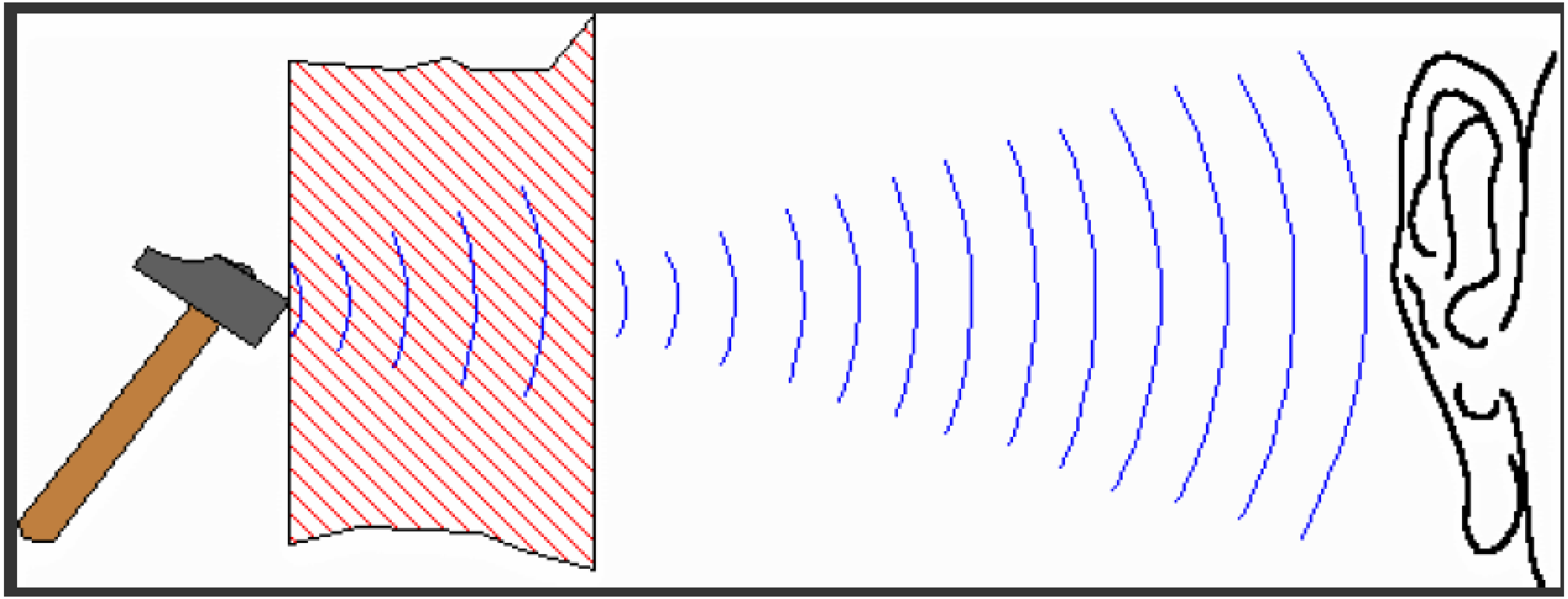
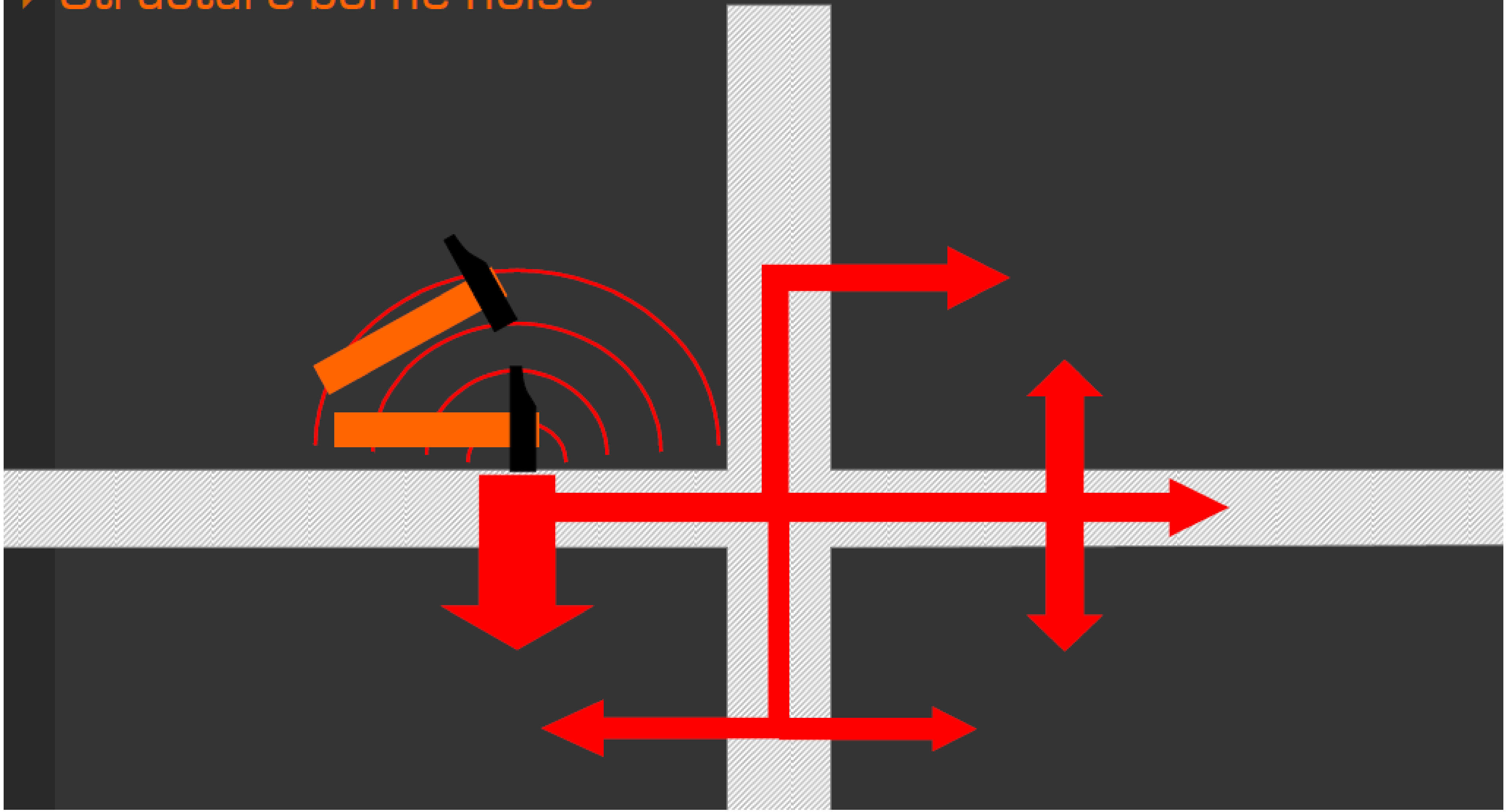
Chapter 5
Isolation of structure-borne noise and vibration

- Structure-borne sound that is transmitted through solid material is essentially a vibration of the material.
- Structure-borne sound travels through solid materials usually in direct mechanical contact with the sound source, or from an impact on that material.
- Examples are foot steps or objects falling on the floor upstairs, a knock at the door, or vibration from loud speakers on the floor.
- All structure-borne sound must eventually become airborne sound in order for us to hear it.
- We can only feel structure-borne sound as vibrations in a material. In most noise control situations, both airborne and structure-borne sound must be considered.

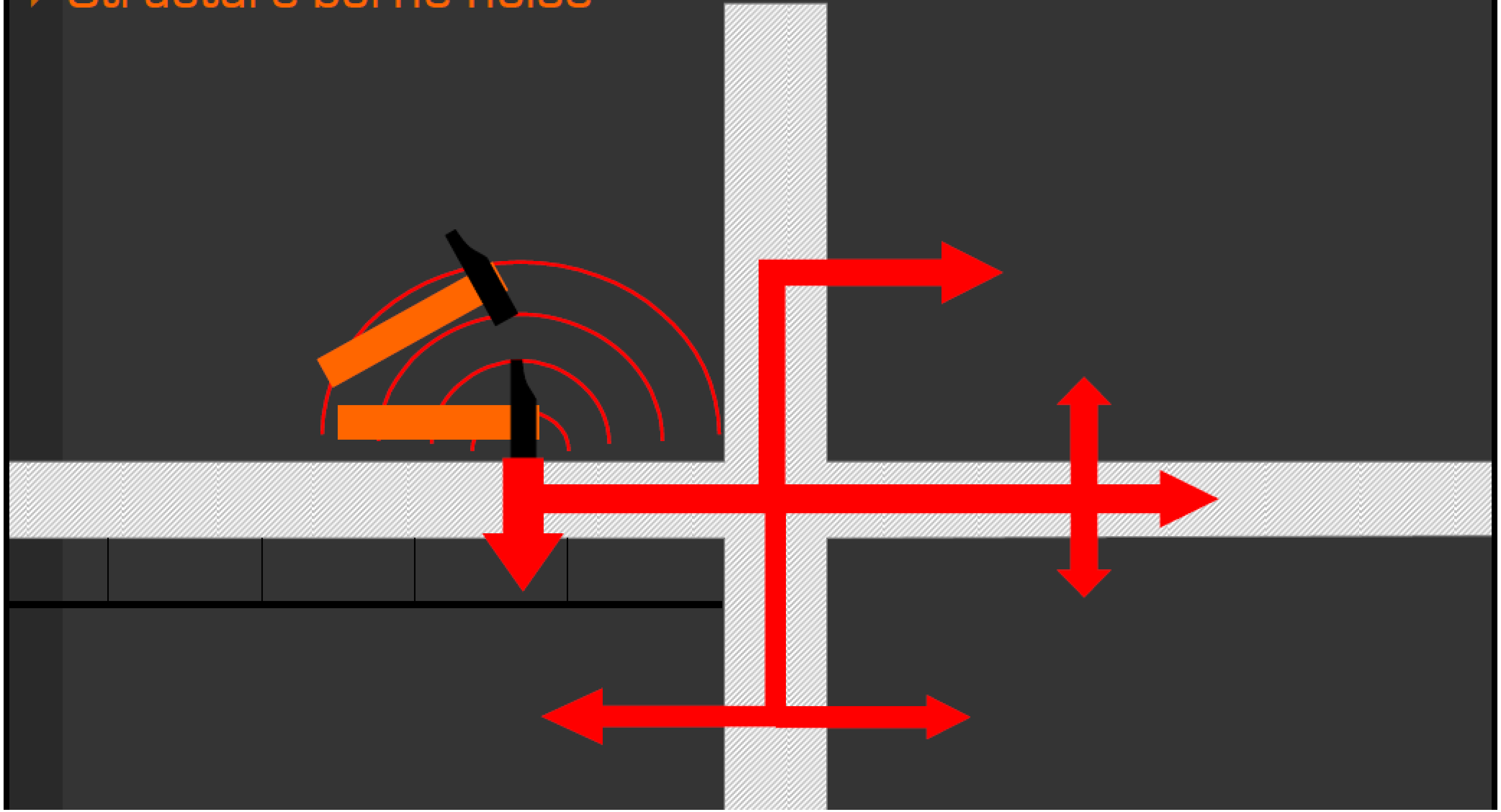
Generation of structure-borne sound



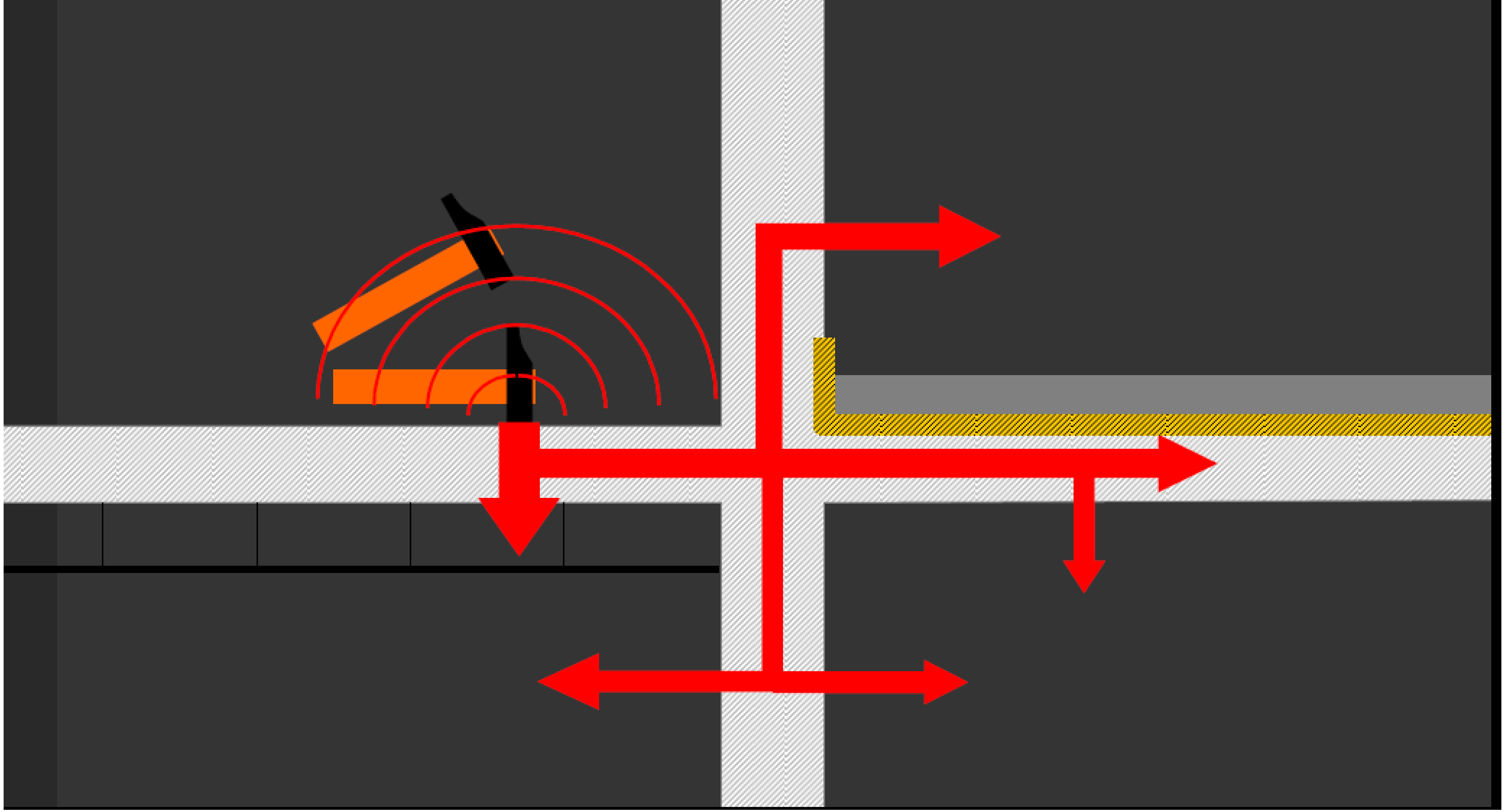
Structure-borne noise



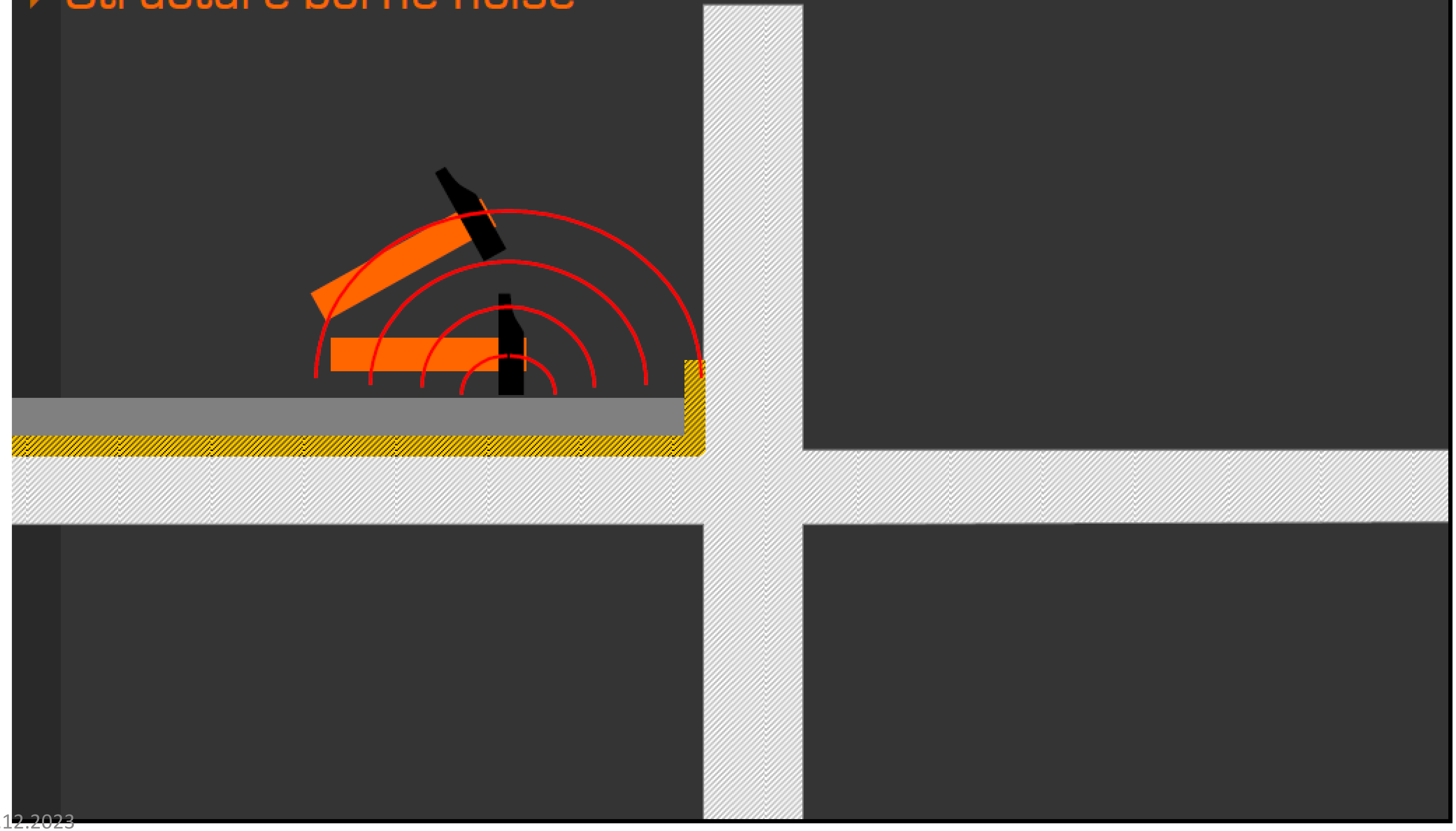
Structure-borne noise



Structure-borne noise



Structure-borne noise



Generation of structure-borne sound

- When impacts resulting from footsteps, the slamming of doors, furniture movement, etc. are transferred to the building structure, there is a resulting vibration that is propagated through the structure, known as structure-borne sound.

- Vibration of mechanical equipment in the building such as a pump, blower, elevator, refrigerator, etc. generates structure-borne sound as steady state sources.

- Plumbing and piping for steam or water, for example, also generate structure-borne sounds at taps and valves and convey those intermittent structure-borne sounds through themselves and the building structure.

- Sound generated in a room excites the walls, ceiling and floor into vibration, which is also propagated as sound-induced structure-borne sound.

- Structure-borne sound is perceived by a listener as a consequence of the airborne sound radiated from the vibrating surfaces.

- In order to quantitatively predict the generation of structure-borne sound, we have to;

- *calculate the vibration velocity or acceleration* that occurs in the structure from a knowledge of the exciting force of impact or driving force of vibration that causes the structure-borne sound

- *obtain the mechanical impedance* at the receiving point.

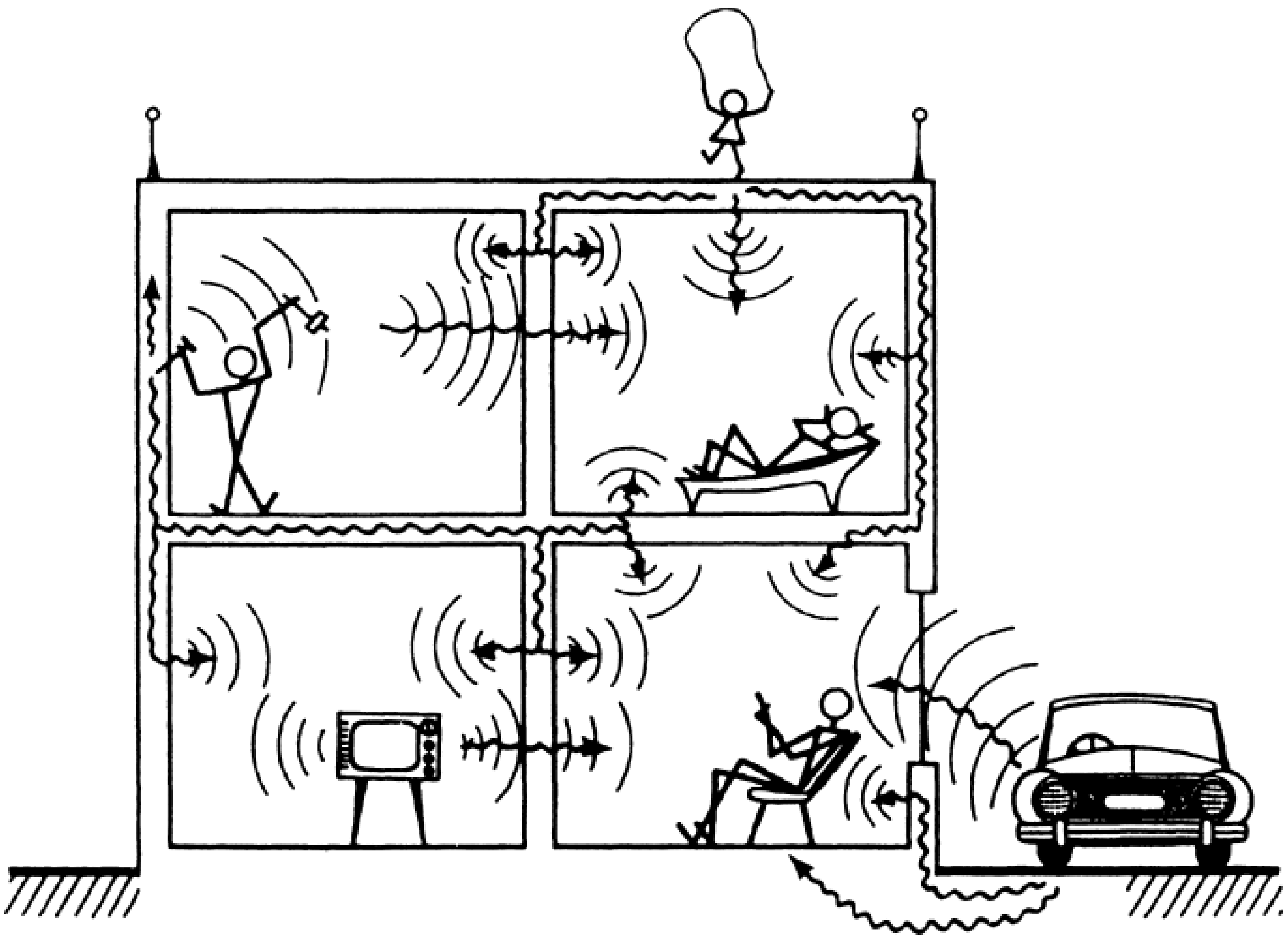


Figure 7.1 Transmission of airborne and structure-borne sound.

Measurement of structure-borne sound

- A vibration pickup is mounted rigidly on a vibrating solid surface and detects the vibration perpendicular to the surface.

- In order to eliminate the effect of the pickup itself, a very small and light piezoelectric sensor is often used. The data are given in terms of the velocity level L_v, which is suitable for comparing with airborne sound data.

$$L_v = log_{10}(\frac{v^2}{v_0^2})$$

where v^2 is the mean square velocity, and v_0 is the reference value.

- Although the ISO 1683 Standard recommends $v_0=10^{-9}$ ms^{-1}, in this text we use $v_0=5\times10^{-8}$ (ms^{-1}) because it is more convenient for calculating the sound radiation.

Since v is related to the acceleration a (m s^{-2}) where $a=2\pi fv$, L_vc an also be related to the acceleration level L_a as follows

$$\frac{v}{v_0} = \frac{a}{a_0} \cdot \frac{a_0}{2\pi f v_0}$$

$$L_v = L_a + 20log_{10}(\frac{a_0}{2\pi f v_0})$$

where a_0 is the arbitrary reference value for L_a.

(The reference $a_0=10^{-6}$ ms^{-2} is recommended by ISO1683.) $v_0=10^{-9}$ ms^{-1}, in this text we use v_0 $=5\times10^{-8}$ (ms^{-1}) because it is more convenient for calculating the sound radiation.

Sound radiation ratio of vibrating piston

- When an infinite plane rigid wall vibrates as a piston with velocity *v*, the airparticles in contact with the wall surface also vibrate with velocity *v*, so thesound pressure is $\rho c v$ since the impedance of the air is ρc.
- The sound power level is,

$$L_w = log_{10}\left(\frac{\rho c v^2}{10^{-12}}\right) = 10log_{10}\left(\frac{v^2}{v_0^2}\right) + log_{10}\left(\frac{\rho c v_0^2}{10^{-12}}\right)$$

substituting $v_0 = 5 \times 10^{-8}$ ms^{-1}, the second term can be neglected, then $L_W = L_v$, and the velocity level is the sound radiation power level itself.

- When the size of the plate is less than the wavelength of the sound in air,

the air particles adjacent to the plate surface move into the surroundings or to the rear side, so that pressure changes do not occur.

- This fact means that the sound radiation efficiency varies with the relative sizes of the plate and wavelength.

Logarithmically, we can write

$$10\log(\sigma_{rad}) = L_W - (L_v + 10\log S)\ (dB)$$

where σ_{rad} is the radiation ratio.

This is the difference between the power level and the velocity level when S=1m^2.

At higher frequencies;

- where the wavelength is smaller than the piston diameter
- the value of σ_{rad} becomes unity, and
- the velocity level L_v becomes equal to the power level L_W per unit area.

At lower frequencies;

- at which the wave length is larger than the diameter
- the value decreases by 6 dB.

Sound radiation ratio for bending vibration

- If a wide wall is set into free bending vibration by any means, it radiates a plane wave in the direction θ which satisfies the relation

$$\sin\theta = c/c_B$$

- Therefore, when $c < c_B$, i.e. $f > fc$ for frequencies higher than the **critical frequency**, the radiation ratio $\sigma_{\mathrm{rad}} = 1$.

- When $f = fc$, σ_{rad} is somewhat larger than one, and when $f > f_c$ the direction which satisfies $\sin\theta = c/c_B$ does not exist. Then, even if the air particles in contact with the surface are moved by bending vibration of the wall, they do not create any pressure change.

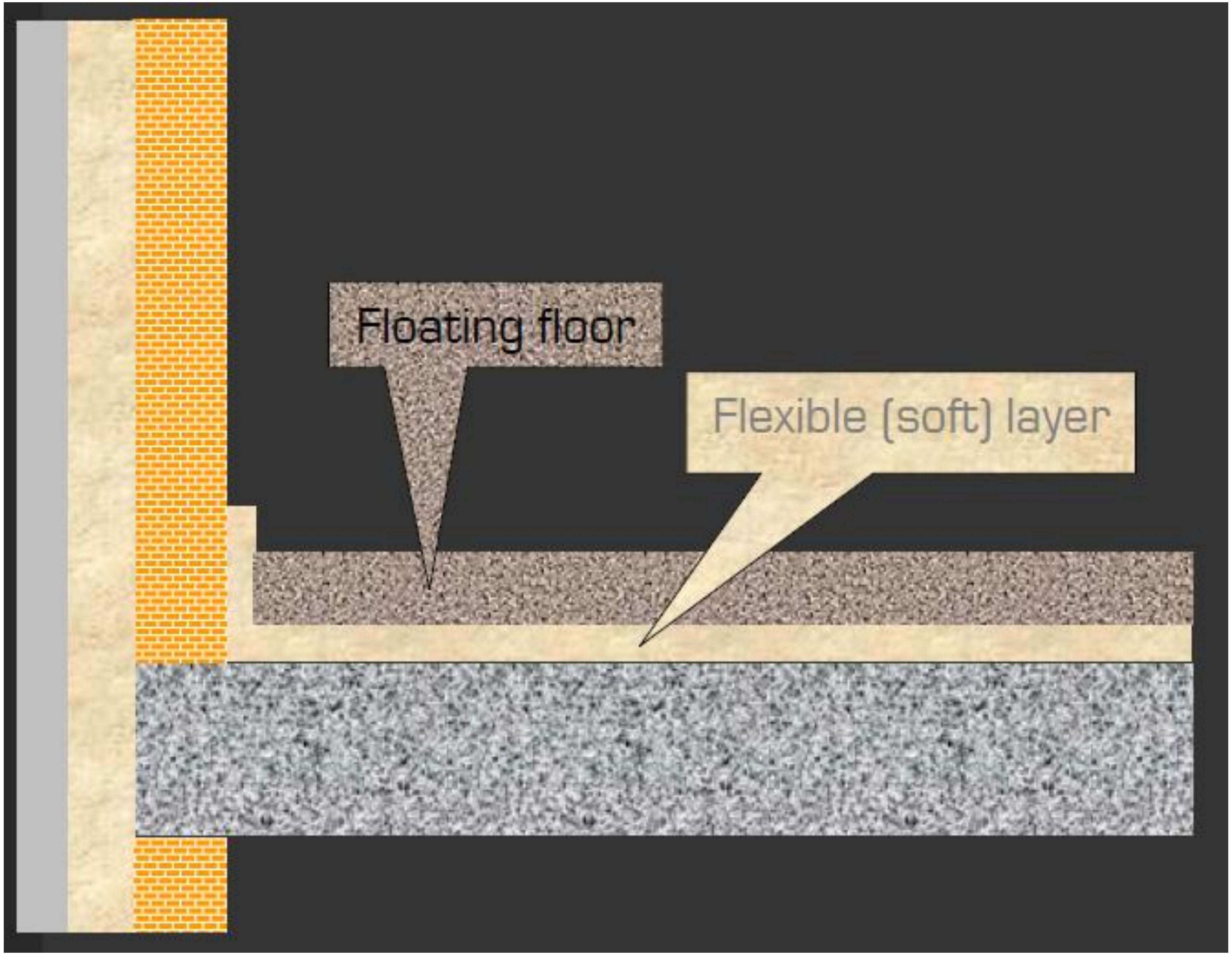
- That is, the radiation ratio is very much decreased and its value depends on the value of f/fc and of the internal energy losses.

How can we solve this problem???

- ***Reduction of structure-borne noise***

- Structure-borne sound waves are reflected and attenuated during propagation more or less at every discontinuity,

- such as;
  - ✓ at a sudden change in cross-section or material,
  - ✓ due to changes in direction at bends or branches,
  - ✓ due to added masses.


Floating floor
Flexible (soft) layer

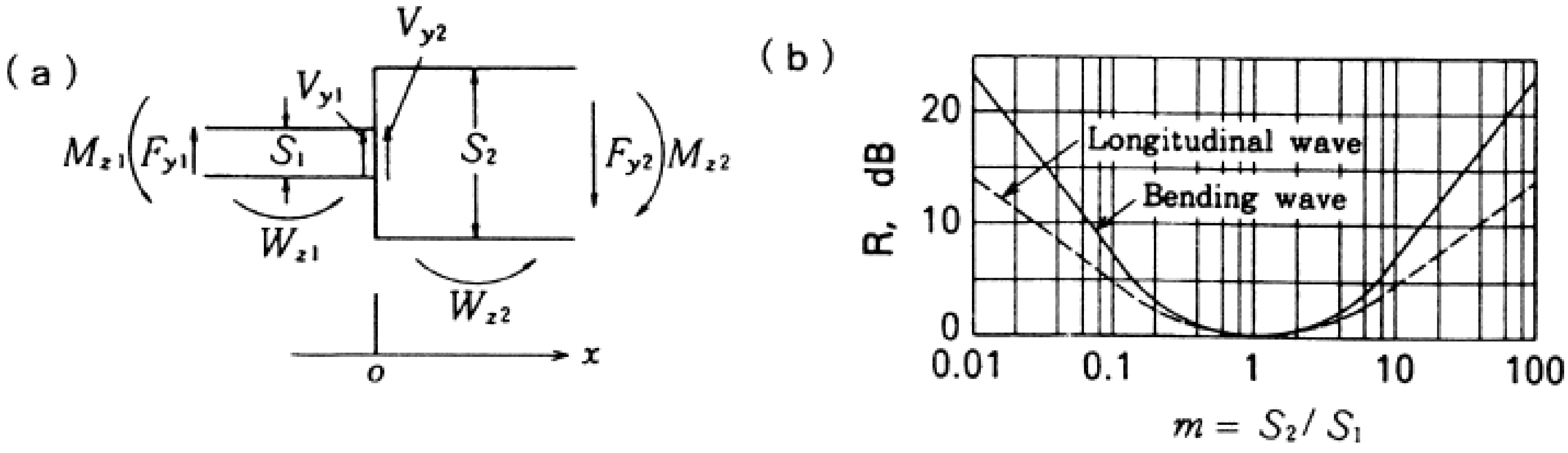
A. Reduction by change of cross-section

A longitudinal wave is attenuated at a sudden change of cross-section.

Then *transmission loss* is

$$R_B = 10 \log_{10} \left(\frac{X^{5/4} + X^{3/4}}{1 + X^2/2 + X^{1/2}} \right)^2 \text{(dB)}$$

where $X = m + m^{-1}$ and $m = S_2/S_1$.



- These values are shown in Figure (b), together with the values for the longitudinal wave.

- We find that a cross-sectional change does not give a large reduction of structure-borne noise in building practice.

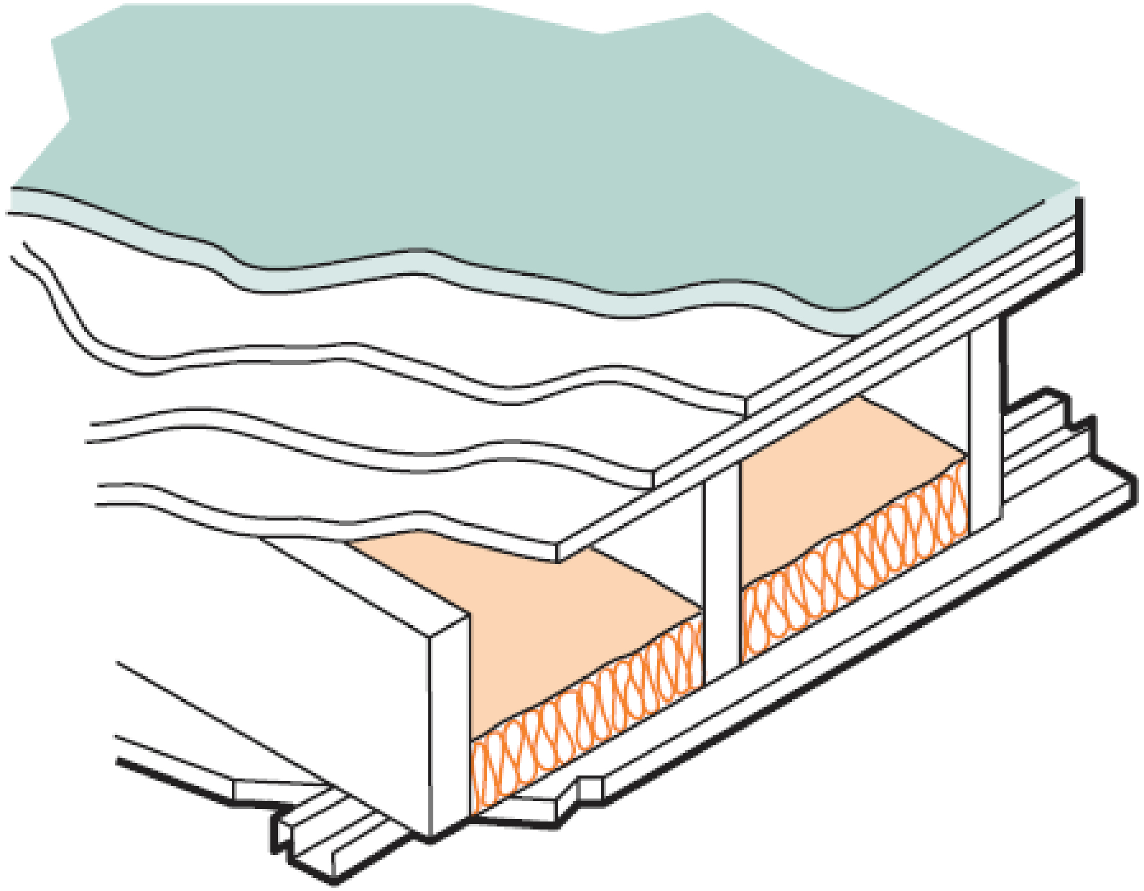


Fig. 14. Floor/ceiling assembly with carpet and pad, particle board underlayment, plywood subfloor, resilient channels and gypsum board ceiling,with fiber glass insulation in joist cavities. STC = 53; IIC = 73.

B. Reduction by bends and branches at right angles

When a free bending wave reaches a bend or a branch at a right angle in a bar or plate, the behaviour of reflection and transmission at these junctions is complicated as some of the partial wave changes its wave type.

Some examples of the results of theoretical analysis are shown in Figures 7.7 and 7.8.

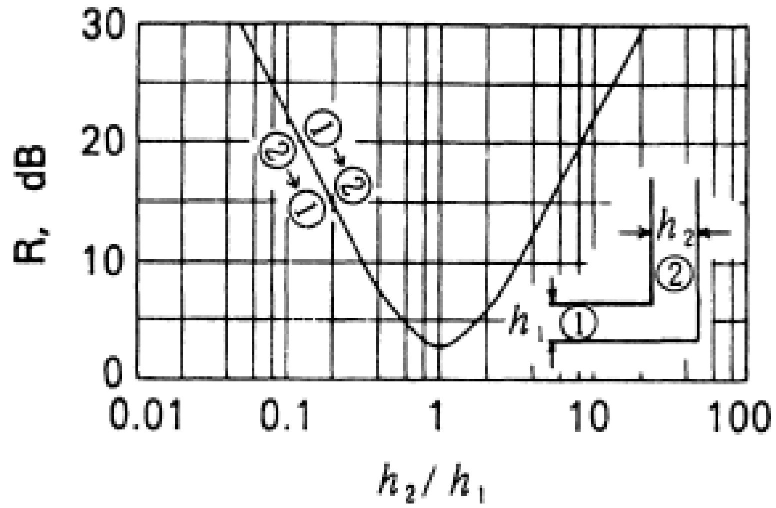


Figure 7.7 Transmission loss for bending waves at corners (Cremer *et al.* Lit. B19).

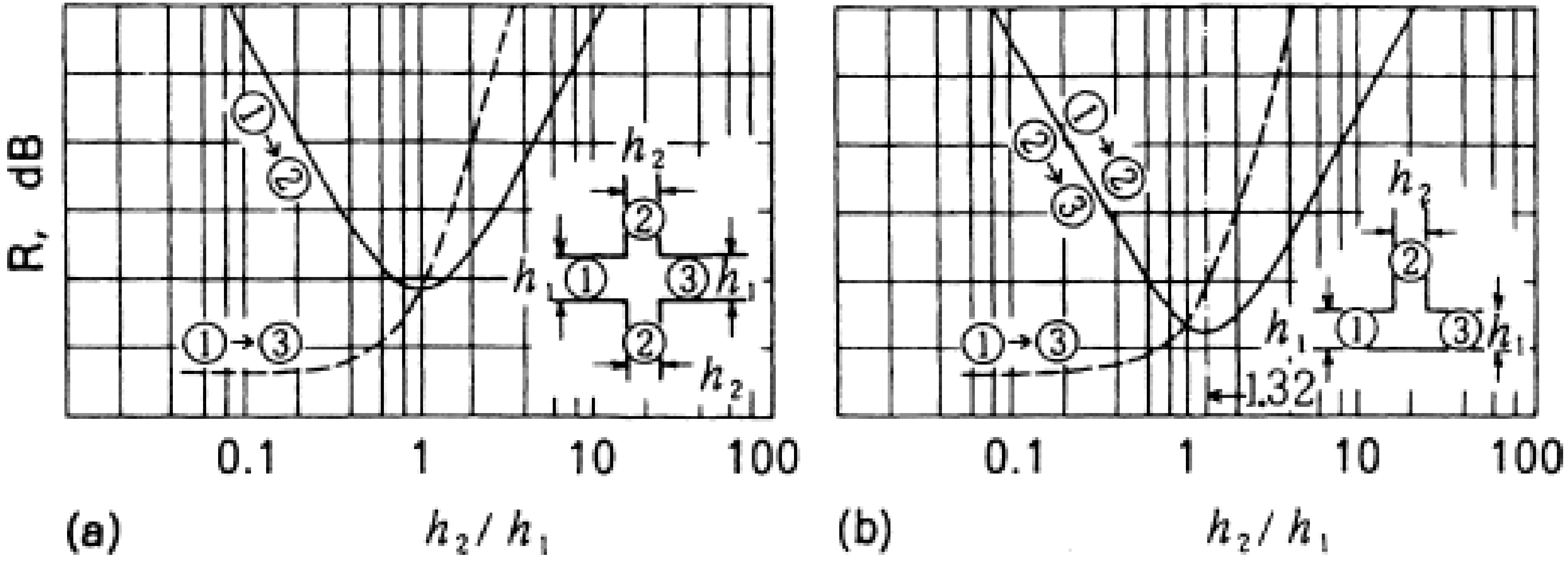


Figure 7.8 Transmission loss for bending waves (Cremer *et al.* Lit. B19). (a) At plate intersections; and (b) at plate branch.

Further reductions may be obtained by adding masses en route or at bends and branches, such as ribs, beams or columns, which are called blocking masses. Also, with random incidence at the junctions, a little more reduction is possible, because with oblique incidence the reduction increases with the angle of incidence.

C. Reduction by different materials

a. Reduction at the boundary between two materials

The behaviour of a longitudinal wave incident normally on a boundary between two different materials, has already been illustrated in Figure 1.8.

The transmission loss is

$$R = 10\log\frac{p_i v_i}{p_t v_t} = 10\log\frac{1}{t_p \cdot t_v} = 10\log\frac{(Z_1+Z_2)^2}{4Z_1Z_2}(\mathrm{dB})$$

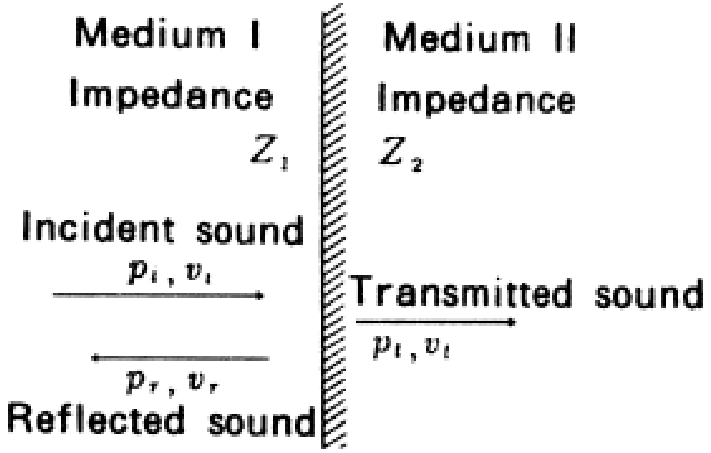


Figure 1.8 Reflection and transmission at the boundary plane between two media.

b. Reduction by resilient layers

Resilient layers, such as rubber, springs, etc., are efficient means of reducing structure-borne sound.

The softer the resilient materials the more effective they are.

However, when the interlayer thickness becomes large, the phase shift in the material has to be taken into account, as the total transmission may occur in the important frequency region.

As for bending waves, the behaviour is complicated by deformation of the resilient material.

The total transmission can be found at the particular frequency 170 Hz, in Figure.

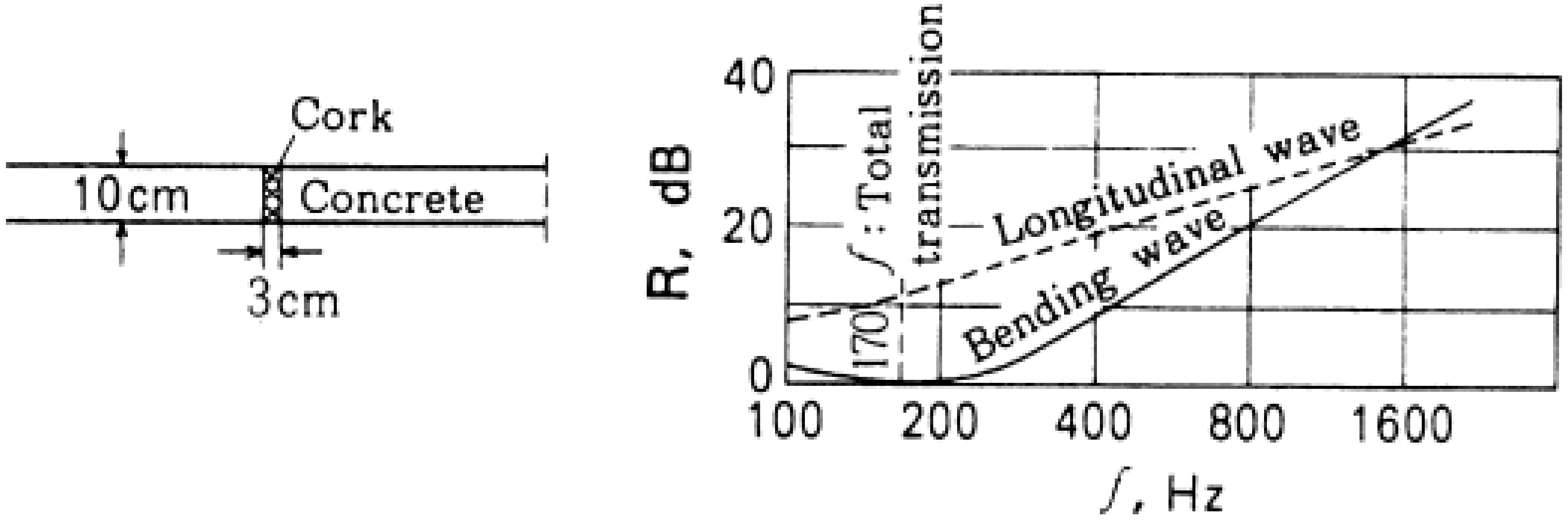


Figure 7.9 Transmission loss of an elastic interlayer (Cremer *et al.* Lit. B19).

D. Reduction of structure-borne noise in a real building

- A real building is a complicated combination of plates and bars that form the construction of walls or floors and columns or beams, respectively.
- It is so difficult to deal with structure-borne noise analytically that statistical energy analysis is often used.
- However, there are still many problems left in attempting to obtain a precise estimation of structure-borne noise.

Figure 7.10 shows an example of measured structure-borne noise levels in rooms caused by the vibration excited by a concrete chipping machine in an existing hospital, which has a rather simple construction of reinforced concrete, compared with values calculated by the method of SEA (Furukawa *et al. 1990).*

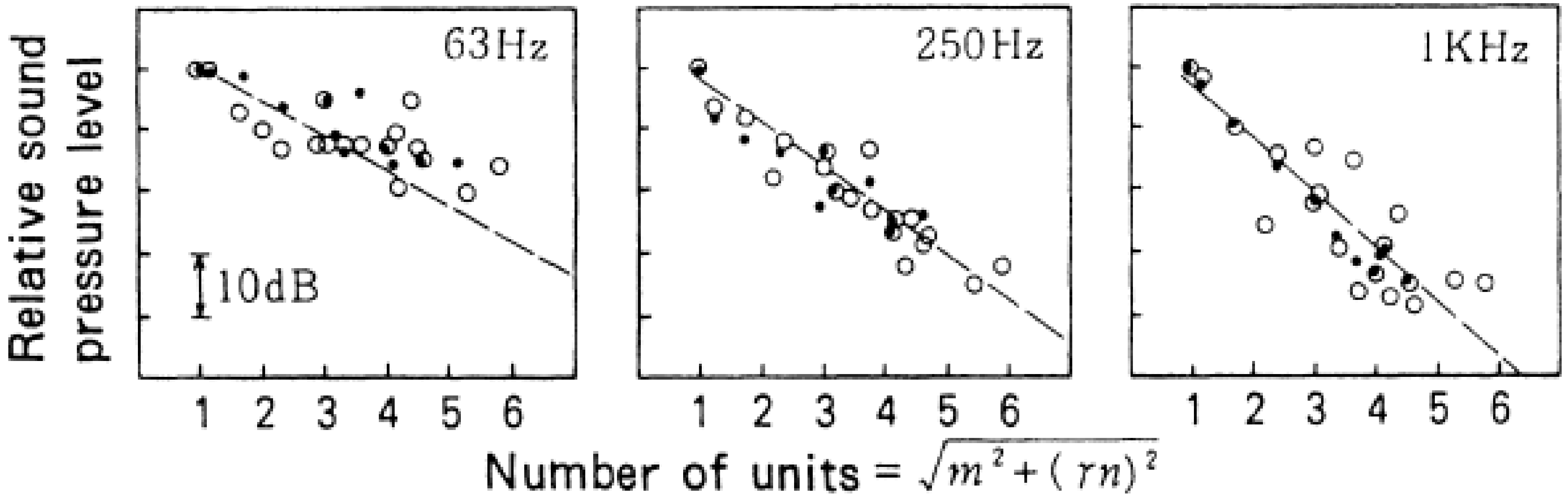
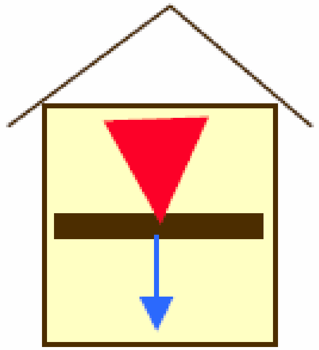


Figure 7.10 Attenuation of structure-borne sound measured in an existing 10 storey building. The unit is $(6.0 \times 5.9)\,\text{m}^2 \times 2.9\,\text{m}$ high, m and n are the number of rooms counted horizontally and vertically, respectively, γ is a proper weighting factor. The circles ∘ and • are measured on the floors above and under the excited wall, respectively. Dashed lines are calculated by the SEA method.

Measurement and rating of impact sound insulation

- With impact sound it is the level of noise produced in the receiving room which is of interest and not the level of the impact sound itself.
- The amount of insulation provided by building elements against structure-borne noise is only measured and classified for floors and ceilings.
- A standard impact machine specified by ISO 140-6 is used for this purpose as follows.



- Impact sound insulation must be measured using a sound source whose characteristics are accurately known; the sound caused by i.e. walking or dropping items on the floor vary and thus cannot be used as sound source.

- *Standardized tapping machine* is used for measuring.

ISO 140-6 specifies the details about tapping machine.

- It should have 5 hammers, each of weight 0.5 kg, placed in line, with 40 cm between both ends. The hammers are freely dropped from 4 cm high onto the specimen successively, at a rate of 10 times per second.

- The size of the test specimen should be between 10 and 20 m^2 with the shorter edge length not less than 2.3m.

- The tapping machine should be placed in at least four positions. The hammer connection line should be orientated at 45◦ to the direction of the beams or ribs. The distance of the tapping machine from the edges of the floor should be at least 0.5 m.

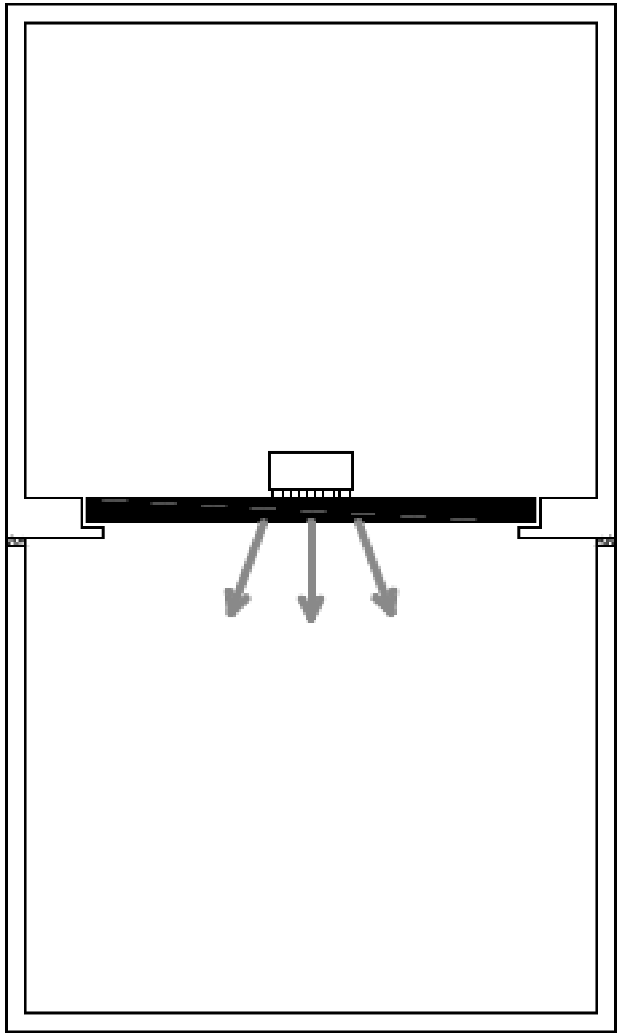
- The impact sound pressure level in the receiving room should be averaged.

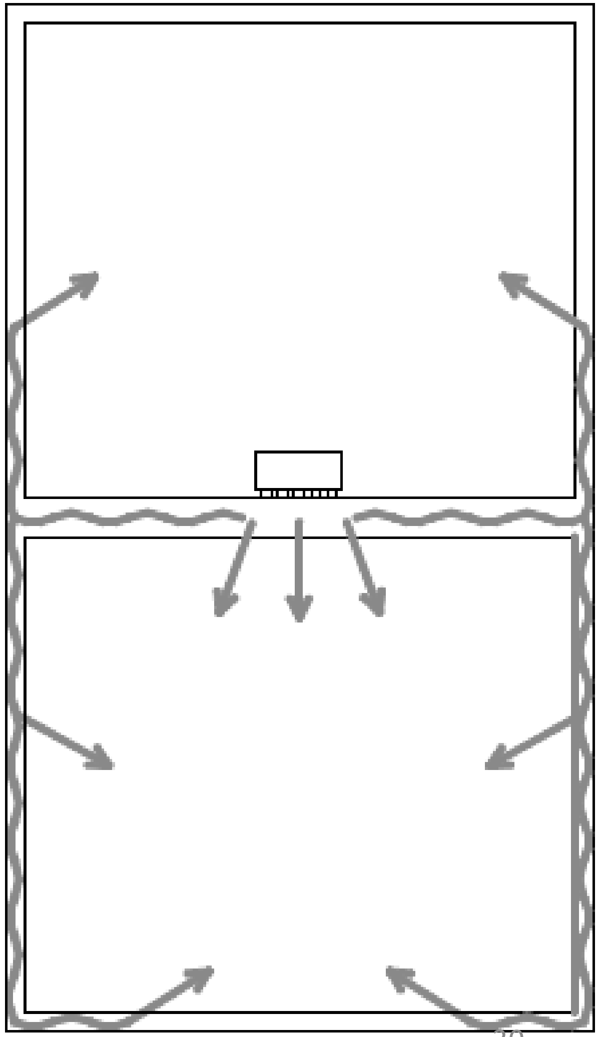
- The sound pressure level should be measured using 1/3 octave or octave band filters of which the frequency range should be at least from 100 to 3150 Hz (preferably 4000 Hz) for 1/3 octave bands, and from 125 to 2000 Hz for octave bands.

Laboratory measurement of impact sound insulation of floors

- The test specimen is installed in the test opening *between two reverberant rooms* as shown in Figure.

- *The space and time average sound pressure levels in the receiving room*, when the test floor is excited by the standard tapping machine, are measured.





Impact sound pressure level

- The sound pressure levels in the receiving room caused by the **tapping machine** in the source room are measured in 1/3 bands 100 – 3150 Hz

- The measurement is typically conducted in a space below the source room but can also be performed in horizontal direction or even diagonally (regulations apply also in this case)

- The impact sound pressure level caused by the tapping machine: *L'* (field measurement), *L* (laboratory measurement)

- The **impact sound pressure levels L_i** [dB] measured in different parts of the room are averaged:

$$L = 10\lg\left(\frac{1}{n}\sum_{i=1}^{n}10^{L_j/10}\right)$$

Impact sound pressure level

- The sound level in a space caused by the tapping machine depends on the absorption area of the receiving room *A*, which is determined by measuring the reverberation time *T* and volume *V* of the receiving room (connection according to Sabine formula.

- By measuring the absorption area the impact sound pressure levels in different spaces can be made independent of room attenuation (furnishings etc.) and volume and thus comparable.

- The energy-average of the measured impact sound pressure levels is normalised to an absorption area of 10 m^2

Normalised impact sound pressure level

- Normalised impact sound pressure level at a certain frequency measured in a laboratory:

$$L_n = L_i + \log(\frac{A}{A_0})$$

where L_i is the impact sound pressure level in the receiving room, A is the sound absorption area obtained from the measured reverberation time and A_0=10 m^2.

- And in the field:

$$L'_n = L_i + \log(\frac{A}{A_0})$$

Standardized impact sound pressure level

- Standardized impact sound pressure at a certain frequency measured in a laboratory:

$$L_{nT} = L_i - \log(\frac{T}{T_0})$$

Where L_{nT} is the impact sound pressure level corresponding to the 0.5 second reference reverberation time T_0=0.5 s.

- And in the field:

$$L'_{nT} = L'_i - \log(\frac{T}{T_0})$$

Exercise: In measurements made between two adjacent rooms in a building, the impact sound pressure level corresponding to the 10 m^2 reference absorption area in the receiving room is 70 dB. The total wall area of the receiving room is 180 m^2, and the average absorption coefficient in the receiving room is 0.3 and the reverberation time is 1.2.

a) What is the impact sound pressure level in decibels measured in the receiver room?
b) What is the impact sound pressure level corresponding to the 0.5 second reference reverberation time in the receiving room?

Solution: In measurements made between two adjacent rooms in a building, the impact sound pressure level corresponding to the 10 m^2 reference absorption area in the receiving room is 70 dB. The total wall area of the receiving room is 180 m^2, and the average absorption coefficient in the receiving room is 0.3 and the reverberation time is 1.2.

a) What is the impact sound pressure level in decibels measured in the receiver room?

b) What is the impact sound pressure level corresponding to the 0.5 second reference reverberation time in the receiving room?

a)

$$L_n = L_i + 10log\left(\frac{A}{A_0}\right) \rightarrow L_i = L_n - 10log\left(\frac{A}{A_0}\right)$$

$$L_i = 70 - 10log\left(\frac{0,3 * 180}{10}\right) = 62,68\ dB$$

b)

$$L_{nT} = L_i - 10log\left(\frac{T}{T_0}\right) = 62,18 - 10log\left(\frac{1,2}{0,5}\right) = 58,38\ dB$$

Exercise: In the measurements made in two adjacent volumes of 10mx9mx4m, the impact sound pressure level in the receiving room is 76 dB, the sound absorption coefficients of the materials used are 0.3 for the walls, 0.25 for the ceiling and 0.15 for the floor, respectively.

a) What is the normalized impact sound pressure level measured in the receiving room?
b) What is the standardized impact sound pressure level in the receiving room?

Solution: In the measurements made in two adjacent volumes of 10mx9mx4m, the impact sound pressure level in the receiving room is 76 dB, the sound absorption coefficients of the materials used are 0.3 for the walls, 0.25 for the ceiling and 0.15 for the floor, respectively.

a) What is the normalized impact sound pressure level measured in the receiving room?
b) What is the standardized impact sound pressure level in the receiving room?

Area=2(10x9+10x4+9x4)=2x166=332 m^2

*A_{wall}=2(10x4+9x4)*0,3=45,6 sabin*

A_{floor}=90x0,15=13,5 sabin, $A_{ceiling}$=90x0,25=22,5 sabin, Atoplam=81,6 sabin

$$L_n = L_i + 10log\left(\frac{A}{A_0}\right) = 76 + 10log\left(\frac{81{,}6}{10}\right) = 85{,}12\ dB$$

$$L_{nT} = L_i - 10log\left(\frac{T}{T_0}\right) = 85{,}19 - 10log\left(\frac{0{,}16x360}{0{,}5x81{,}6}\right) = 74{,}51\ dB$$

Single number rating of impact sound insulation of floors

- As for airborne sound insulation, a method of single number rating forimpact sound insulation of floors is formalised by ISO 717-2.

- *Weighted normalised impact sound pressure level* $L'_{n,w}$ (field)/ $L_{n,w}$ (laboratory) is determined from the measured impact SPLs according to ISO 717-2 in one-thirdoctave bands 100 – 3150 Hz.

- The reference curve (ISO 717-2) is shifted in 1 dB steps to such a position that the sum of unfavourable deviations from the reference curve is ≤ **32.0dB.**

- Unfavourable deviation means that the measured impact SPL is higherthan the value of the reference curve at a certain frequency.

- Weighted normalised impact sound pressure level equals the value of the reference curve at 500 Hz.

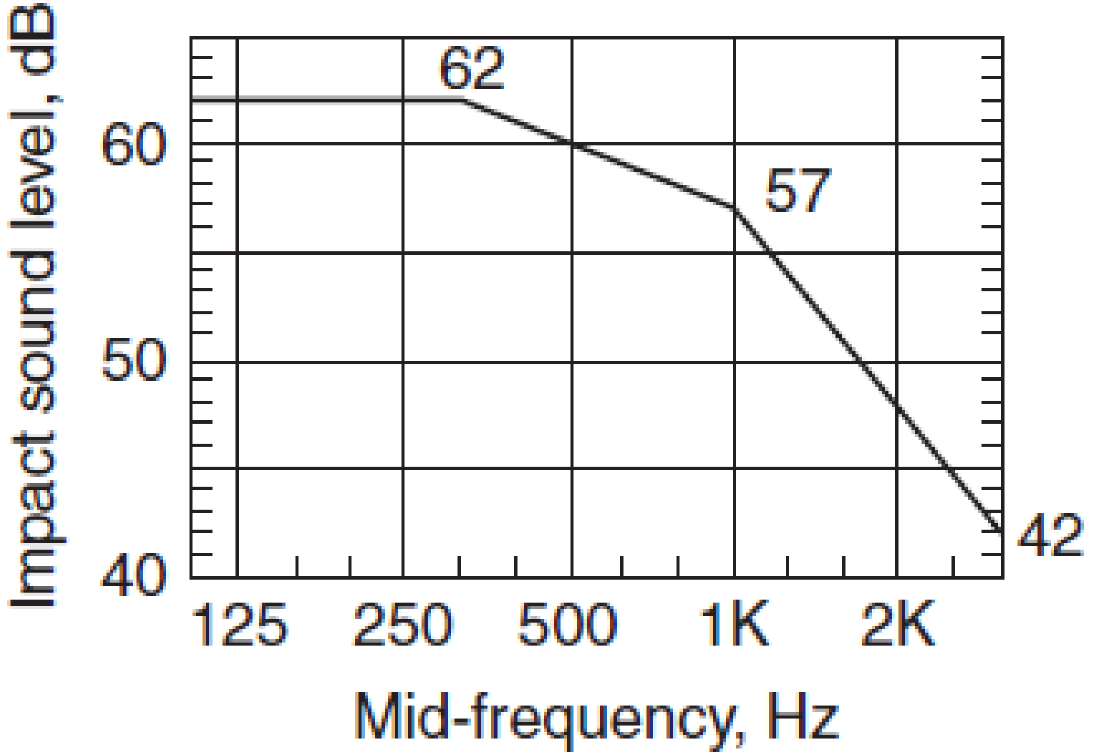


Figure 7.11 Curve of reference value for floor impact noise (ISO 717-2).

Spectrum adaptation terms

- The characteristic frequency of the floor topping and other adjoining structures on the load bearing floor is typically 30...500 Hz.
- The excitation caused by walking may cause low-frequency ”boomy” sound in the receiving room, this phenomenon typically occurs below 100 Hz.
- Hearing sensitivity decreases topwards low frequencies but low frequency impact sounds (< 100 Hz) nevertheless have large impact on subjectively perceived impact sound insulation.
- Here lies a conflict: current regulations of impact sound insulation are based on the weighted normalised impact SPL which is determined from 100 Hz upwards.

- **Standard SFS 5907**:
  - Recommendation to extend measurement range to 50 Hz 1/3-octave band.
  - Spectrum adaptation term C_I from frequency range 100-2500 Hz and $C_{I,50\text{-}2500}$ for range 50-2500 Hz.

Spectrum adaptation terms

- Spectrum adaptation terms are presented with the measuredimpact SPL as follows: $L'_{n,w}(C_{I,}C_{I,50\text{-}2500})$= 49(1;3) dB

- $C_{I,50–2500}$ is calculated from the normalised impact SPLs measured in 1/3-bands 50-2500 Hz and the impact SPL:

$$C_I = 10\lg \sum_{i=50}^{2500} 10^{L_{n,i}/10} - 15 - L`_{n,w}$$

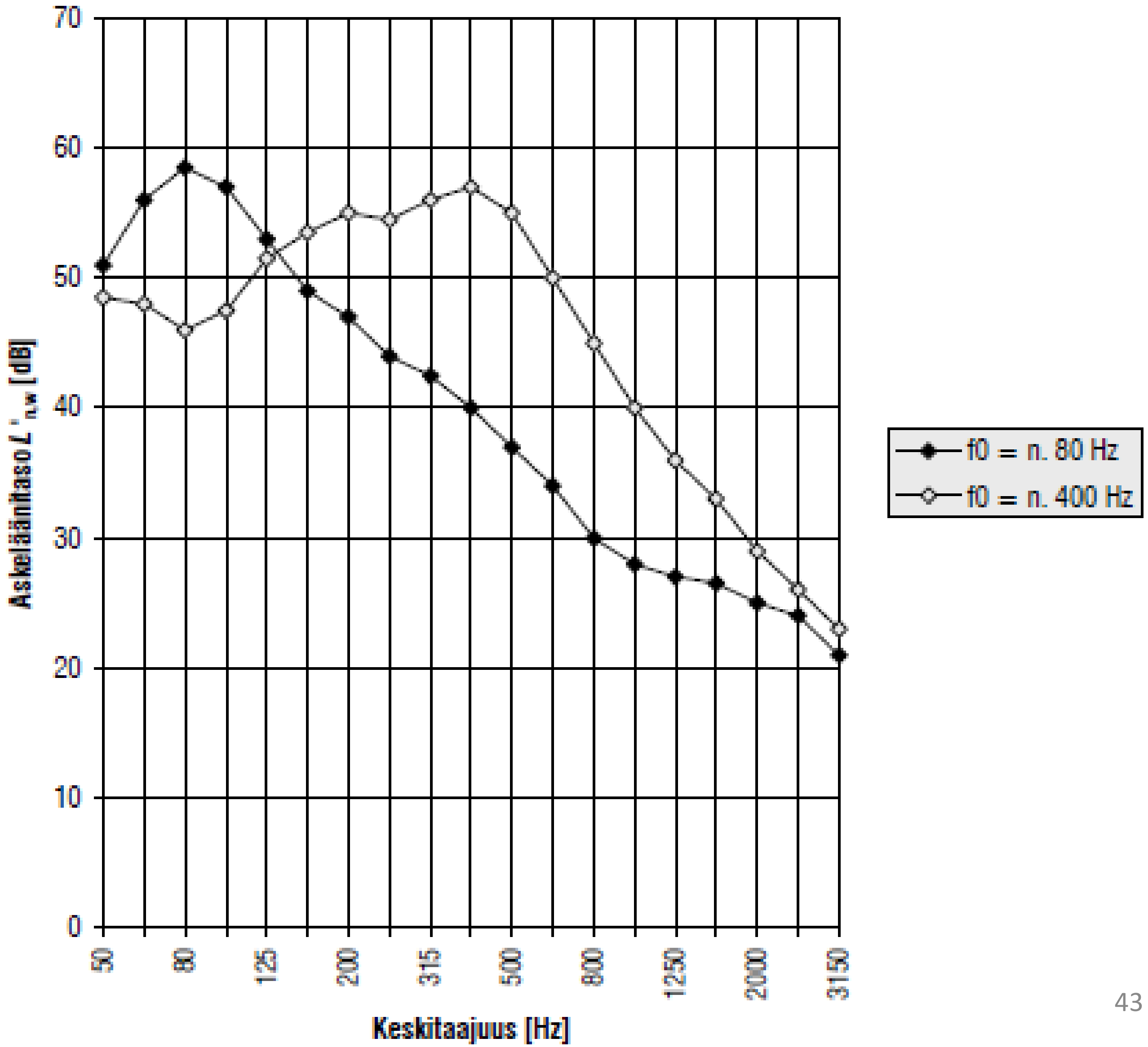
- Quantity $L'_{n,w}$+ $C_{I,50\text{-}2500}$ has been shown to better correlate with subjectively perceived impact sound insulation than the non-weighted value.

- Current regulations do not, however, require the use of spectrum adaptation terms.

Spectrum adaptation terms: Example 1

- Floor 1: lightweight floating floor on top of load bearing structure, f_0= 80 Hz
  – $L'_{n,w}$ **= 42 dB**
  – $C_{I,50\text{-}2500}$ = 6 dB
  – $L'_{n,w} + C_{I,50\text{-}2500}$ **= 48 dB**

- Floor 2: parquet + flexible underlay on load bearing structure, f_0= 400 Hz
  – $L'_{n,w}$ **= 49 dB**
  – $C_{I,50\text{-}2500}$ = 0 dB
  – $L'_{n,w} + C_{I,50\text{-}2500}$ **= 49 dB**



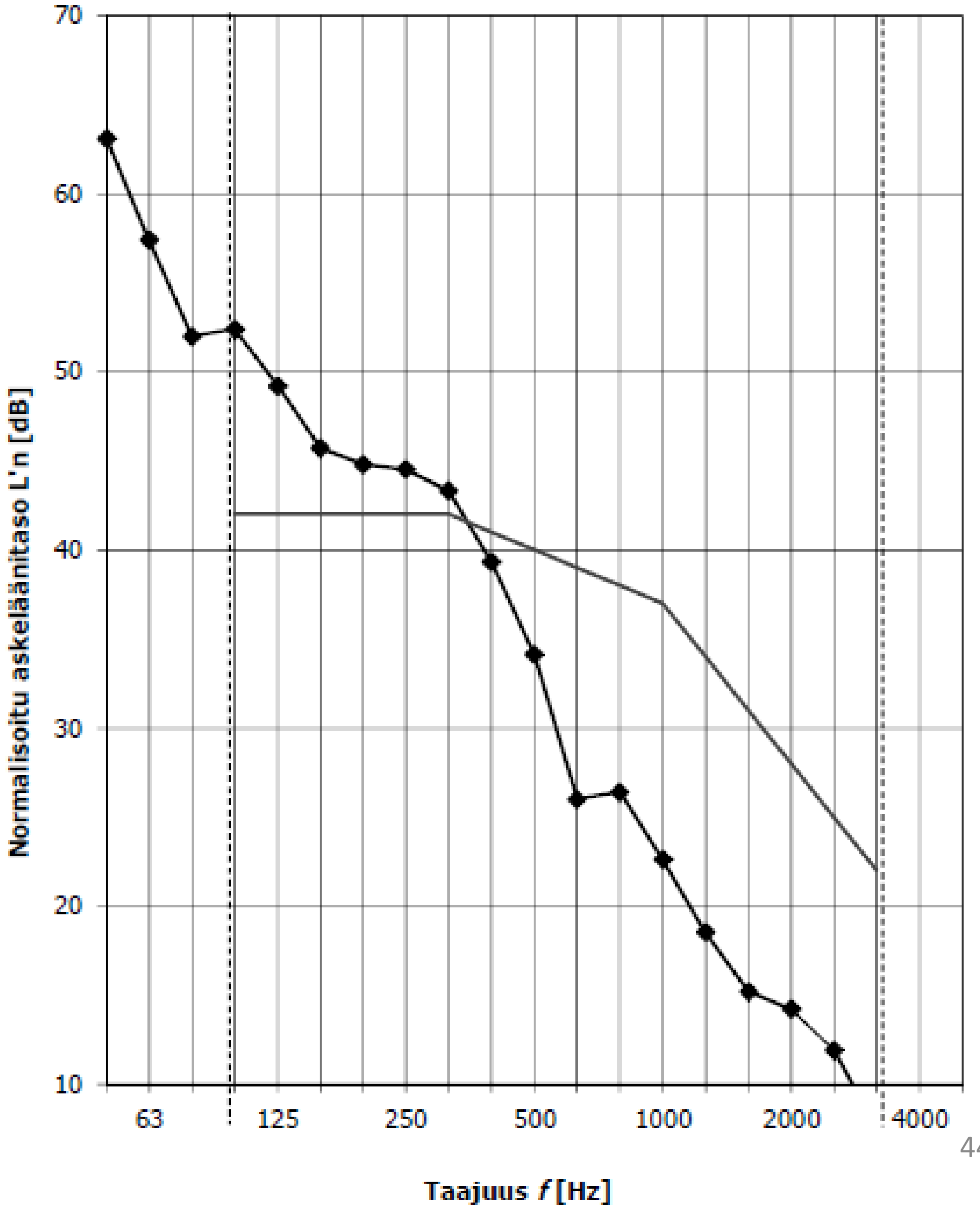
Spectrum adaptation terms: Example 2

- Measured impact SPL:

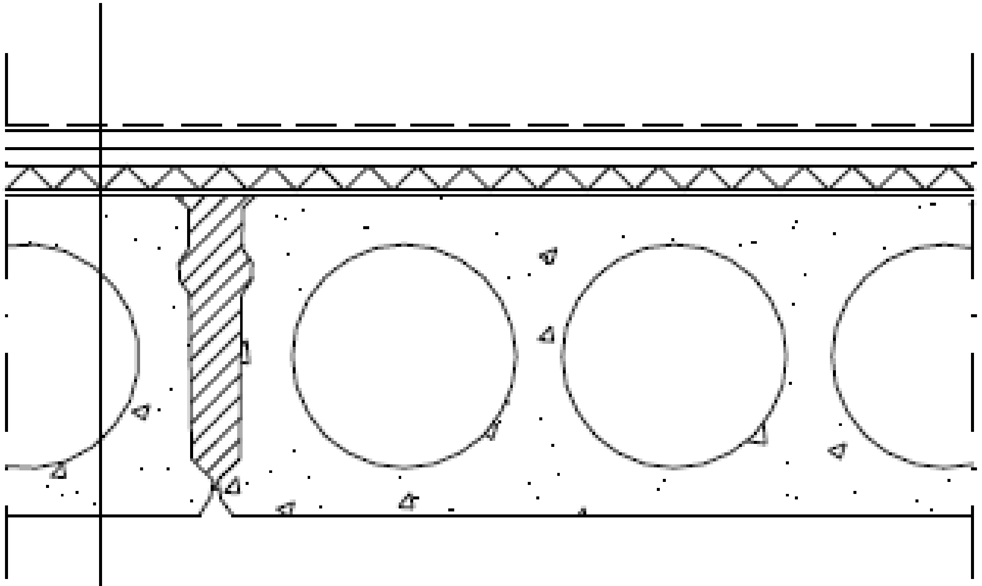
$L'_{n,w}$ $(C_{I,}C_{I,50\text{-}2500}$ $)$ = 40(1;10)

- Structure: old wooden floor structure with new floating floor added (gypsum mass, mineral wool)

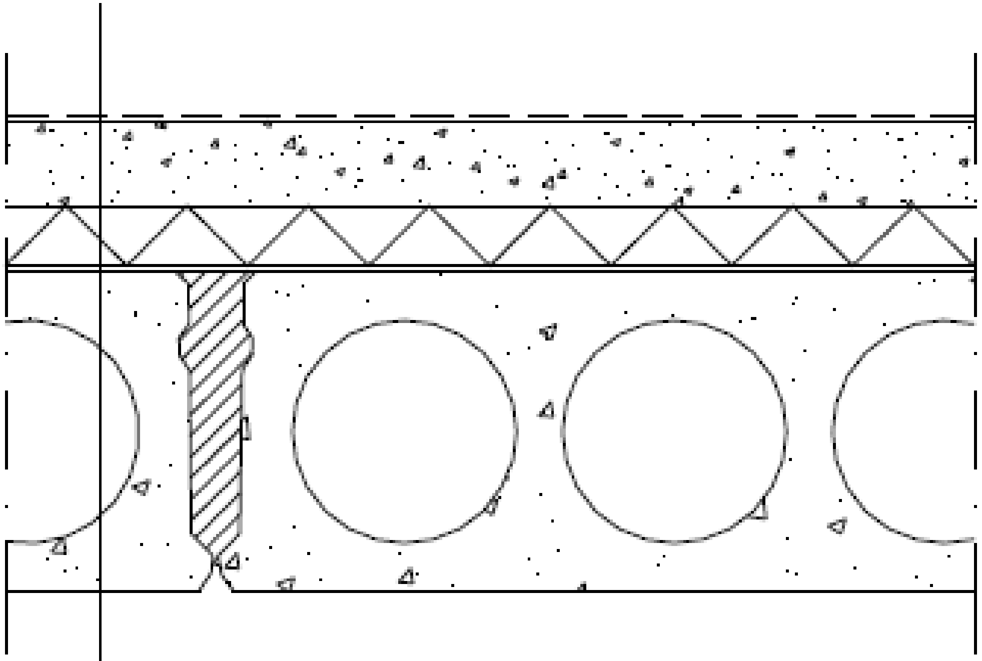
Clearly fulfills current regulations but is the impact sound insulation subjectively good?



Floating floors



- Lattianpäällyste
- Rakennuslevy (15 kg/m2)
- Rakennuslevy (15 kg/m2)
- Eristekerros, s' < 50 MN/m3
- Tasoite 5-20 mm
- Kantava rakenne



- Lattianpäällyste
- Kelluva betonirakenne 80 mm
- Eristekerros, s' < 50 MN/m3
- Tasoite 5-20 mm
- Kantava rakenne

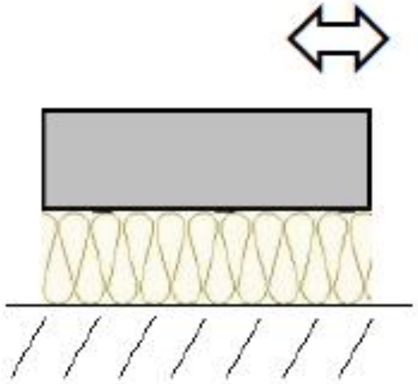
Floating floor theory: simple harmonic motion

- *Simple harmonic oscillator* comprises of a mass attached to a spring (mass-spring system)
- The resonance frequency of simple harmonic oscillator is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where *k* [N/m] is the spring constant and *m* is mass.

- *A floating floor is a similar mass spring system*, but instead of *k* and *m*, we now have the dynamic stiffnesss\` [MN/m$^3$] of the elastic layer and the surface mass *m*\`[kg/m^2] of the floating floor layer
- Replacing *k* with *s*\` and *m* with *m*\` in the above equation gives the *resonance frequency of the floating floor* (show!)



$$f_0 \cong \frac{1}{2\pi}\sqrt{\frac{s'}{m'}}$$

Floating floor theory: simple harmonic motion

The resonance frequency of the floating floor, f_0, is acoustically the most important factor of floating floors.

• It depends on *the surface density of the floating floor layer m' and the dynamic stiffness of the insulation layer) s'*:

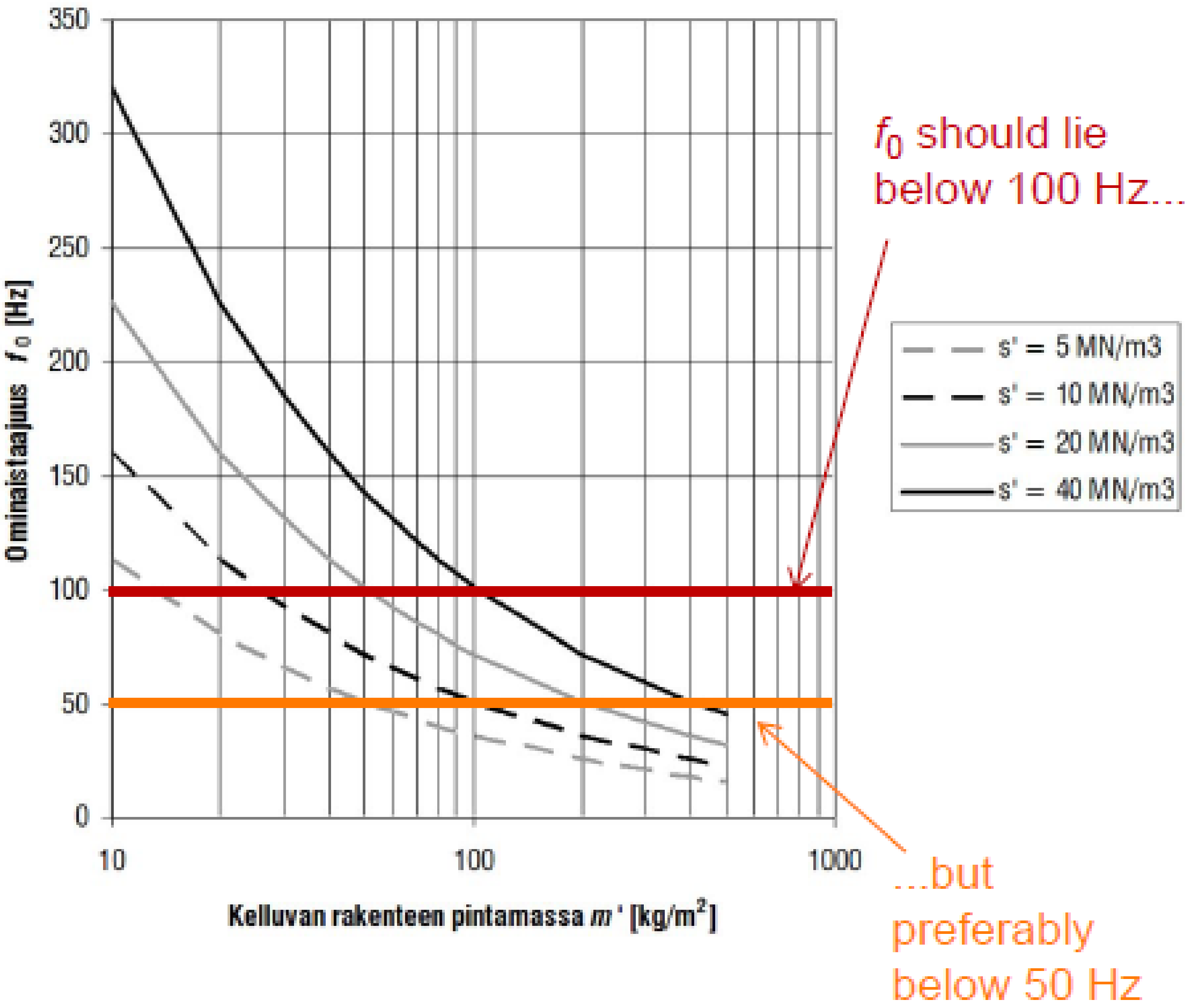
$$f_0 = \frac{1}{2\pi}\sqrt{\frac{s'}{m'}}$$

• For the floating floor structure to have good subjectively perceived impact sound insulation, *the resonance frequency should be as low as possible*; in apartmenet buildings minimum goal is f_0<100 Hz, while f_0< 50 Hz if preferrable.

Floating floor theory: simple harmonic motion

- *The resonance frequency of the floating floor can be lowered by* decreasing the dynamic stiffness of the insulation material and/or increasing the mass of the floating layer.

- The dynamic stiffness of insulation materials (mineral wools etc.) used in apartment buildings is in the range of 8-50 MN/m^3



Example:

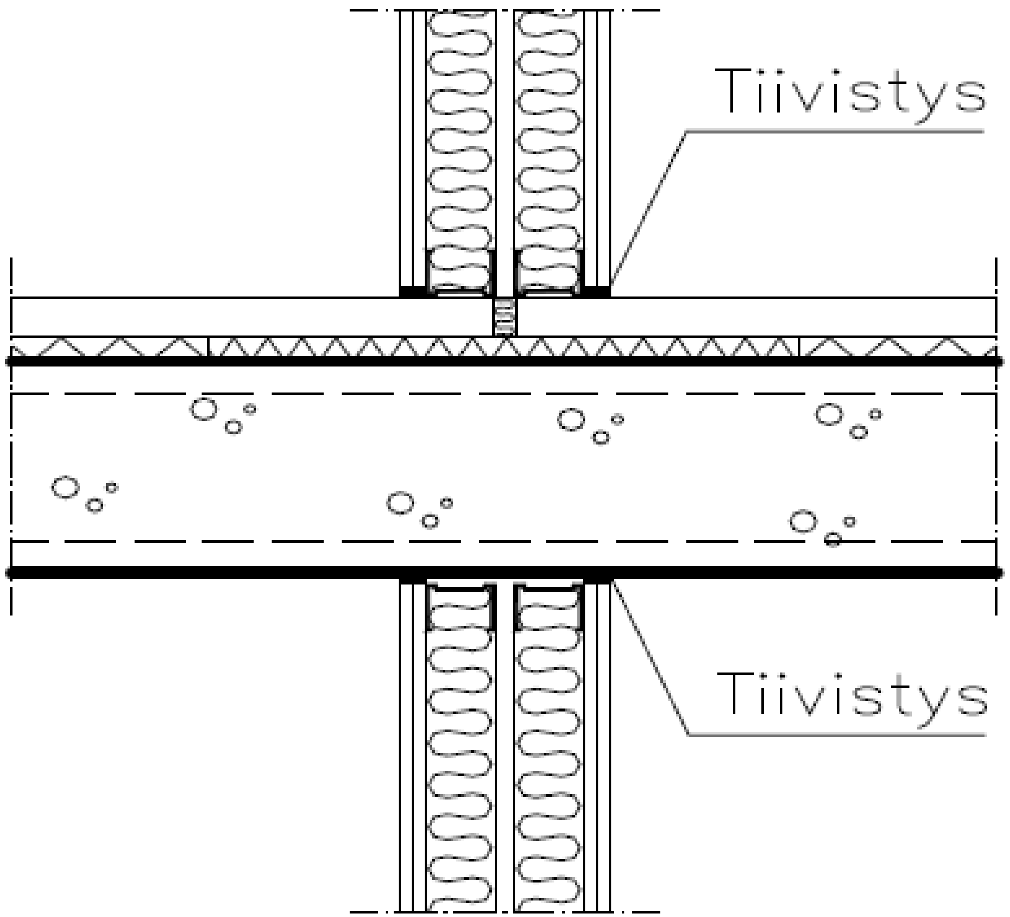
The effects of mass and dynamic stiffness on the resonance frequency of floating floor is shown as in table below.

m [kg/m^2]	s' [MN/m^3]	f_0 [Hz]
30	12	101 Hz
60	50	146 Hz
200	8	32 Hz

Floating floor

- Floating floors constitute a significant flanking transmission path between rooms; **to avoid flanking transmission**, the floating structure has to be truncated at the partition Junction

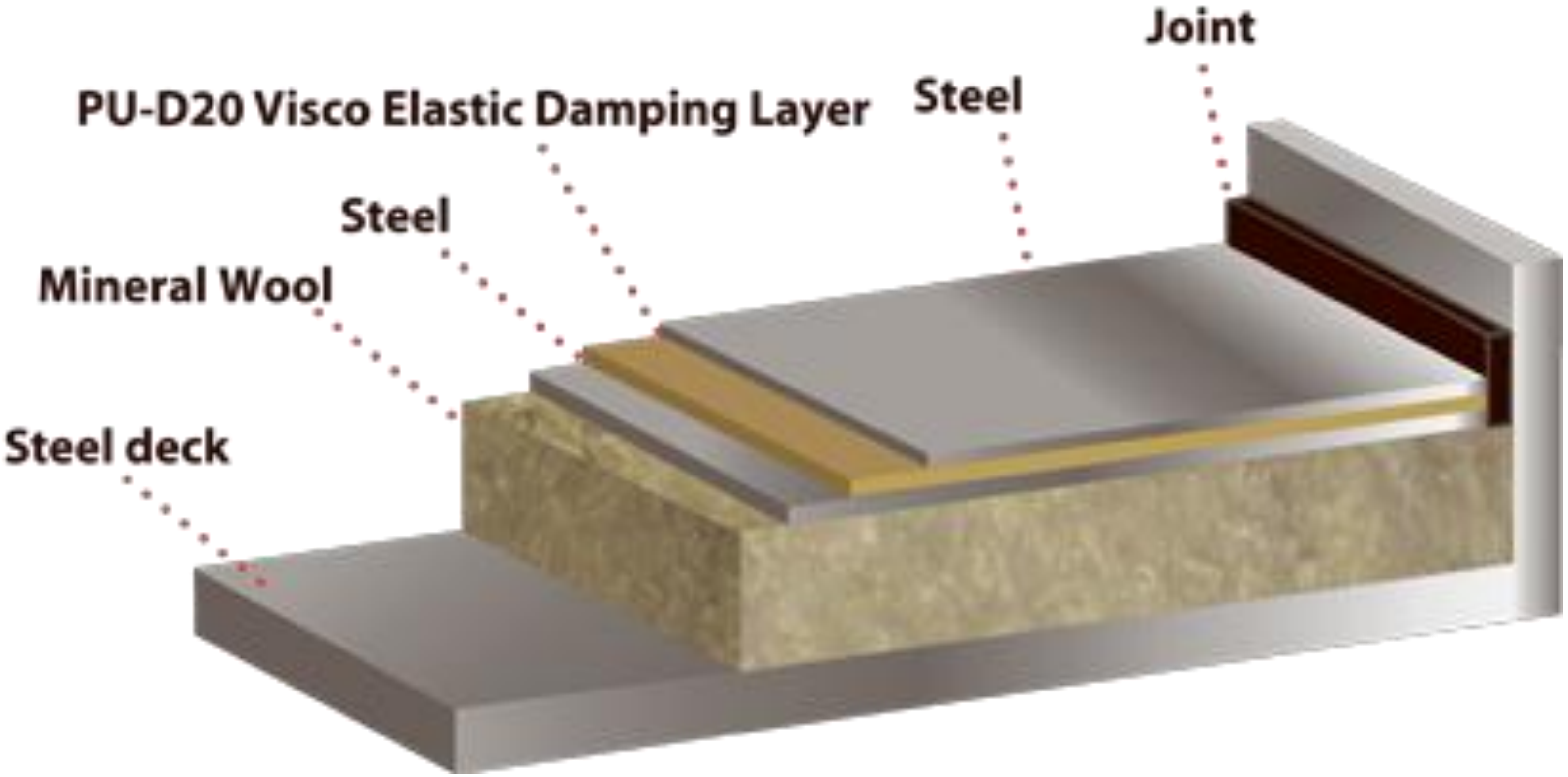
- If necessary, mineral wool with greater load bearing capacity is used under the partition



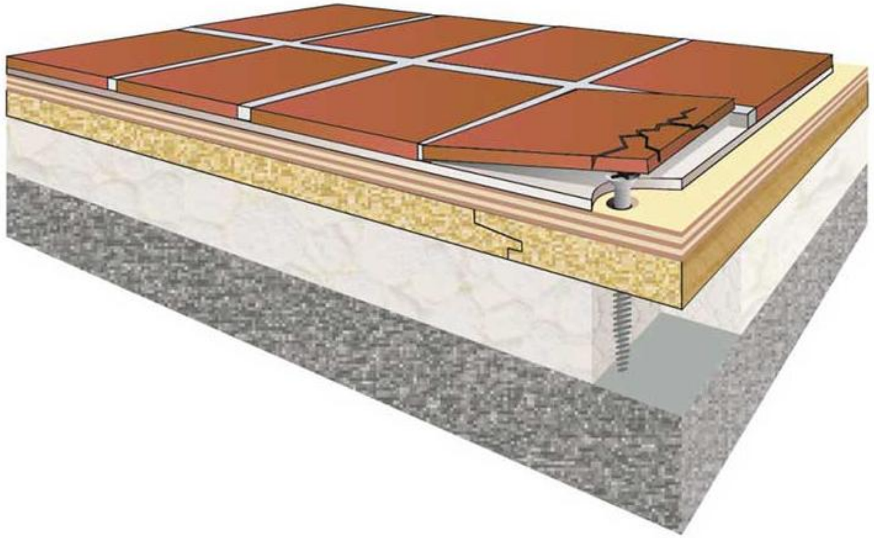
Floating floor

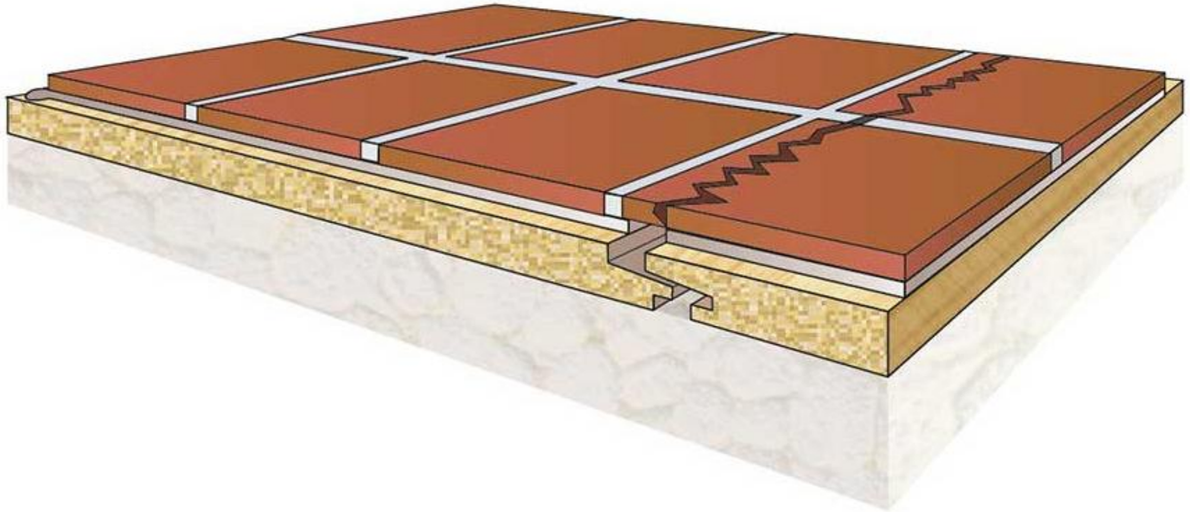
- Floating floor can also be implement *using vibration isolation materials*

- Example: floating floor supported by strips of Sylomer vibration isolation material, the Sylomer strips have been installed on top of wooden beams of the old floor structure, the floating layer is made of gypsum floor boards

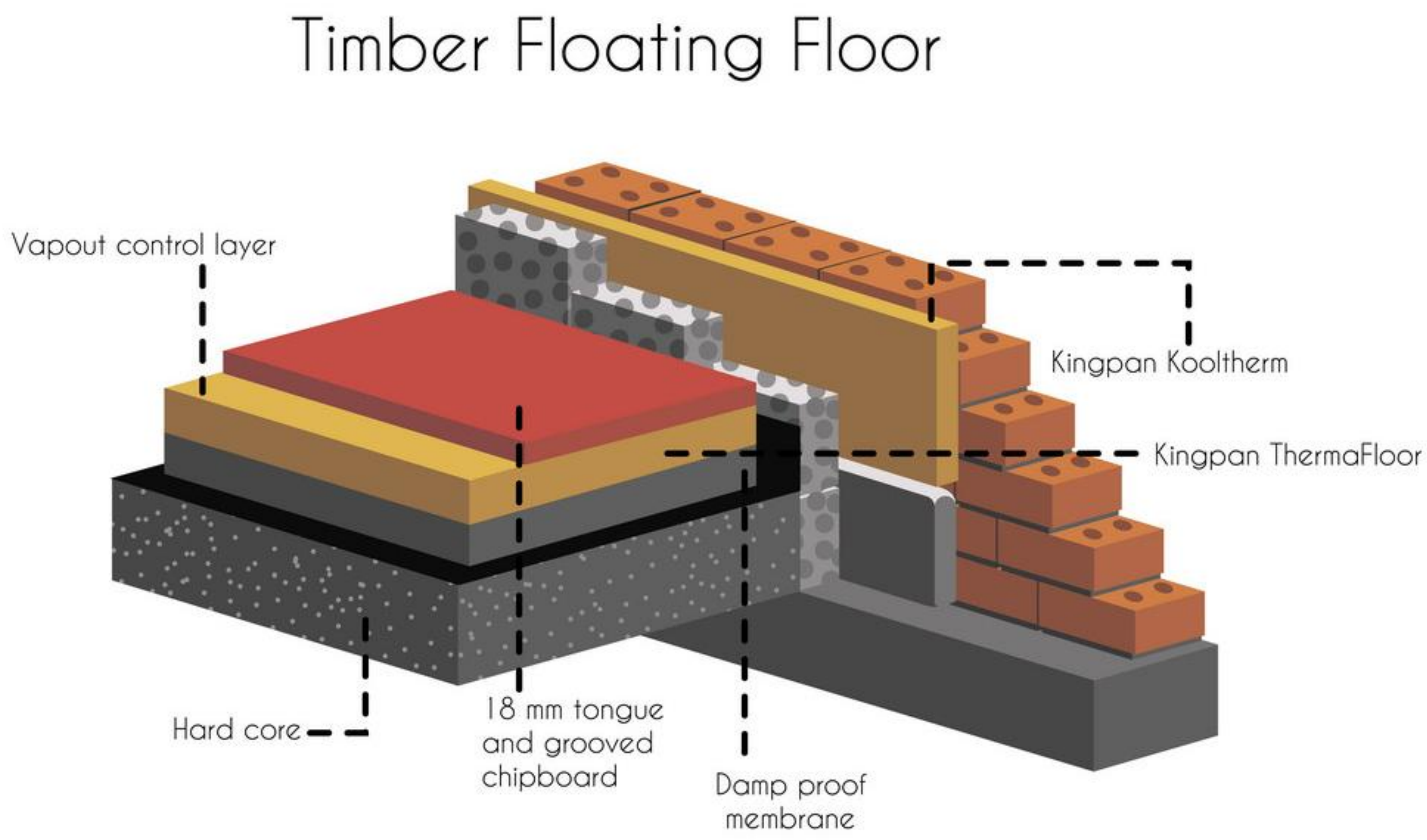

Joint
PU-D20 Visco Elastic Damping Layer
Steel
Steel
Mineral Wool
Steel deck

Tiling onto floating floors





Unsupported joints

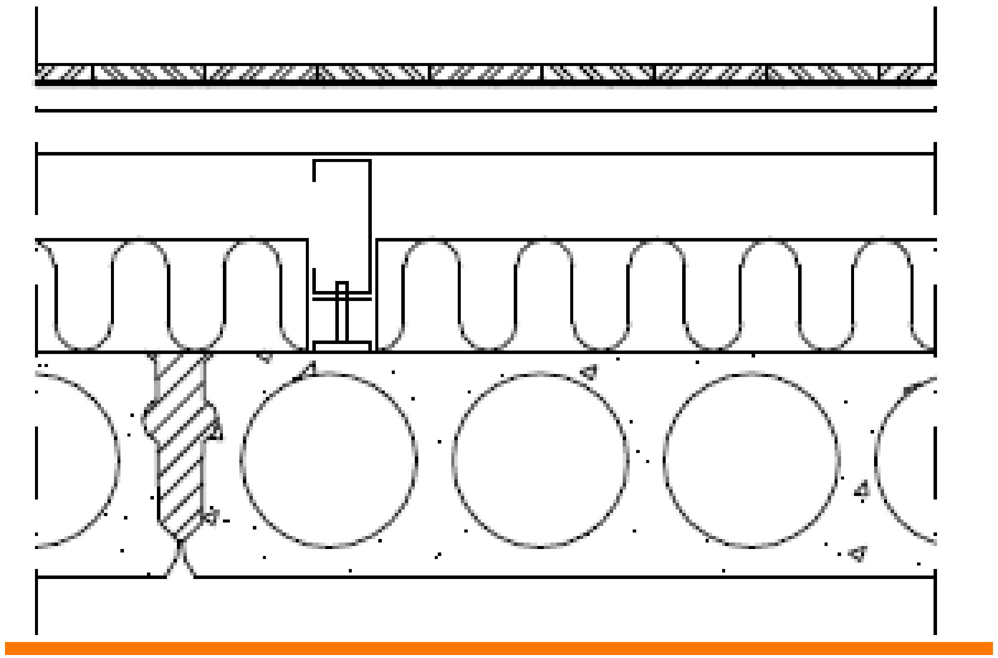

Timber Floating Floor
Vapout control layer
Kingpan Kooltherm
Kingpan ThermaFloor
Hard core
18 mm tongue
and grooved
chipboard
Damp proof
membrane

Access floor

- Access floors constitute a particular type of floating floors, they enable making HVAC installations hidden in the airspace between the floor board and load bearing structure
- Acoustical issues with access floors:

– Reverberation of the airspace heard as a boomy sound in the room, can be avoided by installing sound absorbing layer of mineral wool etc. In the airspace (usually ≥ half of the height of the airspace)

– Flanking transmission via the floor boards of the access floor; the solution is to build the floor and partition so that the floor structure does not extend continuously from room to room




Source GAMMA Industries

Suspended ceilings

- Suspended ceilings *improve impact sound insulation* but not as significantly as flexible floor coverings.

- Suspended ceiling *decreases the sound level in the lower room caused* by impact in the source room and transmitted to the lower room as vibration.

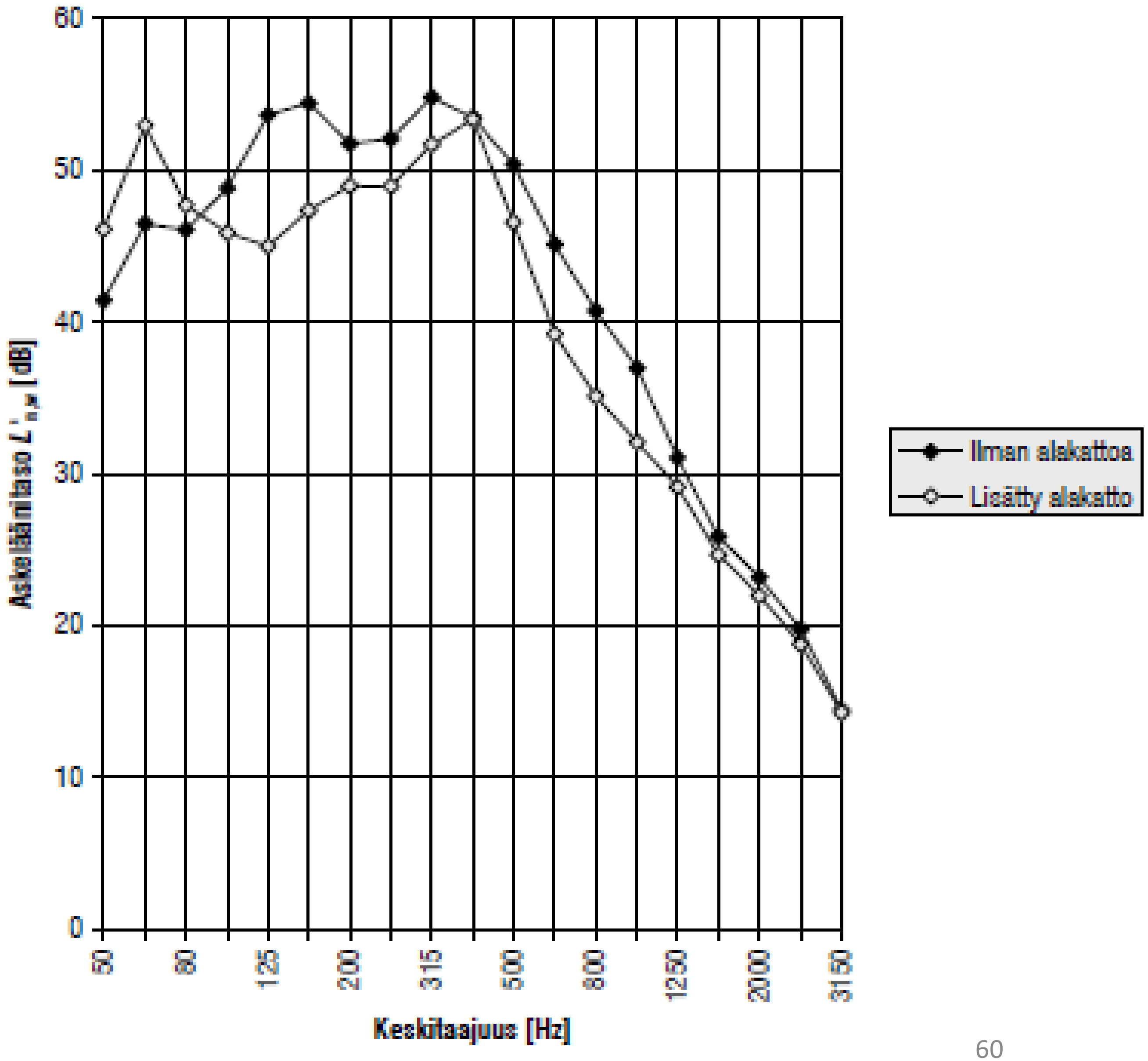
- Suspended ceiling does not, however, decrease the impact sound transmitted between spaces as flanking transmission.

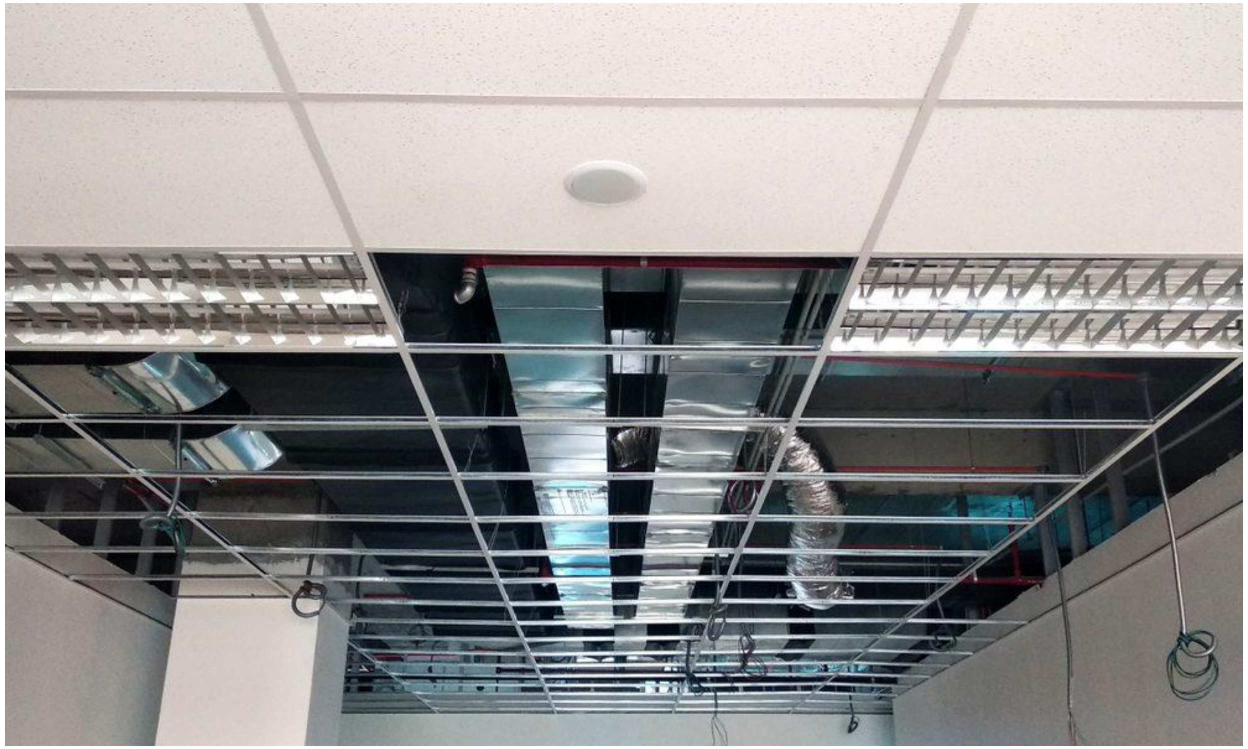
- Due to flanking transmission, the reduction in $L`_{n,w}$ achieved with suspended ceilings is typically 3...5 dB at maximum.

Suspended ceilings

Example, effect of suspended ceiling on impact sound insulation: without susp. ceiling $L`_{n,w}$ = 47 dB,with susp. ceiling $L$`n,w = 43 dB

- Floor: parquet on 240 mm concrete
- Susp. ceiling: 1 x building board, steel studs and mineral wool 70 mm
- Note: at low frequencies suspended ceiling can actually lead to deterioration of impact sound insulation because of the mass-air-mass resonance of the double strucuture formed by the suspended ceiling board, air space and load bearing structure (typically < 200 Hz)



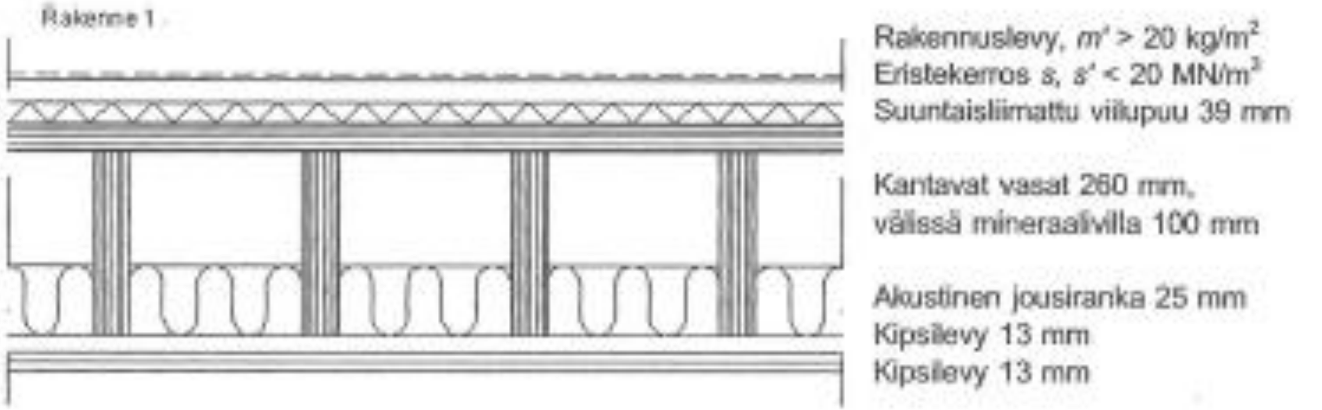


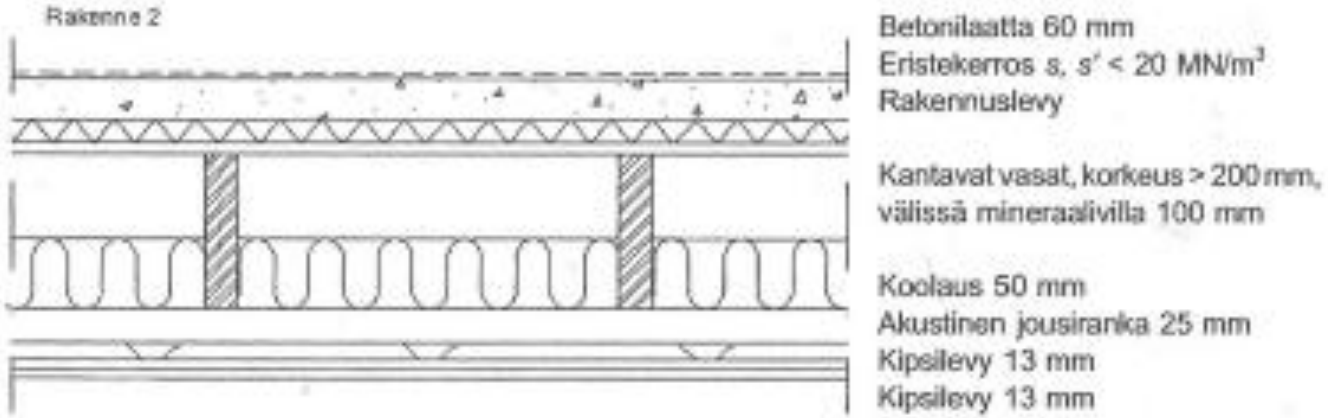
Lightweight floors

- The load bearing structure in lightweight floors are steel studs, wood joists or similar structures

- Total mass of the floor is typically below 100 kg/m^2

- Impact sound insulation of lightweight floors is not based on mass and flexible floor coverings (as was the case with massive floors), but rather on acoustically decoupled plate layers





	Rakenne 1	Rakenne 2
$L'_{n,w}$	47	47
$C_{I,50\text{-}2500}$	6	2
$L'_{n,w} + C_{I,50\text{-}2500}$	53	49

Light weight floors

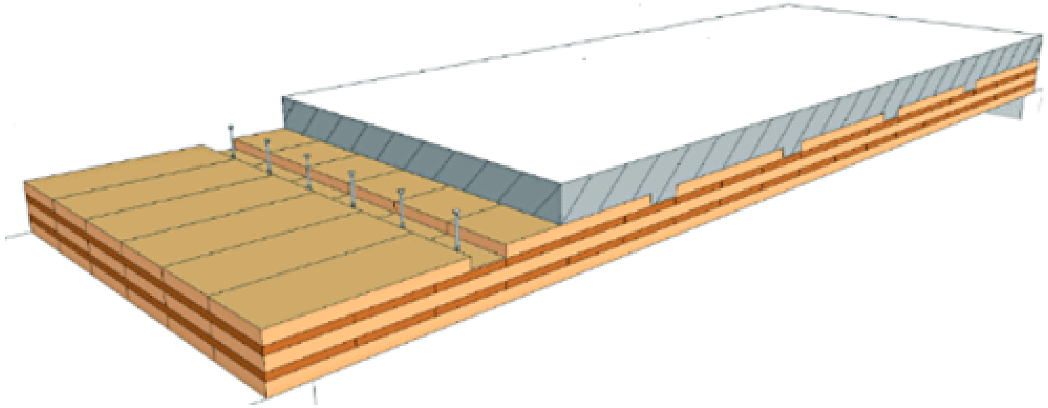
- As ”rules of thumb”, the impact sound insulation of *light weight floor structure improves when:*

– The height of the airspace formed by the load bearing structure increases (typical height 300...400 mm)
– The amounf sound absorbing material in the airspace increases
– The resonance frequencies of the floating floor and suspended ceiling decreases

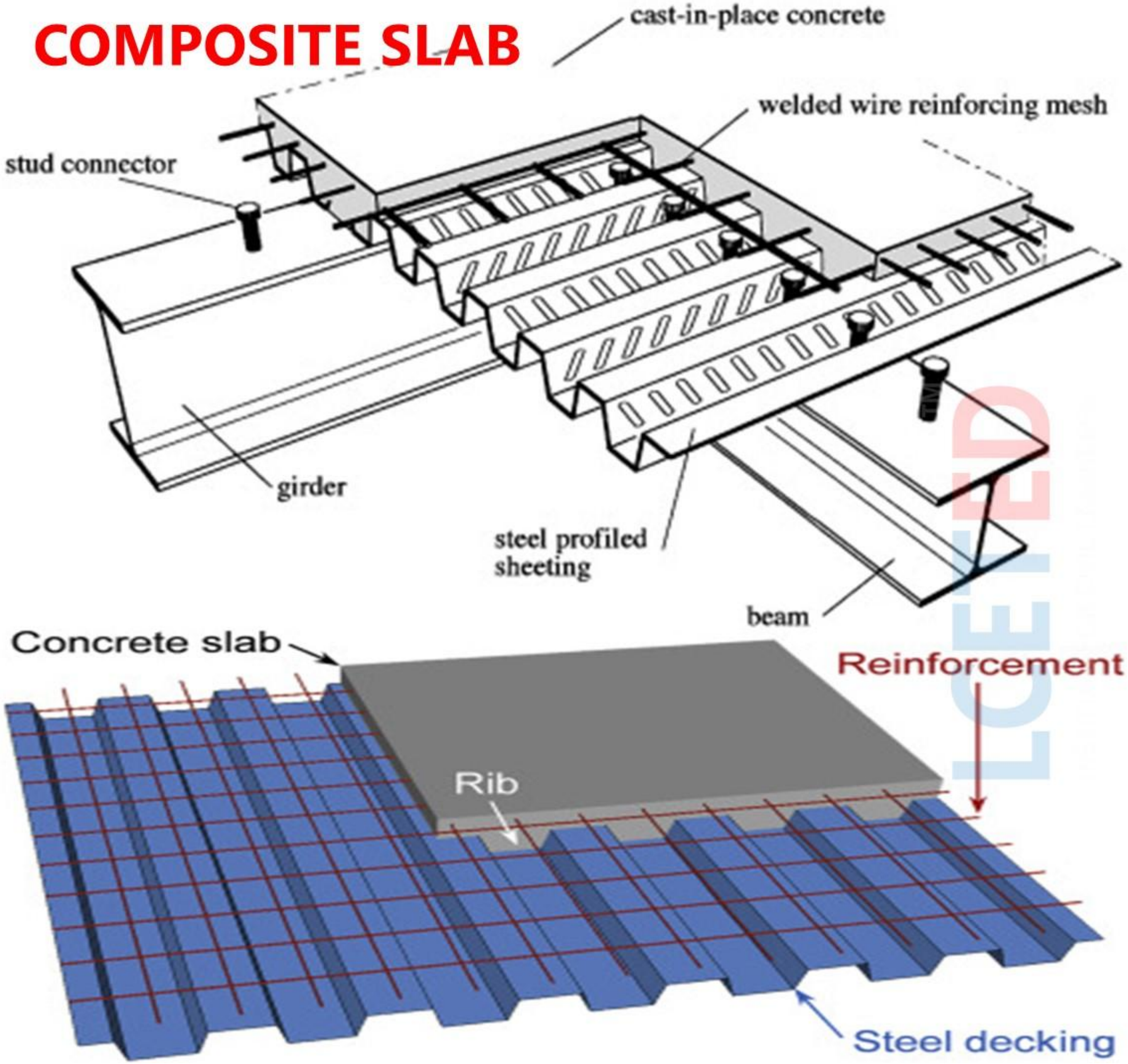
- When evaluating the impact sound insulation of light weight floors it is important to consider insulation at low frequencies,because the acoustical function of the structure is based onthe resonance frequencies of its building layers.

- It is typical to lightweight floors that the impact SPL is highest at the low frequency region.
- spectrum adaptation term $CI_{,50\text{-}2500}$ should be considered ≤ 53 dB

Light weight concrete floors



COMPOSITE SLAB



Design of impact sound insulation
EN 12354-2 calculation model

- The simplified model applies to floors covered with flexible topping, it should not be used with floating floors.

- The calculation accuracy compared to measurement results is **± 2 dB** in 60 % of the cases, in all cases the difference between calculated and measured impact SPL has been **± 4 dB.**

→ when calculating the impact sound insulation of floors with the model, a safety margin has to be left between the calculated and required impact SPL.

Design of impact sound insulation
EN 12354-2 calculation model

- As a general rule: impact sound insulation requirements must be fulfilled, not only between dwellings, but also from other spaces to dwellings.
- Shared-use spaces

– Saunas, laundry rooms and drying rooms, club rooms etc.

– Usually hard floor materials, e.g. mosaic tiles on concetrete, water proofing requirements must also be considered.

- Retail spaces, shops

– Noise sources: rumbling of trolley wheels, people walking etc.

– Special consideration: loading docks / areas.

- Waste rooms

– Noise sources: rumbling of trash bin wheels on the floor, bins hitting the walls, banging of the lids of the bins etc.

Design of impact sound insulation
EN 12354-2 calculation model

- **Stairwells, stairs**

– Impact sound insulation from stairs, storey and intermediate landings to dwellings
– Floor material of the first level of the stairwell usually hard due to wear resistance (e.g. masonry tiles on concrete) → horizontal impact sound insulation to dwellings must be considered
– Stairs within dwellings must also meet requirements
→ possible need for vibration insulation of stairs
– Open galleries

- **Other considerations**

– Lofts (parvet)
– Roof terraces above dwellings: regulations do not apply but in some cases can cause complaints → vibration insulation possible

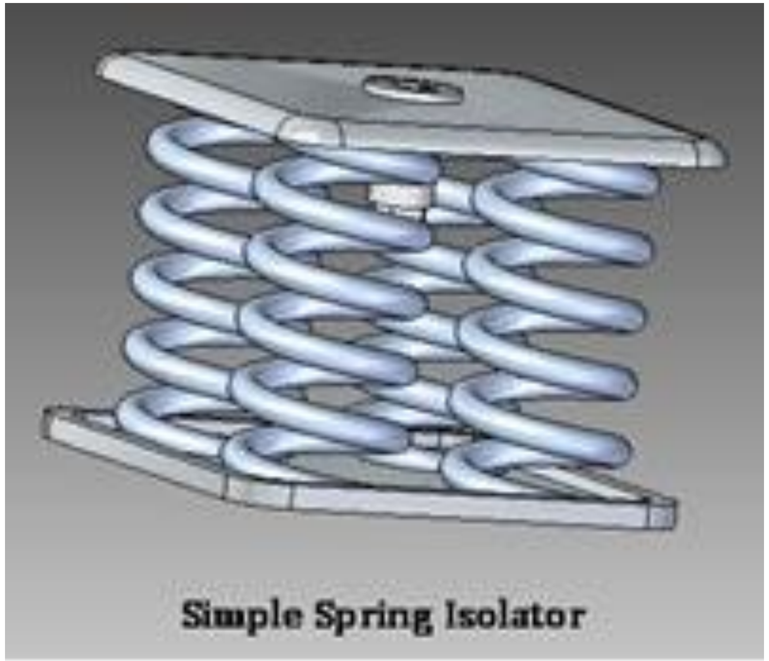
Vibration isolation

- The vibration of equipment attached to the building frame causes structure borne sound.
- Structure borne sound traverses along structures and excites air molecules into vibration causing air borne sound in the receiving room
- Air condition machinery usually have built in vibration isolators, while other types of equipment have not:

–Frequency regulators
–Pumps
–Compressors

- Vibration isolation needs to specifically designed.

Vibration isolator



Vibration isolator

Principle of vibration isolation

- In order to deal precisely with the vibration of a solid body, vibrations in each direction of a three-dimensional coordinate axis, around which rotational vibrations can also take place, need to be considered.

- This results in a requirement for analysis of 6 d.f. (degree of freedom). However, the principle of vibration damping is presented here on the basis of a simple vibration system based .

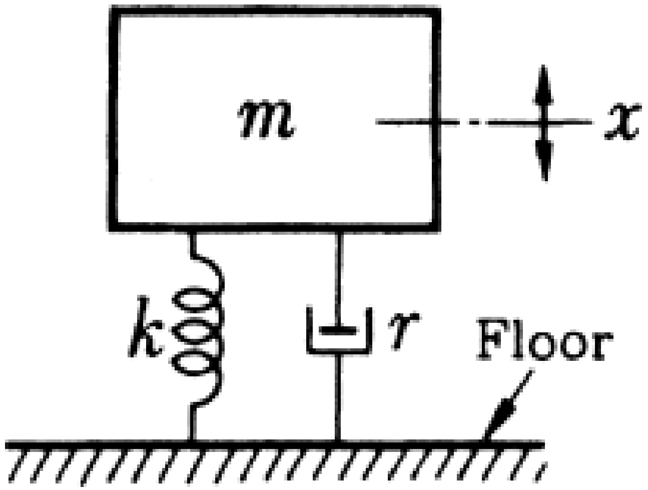


Figure 7.13 Principles of vibration isolation.

Vibration of a 1-degree-of-freedom system

A body whose mass is *m* rests on an elastic spring, which has elastic modulus *k*. When it is forced to vibrate in the vertical direction by an external force *P* cos *ωt*, its motion can be represented by

$$m\frac{d^2x}{dt^2} + r\frac{dx}{dt} + kx = Pcos(wt)$$

where *r* is the frictional resistance factor. If the vibrational driving force to the floor is P_t

$$P_t = kx + r\frac{dx}{dt}$$

Transmissibility is the ratio of vibration of the isolated surface to that of the source. Vibrations are never eliminated, but they can be greatly reduced.Then, the vibration transmissibility *T* is derived

$$T = \frac{|P_t|}{|P|} = \left\{ \frac{1 + \left(2 \cdot \frac{\omega}{\omega_n} \cdot \frac{r}{r_c}\right)^2}{\left(1 - \frac{\omega^2}{\omega_n^2}\right)^2 + \left(2 \cdot \frac{\omega}{\omega_n} \cdot \frac{r}{r_c}\right)^2} \right\}^{1/2}$$

Where

$\omega_n = 2\pi f_n = \sqrt{k/m}$,

f_n is the natural frequency, and

r_c *is* the critical damping resistance,

$$r_c = 2m\omega_n = 2\sqrt{mk}$$

When the resistance is zero, r=0, then,

$$T = \frac{1}{\left|1 - \left(\frac{\omega}{\omega_n}\right)^2\right|} = \frac{1}{\left|1 - \left(\frac{f}{f_n}\right)^2\right|}$$

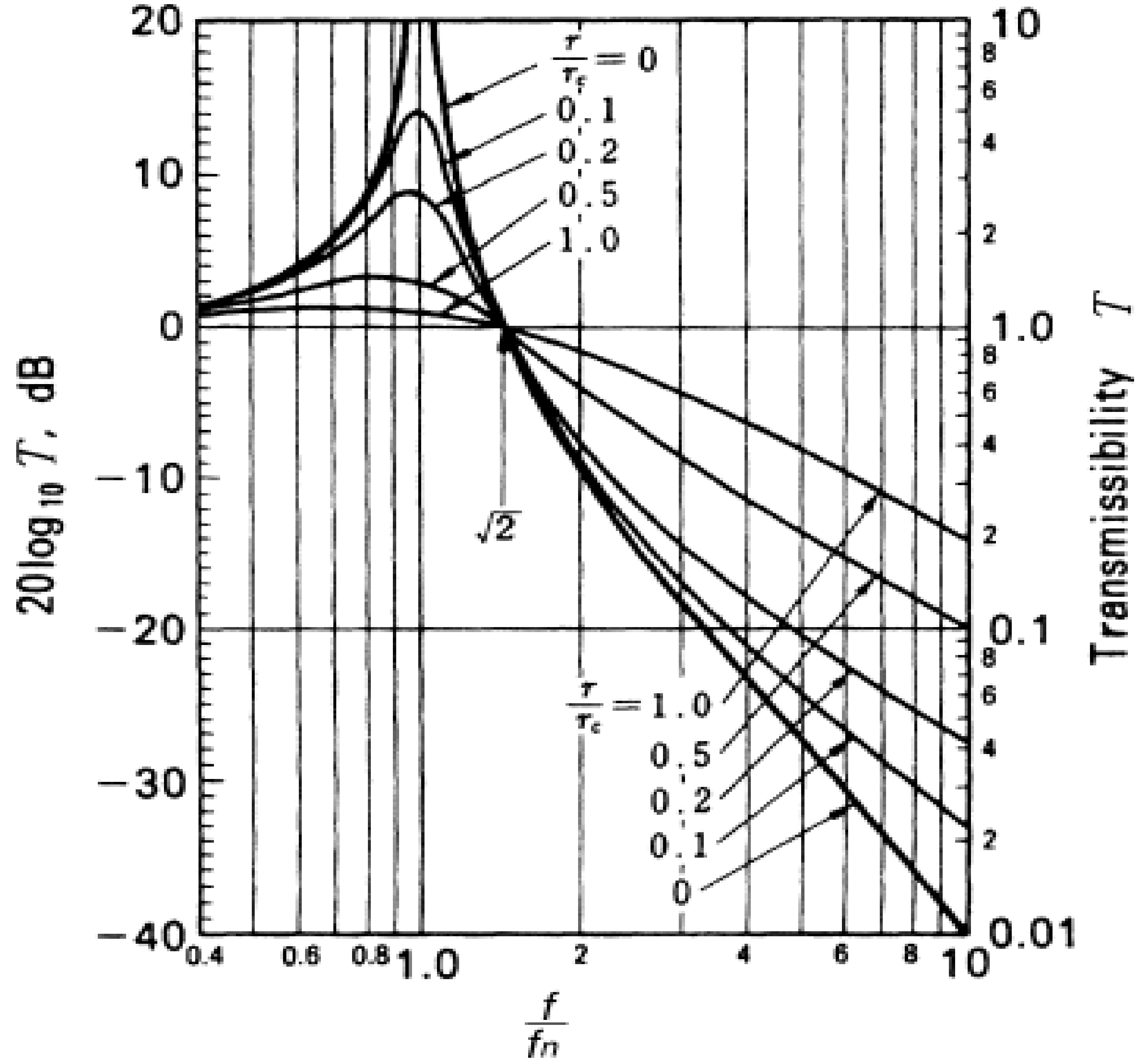


Figure 7.14 Vibration transmissibility vs normalised frequency.

- As Figure 7.14 clearly shows,
- when $\frac{f}{f_n} < \sqrt{2}$, the force transmitted is greater than the applied force. At the point where the driving frequency and the natural frequency are equal, the transmitted force theoretically becomes infinite because *r* = 0.

- When $\frac{f}{f_n} = \sqrt{2}$, then the transmitted force equals the applied force.

- At higher frequencies we start to get isolation, and

for vibration isolation $f\ /f_n > 4$ should be the aim.

- The above discussion can be applied in the reverse direction in Figure 7.13, where vibration is transmitted from the floor tothe mass *m*.

- Thus, in order to produce a quiet room that is isolated from vibration and from the transmission of structure-borne sound, the room considered as a mass *m* should be supported on a suitable spring system,which is generally called a **floating structure**.

Vibration isolation design

When a body whose weight is W (kg) is loaded on an elastic spring whose elastic modulus is k (kg cm^{-1}), the deflection δ is

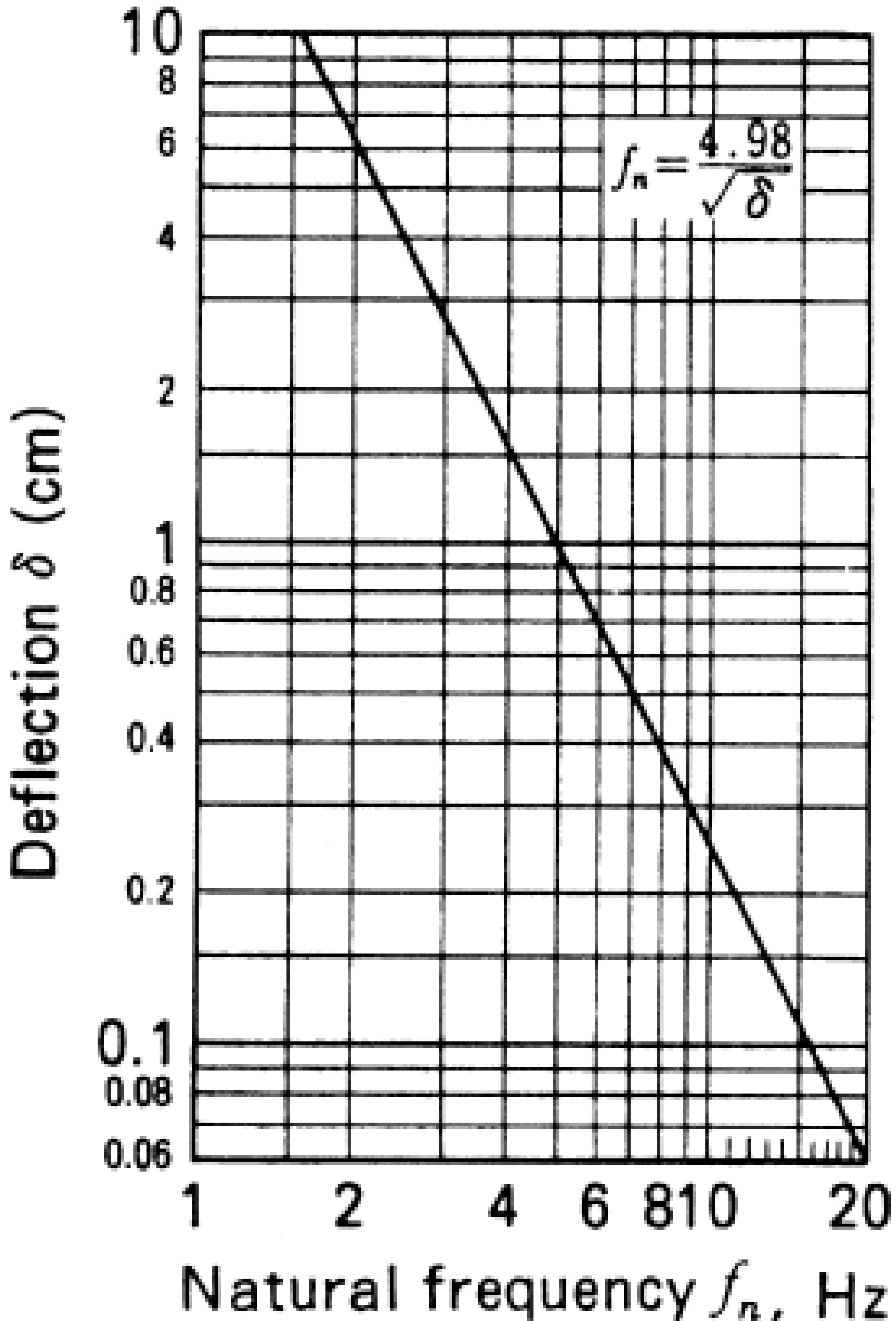
$$\delta = \frac{W}{k} \quad (cm)$$

The natural frequency of this vibration system, ignoring resistance, is

$$f_o = \frac{1}{2\pi}\sqrt{\frac{kg}{W}} = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}} \approx \frac{4.98}{\sqrt{\delta}}$$

where $g=980\ cms^{-2}$ is the acceleration due to gravity.
The natural frequency f_n is determined by the static deflection δ. This relationship is shown in Figure 7.15.

Figure 7.15 Static deflection vs natural frequency.



The design procedure is as follows:

- Knowing the frequency f of the vibration source, f_0 is determined from Figure 7.14 in order to secure sufficient attenuation.

- To realise this, the necessary deflection δ is obtained from Figure 7.15.

- Select the vibration isolation material to maintain the δ while supporting the total weight W.

- For perfectly elastic materials, it must be noted that except for steel springs, all other materials have a non-linear relationship between load and deflection so that dynamic deflections are smaller than static deflections.

- Therefore, the value of δ in Figure 7.15 must be increased by a correction factor indicated in Table 7.1.

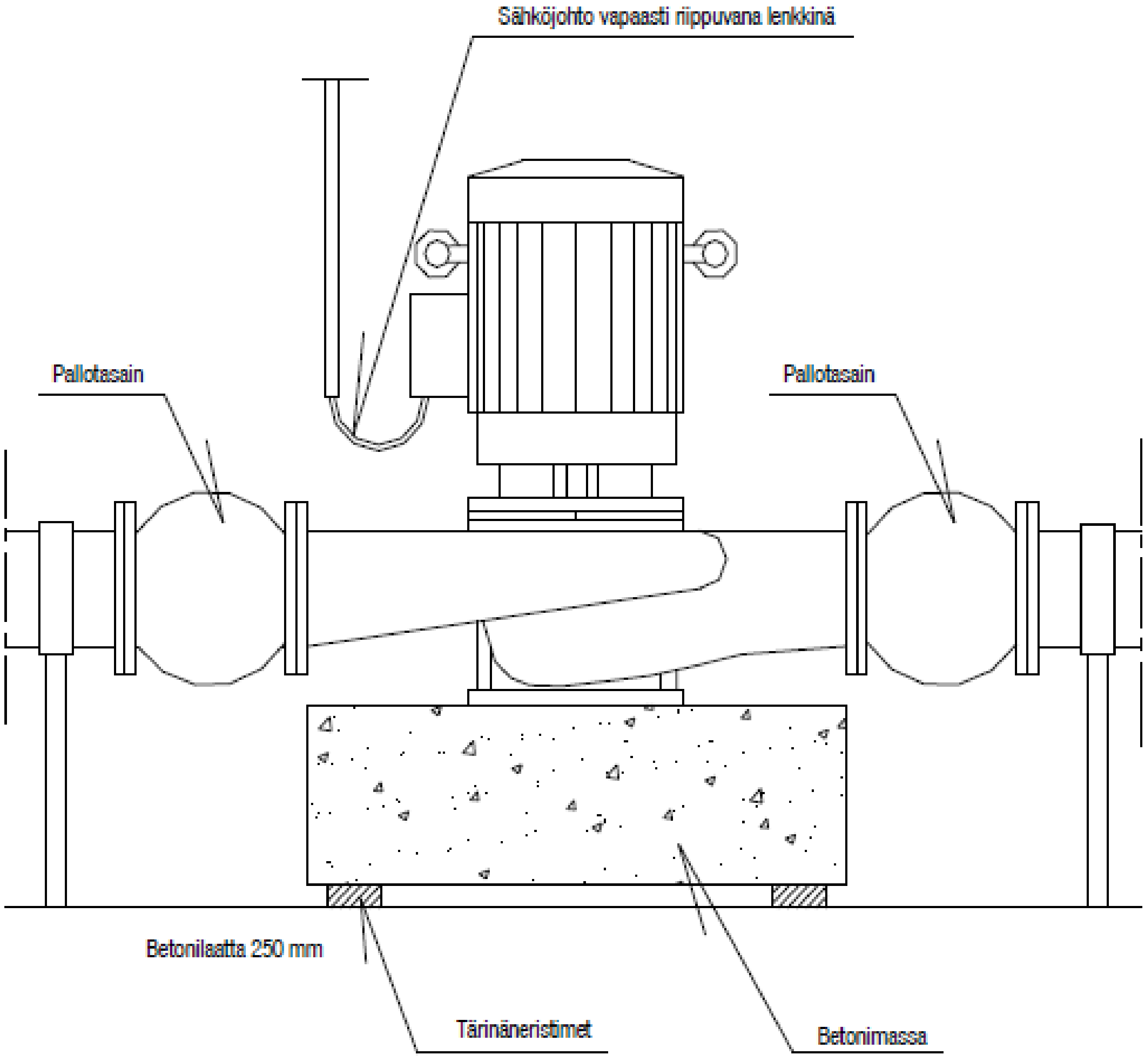
Vibration isolation design

- Design of vibration isolation of a simple mass-spring system assumes that the surface **is rigid** and massive with no resonances of its own

- Floating floor must not be done below vibration isolate dequipment because the resonance frequency of the floating floor may coincide with that of the vibration isolators in which case no vibration isolation is achieved.

–E.g. air condition machinery rooms:
-no floating floor because the air condition equipment have built-in vibration isolators

Vibration isolation design



Vibration isolation–incorrect design

Vibration isolation correct design

Achieving Higher Impact Noise Performance in Design

1. Programming

- As with most problems related to noise control, positioning noisy areas so that they are far from quiet areas is often the best of the solutions available.
- To mitigate problems that might arise from impact noise, consideration should be given as to whether a parti that involves vertically stacking residential units is necessary at all.

2. Damping at point of impact

- The most effective method to bolster the performance of a floor-ceiling assembly is to prevent the impact sound energy from entering the building structure altogether.
- This can be achieved by specifying carpet with a soft underlayment, cork, or rubber tile surfaces.
- Of course, even if carpet is specified, occupants may swap out their soft surface for a hard one sometime after taking ownership of a unit, *significantly* decreasing its impact noise performance.

3. Damping between a hard finish surface and a structural surface

- A resilient underlayment can consist of a mesh, pad, board, or mat layer.
- These are typically proprietary systems and are not equal in performance.
- In general, thick underlayments far outperform thinner underlayments, and those with thicknesses less than 3/8 inch should be avoided, especially in light wood construction.
- In concrete construction, a "floating floor" may be used to isolate a concrete pad from the structural floor below it.
- In this system, a second floor surface hovers on spring or neoprene isolators.
- Most of the effective underlayments will add a not-insignificant thickness to the floor assembly, which can complicate the installation of cabinets and doors.
- When designing for an underlayment or floating floor, carefully detail to eliminate flanking paths at penetrations and walls.

4. *Damping between the structural floor and the ceiling below*

- Generally, floor-ceiling assemblies with ceilings out perform those with exposed overhead structure.
- Decoupling the ceiling from the structure with spring hangers, resilient channel, or resilient brackets, increases performance further.
- For concrete construction, maintain four inches minimum airspace between the ceiling and the structure above it (eight inches is better).

5. *Insulation in the cavity*

- The use of sound-absorbing fiberglass, cellulose, or mineral wool insulation in the cavity between the floor above and the ceiling below increases impact insulation performance.
- This “fuzz” in the cavity benefits frame construction only slightly but has a more meaningful impact in concrete constructions with suspended ceilings.

6. *Stiffness and mass*

- While "click-clack" sounds are associated with an inadequately resilient floor surface assembly, a "thud" sound is associated with insufficient stiffness.
- In wood construction, short joist spans, nominally those 14 feet or less, outperform floors with longer joist spans in the field; floors with denser joist spacing, 16 inches on-center or less, outperform floors with sparser joist spacing.
- Lab tests published for floor-ceiling assemblies do not currently account for the variability of joist spans, and manufacturers may disingenuously test a stiffer structure in the lab than normally specified in the field to bolster a product's IIC (Impact insulation class (IIC) provides a single-number rating and a means for comparing the performance of floor-ceiling assemblies for the transmission of impact noise.) numbers.
- To achieve appropriate stiffness and mass in wood construction, a concrete or gypsum-concrete floor topping should be used.

7. *Flanking*

- The acoustical benefit of underlayments or resilient ceiling mounts can be compromised if the independence of resilient components is short-circuited.
- Special care is required in detailing and construction oversight to ensure that resiliently supported floors, floated floors, and resiliently hung ceilings make no rigid contact with structure that bridges between floors.
- When floors are isolated on an underlayment or floated, use a soft proprietary perimeter board at the edge of the floor surface in each room to keep structure-borne acoustic energy from transferring to the walls.
- Floor moldings should be attached to the walls, but make no mechanical contact with the resiliently mounted floor (use non-hardening caulk). Nor should spring- and resiliently hung ceilings mechanically contact walls (again, use non-hardening caulk to make the seal).
- Be wary: Pipes, conduit, ducts, and other services penetrating a damped floor-ceiling assembly will short-circuit the resilient layer unless carefully detailed so as to avoid simultaneous mechanical contact with the floor surface and ceiling or structure.

Example: Choose the **incorrect** statement

a) Structure-borne sound that is transmitted through solid material is essentially a vibration of the material.

b) All structureborne sound must eventually become airborne sound in order for us to hear it.

c) Structure-borne sound is perceived by a listener as a consequence of the airborne sound radiated from the vibrating surfaces.

d) Air-borne sound means sound which has travelled through the air for the great majority of its journey.

e) Impact sound vibration travels through the actual fabric of the building, and it is well known that bricks and concrete are good conductors of vibration.

Example: Which is not correct about floating floor?

a) The floating floor structure is used to have good subjectively perceived impact sound insulation.

b) The resonance frequency of the floating floor can be lowered by decreasing the dynamic stiffness of the insulation material and/or increasing the mass of the floating layer.

c) Floating floors constitute a significant flanking transmission path between rooms.

d) The resonance frequency should be minimum 500 Hz.

e) If necessary, mineral wool with greater load bearing capacity is used under the partition.

Example: Choose the **incorrect** statement.

Choose the incorrect statement.

A. **Floating floors** constitute a particular type of floating floors, they enable making HVAC installations.

B. Floating floors constitute a significant flanking transmission path between room

C. **To avoid flanking transmission,** the floating structure has to be truncated at the partition Junction.

D. Reduction of impact sound pressure level *can only be used in the design of massive masonry floor structures.*

E. For the floating floor structure to have good subjectively perceived impact sound insulation, *the resonance frequency should be as low as possible.*

Thank You For Your Attention.

TAKE CARE YOUR SELVES.

References

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3. Industrial Noise Control and Acoustics, Randall F. Barron