Comparison of structure-borne sound power injected to heavyweight and lightweight constructions
Introduction

- Context
  - Standardized method available to estimate structure-borne power of equipment installed in **heavy** buildings
    - EN 15657-1
  - COST Action FP0702 and CEN/TC126/WG7 are working on a method suitable for equipment installed in **lightweight** buildings
    - Based on mobility
    - EN 15657-2 in preparation
Introduction

- Goals of present study
  - Use mobility method to estimate the **installed power** of a given source
    - Structural power injected into the receiving structure
  - Compare results for heavy and lightweight structures

- Next step: use installed power values to calculate structure-borne noise in building
  - Presentation by M. VILLOT
Prediction method

- Installed power for **single point source**

\[
W_{s,\text{inst}} = \frac{1}{2} \frac{\text{Re}\{Y_R\}}{\left|Y_R + Y_S\right|^2} \left|V_{sf}\right|^2
\]

- **Input data**
  - Source and receiver mobilities at the contact point (complex)
  - Source free velocity at the contact point
  - All directly measurable

- **Assumptions**
  - Rigid point connection between source and receiving structure
  - Single component excitation: direction normal to the receiver plane
  - Moment excitation is neglected
Prediction method

- Installed power for **single point source**
  - Simplification regarding mobility ratio
    - “Force source”
      \[
      \left| \frac{Y_R}{Y_S} \right| \leq \frac{1}{3} \quad \longrightarrow \quad W_{S,\text{inst}} = \frac{1}{2} \frac{\text{Re}\left\{ Y_R \right\}}{Y_S^2} \left| v_{sf} \right|^2
      \]

  - « Matched mobility »
    \[
    \frac{1}{3} < \left| \frac{Y_R}{Y_S} \right| < 3 \quad \longrightarrow \quad W_{S,\text{inst}} = \frac{1}{8} \frac{\text{Re}\left\{ Y_R \right\}}{Y_R^2} \left| v_{sf} \right|^2
    \]
Prediction method

- Installed power with **multiple contacts** between source and receiving structure
  - Need to make assumptions on the correlation between forces at the contact points
  - Case 1: no correlation
    - Each contact can be seen as a point source
    - Total power = sum of installed powers for each point source
Prediction method

- Installed power with **multiple contacts** between source and receiving structure
  - Case 1: no correlation
    - Need to determine source and receiver **point mobility** at each contact point (magnitude + real part)
    - Can they be measured in **1/3 octave** bands?
Prediction method

Magnitude of point mobility (m/Ns)

Real part of point mobility (m/Ns)

Narrow band measurement
1/3 octave band measurement (cross-spectrum)
1/3 octave band measurement (autospectrum)

Narrow band measurement
Third octave band measurement
Prediction method

- Installed power with **multiple contacts** between source and receiving structure
  - Case 2: correlation between forces at the connections
    - Calculation using **effective mobility** at each contact

\[
W_{S,\text{inst}} = \frac{1}{2} \sum_{i}^{N} \text{Re}\left\{ Y_{R,i}^\Sigma \right\} \left| \frac{Y_{R,i}^\Sigma + Y_{S,i}^\Sigma} {Y_{R,i}^\Sigma + Y_{S,i}^\Sigma} \right|^2 |V_{Sf,i}|^2
\]

\[
\bar{Y}_i^\Sigma = Y_{ii} + \sum_{j \neq i}^{N} \frac{F_j}{F_i} Y_{ij}
\]

Contact forces: unknown
Prediction method

- Installed power with **multiple contacts** between source and receiving structure
  - Case 2: correlation between forces at the connections
    - Hypothesis:
      \[
      \frac{F_j}{F_i} = 1
      \]
    - Assuming random phase difference between forces:
      \[
      \text{Re}\left\{ \overline{Y_i} \Sigma \right\} \approx \text{Re}\left\{ \overline{Y_{ii}} \right\}
      \]
      \[
      \left| \overline{Y_i} \Sigma \right|^2 \approx \left| \overline{Y_{ii}} \right|^2 + \sum_{j \neq i}^N \left| \overline{Y_{ij}} \right|^2
      \]
    - 1/3 octave band:  
      - ✓
      - ✓
      -  

Prediction method

- **Transfer mobility** measurement in 1/3 octave bands?
  - Cross-spectrum gives wrong results!
  - Estimation using force and velocity autospectra seems more reliable

\[
\left| Y_i \right|^2 \approx \left| Y_{ii} \right|^2 + \sum_{j \neq i}^N \left| Y_{ij} \right|^2
\]
**System description**

- Source: water evacuation duct
  - PVC Ø 10cm
  - Fixed to a separating wall through 2 points spaced by 1.25m
  - Controlled water flow rate inside the pipe
▪ **System description**
  ▪ Heavy receiver
    ▪ 100mm thick concrete blocks
  ▪ Lightweight receiver
    ▪ 10mm thick OSB + 2 gypsum boards (12.5mm thick)
    ▪ Wood studs every 60cm
    ▪ Contact points on a stud (edge of gypsum board) or at bay
Source characterization

- Velocity level (dB re 5 × 10^-8 m/s)
- Frequency (Hz)

- Magnitude of mobility (m/Ns)
- Frequency (Hz)

Graphs showing data for 0.5 L/s, 1 L/s, 2 L/s, 4 L/s, Point 1, Point 2, and Transfer.
- Heavy receiver characterization
  - Transfer mobility of the same order as point mobility
    - Considered case: 1 source with 2 correlated contact points
  - Receiver mobility much lower than source mobility
    - “Force source” simplification
Lightweight receiver characterization

- Transfer mobility lower than point mobility
  - Considered case: 2 separate point sources
- Mobility comparable to that of the source
  - “Matched-mobility” simplification
- Water flow rate = 2L/s
  - In situ toilet flushing
- 10-20 dB difference between heavy and lightweight receivers
- Lightweight wall: source location is not significant
Conclusions

- Mobility method applied to a simple case
  - Source with 2 contact points with receiving structure
  - 2 types of receivers considered
    - Heavy separating wall
    - Lightweight separating wall (bay or stud location)
  - Installed power calculation
    - Simplification regarding receiver/source mobility ratio
    - Assumptions based on receiver point/transfer mobility ratio
  - Results
    - Installed power is much higher for the lightweight receiver
Conclusions

- Further work
  - Installed power calculation for other source/receiver configurations
    - Timber frame floor
    - 3-contact source

- EN 15657-2
  - Determination of the installed power of equipment installed in lightweight structures
  - Based on the mobility method
Thank you for your attention