December 3, 2020

Impact Noise

Vibro-Acoustics Consortium Web Meeting

University of Kentucky

References

- ASTM E492 – Standard Test Method for Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies Using the Tapping Machine
- ASTM E989 – Standard Classification for Determination of Single-Number Metrics for Impact Noise
- ASTM E1007 – Standard Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling Assemblies and Associated Support Structures
- Standards are used to assess footfall noise.

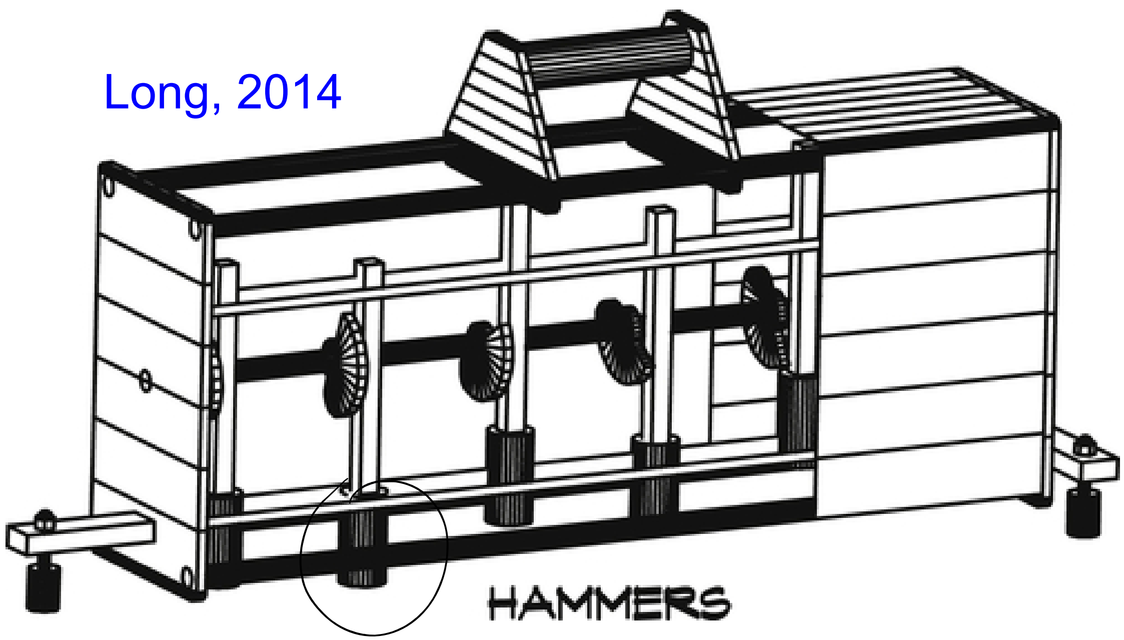
Standard Tapping Machine

Brüel and Kjaer Type 3207

- 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

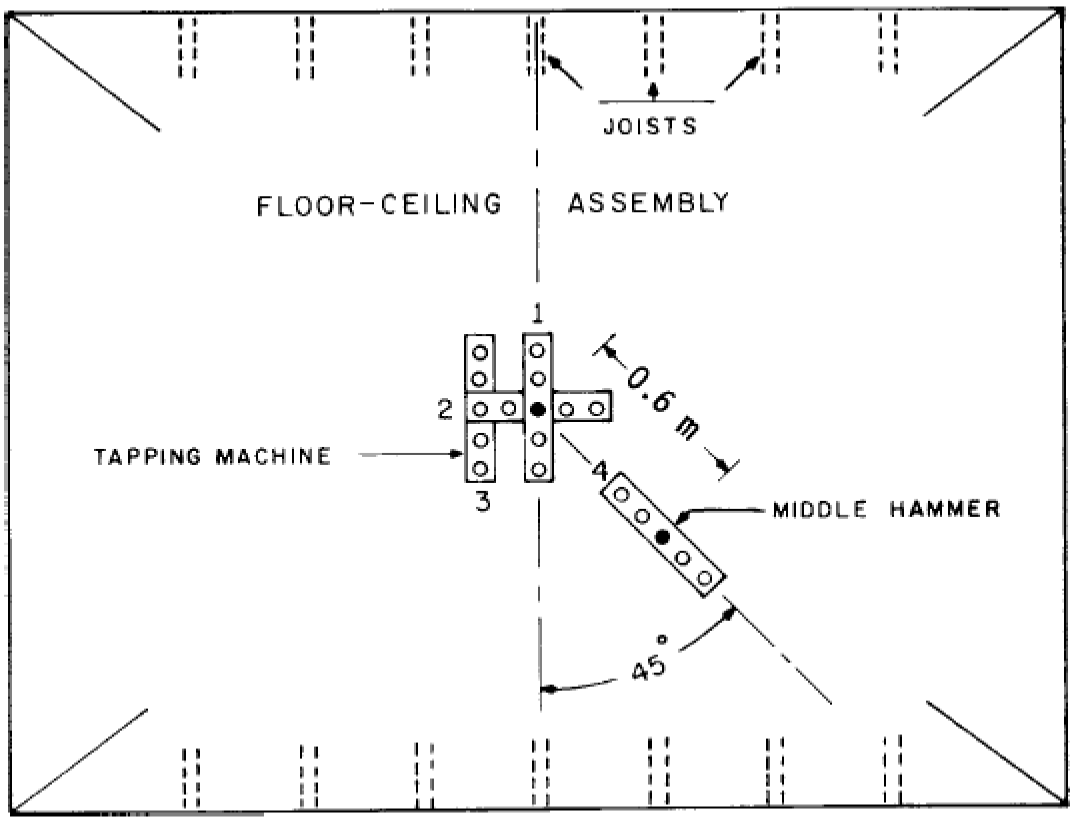
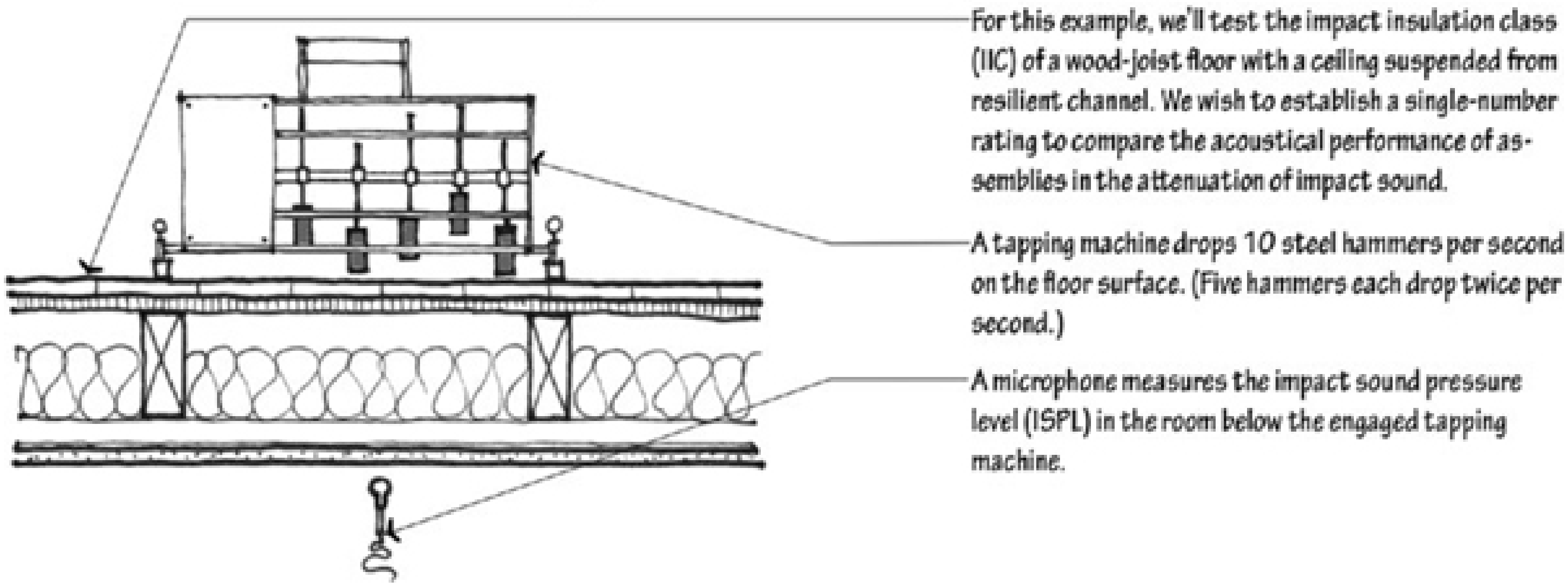


FIG. 1 Tapping Machine Positions

ASTM E1007

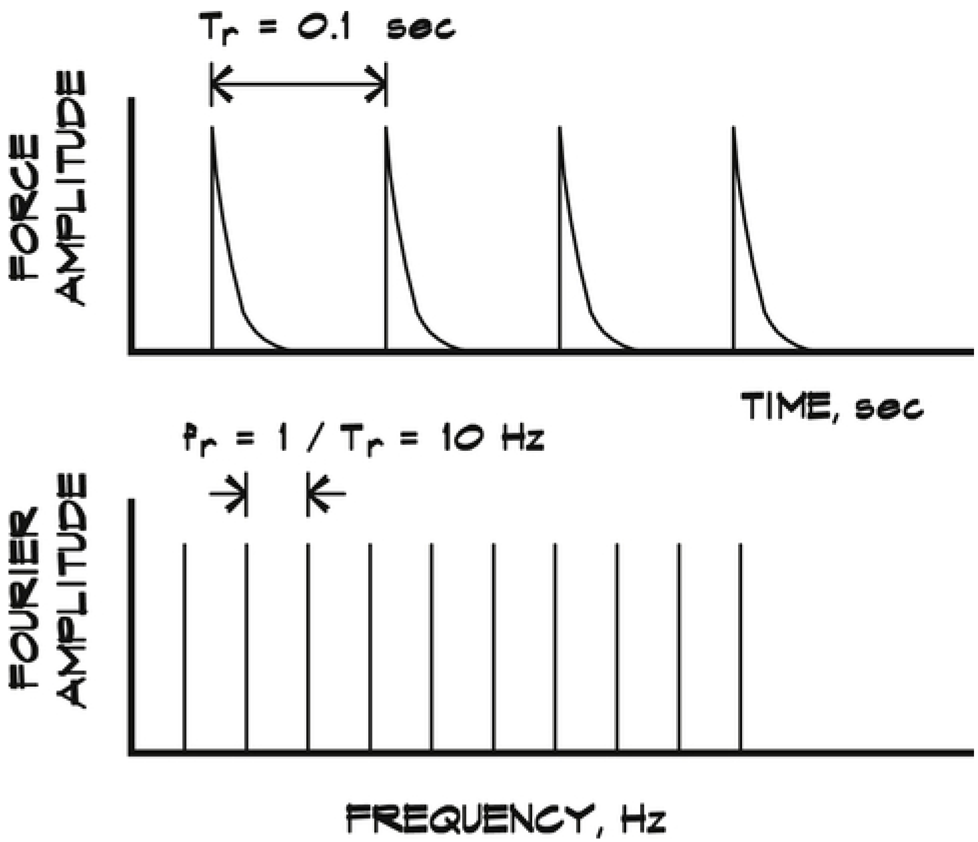
Impact Insulation Class Measurement

Ermann, 2015



Tap Machine Signal

Long, 2014



Fourier Amplitude

$$F_n \cong \frac{2}{T_r} \int_0^{T_r} f(t)dt = 2f_r m v_0$$

$$F_n \cong 2f_r m\sqrt{2gd}$$

d drop distance
m mass

Impact Insulation Class

The impact noise isolation capability of a floor

$$L_n = L_P - 10\log\frac{A_0}{S\bar{\alpha}_{S,ab}}$$

where

L_n normalized impact sound pressure level

L_P 1/3-octave band sound pressure level as measured, dB

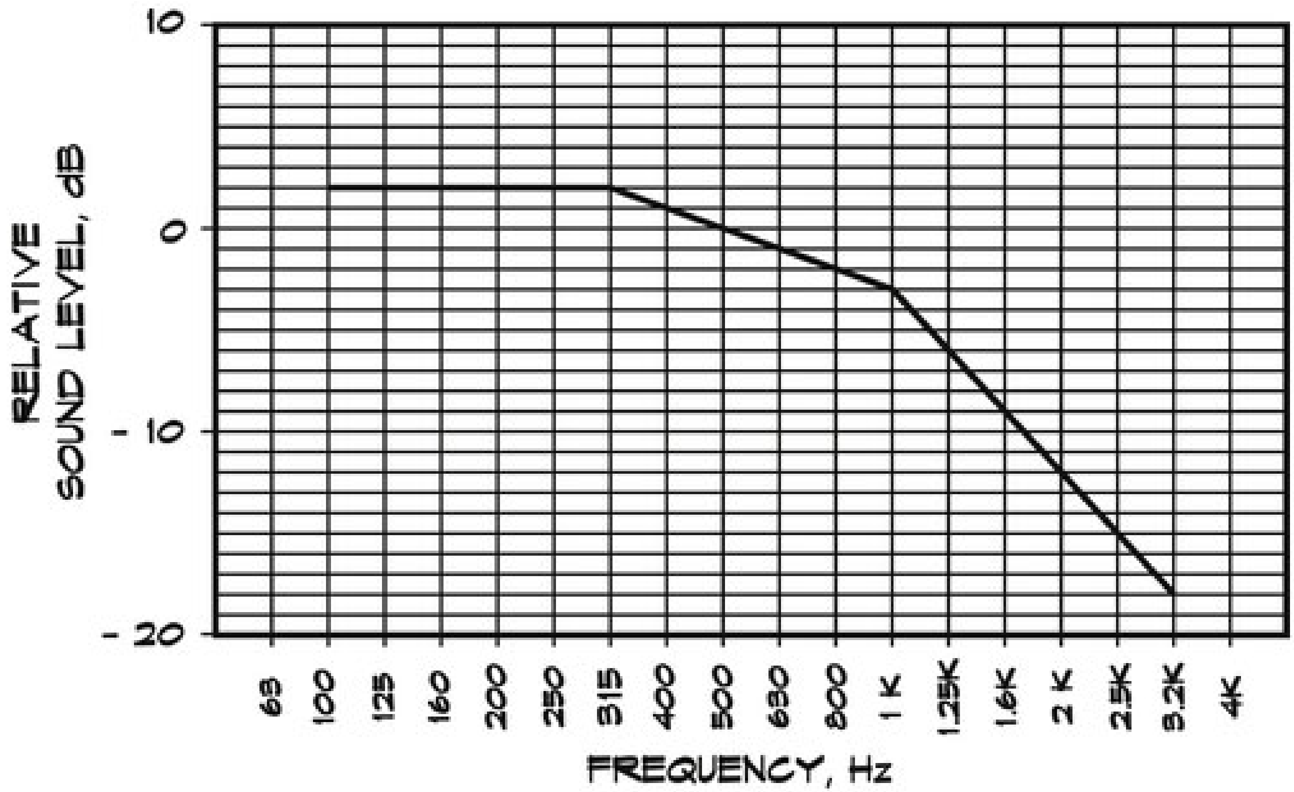
$S\bar{\alpha}_{S,ab}$ total absorption in receiving room, m^2

A_0 reference value of absorption, 10 m^2

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

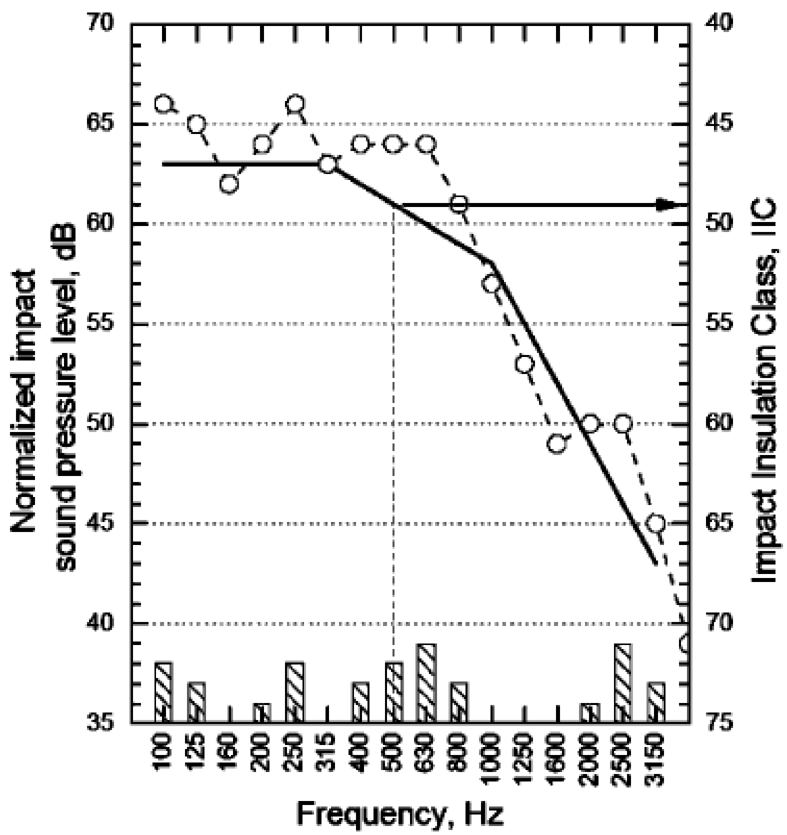
Impact Insulation Class

Reference contour for calculating impact insulation class (Long, 2014)



Impact Insulation Class

ASTM E989



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.

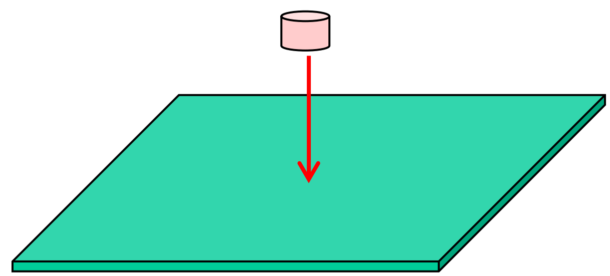
Infinite Panel Expression

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



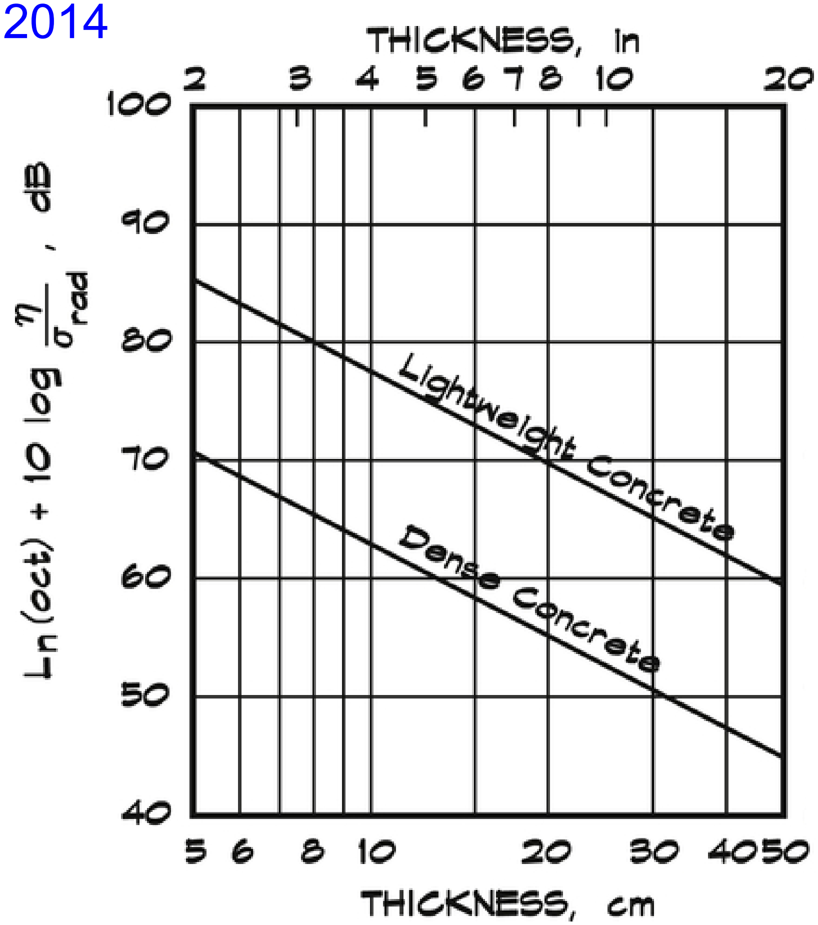
$$L_n(\text{oct}) = 10\log_{10}\left(\frac{4}{5.1}\frac{(\rho c)^2\sigma_{rad}}{p_{ref}^2 A_0 \rho_m^2 c_L \eta h^3}\right)$$

ρ_m density of panel (kg/m³)
E_m elastic modulus of panel (Pa)
η loss factor of panel
$c_L = \sqrt{E/\rho_m}$ (m/s)
h plate thickness (m)

σ_{rad} radiation efficiency
$p_{ref} \cong 20 \times 10^{-6}$ Pa
$A_0 = 10$ m²

Infinite Panel Results

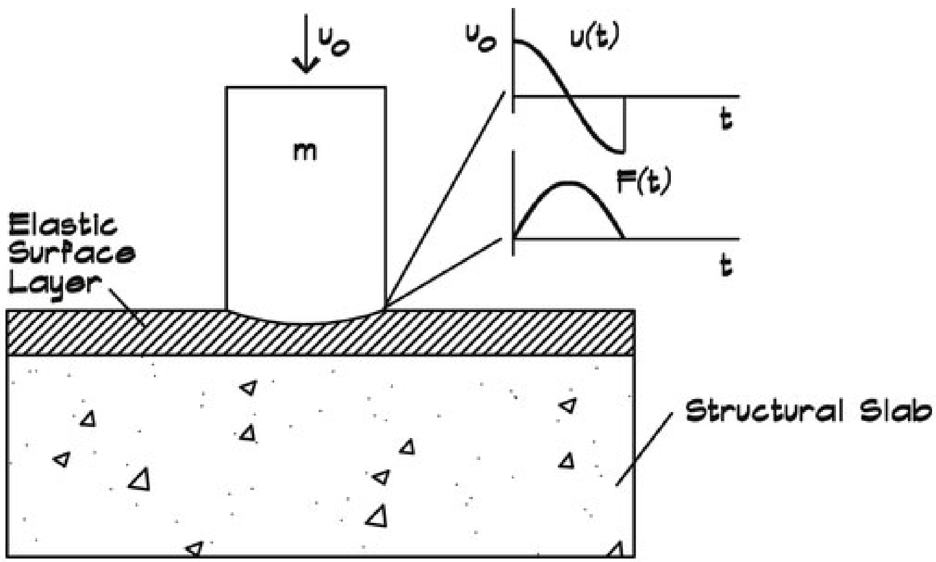
Long, 2014



dB levels are typical of those using a tapping machine.

Add an Elastic Layer

Long, 2014



E	elastic modulus of layer
A_h	area of hammer
m	mass of hammer
h	thickness of layer

Add an Elastic Layer Improvement

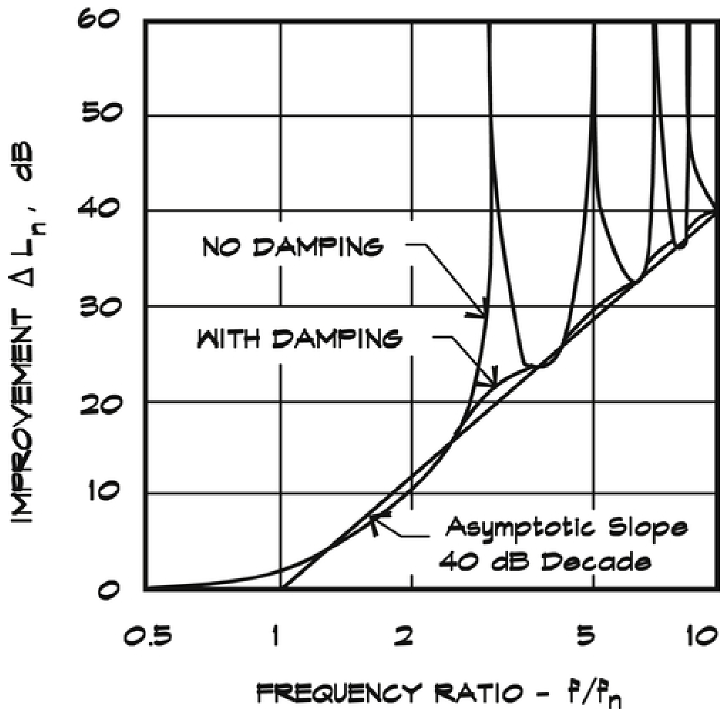
$$\Delta L_n = 20 \log \left(\frac{4\pi}{\sin(\alpha)/\alpha + \sin(\beta)/\beta} \right)$$

$$\alpha = \frac{\pi}{2}\left(1 - n\frac{f_r}{f_0}\right) \qquad \beta = \frac{\pi}{2}\left(1 + n\frac{f_r}{f_0}\right)$$

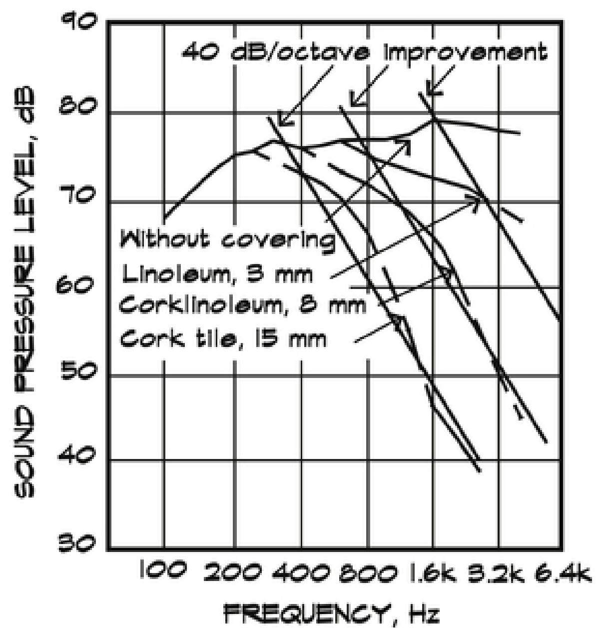
$f_r = 10$ Hz and $n = 1, 2, 3, \ldots$

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{A_h}{m}}\sqrt{\frac{E}{h}}$$

Add an Elastic Layer Improvement

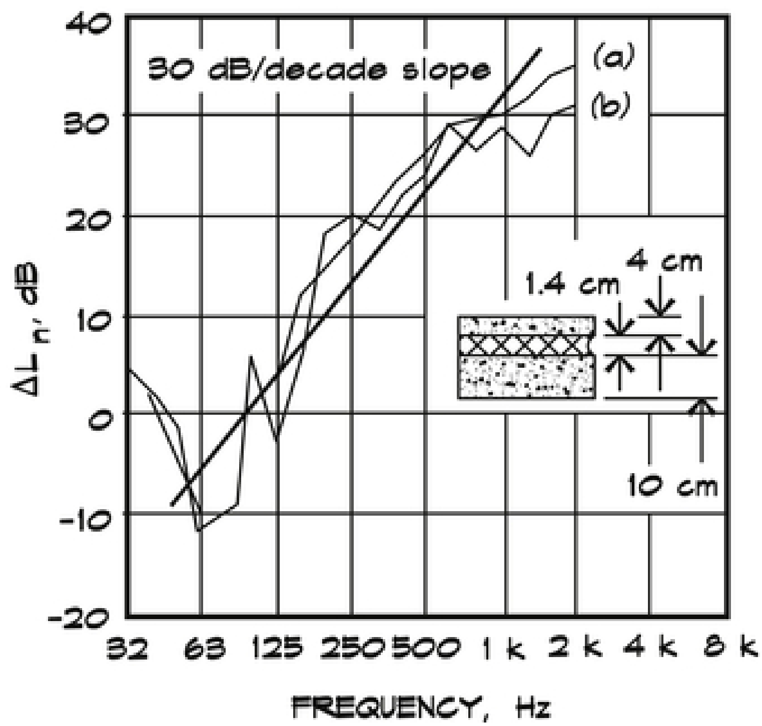


Footfall noise level under a 12 cm thick concrete floor with various floor coverings (Measured data by Cremer and Heckl, 1973)



Resonantly Reacting Floating Floor

a) Standard tapping machine b) High-heeled shoes
Note the negative ΔL_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

ρ_{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
ρ_m	density of floating slab
η_1	loss factor of floating slab
n'	number of resilient mounts per unit area of slab, m^2
ω_l	resonant frequency of floating slab