Impact Noise

Vibro-Acoustics Consortium Web Meeting
University of Kentucky

Vibro-Acoustics Consortium
References

- ASTM E989 – Standard Classification for Determination of Single-Number Metrics for Impact Noise
- Standards are used to assess footfall noise.
Standard Tapping Machine

• A standard tapping machine is used to rate the impact noise isolation of floors in dwellings.
• Tapping machine consists of five hammers each weighing 500 g, and dropping from a height of 4 cm.
• Each impacts the surface at 2 Hz providing an operating frequency of 10 Hz.
Standard Tapping Machine

Long, 2014
Tapping Machine Positions

FIG. 1 Tapping Machine Positions

ASTM E1007
Impact Insulation Class Measurement

Ermann, 2015

For this example, we’ll test the impact insulation class (IIC) of a wood-joist floor with a ceiling suspended from resilient channel. We wish to establish a single-number rating to compare the acoustical performance of assemblies in the attenuation of impact sound.

A tapping machine drops 10 steel hammers per second on the floor surface. (Five hammers each drop twice per second.)

A microphone measures the impact sound pressure level (ISPL) in the room below the engaged tapping machine.
Tap Machine Signal

Long, 2014

Fourier Amplitude

\[ F_n \approx \frac{2}{T_r} \int_0^{T_r} f(t) \, dt = 2f_r m v_0 \]

\[ F_n \approx 2f_r m \sqrt{2gd} \]

\( d \) drop distance

\( m \) mass
Impact Insulation Class

The impact noise isolation capability of a floor

\[ L_n = L_P - 10 \log \frac{A_0}{S\alpha_{S,ab}} \]

where

- \( L_n \): normalized impact sound pressure level
- \( L_P \): 1/3-octave band sound pressure level as measured, dB
- \( S\alpha_{S,ab} \): total absorption in receiving room, m²
- \( A_0 \): reference value of absorption, 10 m²

For field measurements, California drops the second term on the right-hand side, so it is less strict.
Impact Insulation Class

Reference contour for calculating impact insulation class (Long, 2014)
The reference contour is shifted until
- the sum of positive differences is less than 32 dB.
- the maximum deficiency in a frequency band does not exceed 8 dB.

The normalized sound pressure level at 500 Hz is subtracted from 110 dB to obtain the impact insulation class (IIC).

Field IIC tests normally fall about five points below the laboratory test and apply only to the room in which they are measured. Receiving rooms should meet a minimum volume requirement.
Infinite Panel Expression

**Fourier Amplitude**

\[ F_n \cong \frac{2}{T_r} \int_0^{T_r} f(t)dt = 2f_r m \sqrt{2gd} \]

- \( d \) drop distance (40 mm)
- \( m \) mass (500 grams)
- \( f_r \) impact frequency (10 Hz)

Assume infinite plate and perform power balance

\[ L_n(\text{oct}) = 10 \log_{10} \left( \frac{4}{5.1} \frac{(\rho c)^2 \sigma_{rad}}{p_{ref}^2 A_0 \rho_m^2 c_L \eta h^3} \right) \]

- \( \rho_m \) density of panel (kg/m\(^3\))
- \( E_m \) elastic modulus of panel (Pa)
- \( \eta \) loss factor of panel
- \( c_L = \sqrt{E/\rho_m} \) (m/s)
- \( h \) plate thickness (m)

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Long, 2014

dB levels are typical of those using a tapping machine.
Add an Elastic Layer

Long, 2014

\[ E \quad \text{elastic modulus of layer} \]
\[ A_h \quad \text{area of hammer} \]
\[ m \quad \text{mass of hammer} \]
\[ h \quad \text{thickness of layer} \]
Add an Elastic Layer Improvement

\[ \Delta L_n = 20 \log \left( \frac{4\pi}{\sin(\alpha) / \alpha + \sin(\beta) / \beta} \right) \]

\[ \alpha = \frac{\pi}{2} \left( 1 - n \frac{f_r}{f_0} \right) \quad \beta = \frac{\pi}{2} \left( 1 + n \frac{f_r}{f_0} \right) \]

\[ f_r = 10 \text{ Hz and } n = 1, 2, 3, \ldots \]

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{A_n}{m}} \sqrt{\frac{E}{h}} \]
Add an Elastic Layer Improvement

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**Graphs:**
- **Left Graph:**
  - Title: IMPROVEMENT ΔLₙ, dB
  - X-axis: FREQUENCY RATIO - P/Pₙ
  - Y-axis: IMPROVEMENT ΔLₙ, dB
  - Legend: NO DAMPING, WITH DAMPING
  - Asymptotic Slope: 40 dB Decade

- **Right Graph:**
  - Title: Footfall noise level under a 12 cm thick concrete floor with various floor coverings (Measured data by Cremer and Heckl, 1975)
  - X-axis: FREQUENCY, Hz
  - Y-axis: SOUND PRESSURE LEVEL, dB
  - Legend: 40 dB/octave improvement, Without covering, Linoleum, 5 mm, Cork-linoleum, 8 mm, Cork tile, 15 mm
Resonantly Reacting Floating Floor

(a) Standard tapping machine  b) High-heeled shoes
Note the negative $\Delta L_n$ in the vicinity of the resonant frequency.
Summary

• Building acousticians assume that impact noise is unavoidable.
• Standard tapping instrument is used to simulate the impact.
• Impact Insulation Class (IIC) is a standard way of assessing how readily impact noise is transmitted to the floor below.
• Impact noise can be reduced by increasing the thickness of the floor, adding an elastic layer, or using a floating floor.
• Perhaps similar ideas can be integrated into buzz and rattle assessment and mitigation.
 Locally Reacting Floating Floor

Heavily Damped Floating Floor

\[ \Delta L_n = 20 \log \left[ 1 + \left( \frac{f}{f_0} \right)^2 \right] \approx 40 \log \frac{f}{f_0} \]

where

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{k'}{\rho_{s_1}}} \]

\( k' \)  dynamic stiffness per unit area

\( \rho_{s_1} \)  mass per unit area of floating slab
Resonantly Reacting Floating Floor

Lightly Damped Floating Floor

\[ \Delta L_n(\omega) \approx 10 \log \left( 2.3 \sqrt{\frac{E_m}{\rho_m} h_1 \eta_1 n' \frac{\omega^3}{\omega_l^4}} \right) \]

- \( h_1 \): thickness of floating slab, m
- \( E_m \): elastic modulus of floating slab
- \( \rho_m \): density of floating slab
- \( \eta_1 \): loss factor of floating slab
- \( n' \): number of resilient mounts per unit area of slab, m²
- \( \omega_l \): resonant frequency of floating slab