POLITECNICO DI MILANO

Acoustics in Buildings:

Building Acoustics

Prof. Livio Mazzarella and Maria Cairoli

Department of Energy

Two targets

Acoustics in Building has two targets

- **Acoustical Quality**
  - **Quality of the sound in closed space (also sound insulation, but mainly sound absorption, first reflection utilization to reinforce the sound, etc.)**

    ➔ *Sound Correction*

Room Acoustics

Architectural Acoustics

- **Acoustical Comfort**
  - **Reduction of Sound Pollution ➔ Noise**
  - **Sound Insulation (Soundproofing)**

    ➔ *Noise Reduction*

Building Acoustics

Acoustic Comfort

Noise disturbance evaluation

- Noise rating depends on:
  - **the objective characteristics of the noise as L_p , spectrum, presence of pure tones, time distribution;**
  - **environmental and urban characteristics;**
  - **the subjective characteristics of the person subjected to noise;**
  - **psychological circumstances, as**
    - feeling the noise easily preventable,
    - when noise recalls unpleasant mental associations,
    - when the noise source is or not is of any interest for the listener;
    - if the listener is addicted or not to the presence of noise;
    - the type of activity carried out (work => sleep);
    - if the noise contains information (words or music)

Noise disturbance evaluation

- Noise evaluation indices:
  - **must consider the objective characteristics of the noise**
  - **must take into account the average individual reactions**
  - **must evaluate environmental conditions**

- Several indicators based on:
  - **Spectral composition**
  - **statistical analysis of sound pressure levels**
  - **evaluation of the sound energy received in a certain time interval**
  - **abandoned indices based only on the measurement of the "loudness"**

Noise Reduction in confined environments

- Target:
  - **ensure a certain degree of comfort**

- Means:
  - **reduce the noise source emission (*sound insulation of the source*)**
  - **reduce sound transmission from the source to the receptor (*sound insulation of partitions and structures*)**

Relevant EN Standards to use at the design stage

- EN ISO 12354-1:2017 - Building acoustics - Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms
- EN ISO 12354-2:2017 - Building acoustics - Estimation of acoustic performance of buildings from the performance of elements - Part 2: Impact sound insulation between rooms
- EN ISO 12354-3:2017 - Building acoustics - Estimation of acoustic performance of buildings from the performance of elements - Part 3: Airborne sound insulation against outdoor sound
- EN ISO 12354-4:2017 - Building acoustics - Estimation of acoustic performance of buildings from the performance of elements - Part 4: Transmission of indoor sound to the outside
- EN 12354-5:2009 - Building acoustics - Estimation of acoustic performance of buildings from the performance of elements - Part 5: Sounds levels due to the service equipment
- EN 12354-6:2006 - Building acoustics - Estimation of acoustic performance of buildings from the performance of elements - Part 5: Sounds absorption in enclosed spaces

Relevant EN ISO Standards to use at the verification stage (on field)

- EN ISO 16283-1:2018 - Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation
- EN ISO 16283-2:2018 - Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 2: Impact sound insulation
- EN ISO 16283-3:2016 - Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 3: Façade sound insulation

Relevant UNI (Italian) Standards to use at the design stage

Guidelines

- UNI/TR 11175:2005 - Acustica in edilizia – Guida alle norme serie UNI EN 12354 per la previsione delle prestazioni acustiche degli edifici – applicazione alla tipologia costruttiva nazionale
- UNI 11296:2009 - Acustica – Linee guida per la progettazione, la selezione, l'installazione e il collaudo dei sistemi per la mitigazione ai ricettori del rumore originato da infrastrutture di trasporto
- UNI 11444:2012 - Acustica in edilizia - Classificazione acustica delle unità immobiliari - Linee guida per la selezione delle unità immobiliari in edifici con caratteristiche non seriali

Standards

- UNI 11367:2010 - Acustica in edilizia - Classificazione acustica delle unità immobiliari - Procedura di valutazione e verifica in opera

The noise disturbance according to the Law: Building acoustic requirements D.P.C.M 5-12-1997

Building Category	R'_w	$D_{2m,n,T,W}$	$L'_{n,w}$	L_{ASmax}	L_{Aeq}
D	55	45	58	35	25
A,C	50	40	63	35	35
E	50	48	58	35	25
B,F,G	50	42	55	35	35

R'_w Weighted Apparent Sound Reduction Index, in dB(A)

$D_{2m,n,T,w}$ Facade Weighted Standardized Level Difference Index, in dB(A)

$L'_{n,w}$ Weighted Normalized Impact Sound Pressure Level Index, in dB(A)

L_{ASmax} Maximum A-weighted sound pressure level with time constant slow, in dB(A)

L_{Aeq} Equivalent Continuous Sound Pressure Level, A-weighted, in dB(A)

- Category A: buildings used as residences or similar
- Category B: buildings used as offices and similar
- Category C: buildings used as hotels, guest houses and similar activities
- Category D: buildings used as hospitals, clinics, nursing homes and similar
- Category E: buildings used for school activities at all levels
- Category F: buildings used for recreation or worship or similar activities
- Category G: buildings used for commercial or similar purposes

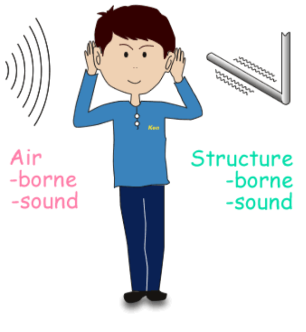
Noise Evaluation Indices

According to D.P.C.M 5-12-1997 Noise Evaluation Indices are then building sound insulation characteristics as:

- R'_w : Weighted Apparent Sound Reduction **Index** between rooms, derived from the spectral distribution of:
  - R': Apparent Sound Reduction, which is or directly measured or derived form R estimation,
  - R: Sound Reduction (partition transmission loss, TL) (in Octave Bands or 1/3-Octave Bands)
- $D_{2m,n,T,w}$ Facade Weighted Standardized Level Difference (**Index)**, which depends on R' and on the reverberation time of the receiving room
- $L'_{n,w}$ Weighted Normalized Impact Sound Pressure Level **(Index)**

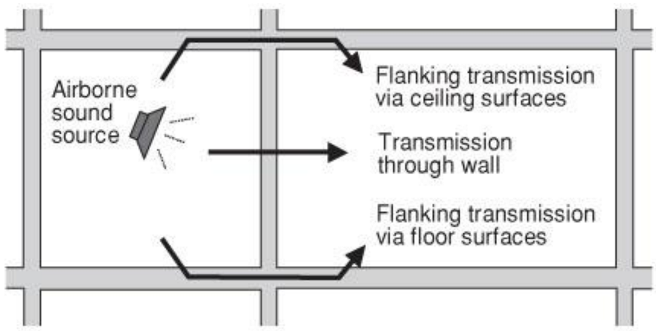
NOTE: All these quantities are one-value quantities evaluated at 500 Hz according to EN ISO 717-1 and 717-2

Airborne Noise

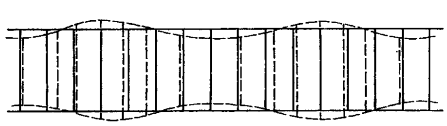


Sound Transmission

- Direct Airborne Transmission: air-partition-air
- Indirect Airborne Transmission : air-flanking structures-air

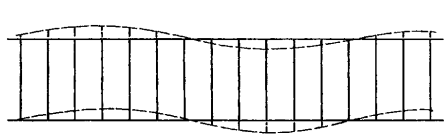


Partitions Vibration



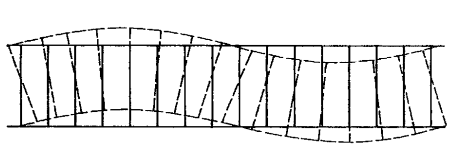
(a) Quasi-longitudinal wave
(transverse displacements exaggerated)

$$c_L = \sqrt{\frac{E}{\rho\left(1-\nu^2\right)}}$$



(b) Transverse shear wave

$$c_T = \sqrt{\frac{E}{2\rho\left(1+\nu\right)}}$$



(c) Flexural (bending) wave

$$c_b = \sqrt[4]{\frac{h^2 E}{12\rho\left(1-\nu^2\right)}} \cdot \sqrt{\omega}$$

Prof. Livio Mazzarella - Dipartimento di Energia
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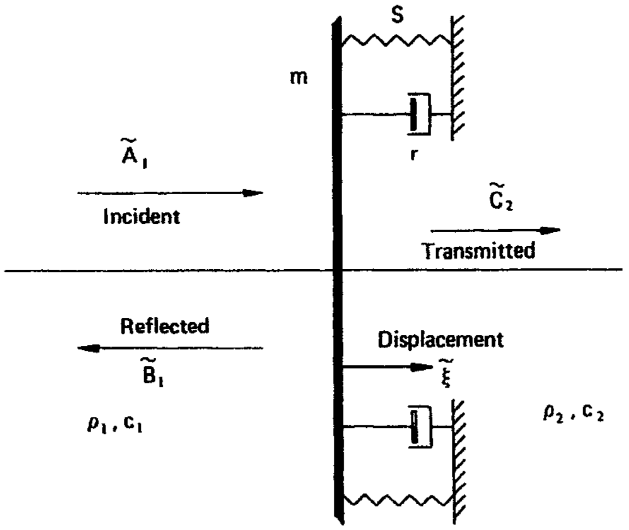
Normally Loaded Partition: Mass-Spring-Dumper 1 D.F. Model



Oblique Sound Waves Incidence: Coincidence Phenomenon

Increase in sound transmission in flexural vibration of a partition induced by an obliquely incident acoustic wave

There is Coincidence when: $k_b = k \cos\theta$

$$f_{co} = \frac{c^2}{\pi \cos^2\theta}\sqrt{\frac{3\rho(1-v^2)}{s^2 E}}$$

$$\lambda_{co} = \frac{c}{f_{co}}$$

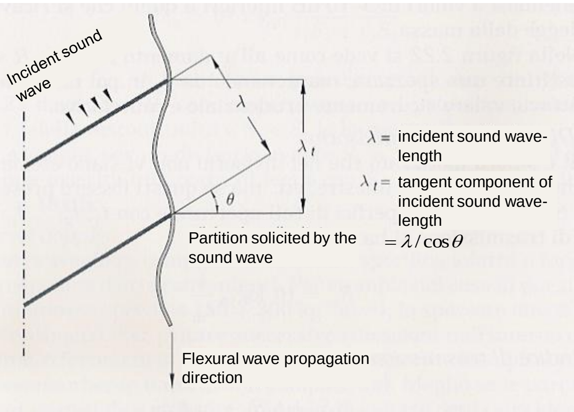
with E elastic modulus

v Poisson's coefficient

s partition thickness

ρ mass density

$$\lambda_{co} = (\lambda_b \equiv \lambda / \cos\theta)$$

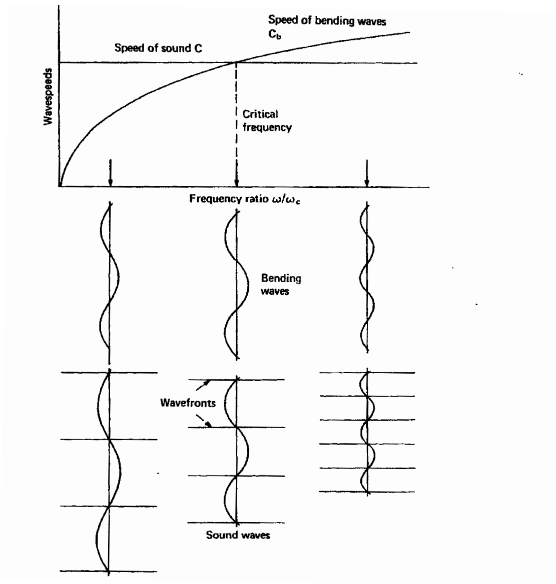


Coincidence Phenomenon

For each angle θ there is coincidence only when the sound speed c in air is equal to the flexural wave speed in the partition, c_b :

$$c_b = \sqrt{\omega} \cdot \sqrt[4]{D/m^*}$$

it possible only at an unique frequency, f_{co}



Transmission Loss (or Sound Reduction)

The Transmission Loss, TL, or Sound Reduction, R, of a partition **without any discontinuity** is defined as:

$$R = TL = 10 \cdot \log_{10}\left(\frac{\dot{W}_{inc}}{\dot{W}_{tras}}\right) = 10 \cdot \log_{10}\left(\frac{1}{\tau}\right)$$

where

- $\dot{W}_{inc}$ the power of incident wave coming towards a defined partition
- $\dot{W}_{tras}$ is the power of transmitted wave going away from the defined partition
- τ is the partition transmission coefficient (or acoustics transmittance)

Composite Transmission Loss

The composite transmission loss of a partition **compound of different elements** is defined as:

$$R_m = TL_m = 10 \cdot \log_{10}\left(\frac{1}{\tau_m}\right) = 10 \cdot \log_{10}\left(\frac{\sum_{i=1}^{N} S_i}{\sum_{i=1}^{N} S_i \tau_i}\right) = 10 \cdot \log_{10}\left(\frac{\sum_{i=1}^{N} S_i}{\sum_{i=1}^{N} S_i 10^{\frac{-R_i}{10}}}\right)$$

where

S_i is the area of the surface of the i-th element

τ_i is the transmission coefficient of the i-th element **in parallel**

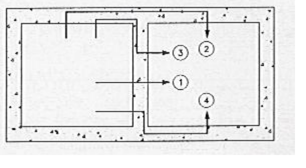
R_i is the transmission loss of the i-th element **in parallel**

Apparent Transmission Loss R': flanking phenomena

The transmission loss between **two adjacent rooms** A and B is defined as:

$$R' = R_{A,B} = 10 \cdot \log_{10}\left(\frac{\dot{W}_i}{\dot{W}_t + \dot{W}_{lat}}\right) =$$

$$= 10 \cdot \log_{10}\left(10^{\frac{-R_1}{10}} + \sum_{i=1}^{M}\sum_{j=1}^{N} 10^{\frac{-R_{i,j}}{10}}\right)$$



where

R_1 is the transmission loss of the common partition, related to ***the direct transmission***

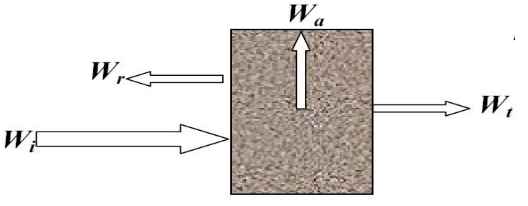
M is the number of structural elements that constitute the envelope of the disturbed environment

N is the number of indirect sound transmission routes through the other elements

R_{ij} is the transmission loss of i-th element related to the j-th **indirect transmission** path

Acoustic absorption

The absorption mechanisms are manifold: the sound vibration can put in motion the surface, or is the air contained in the porosity of the material to come into movement, or both phenomena may occur simultaneously. In any case, the outcome is the dissipation of sound energy into internal energy (heat).



The absorbed fraction of the incident energy in the reflection from a wall is called *sound absorption coefficient* α

Acoustic Isolation ➔ Level Difference

Assuming diffuse sound field in both confined spaces (disturbing 1 and disturbed 2) and considering the flanking effects, it is :

$$D = L_{P_1} - L_{P_2} = R' - 10 \cdot \log_{10}\left(\frac{S_w}{A_2}\right)$$

with

- D is the **Level Difference** or **Noise Reduction**
- R' is the apparent sound transmission loss
- S_w is the area of one surface of the partition
- A_2 is equivalent sound absorption area of receiving space

with

$$A_2 = \sum_{i=1}^{N} S_i \cdot \alpha_i \qquad \alpha_i = \text{absorption coefficient}$$

Normalized Level Difference

Normalized Level Difference is the difference in the space and time sound pressure levels, Lp_1 e Lp_2 , produced in two rooms by one or more sound sources in one of them, when the receiving room is assumed to have a reference equivalent sound absorption area:

$$D_n = L_{P_1} - L_{P_2} + 10 \cdot \log_{10}\left(\frac{A_0}{A_2}\right)$$

where

D_n is the **Normalized Level Difference**

A_0 is the reference equivalent sound absorption area (=10 m^2 ISO 140)

A_2 is the equivalent sound absorption area of the receiving room

with $A_2 = \sum_{i=1}^{N} S_i \cdot \alpha_i$ α_i = absorption coefficient

Standardized Level Difference

Standardized Level Difference is the difference in the space and time sound pressure levels, Lp_1 e Lp_2 , produced in two rooms by one or more sound sources in one of them, when the receiving room is assumed to have a reference value of the reverberation time:

$$D_{n,T} = L_{P_1} - L_{P_2} + 10 \cdot \log_{10}\left(\frac{T_{60}}{T_0}\right)$$

where

$D_{n,T}$ is the **Standardized Level Difference**

T_0 is the reference value of the reverberation time (=0,5 s)

T_{60} is the reverberation time of the receiving room

Relation between quantities D_n and D_{nT}

The relations between the Normalized level difference, D_n, and Standardized level difference, D_{nT} is then:

$$D_{\mathrm{n}} = D_{\mathrm{nT}} - 10 \cdot \log_{10}\left(\frac{0.16\,V}{T_0 A_0}\right) = D_{\mathrm{nT}} - 10 \cdot \log_{10}(0.32\,V)$$

Relation between quantities D_n, D_{nT} and R'

The relations between the apparent sound reduction index, R', and the Normalized level difference, D_n, and Standardized level difference, D_{nT} are then:

$$D_{\mathrm{n}} = R' - 10 \cdot \log_{10}\left(\frac{S_w}{A_0}\right) = R' - 10 \cdot \log_{10}\left(\frac{S_w}{10}\right)$$

$$D_{\mathrm{nT}} = R' + 10 \cdot \log_{10}\left(\frac{0.16\,V}{T_0 S_w}\right) = R' + 10 \cdot \log_{10}\left(\frac{0.32\,V}{S_w}\right)$$

where

V is the volume of the receiving room, in cubic metres

Facade Standardized Level Difference

Facade Standardized Level Difference is the difference between sound pressure levels $Lp_{1,2m}$ e Lp_2 , the first measured at 2 meters from the facade front, the second measured inside the room, corrected by a term which eliminates in a conventional manner the reinforcing effect of the reverberant field:

$$D_{2m,n,T} = L_{P_1,2m} - L_{P_2} + 10 \cdot \log_{10}\left(\frac{T_{60}}{T_0}\right)$$

dove

$D_{2m,n,T}$ is the **Standardized Level Difference when L_{p1} is measured at 2 meters from the facade**

T_0 is the reference value of the reverberation time (=0,5 s)

T_{60} is the reverberation time of the receiving room

Facade Normalized Level Difference

Facade Normalized Level Difference is the difference between sound pressure levels $Lp_{1,2m}$ e Lp_2 , the first measured at 2 meters from the facade front, the second measured inside the room, when the receiving room is assumed to have a reference equivalent sound absorption area:

$$D_{2m,n} = L_{P_1,2m} - L_{P_2} - 10 \cdot \log_{10}\left(\frac{A_2}{A_0}\right)$$

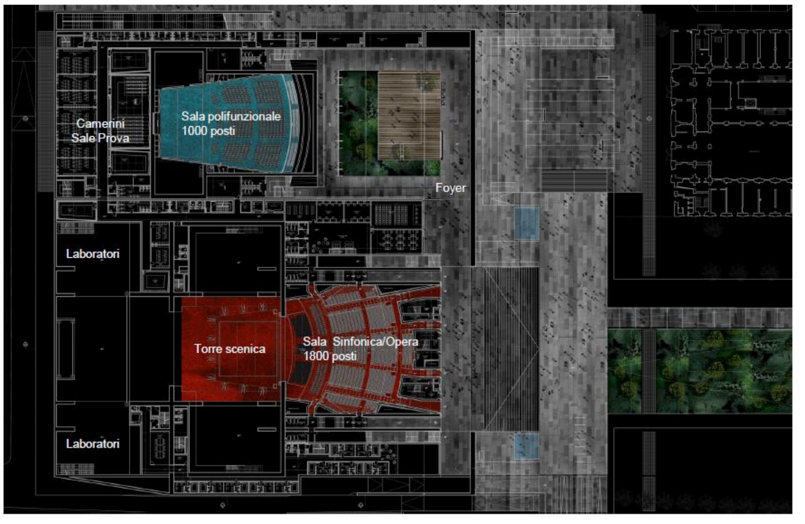
dove

$D_{2m,n}$ is the **Normalized Level Difference when L_{p1} is measured at 2 meters from the facade**

A_2 is equivalent absorption area

A_0 is the reference equivalent sound absorption area (=10 m^2 ISO 140)

- Transmission Loss R': some examples in building



Exercise 1

Exercise

Charatterize R'w for different adiacent spaces, consider all the combinations

office	office	R'w > 42 dB
Bathroom	Bathroom	R'w > 52 dB
Dressing room	Dressing room	R'w > 48 dB
Rehearsal room	Rehearsal room	R'w > 60 dB
Auditorium space	Auditorium space	R'w > 60 dB

Exercise 2

Exercise

create an excel file to sum Sound Pressure Levels for Incoherent Sound

Lp1	75 dB
Lp2	52 dB
Lp3	48 dB
Lp4	80 dB
Lp5	60 dB

Exercise 3

Exercise

Evaluate the R'w for the main partitions

Create a database

Collecting R'w datasheet for:

-windows

-doors

-walls