Numerical modelling of impact noise

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Outline

- Motivation

- Approach to the problem
  - Modelling the impact force
  - Computing the displacement field and the radiated power
  - Obtaining the outputs of interest

- Developed models
  - Infinite plates
  - Modal analysis for finite plates
  - Coupled plates

- Conclusions
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**Impact noise:** noise level in rooms due to the impact of an object hitting the building structure.

Situation: Current trend of the regulations is restrictive (*i.e.* Código Técnico de la Edificación).

88 dB (NBE-CA-88) → 65 dB (April 2009)
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Approach to the problem

Three main methods:

- Energy average thinking (SEA)
- Simplified methods
- Solving vibroacoustic equations by means of numerical methods
  - Modelling the impact force
  - Computing the displacement field
  - Obtaining the radiated power
  - Computing the outputs of interest
Modelling the impact force

- Excitation: point force (tapping machine).
- Modelling: influence of the floor characteristics.
- Formulation: proposed by Brunskog.
Computing the displacement field and the radiated power

- Displacement field: governing equation
  \[ D \Delta^2 \hat{u} - \omega^2 \rho_s \hat{u} = q \]
  where \( \hat{u} = \hat{u}(x, \omega) \).

- Radiated power: generic expression
  \[ \Pi_{rad} = \int_{s} \mathbf{l} \cdot \mathbf{ds} = \frac{1}{2} \text{Re} \left( \int_{s} p \hat{\mathbf{v}}^* \, ds \right) \]
  where \( \hat{\mathbf{v}} = j\omega \hat{u} \).
Obtaining the outputs of interest

- Normalised impact noise pressure level ($L_n$)
  \[ L_n = 10 \log \left( \frac{\Pi_{Rad}}{p_{ref}^2} \frac{4\rho c}{A_0} \right) \text{ dB}. \]
- Adjusted normalised impact noise pressure level ($L_{n,w}$).
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Models for a single plate

Infinite plate radiating into an infinite half-space

- Widely used. Detailed in the bibliography.
- Implies spatial Fourier transformation of the displacement.

\[
\tilde{u} = \frac{F_0 e^{i(\alpha x_0 + \beta y_0)}}{D (\alpha^2 + \beta^2)^2 - \rho_s \omega^2}
\]

\[
\Pi_{rad} = \frac{k \rho c}{8\pi^2} \int \int_{\alpha^2 + \beta^2 \leq k^2} \frac{\omega^2 |\tilde{u}(\alpha, \beta)|^2}{\sqrt{k^2 - \alpha^2 - \beta^2}} d\alpha d\beta
\]
Models for a single plate

Finite plate simply supported along its edges

\[ \hat{u}(x, y) = \sum a_{pq} \Psi_{pq}(x, y) \]

- The eigenfunctions of the plate can be found analytically

\[ \Delta^2 \Psi_{pq} - k_{pq}^4 \Psi_{pq} = 0 \Rightarrow \Psi_{pq} = \sin \left( \frac{p\pi}{L_x} x \right) \sin \left( \frac{q\pi}{L_y} y \right) \]

- Modal contributions are uncoupled

\[ a_{pq} = \frac{4 F_0 \Psi_{pq}(x_0, y_0)}{(D k_{pq}^4 - \omega^2 \rho_s) L_x L_y}; \quad \Pi_{\text{rad}} = \frac{\omega \rho}{4\pi} \int \int \hat{\nu}(x', y') \hat{\nu}^*(x, y) \frac{\sin(kr)}{r} d\Omega d\Omega' \]
Comparison with experimental measurements
**Parametric analysis**

**Thickness**

<table>
<thead>
<tr>
<th>h (m)</th>
<th>$L_{n,w}$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>88</td>
</tr>
<tr>
<td>0.1</td>
<td>80</td>
</tr>
<tr>
<td>0.2</td>
<td>72</td>
</tr>
<tr>
<td>0.4</td>
<td>62</td>
</tr>
</tbody>
</table>
Parametric analysis

Loss factor

\[
\eta \ \text{L}_n, w \ (\text{dB})
\]

<table>
<thead>
<tr>
<th>(\eta)</th>
<th>(L_{n,w}) (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 %</td>
<td>97</td>
</tr>
<tr>
<td>1.5 %</td>
<td>80</td>
</tr>
<tr>
<td>3 %</td>
<td>77</td>
</tr>
<tr>
<td>4.5 %</td>
<td>75</td>
</tr>
</tbody>
</table>
Models for multiple plates

- Linking: elastic joint \( M = k_\theta (\theta_1 - \theta_2) \).
- The same basis of functions is used.
- The weak form is developed: the bending moments are imposed.

\[
\int_\Omega \left( k_{lm}^4 - \frac{\omega^2 \rho_s}{D} \right) \hat{u} \nu \, d\Omega + \frac{1}{D} \left[ \left( \int_{y=0}^{y=L_y} M_x \nabla_n \nu \, dy \right)_{x=0} + \left( \int_{y=0}^{y=L_y} M_x \nabla_n \nu \, dy \right)_{x=L_x} \right] + \left( \int_{x=0}^{x=L_x} M_y \nabla_n \nu \, dx \right)_{y=0} + \left( \int_{x=0}^{x=L_x} M_y \nabla_n \nu \, dx \right)_{y=L_y} = \frac{1}{D} \int_\Omega q \nu \, d\Omega
\]
Models for multiple plates

Coupled system:

\[
\begin{bmatrix}
D_1 + k_\theta C & k_\theta E \\
k_\theta G & D_2 + k_\theta H
\end{bmatrix}
\begin{bmatrix}
a \\
b
\end{bmatrix}
= 
\begin{bmatrix}
f_1 \\
0
\end{bmatrix}
\]

Cases of interest:

Four plates

T-shaped structure

Cases of interest:

Four plates

T-shaped structure
Two plates

Dependence on $k_\theta$
Dependence on $k_\theta$
T-shaped structure

Dependence on $k_\theta$ floor-wall. Continuous floor.
T-shaped structure

Dependence on $k_\theta$ floor-wall. Non-continuous floor.
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- The thickness and loss factor of a floor are important parameters for the impact noise level.
- Elastic joints through the floor lower the impact noise in adjacent rooms.
- Floor-wall flanking transmission becomes important when floor-floor transmission is low.
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