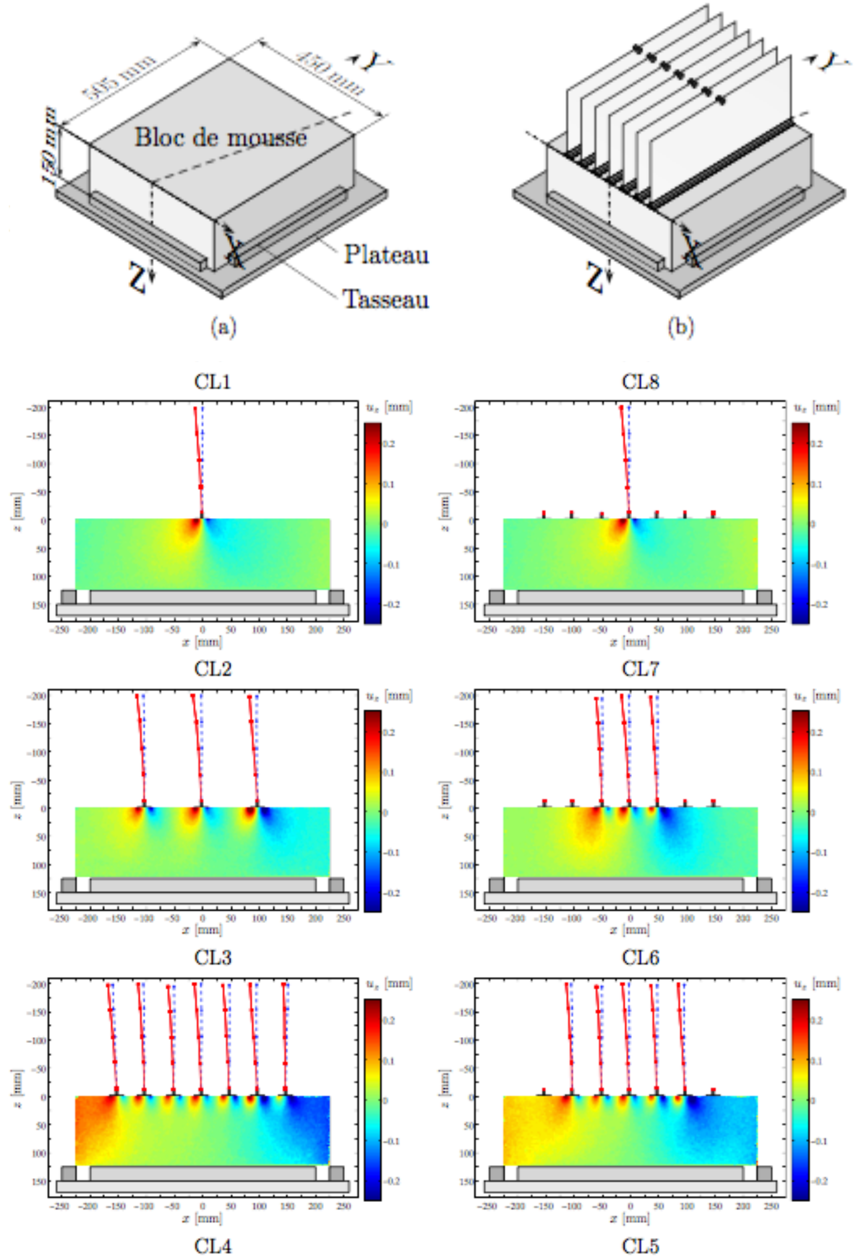


Figure 5.8 : *Mesure par corrélation des champs de déplacements verticaux u_z dans la couche élastique pour les différentes configurations de métasurface résonante.*

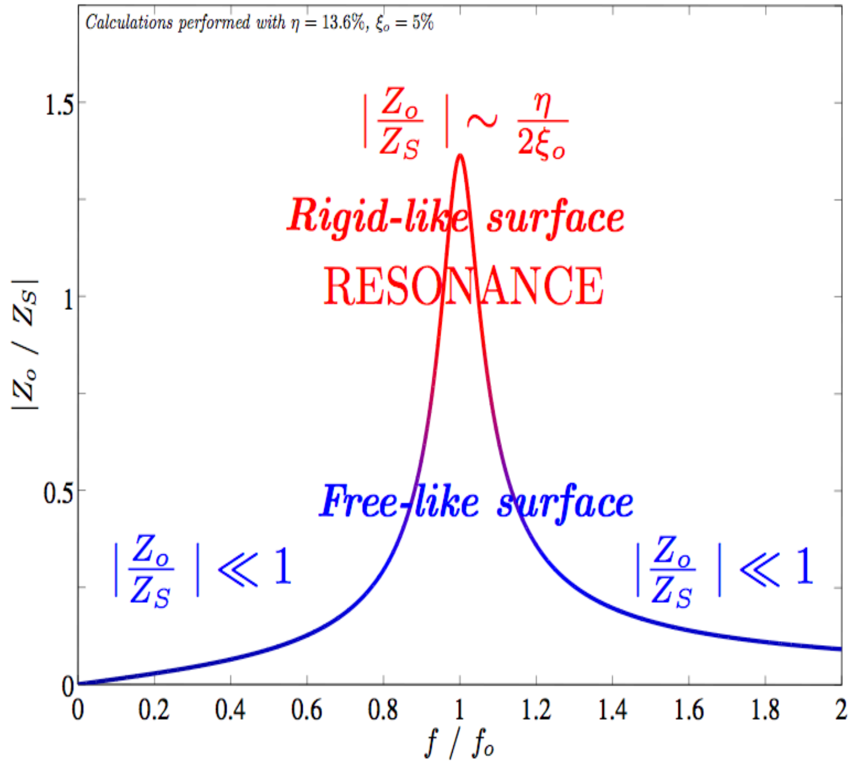
Macro boundary condition

Equivalent Impedance of the «city»

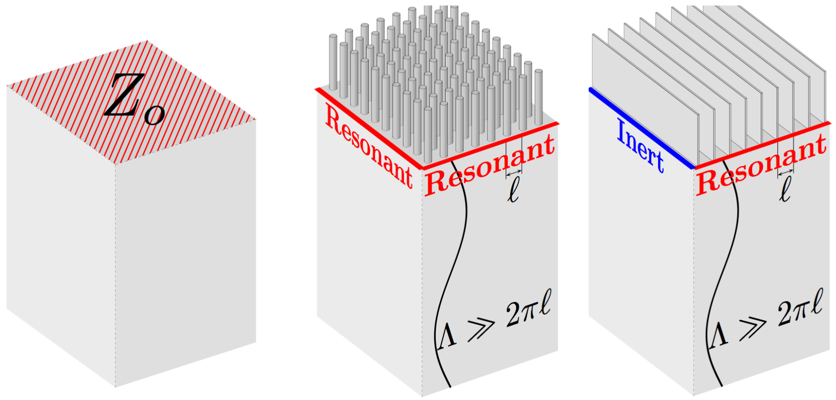
$$[C{:}e_x(U^0)].n_\Gamma - [Z^0]\, i\omega\, U^0 = 0$$

$$\frac{Z_o}{Z_S} = \boldsymbol{\eta}\, \frac{i\frac{f}{f_o} + 2\xi_o \frac{f^2}{f_o^2}}{1 - i2\xi_o \frac{f}{f_o} - \frac{f^2}{f_o^2}}$$

$$\boldsymbol{\eta} = \frac{m_o\, 2\pi f_o}{|\Sigma| \sqrt{\rho\mu}}$$



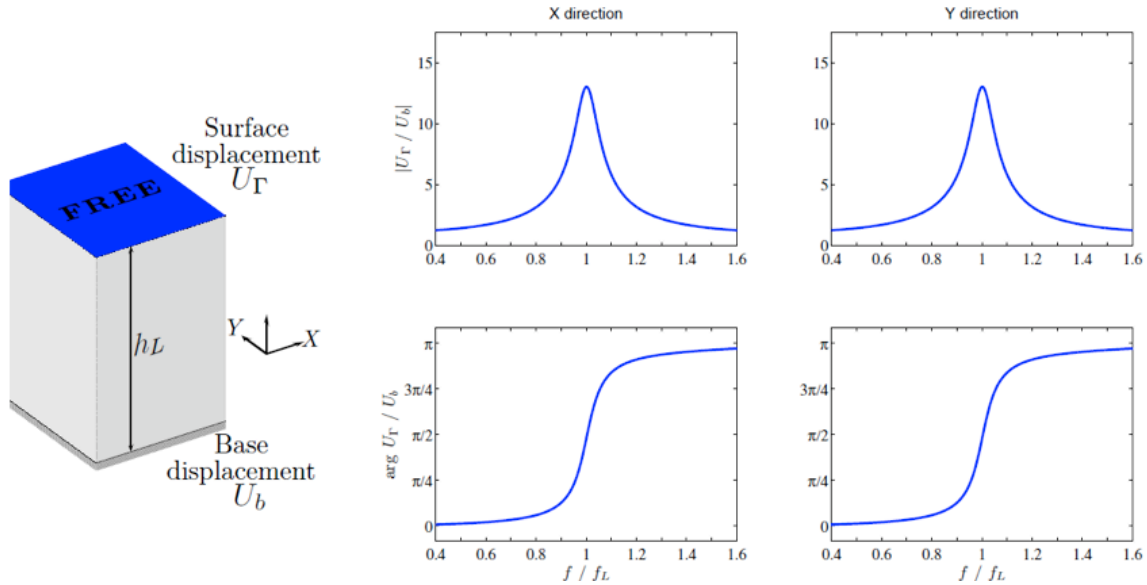
Unconventional mixed conditions



City resonance = Layer resonance

No city

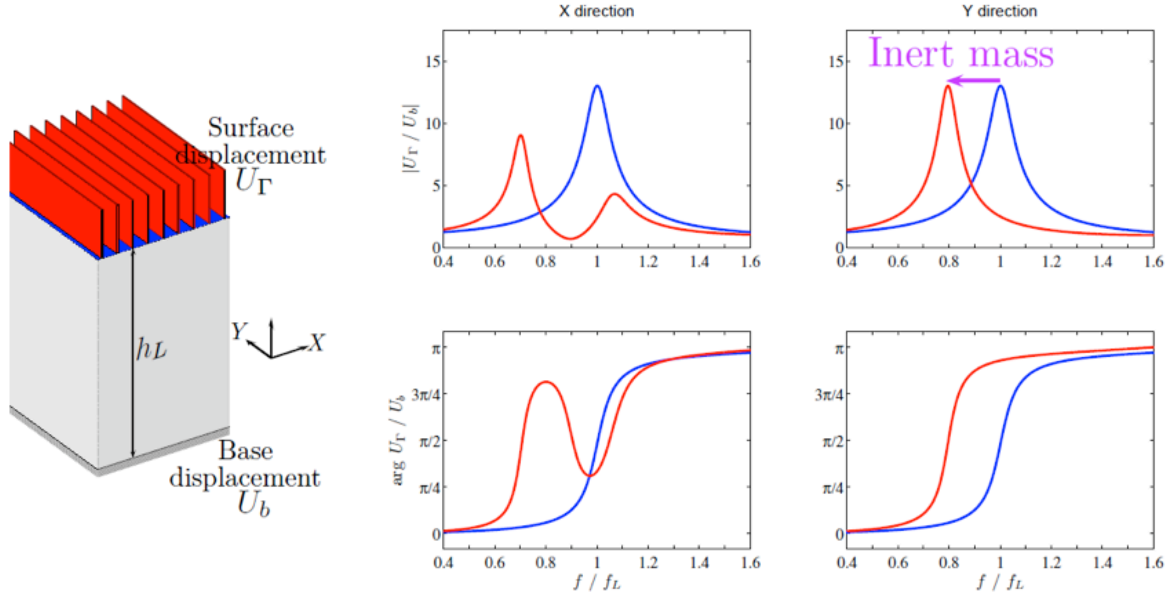
Identic response in X&Y



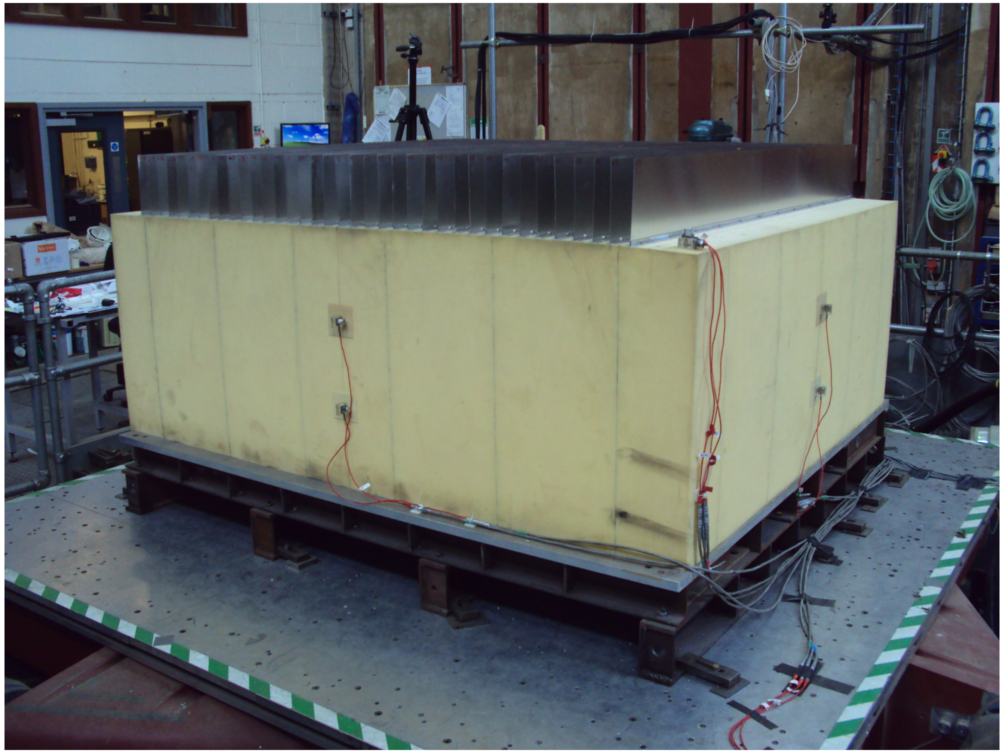
Anisotropic city

Anti resonance in X

Shift in Y



Experiments



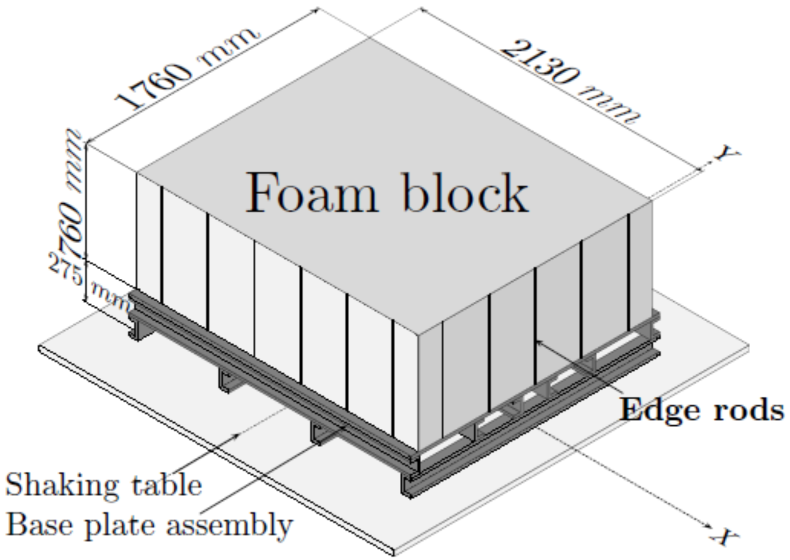
Shaking Table (Blade) - Bristol University

Series project (EU)

Design

Layer

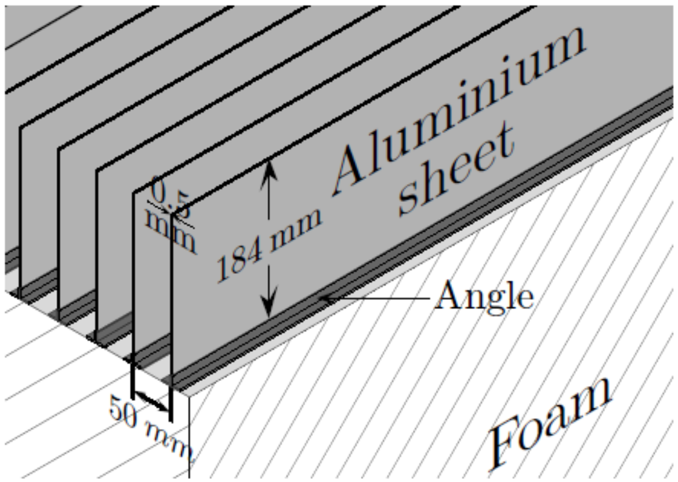
- Elastic, linear, isotropic
- Eigenfrequency $f_L < 15\ Hz$
- Aspect ratios > 2



- $h_L = 76\ cm$
- $f_L = 9.36\ Hz$ in X ($9.11\ Hz$ in Y)
- $\xi = 4.9\ \%$

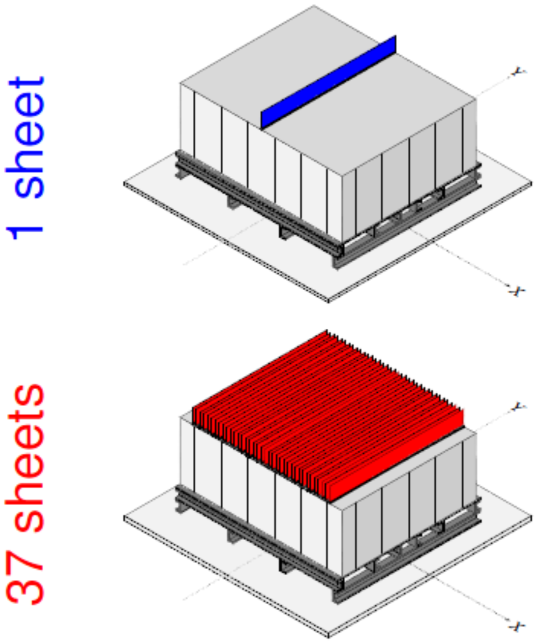
City

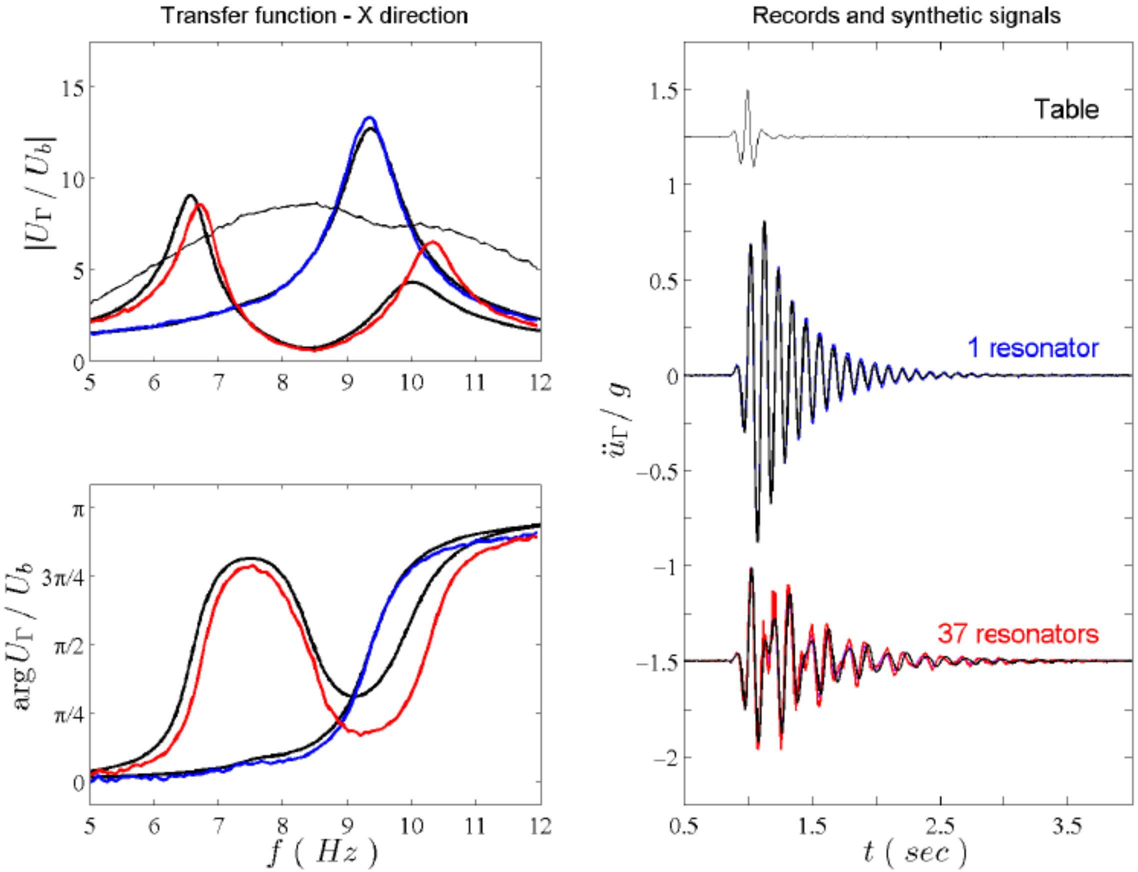
- Period width $\ell \ll \Lambda$ Wavelength
- Eigenfrequency $f_o \approx f_L$
- Modal mass $m_o \sim$ Mass of layer under period



- Period width $\ell = 5\ cm$
- $f_o \approx 8.4\ Hz \quad \xi_o \approx 5\ \%$
- $\eta \approx 13.6\%$ (*Mexico* : $\eta \sim 10\%$)

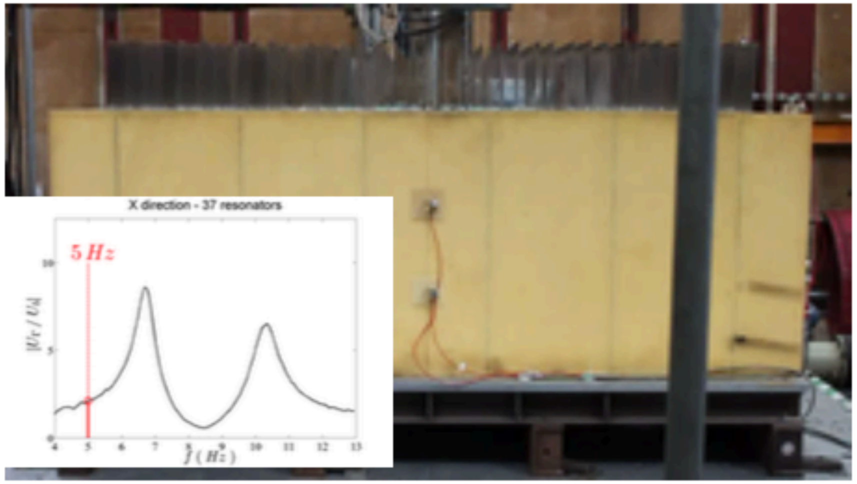
Drastic changes in records

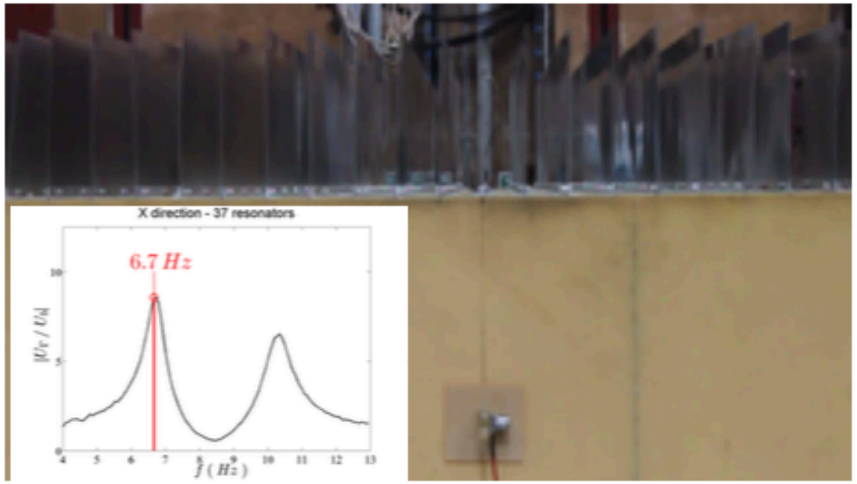


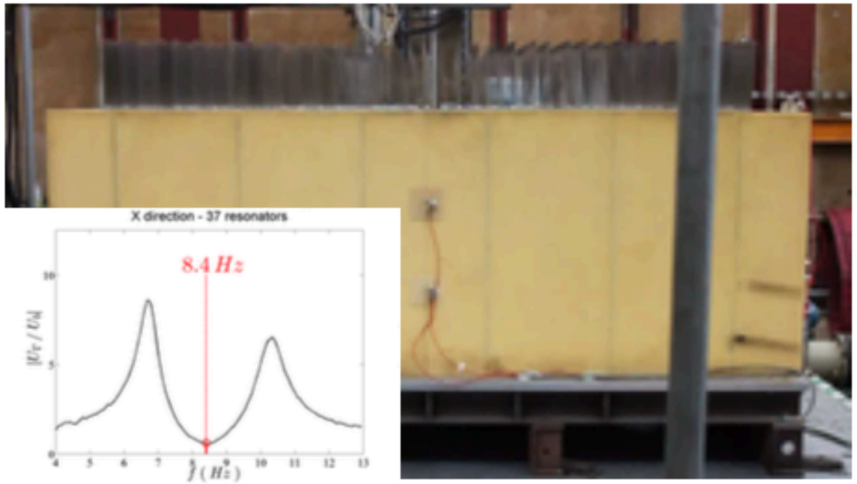


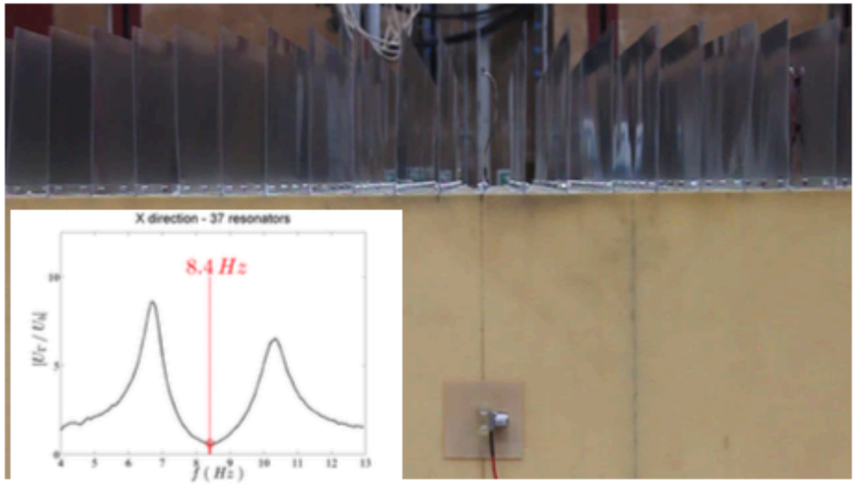
- 1 sheet : usual temporal response of a layer
- 37 sheets : drastic change in shape of records and lower amplitude
- City impedance analysis is accurate temporaly

Drastic change in modal shapes - videos

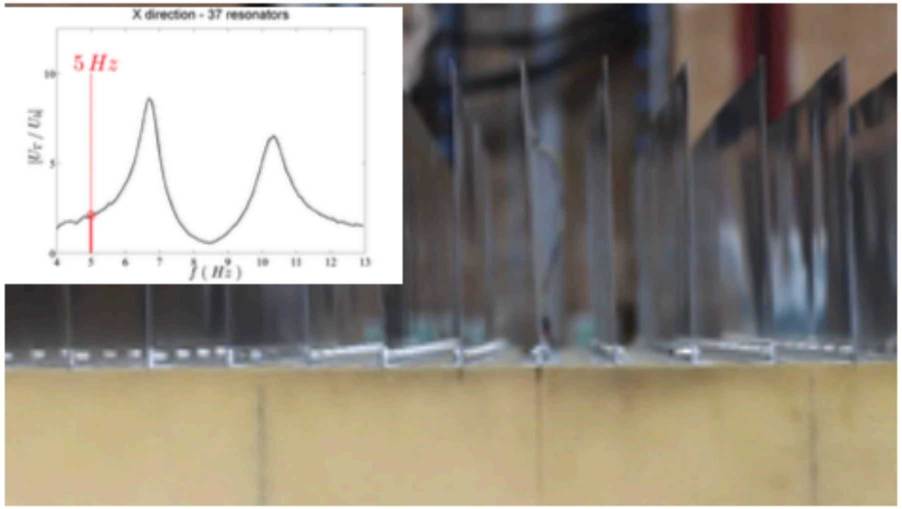


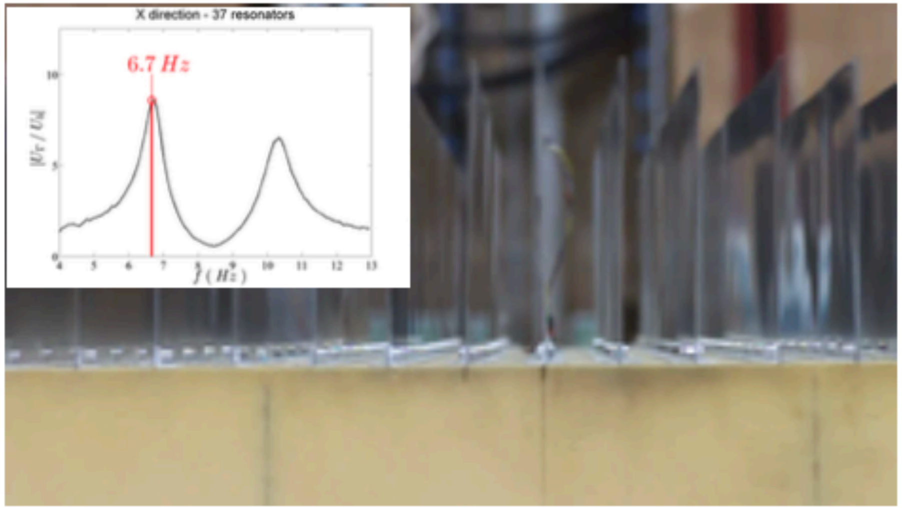


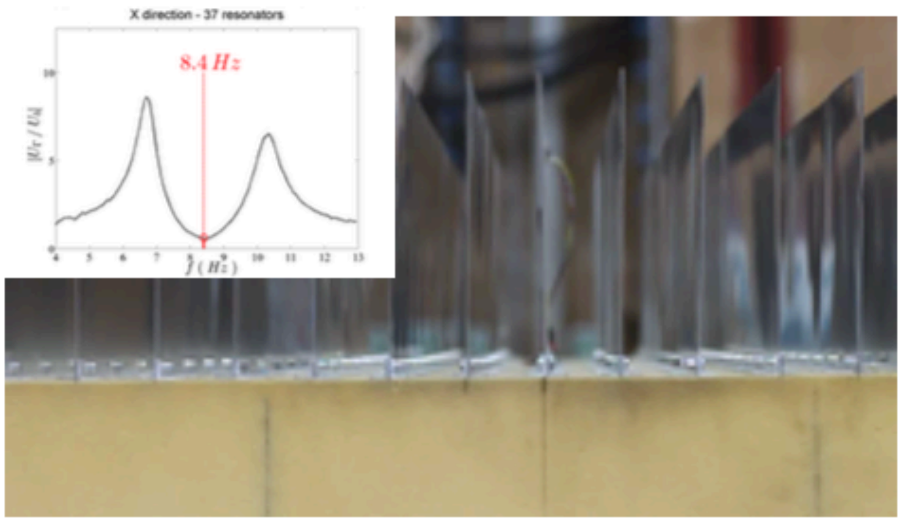


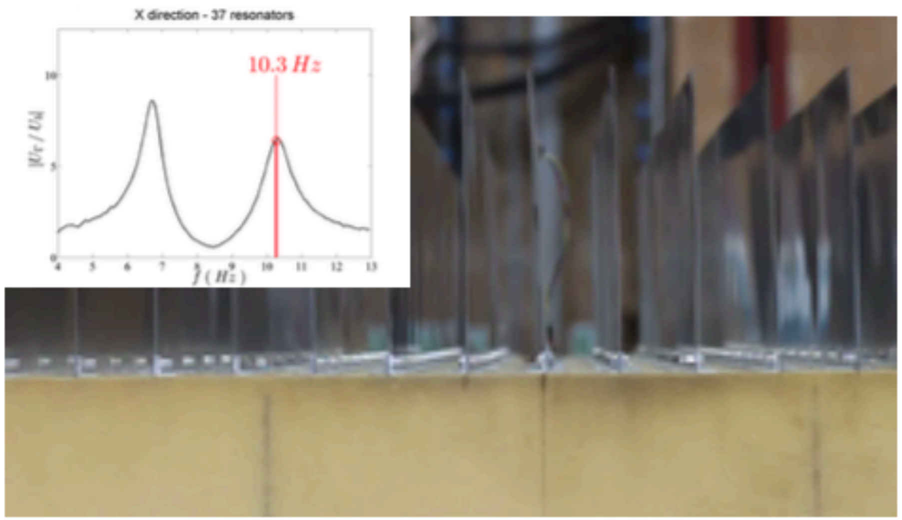


Other videos

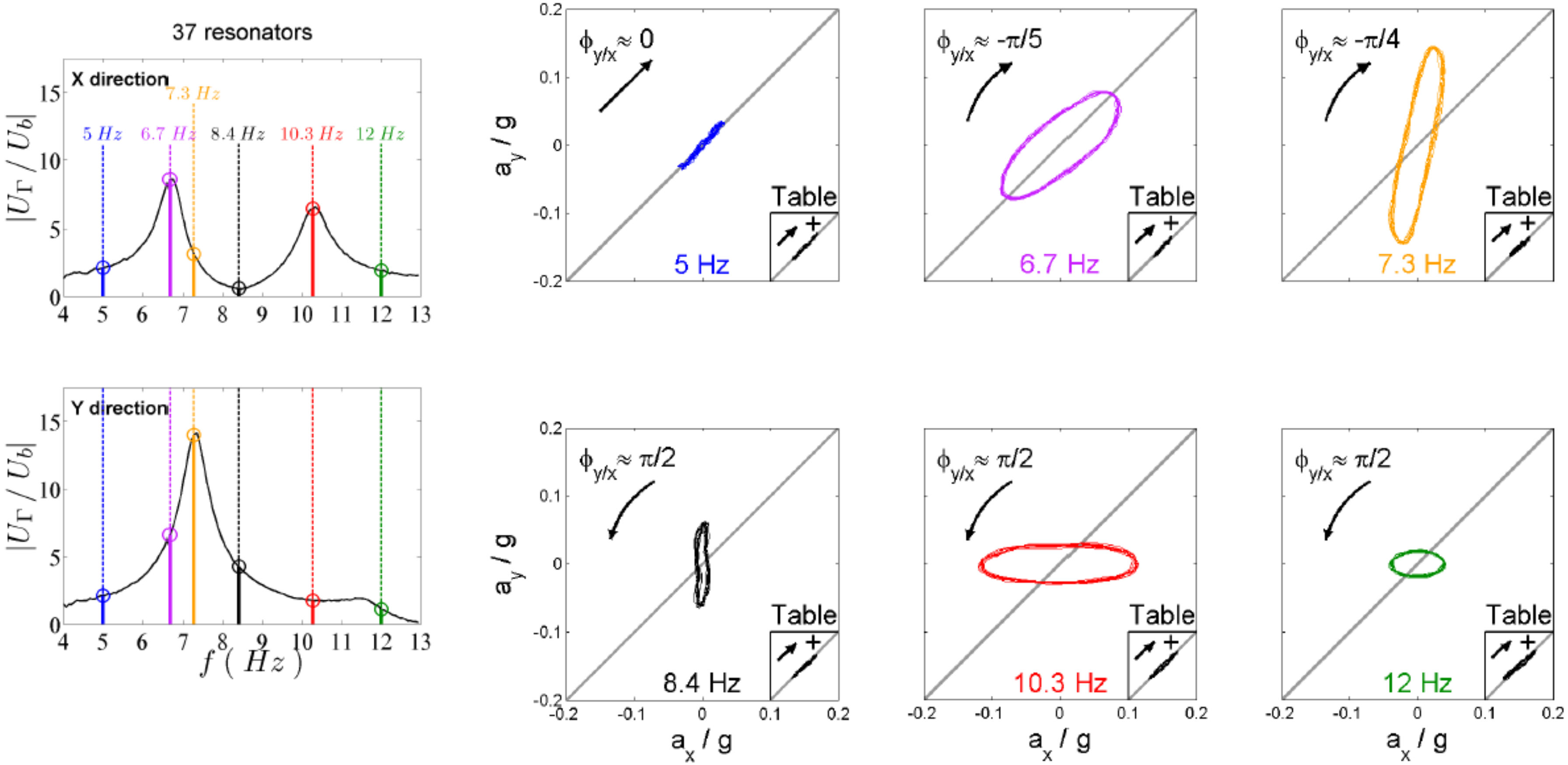








Depolarization



Depolarization :

- frequency-dependent
- due to surface anisotropy
- Affects : direction, ellipticity, orientation

Learnings

2D transposition

Scale separation	&	Codynamic regime
3D-Large wavelenght	&	Local resonance
Forcing motion		Forced regime

Effect of the resonator

Boundary layer (quasi-static regime)

Effective unconventional impedance — Mixed boundary conditions : Free/rigid

Physics of the resonator

According to spatial orientations — Mode conversion

Depolarization

High dispersion and band gaps

Conclusion on Inner resonance ...

General principles for design $\varepsilon = 2\pi\, l/\Lambda \approx \lambda_R / \Lambda_C$

Carrying constituent connected & Resonant constituent

Forcing	Forced regime
High contrast	Morphology or Parameters

Resonant constituent : Source term on the **macroscopic balance**

Momentum balance	Unconventional mass
Mass balance	Unconventional stiffness

Local out of equilibrium regime

Elasto-inertial resonator	High dispersion and band gap
Visco-inertial resonator	Enhanced damping

Tunable design of interest for

Civil engineering ; Structures; Acoustics

... and on homogenisation

Scale separation enables

Handle ill conditionned problems

High contrasts - geometric ; mechanic

Adress 1D, 2D, 3D problems

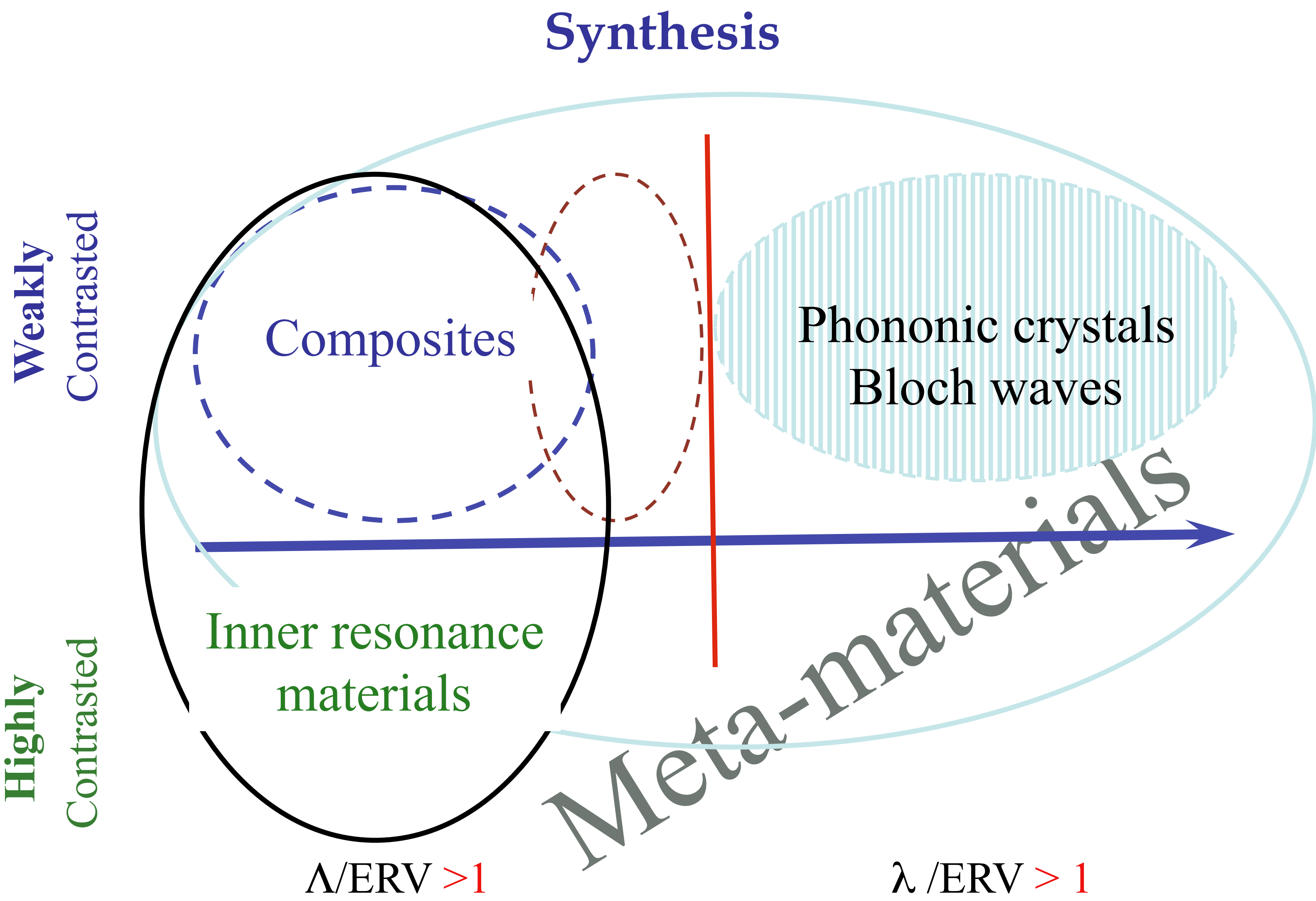
Quasi-analytical formulations

Provide parametrized unconventional descriptions

Higher gradient continuum

Meta-materials / Meta-surface

Of interest for engineering practice (from nano to metric scale)


Synthesis
Weakly
Contrasted
Composites
Phononic crystals
Bloch waves
Inner resonance
materials
Highly
Contrasted
Meta-materials
Λ/ERV >1
λ /ERV > 1

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P. Fossat

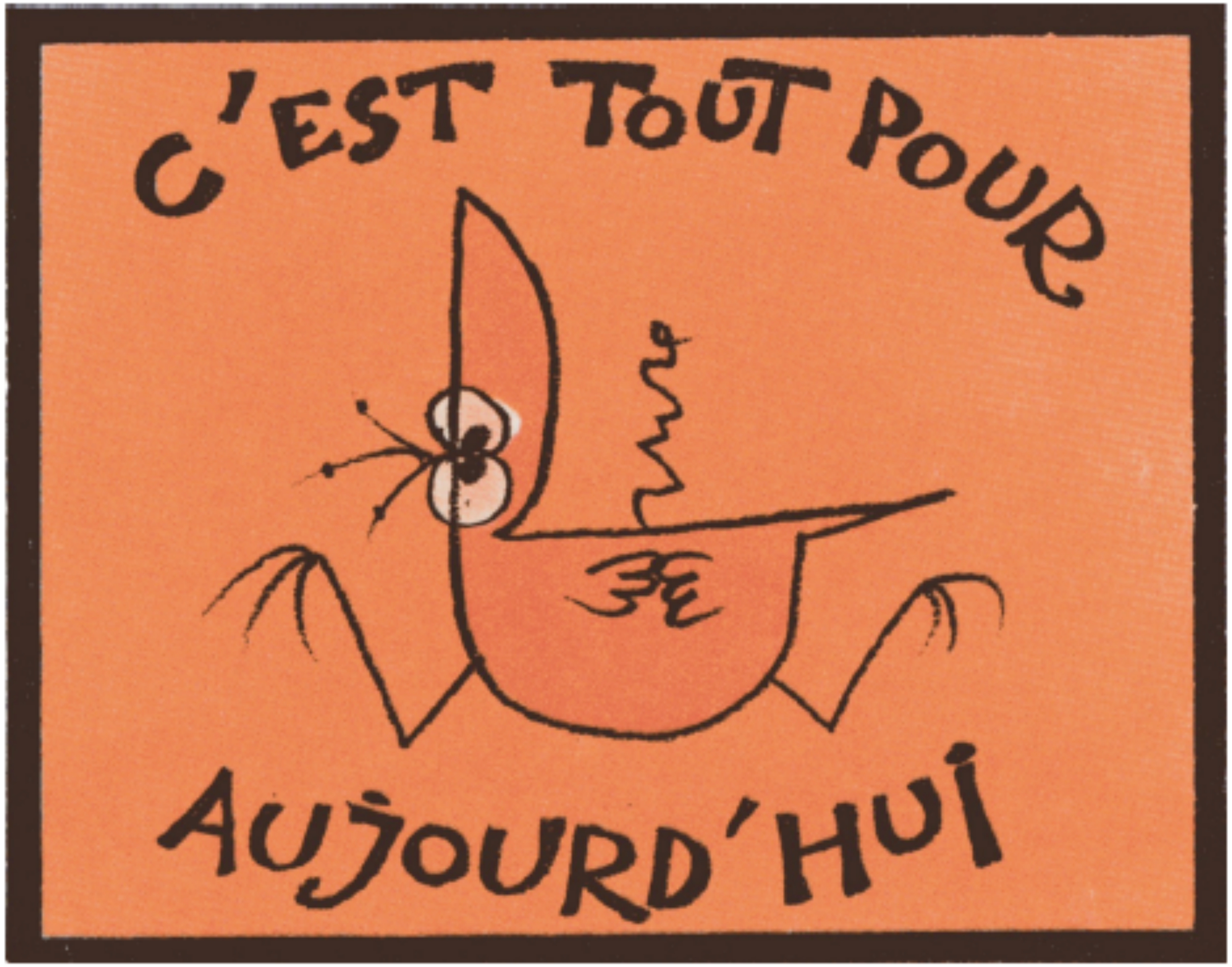
S. Hans

X. Olny

L. Schwan

J. Soubestre

Merci de votre attention !


C'EST TOUT POUR
AUJOURD'HUI

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