Lecture 3, part 1
Impact sound insulation

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Impact sound insulation (Askelääneneneristys)

"Kun halutaan parantaa jonkin valmiin välipermannnon iskuääneneristystä, on lähimpänä kovan lattian peittäminen pehmeällä, huokoisella matolla tms."

Yli-insinööri Paavo Arni 1949
Measurement of impact sound level
Tapping machine (askeläänikoje)

• 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 has 5 hammers each weighing 0.5 kg which drop on the floor from a height of 40 mm

• The hammers hit the floor 10 times per second
Measurement of impact sound level
Laboratory vs. field
Impacts sound pressure level (askeläänitasoluku)

- 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: $L'_{\text{field measurement}}$, $L_{\text{laboratory measurement}}$
- The impact sound pressure levels $L_i$ [dB] measured in different parts of the room are averaged:

$$ L = 10 \log \left( \frac{1}{n} \sum_{i=1}^{n} 10^{L_i/10} \right) $$
Impact sound pressure level (askeläänitasoluku)

- 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 (Normalisoitu askeläänítaso)

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

\[ L_n = L_i + 10 \log \frac{A}{A_0} \]

- And in the field:

\[ L'_n = L_i + 10 \log \frac{A}{A_0} \]

- \( A_0 = 10 \text{ m}^2 \)
Determination of weighted normalised impact sound pressure level

\[ L_{\text{n,w}} = 51 \text{ dB} \]
Determination of weighted normalised impact sound pressure level

- As in the case of airborne sound insulation, the measured impact sound insulation is presented as a single number; regulations are also given as single-number values.
- *Weighted normalised impact sound pressure level* (normalisoitu askeläänitasoluku) $L_{n,w}$ (field) / $L_{n,w}$ (laboratory) is determined from the measured impact SPLs according to ISO 717-2 in one-third octave 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 $\leq 32,0$ dB.
  - Unfavourable deviation means that the measured impact SPL is higher than the value of the reference curve at a certain frequency (note the difference to apparent weighted sound reduction index).
  - Weighted normalised impact sound pressure level equals the value of the reference curve at 500 Hz.
Sound caused by walking vs. tapping machine

• The measured impact sound level does not indicate directly what kind of sound levels are caused by activity in the building
• The sound produced by tapping machine and i.e. walking differ in spectrum and level
• In the figure the characteristic frequency of the floor topping material is about 400 Hz (the frequency at which the double structure formed by the floor covering and load bearing floor structure resonates), while the sound level caused by walking is largest at around 80 Hz
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 towards 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 $C_{I,50-2500}$ for range 50-2500 Hz.
Spectrum adaptation terms

- Spectrum adaptation terms are presented with the measured impact SPL as follows: $L_{n,w} (C_i; C_{l,50-2500}) = 49(1;3) \text{ dB}$
- $C_{l,50-2500}$ is calculated from the normalised impact SPLs measured in 1/3-bands 50-2500 Hz and the impact SPL:
  \[ C_I = 10 \log_{10} \sum_{i=50}^{2500} 10^{L_{n,i}/10} - 15 - L_{n,w} \]
- Quantity $L_{n,w} + C_{l,50-2500}$ 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, \( f_0 = 80 \text{ Hz} \)
  - \( L'_{n,w} = 42 \text{ dB} \)
  - \( C_{l,50-2500} = 6 \text{ dB} \)
  - \( L'_{n,w} + C_{l,50-2500} = 48 \text{ dB} \)

- Floor 2: parquet + flexible underlay on load bearing structure, \( f_0 = 400 \text{ Hz} \)
  - \( L'_{n,w} = 49 \text{ dB} \)
  - \( C_{l,50-2500} = 0 \text{ dB} \)
  - \( L'_{n,w} + C_{l,50-2500} = 49 \text{ dB} \)
Spectrum adaptation terms

Example 2

- Measured impact SPL:
  \( L_{n,w}(C_i; C_{i,50-2500}) = 40(1;10) \)
- 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?
Reduction of impact sound pressure level (Askelääneneneristävyyden parannusluku)

- Reduction of impact sound level (askeläänitason alenema) $\Delta L$ [dB] describes how much a floor covering inserted on a heavyweight standard floor (concrete) decreases impact sound level compared to floor with no covering.

- $\Delta L$ is defined as the difference between the measured impact sound levels of the covered and non-covered heavyweight floor in 1/3 frequency bands.
Reduction of impact sound pressure level (Askelääneneristävyyden parannusluku)

- Single-number quantity $\Delta L_w$ [dB] (askelääneneristävyyden parannusluku) is determined as follows:
  - Subtract the reduction of impact sound level $\Delta L$ in 1/3 bands from the impact sound levels of the heavyweight standard floor, and calculate the normalised weighted impact SPL $L_{n,w}$ from the resulting impact sound levels
  - Subtract this from the normalised weighted impact SPL of the heavyweight standard floor $L_{n,eq,0,w}$:
    \[ \Delta L_w = L_{n,eq,0,w} - L_{n,w} \]

- Note: Reduction of impact sound pressure level can only be used in the design of massive masonry floor structures (does not apply to lightweight or floating floors)
Impact sound insulation of floors

Flexible floor coverings

• The impact sound insulation of massive floor structures (hollow core slabs, massive concrete slabs) is based on large mass

• Improving impact sound insulation by increasing the mass of the floor is feasible only up to a certain point (load bearing issues, costs)

  → need for flexible floor toppings

• Typical values of $\Delta L_w$:
  – Soft plastic carpets: $\Delta L_w = 17...20$ dB
  – Parquet + flexible underlay (i.e. Tuplex): $\Delta L_w = 17...18$ dB
  – Floor toppings in hallways: $\Delta L_w = 2...14$ dB
Impact sound insulation of floors
Flexible floor coverings

- Difference in impact SPL between 240 mm concrete floor with no covering (upper graph) and floor covered with flexible plastic carpet, measured in a building
- No covering: $L_{n,w} = 69$ dB
- Covering: $L_{n,w} = 49$ dB

Reduction of impact sound pressure level
Impact sound insulation of floors
Floating floors (kelluvat rakenteet)

- 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
Impact sound insulation of floors
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 stiffness \( s' \) [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!):
  \[ f_0 \approx 160 \sqrt{\frac{s'}{m'}} \]
Impact sound insulation of floors
Floating floors (kelluvat rakenteet)

• The resonance frequency of the floating floor, $f_0$ [Hz], is acoustically the most important factor of floating floors.

• It depends on the surface density of the floating floor layer $m'$ [kg/m$^2$] and the dynamic stiffness of the insulation layer) $s'$ [MN/m$^3$]:

$$f_0 = 160 \sqrt{\frac{s'}{m'}}$$

• For the floating floor structure to have good subjectively perceived impact sound insulation, the resonance frequency should be as low as possible; in apartment buildings minimum goal is $f_0 < 100$ Hz, while $f_0 < 50$ Hz if preferable.
Impact sound insulation of floors
Floating floors (kelluvat rakenteet)

- 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$^3$.

$f_0$ should lie below 100 Hz...

...but preferably below 50 Hz.
Impact sound insulation of floors
Floating floors (kelluvat rakenteet)

- Example: the effects of mass and dynamic stiffness on the resonance frequency of floating floor

<table>
<thead>
<tr>
<th>$m$ [kg/m$^2$]</th>
<th>$s'$ [MN/m$^3$]</th>
<th>$f_0$ [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>12</td>
<td>101 Hz</td>
</tr>
<tr>
<td>60</td>
<td>50</td>
<td>146 Hz</td>
</tr>
<tr>
<td>200</td>
<td>8</td>
<td>32 Hz</td>
</tr>
</tbody>
</table>
Impact sound insulation of floors
Floating floors (kelluvat rakenteet)

- 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 floors: example

- Floating floor can also be implemented 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.
Impact sound insulation of floors
Floating floors (kelluvat rakenteet)

• Current regulations in apartment buildings (in Finland) require floating floor on top of massive load bearing floor structure if the floor covering is:
  – Parquet glued to surface (no flexible underlay)
  – Natural stone
  – Ceramic tile
  – Other hard covering material

• Floating floor must be used always if the load bearing floor is lightweight masonry structure (i.e. Lightweight concrete slab)
Impact sound insulation of floors
Access floors (asennuslattiat)

• 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
Impact sound insulation of floors
Suspended ceilings (alakatot)

- 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.
Impact sound insulation of floors
Suspended ceilings (alakatot)

- 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 structure formed by the suspended ceiling board, airspace and load bearing structure (typically < 200 Hz)
Impact sound insulation of floors
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/m²
- 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
Effect of floating floor and suspended ceiling on the impact SPLs of Structure 1

- A: Structure 1, B: Structure 1 with no floating floor, C: Structure 1 with suspended ceiling boards directly fixed to the wood joists
Impact sound insulation of floors
Lightweight floors

• As ”rules of thumb”, the impact sound insulation of lightweight floor structure improves when:
  – The height of the airspace formed by the load bearing structure increases (typical height 300...400 mm)
  – The amount of 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 lightweight floors it is important to consider insulation at low frequencies, because the acoustical function of the structure is based on the 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 $C_{I,50-2500}$ should be considered
## Impact sound insulation of floors
### Measured values of concrete floors

<table>
<thead>
<tr>
<th>$L'_{n,w}$</th>
<th>Rakenne</th>
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<tbody>
<tr>
<td>$\leq 43$ dB</td>
<td>Lattianpäällyste, kelluva betonilaatta vähintään 80 mm, eristekerrosvähintään 30 mm ($s' \leq 10 \text{ MN/m}^2$), betonilaatta 240 mm</td>
</tr>
<tr>
<td>$\leq 49$ dB</td>
<td>Lattianpäällyste, kelluva betonilaatta vähintään 80 mm, eristekerrosvähintään 30 mm ($s' \leq 10 \text{ MN/m}^2$), ontelolaatasto vähintään 265 mm (380 kg/m$^2$)</td>
</tr>
<tr>
<td>$\leq 53$ dB</td>
<td>Lautaparketti alusmateriaaleineen tai muovimatto ($\Delta L_w \geq 18$ dB), betonilaatta 300 mm</td>
</tr>
<tr>
<td>$\leq 58$ dB</td>
<td>Muovimatto ($\Delta L_w \geq 18$ dB), ontelolaatasto 370 mm (510 kg/m$^2$)</td>
</tr>
<tr>
<td>$\leq 53$ dB</td>
<td>Lautaparketti alusmateriaaleineen ($\Delta L_w \geq 18$ dB), ontelolaatasto 370 mm (510 kg/m$^2$), koolas 50 mm ja mineraalivilla, 2 x kipsilevy 13 mm</td>
</tr>
<tr>
<td>$\leq 58$ dB</td>
<td>Lautaparketti alusmateriaaleineen tai muovimatto ($\Delta L_w \geq 18$ dB), betonilaatta 240 mm</td>
</tr>
<tr>
<td>$\leq 58$ dB</td>
<td>Lautaparketti alusmateriaaleineen tai muovimatto ($\Delta L_w \geq 18$ dB), ontelolaatasto 265 mm (380 kg/m$^2$)</td>
</tr>
</tbody>
</table>

*Current Finnish regulation level*
Design of impact sound insulation
EN 12354-2 calculation model

• Standard EN 12354-2 presents a simplified model for calculating $L_{n,w}$ in buildings with concrete floors.

• The starting point in the calculation is the equivalent impact SPL, which is calculated based on the surface mass $m$ of the floor:

$$L_{n,w,eq} = 164 - 35 \log_{10} \frac{m'}{1 \text{kg} / \text{m}^2}$$

• According to the standard the equation is quite accurate when the mass of the floor is 100...600 kg/m$^2$. 
Design of impact sound insulation
EN 12354-2 calculation model

• Impact sound insulation in the building is calculated by subtracting the improvement in impact sound insulation caused by flexible floor covering and correction term $K$:
  \[ L'_{n,w} = L_{n,w,eq} - \Delta L_w + K \]

• Term $K$ depends on the surface mass of the floor and average surface mass of the flanking walls (table on the next slide)

• The average mass of the walls does not include:
  – The mass of masonry walls on top of which there is a lightweight plate structure with characteristic frequency below 125 Hz
  – The mass of lightweight exterior walls or partitions
Design of impact sound insulation
EN 12354-2 calculation model

<table>
<thead>
<tr>
<th>Mass per unit area of the separating element (floor) in kg/m²</th>
<th>Mean mass per unit area of the homogeneous flanking elements not covered with additional layers in kg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>150</td>
<td>1 1 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>200</td>
<td>2 1 1 0 0 0 0 0 0</td>
</tr>
<tr>
<td>250</td>
<td>2 1 1 1 0 0 0 0 0</td>
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<td>3 2 1 1 1 1 0 0 0</td>
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<tr>
<td>400</td>
<td>4 2 2 1 1 1 1 0 0</td>
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</tr>
<tr>
<td>900</td>
<td>6 5 4 3 3 2 2 2 2</td>
</tr>
</tbody>
</table>
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
Special considerations in dwellings

• 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 concrete, waterproofing requirements must also be considered

• Retail spaces, shops
  – Noise sources: rumbling of trolley wheels, people walking etc.
  – Special consideration: loading docks / areas (lastauslaiturit)

• 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
Special considerations in dwellings

• 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 (luhtikäytäväät)

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