Acoustic properties of hollow brick walls

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Outline

- Introduction / Objectives

- An hybrid homogenization process for STL computation
  - Existing approaches
  - Approach suggested

- Results / Discussion

- Conclusion and outlook
Introduction

Hollow fired clay blocks: what for?

- **Thermal properties** improved thanks to the alveolar pattern of the brick
- Lightweight structures mean better handiness on building sites...

- Very few studies lead on their acoustic features

This work aims at designing an appropriate model to understand and predict the acoustic properties of alveolar brick walls
Sound transmission loss (STL) measured

Experimental STL of 30cm thick hollow brick walls

- Complex acoustic properties! (*inhomogeneous, anisotropic and thick walls*)

\[ R_{\text{mass}} \approx 20 \log \left( \frac{\pi f \rho_s}{\rho_{\text{air}} c_{\text{air}}} \right) \]
An hybrid homogenization process for STL computation

A) Existing approaches :

1) **Finite element method** (FEM)  
   *(Jean & al. acta acustica 2002, Jean & al. 2006 Building acoustics etc…)*
   
   - Complex partitions require fine approaches => FEM
   - Too time consuming if many cavities/ thickness

2) « Semi-analytical » approach  
   *(Maysenholder & al. acta acustica 2003)*
   
   - Complete model to deal with periodically inhomogeneous plates
   - **Unsuitable** solution for complex masonry walls
B) Approach suggested: An homogenized vibratory model

- The hollow brick wall is treated as an equivalent thick orthotropic plate.

**Analytical model** which considers **ALL Lamb modes** in the homogenized brick wall (Skelton & al. JSV 1992)

\[ \tau(f, \theta, \varphi) = |T|^2, \quad T = \frac{2ZL}{L_{12} L_{21}} - \frac{L_{21}}{(L_{11} + Z)(L_{22} - Z)}, \quad Z = \frac{\rho_a c_a}{\cos(\theta)} \]

\[ \tau_{\text{finite}}(f, \theta, \varphi, L_x, L_y) = \tau(f, \theta, \varphi) \sigma(k_a \sin(\theta), \varphi, L_x, L_y) \]

\[ \text{STL} = -10 \log(\tau_f^d) \]

**Problem:** \[ L_{ij}^{eq} = F(\rho_{eq}, C_{\alpha \beta}^{eq}, \ldots) \] Properties of the effective medium ???
Homogenization process:

Complex hollow block

Equivalent homogeneous and anisotropic brick

Numerical modelling (FEM) of mechanical loadings applied to one block:

+ deal with complex geometries

+ consider the elastic properties of the brick material

\[
a \ll \frac{\lambda_{\text{vib}}}{2}
\]
Results

➢ Comparison Measurements / Predictions

\[
\begin{align*}
\rho_s & \approx 125 \text{kg.m}^{-2} \\
20\text{cm thick wall (plastered on one face)}
\end{align*}
\]

\[
\left\{ 
\begin{array}{l}
\rho \approx \frac{m}{V} \approx \frac{\text{mass}}{\text{volume}} = 125 \text{kg.m}^{-2} \\
\rho \text{ is the density.}
\end{array}
\right.
\]

Critical frequency zone

\[
f = f_{c_\text{x}} = \frac{c_a^2}{2\pi h} \sqrt{\frac{12 \rho_{\text{eq}}}{C_{11}^{\text{eq}}}}
\]

\[
f = f_{c_\text{y}} = \frac{c_a^2}{2\pi h} \sqrt{\frac{12 \rho_{\text{eq}}}{C_{22}^{\text{eq}}}}
\]

S1 Lamb mode resonance

\[
f = f_{s_1} = \frac{1}{2h} \sqrt{\frac{C_{33}^{\text{eq}}}{\rho_{\text{eq}}}}
\]

\[
h \uparrow, \rho \uparrow, C_{33}^{\text{eq}} \downarrow \downarrow : \text{unfavourable!}
\]

Experimental

Thick homogenized plate model

Thin plate approximation
Conclusion

• **Hybrid** approach to compute the STL of a hollow brick wall

• Relevance of the homogenization process:

  1) Wide critical zone induced by the anisotropy of the block (**A0 Lamb mode**)

  2) Very low stiffnesses + Thick blocks \{ Thickness vibrations caused by higher order Lamb modes \}

• Importance of many parameters in practice (materials, loss factor…)

• Further work: design of « acoustic » hollow brick, coupling acoustic and thermal requirements …
Appendix

Effectif elastic tensors of hollow blocks studied

\[
C_{\alpha\beta}^{eq} = \begin{pmatrix}
C_{11} = 0.52 & C_{12} = 0.28 & C_{13} = 0.02 & 0 & 0 & 0 \\
C_{12} = 0.28 & C_{22} = 2.3 & C_{23} = 0.09 & 0 & 0 & 0 \\
C_{13} = 0.02 & C_{23} = 0.09 & C_{33} = 0.45 & 0 & 0 & 0 \\
0 & 0 & 0 & C_{44} = 0.42 & 0 & 0 \\
0 & 0 & 0 & 0 & C_{55} = 0.22 & 0 \\
0 & 0 & 0 & 0 & 0 & C_{66} = 0.3
\end{pmatrix}_{\text{GPa}}
\]

\[
C_{\alpha\beta}^{eq} = \begin{pmatrix}
2.34 & 1.34 & 0.02 & 0 & 0 & 0 \\
1.34 & 7.53 & 0.03 & 0 & 0 & 0 \\
0.02 & 0.03 & 0.13 & 0 & 0 & 0 \\
0 & 0 & 0 & 0.63 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.06 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.82
\end{pmatrix}_{\text{GPa}}
\]
Importance of experimental characterization

1) Brick material

- R expérimental
- Tesson caractérisé
- E=10GPa
- E=5GPa

Ultrasonic measurements

<table>
<thead>
<tr>
<th>Density ($\text{kg/m}^3$)</th>
<th>$C_{11}$ (GPa)</th>
<th>$C_{12} = C_{33}$ (GPa)</th>
<th>$C_{44}$ (GPa)</th>
<th>$C_{66}$ (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800±5</td>
<td>3.7±0.3*</td>
<td>11±0.5*</td>
<td>3.9±0.4*</td>
<td>2±0.2*</td>
</tr>
</tbody>
</table>

2) Loss factor

- R expérimental
- Pertes mesurées
- eta=2%

\[ \eta \cong \frac{2.2}{f \times T_r} \]
Derivation of the homogenized elastic constants

\[
E_i = -\frac{F_i L_i}{S_i} \\
\nu_{ij} = -\frac{\varepsilon_j}{\varepsilon_i} = -\frac{u_j L_i}{L_j} \\
\gamma_{ij} = \alpha + \beta \approx \frac{u_i(L_j)}{L_j} + \frac{u_j(L_i)}{L_i} = 2
\]
Additionnal results

37.5cm thick wall (plastered on one face)

- Experimental
- Thick plate model
- Thin plate approximation

\[ \rho_s \approx 400 \text{ kg.m}^{-2} \]

\( f(\text{Hz}) \) vs \( \text{STL (dB)} \)