IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

Architectural Acoustics

Lecture 31: Air Borne Sound Transmission-I

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Learning Objective

Develop the fundamentals of Air borne sound transmission

Explain the parameters that influence sound transmission

Sound Transmission

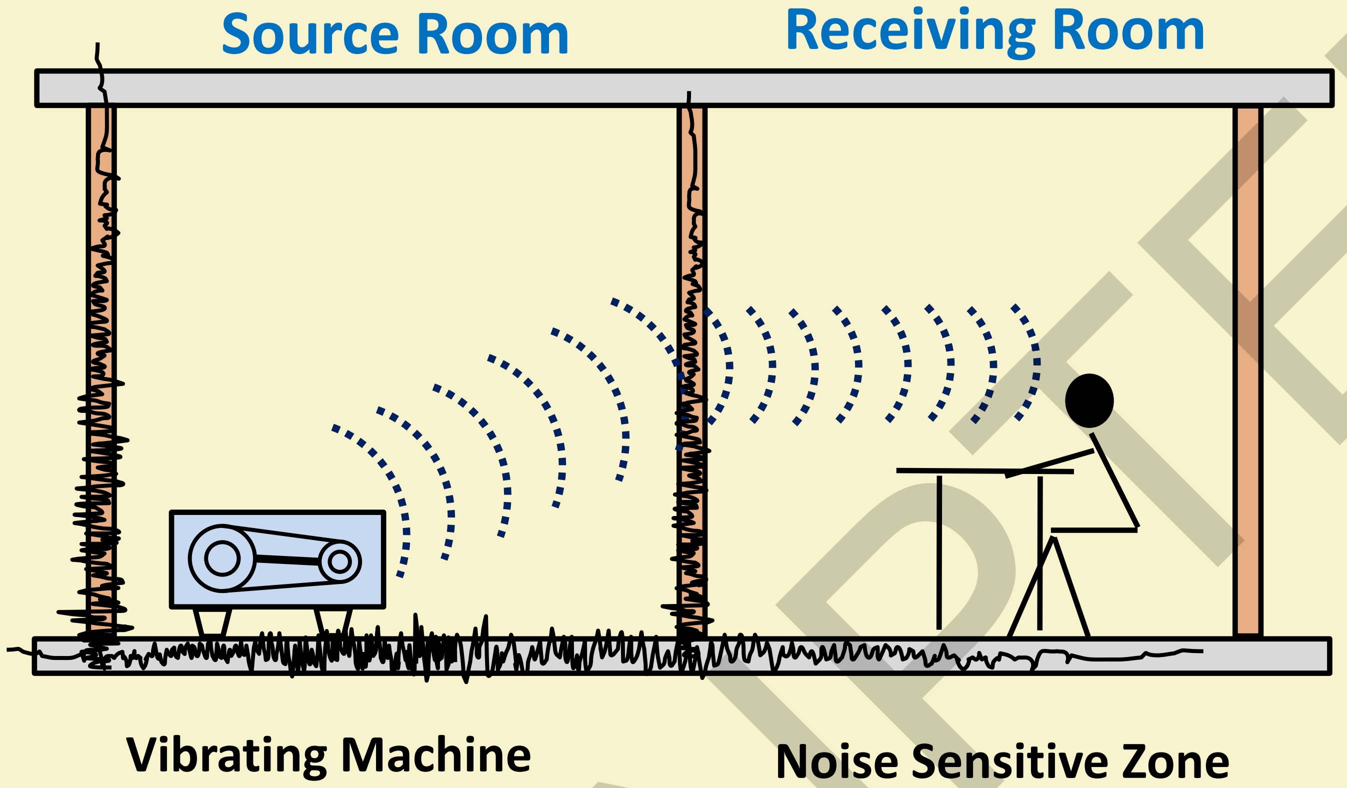
Air Borne Sound Transmission

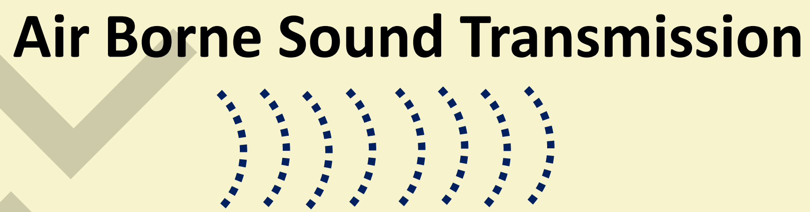
Airborne sound (or **airborne noise**) is **sound** that is transmitted through the air. Typically, airborne sound might be generated by: Speech. Television and radio, animal sounds etc.

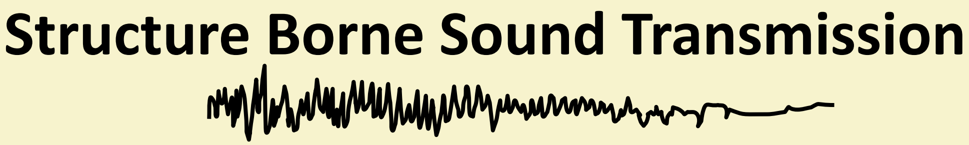
Structure Borne Sound Transmission

Structure Borne Sound is the **sound** which spreads in solid bodies such as walls, floors, ducts, pipes, etc.

Sound Transmission

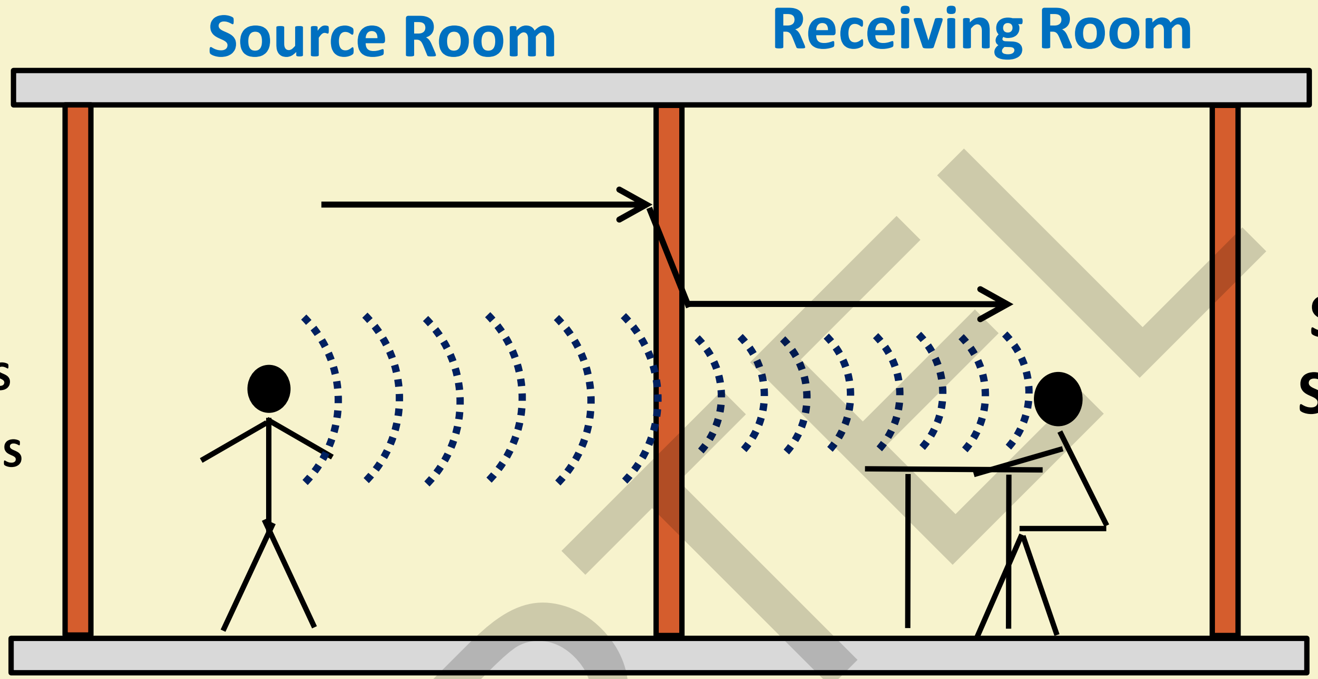






Transmission Loss

SIL = L_S
Sound Power = W_S
Sound Intensity = I_S

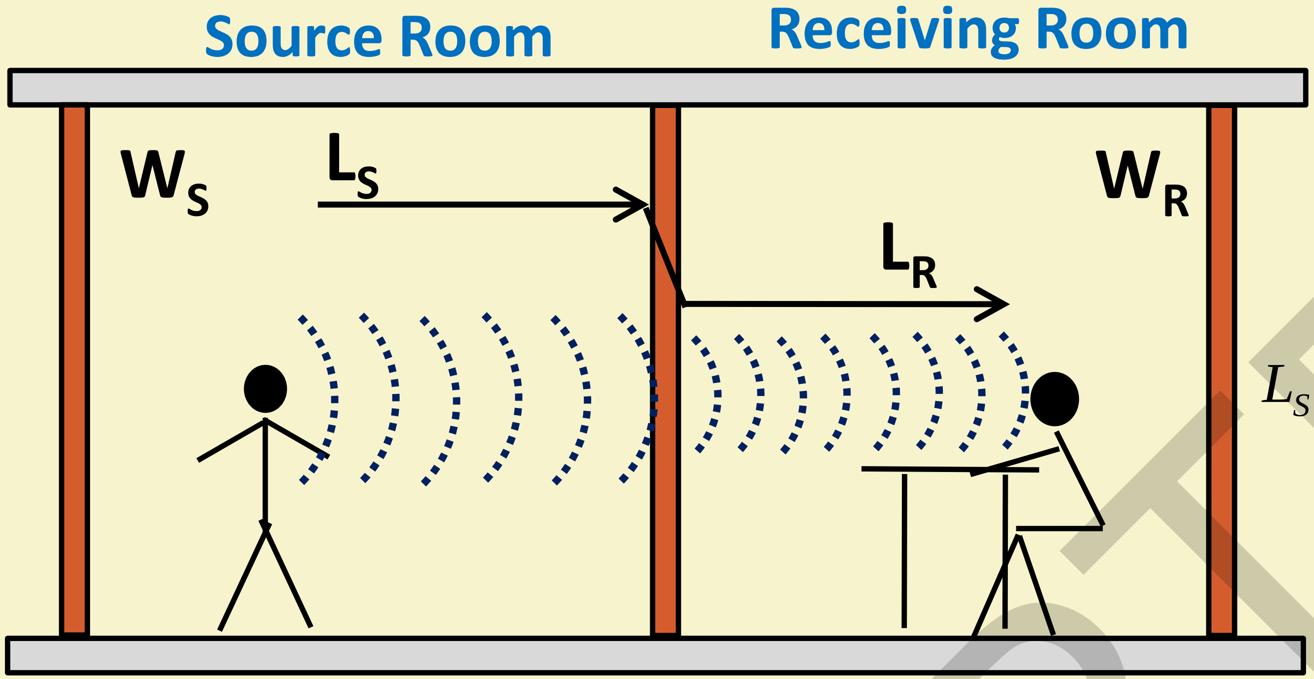


SIL = L_R
Sound Power = W_R
Sound Intensity = I_R

Transmission Loss, TL = (L_S - L_R)

Transmission Coefficient τ = (W_R / W_S)

Transmission Loss



$$L_S = 10\log\frac{W_S}{W_{ref}} \qquad L_R = 10\log\frac{W_R}{W_{ref}}$$

$$\text{Transmission Loss} = (L_S - L_R)$$

$$L_S - L_R = 10\log\frac{W_s}{W_{ref}} - 10\log\frac{W_R}{W_{ref}} = 10\log\frac{W_s}{W_{ref}} \times \frac{W_{ref}}{W_R}$$

$$TL = (L_S - L_R) = 10\log\frac{W_s}{W_R} = 10\log\frac{1}{\frac{W_R}{W_S}} = 10\log\frac{1}{\tau}$$

$$\boxed{TL = 10\log\frac{1}{\tau}}$$

Relation Between **Transmission Loss (TL) and Transmission Coefficient (τ)**

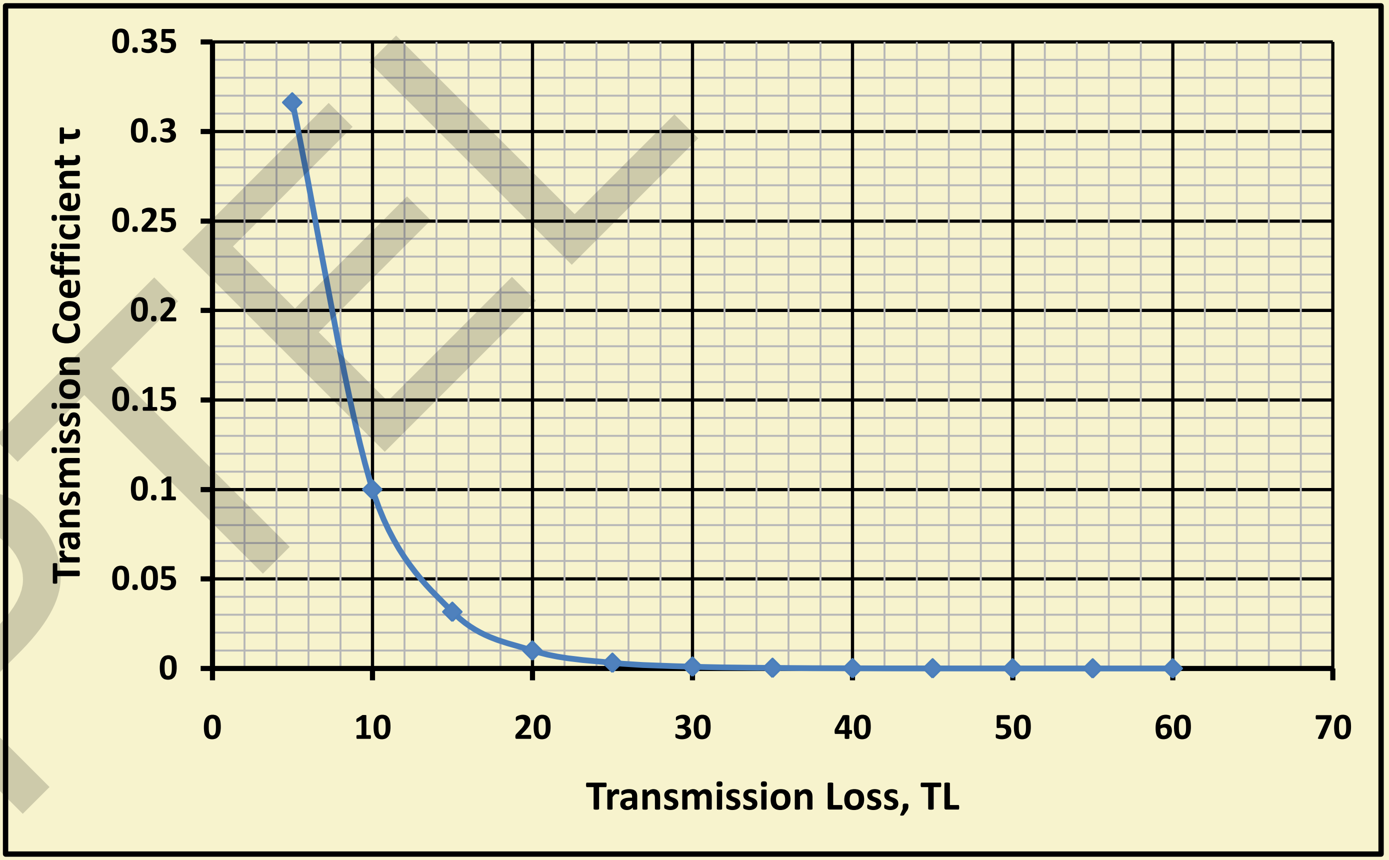
TL can be expressed as:

$$TL = 10\log\frac{1}{\tau}$$

Rearranging the above equation:

$$\log\frac{1}{\tau} = \left(\frac{TL}{10}\right)$$

$$\frac{1}{\tau} = 10^{\left(\frac{TL}{10}\right)} \quad \Rightarrow \quad \tau = 10^{-\left(\frac{TL}{10}\right)}$$



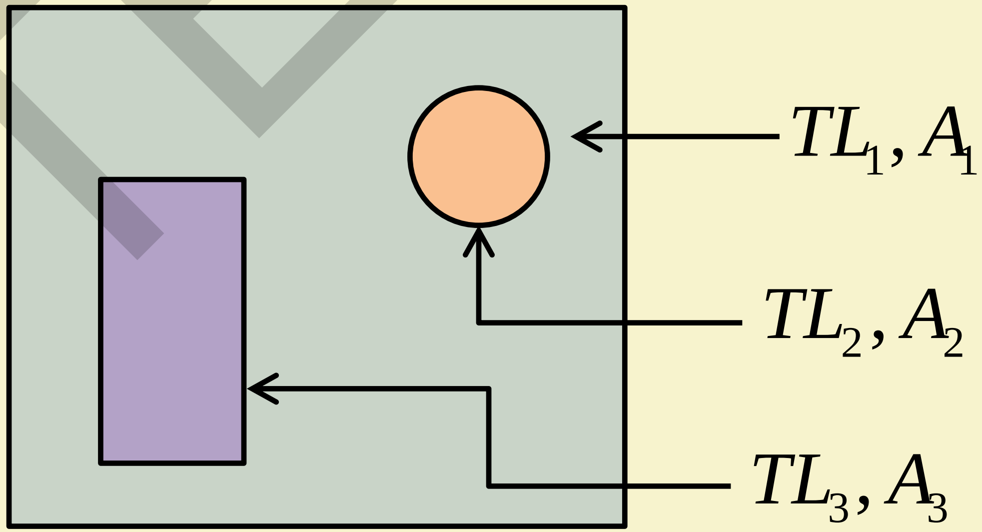
Transmission Loss (TL) of a Composite Wall

The Average value of Transmission Loss (TL) of composite wall should be computed based on the corresponding Transmission Coefficient (τ) and respective Area of the wall

Compute the Transmission Coefficient (τ) from Transmission Loss (TL) .

Then find the Average.

Then re-compute the average Transmission Loss (TL) from average Transmission Coefficient (τ) .



Transmission Loss

Steps:

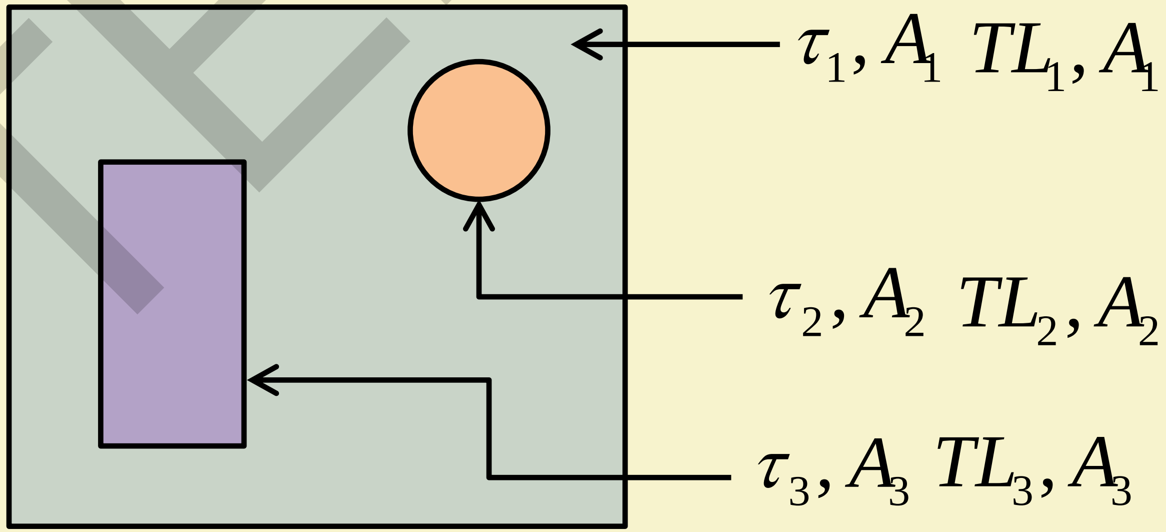
1 **Compute the Transmission Coefficient (τ) of each portion of the wall from Transmission Loss (TL) .**

$$\boxed{\tau = 10^{-\left(\frac{TL}{10}\right)}}$$

2 **Find the Average Transmission Coefficient using the formula below:**

$$\tau_{avg} = \frac{(\tau_1 \times A_1) + (\tau_2 \times A_2) + (\tau_3 \times A_3) + \ldots}{A_1 + A_2 + A_3 + \ldots}$$

$$\boxed{\tau_{avg} = \frac{\sum_{i=1}^{n} \tau_i \times A_i}{\sum_{i=1}^{n} A_i}}$$



3 **Finally find the Transmission Loss from Average Transmission Coefficient**

$$\boxed{TL = 10 \log \frac{1}{\tau}}$$

Transmission Loss

Calculate the Composite Transmission Loss of the Wall

Item	Area	TL	τ
Window	3	20	10^{-2}
Door	2	35	$10^{-3.5}$
Wall	(32-5)= 27	50	10^{-5}

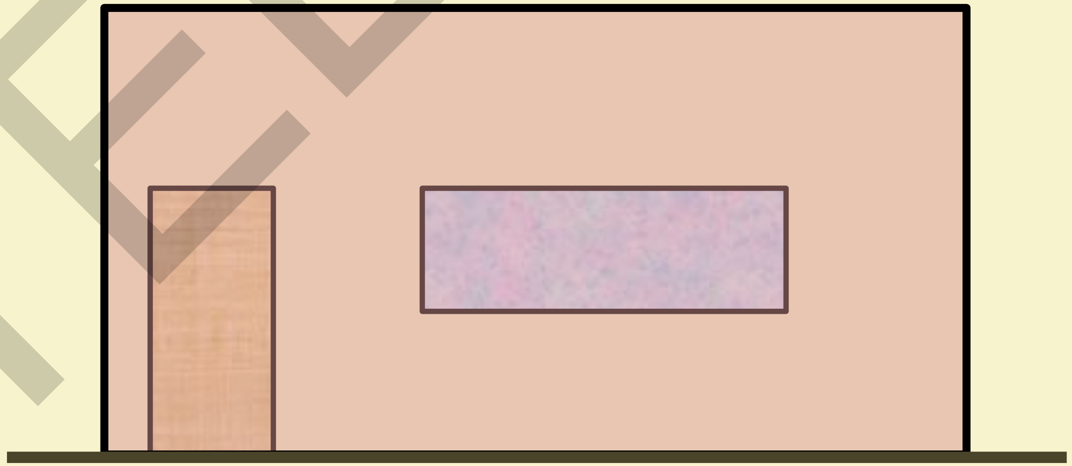
$$\tau = 10^{-\left(\frac{TL}{10}\right)}$$

Average Transmission Coefficient

$$\tau_{avg} = \frac{\left(3\times10^{-2}\right)+\left(2\times10^{-3.5}\right)+\left(27\times10^{-5}\right)}{\left(3+2+27\right)} = \frac{0.0309}{32} = 9.657\times10^{-4}$$

Transmission Loss

$$TL = 10\log\frac{1}{\tau} = 10\log\frac{1}{9.657\times10^{-4}} = 30\text{ dB}$$



Wall: (8mX4m) TL=50dB

Door: (1mX2m) TL=35dB

Window: (3mX1m) TL=20dB

Transmission Loss (TL)

→ **Frequency of the Sound (f)**

Higher the Frequency ….. Higher Transmission Loss

→ **Surface Mass of the Partition Wall (m)**

Surface Mass (m) is the mass of the wall over per square meter wall area

Higher the Surface Mass ….. Higher Transmission Loss

Mass-Frequency Law

The Variation of Transmission Loss (TL) is follow the following Equation

TL = Transmission Loss in dB

f = Frequency of the Sound in Hz

$$\boxed{TL = 20\log(m_s f) - 48}$$

m = Surface Mass of the Partition Wall in Kg/m²

Mass-Frequency Law

$$TL = 20\log(m_s f) - 48$$

$$TL = 20\log m_s + 20\log f - 48$$

So, for 1000 Hz frequency (f=1000 Hz)

$$TL = 20\log m_s + 20\log(1000) - 48$$

$$TL = 20\log m_s + (20\times 3) - 48$$

$$\boxed{TL = 20\log m_s + 12}$$

$$TL = 20\log m_s + 12$$

Mass-Frequency Law

Case I: Let a partition wall having Surface Mass = **m_s**

$$TL_1 = \left(20\log m_s + 12\right)$$

Case II: Let a partition wall having **double the Surface Mass** of previous = **$2m_s$**

$$TL_2 = \left(20\log 2m_s + 12\right)$$

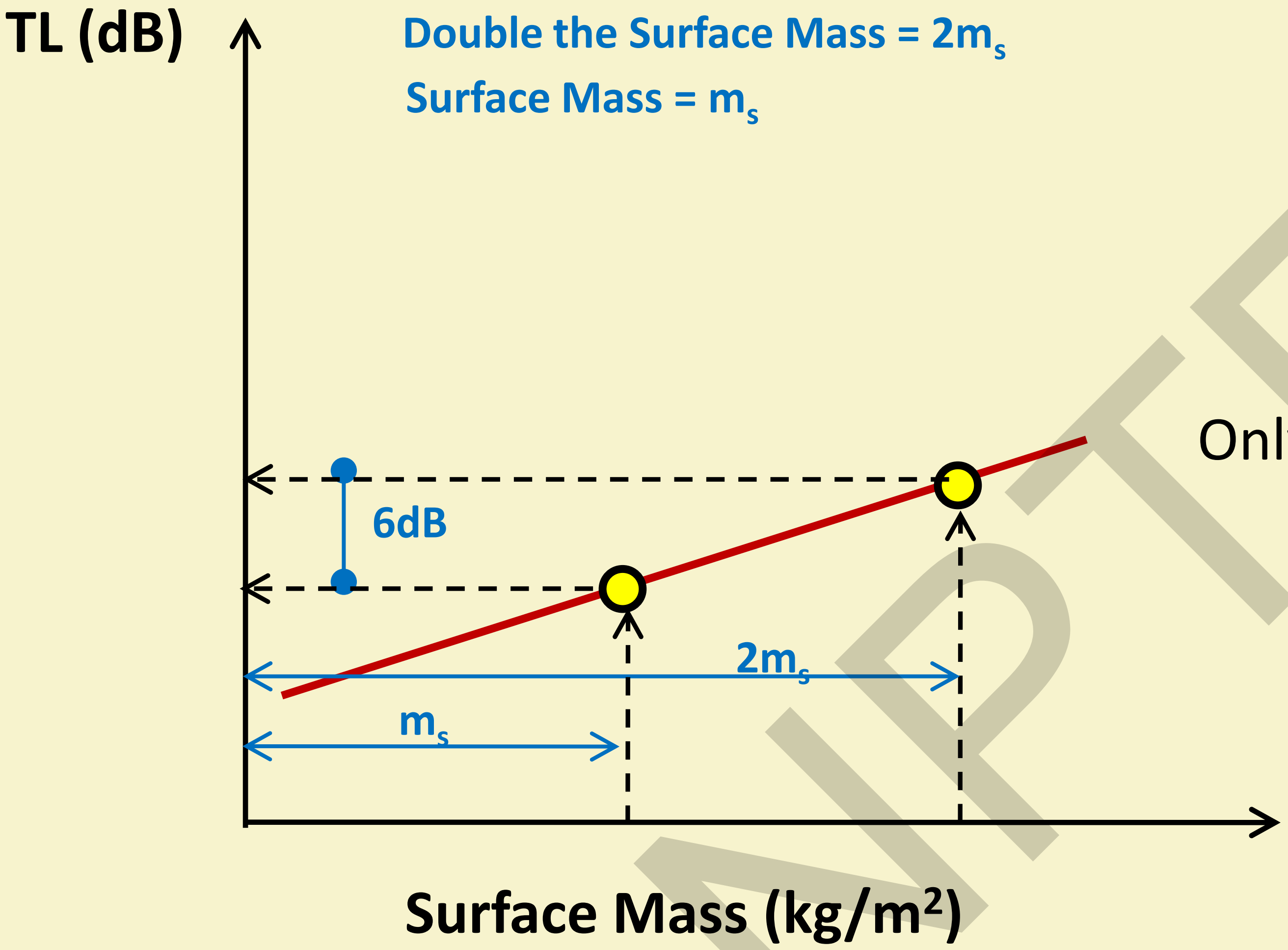
As, Surface Mass increases in the second case, TL value will also increase

$$TL_2 - TL_1 = \left(20\log 2m_s + 12\right) - \left(20\log m_s + 12\right)$$

$$TL_2 - TL_1 = 20\log 2m_s + 12 - 20\log m_s - 12 = 20\log 2m_s - 20\log m$$

$$\Delta TL = 20\log 2 + 20\log m_s - 20\log m_s = 20\log 2 = 6$$

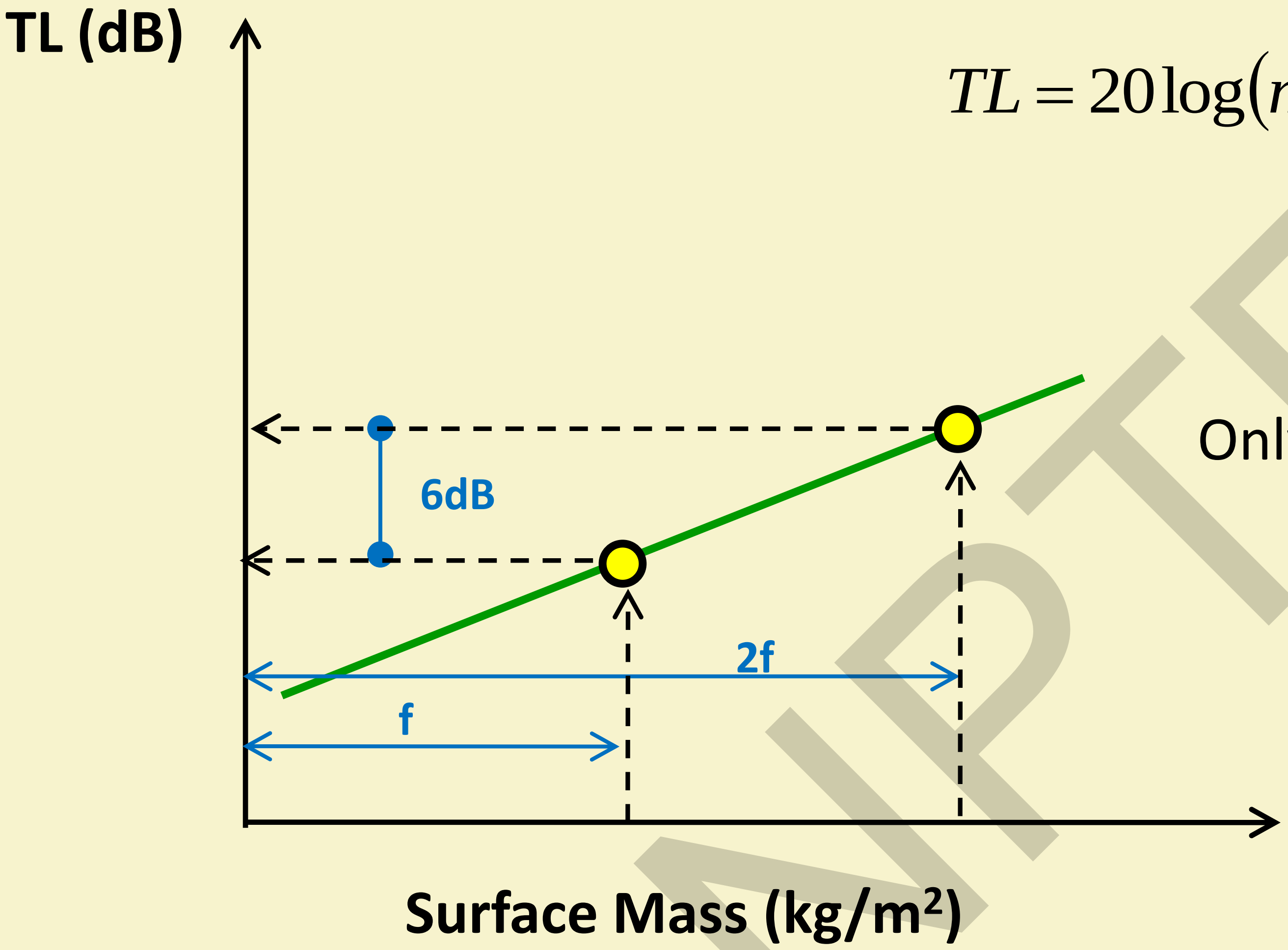
Mass-Frequency Law



By Doubling the Surface Mass….
Only **6dB** increment of Transmission Loss

Mass-Frequency Law

$$TL = 20\log(m_s f) - 48$$



Per Octave ….

Only **6dB** increment of Transmission Loss

Procedure to Find the Transmission Loss from Surface Mass

Get the Material Density and Wall Thickness

Density of Teak Wood = 650 kg/m^3

Let the thickness of the Partition Wall is 25mm (1")

Surface Mass (m_s) is the product of density and thickness

Surface Mass = 650 X 0.025 = 16.25kg/m^2

Finally, Find the Transmission Loss from: $TL = 20\log m_s + 12$ (Specific for 1000 Hz frequency)

$$TL = 20\log(16.25) + 12 = 36\,\mathrm{dB}$$

Transmission Loss of some popular partition wall materials

Material	Density (kg./m^3)	Thickness (mm)	Surface Mass(kg./m^2)	TL (dB)
Steel	7800	25	195	58
Teak Wood	650	25	16.25	36
Gypsum	2300	25	57.5	47
Glass	2700	25	67.5	48
Brick	1900	150	285	61

Enclosure Types

Complete Enclosures

A noise producing machine is completely enclosed by partitions
A 20 to 30 dB noise reduction is achieved by a general type complete enclosure.
The introduction of special isolation system may improve the noise reduction

Partial Enclosures

It sometimes required to have partial enclosure to minimize the airborne noise of a noise producing machine.
In general less than 20 dB noise reduction is achieved by a partial enclosure.
It provides a just shadow effect to the workers, who are directly exposed to the noise

Enclosure wall panel should have sufficient thickness and surface mass.

Steel sheets of thickness 0.3 to 6mm is a popular type of panel wall used for enclosure.

In case of viewing windows and doors, the material should have compatible TL value with the panel Material.

To achieve more than 20 dB noise reduction, double glazing windows must be used.

Enclosure

An acoustical absorptive material lining should be provided inside the enclosure wall panel.

It is due to reduce the reverberation time of the sound within the enclosure.

Properly adopted acoustical lining can effectively reduce the noise by 10 dB.

Joints, material overlapping, openings etc should be properly sealed to avoid any noise leakage.

In case of ventilation openings, the ducts with acoustical lining should be provided.

The doors and openings should be closed firmly against rubber gasket to prevent sound leakage.

Home Work

State the significance of Surface mass and frequency of sound on the transmission loss

Half of the area of a partition wall is having TL=25dB and rest is having TL=50. What will be the resultant TL value of the wall?

Bibliography

1. **Acoustics in the Built Environment**, Duncan Templeton, Architectural Press; 2nd Edition

2. **Architectural Acoustics Illustrated,** Michael Ermann, wiley, 2015

3. **Architectural Acoustics,** Marshall Long, El Sevier, Academic Press,

4. **Mechanical and Electrical Equipment for Buildings**, Walter T. Grondzik, Alison G. Kwok, Benjamin Stein and John S. Reynolds, John Wiley & Sons, Inc. (11th Edition) [Part-IV]

End of Lecture 31: Air Borne Sound Transmission -I

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Architectural Acoustics

Lecture 32: Air Borne Sound Transmission-II

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Learning Objective

Discuss the 'Noise Criteria' curves

Differentiate between 'Transmission Loss' and 'Noise Reduction'

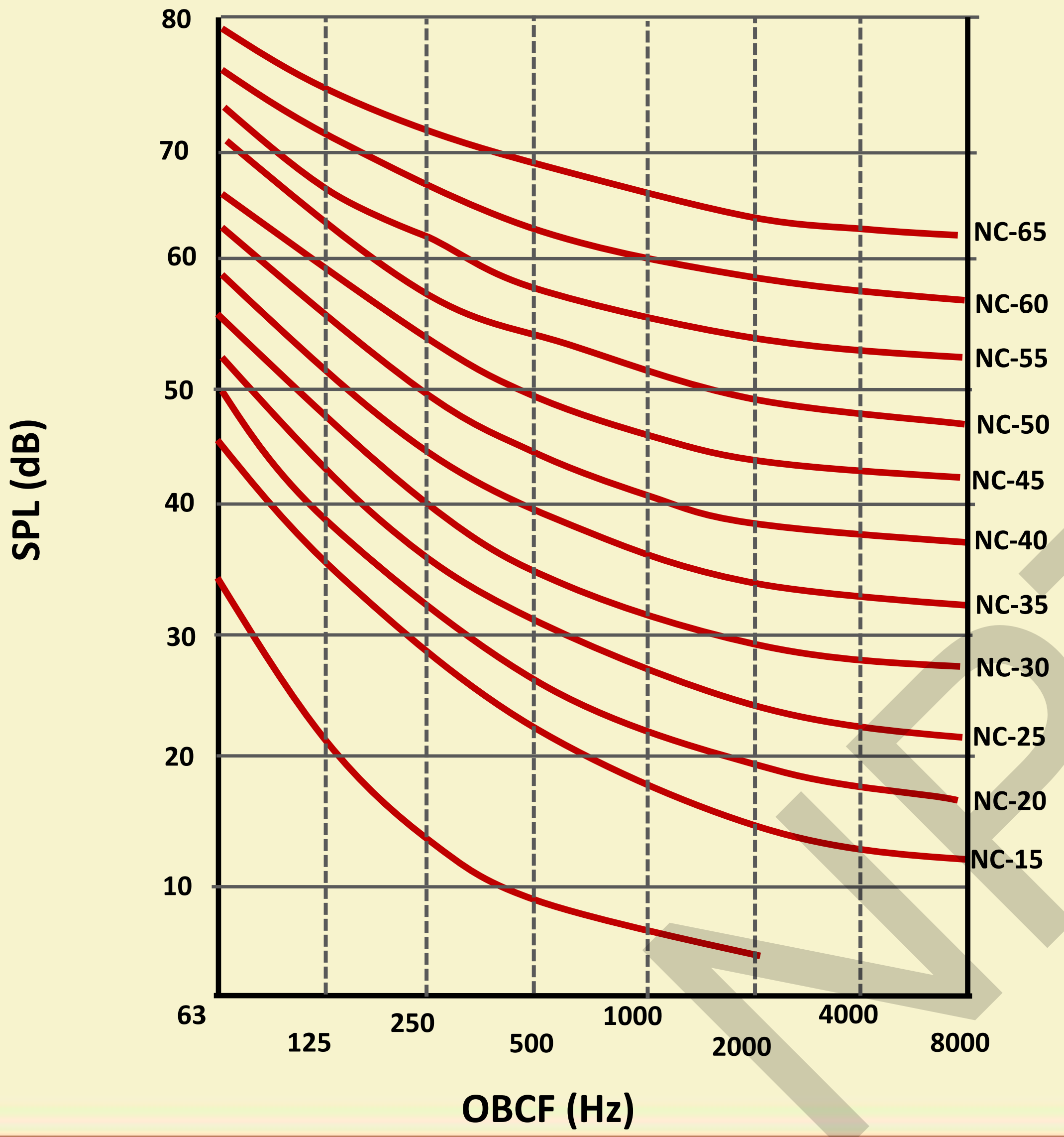
Noise Criteria

The noise criteria (NC) is expressed in a single numerical index to define the maximum allowable noise in a given space. The NC criteria consist of a family of curves that define the maximum allowable octave-band sound pressure level corresponding to a chosen NC design goal.

Background noise may have several undesirable effects:

- **Fatigue**
- **Reduction of productivity**
- **Health and safety**
- **Ability to communicate**

Noise Criteria Curves



Very Noisy …[NC-65, NC-60]

Noisy …[NC-55, NC-50]

Moderately Noisy …[NC-45, NC-40]

Quite …[NC-35, NC-30]

Very Quite …[NC-25, NC-20, NC-15]

Recommended Noise Criteria for Spaces

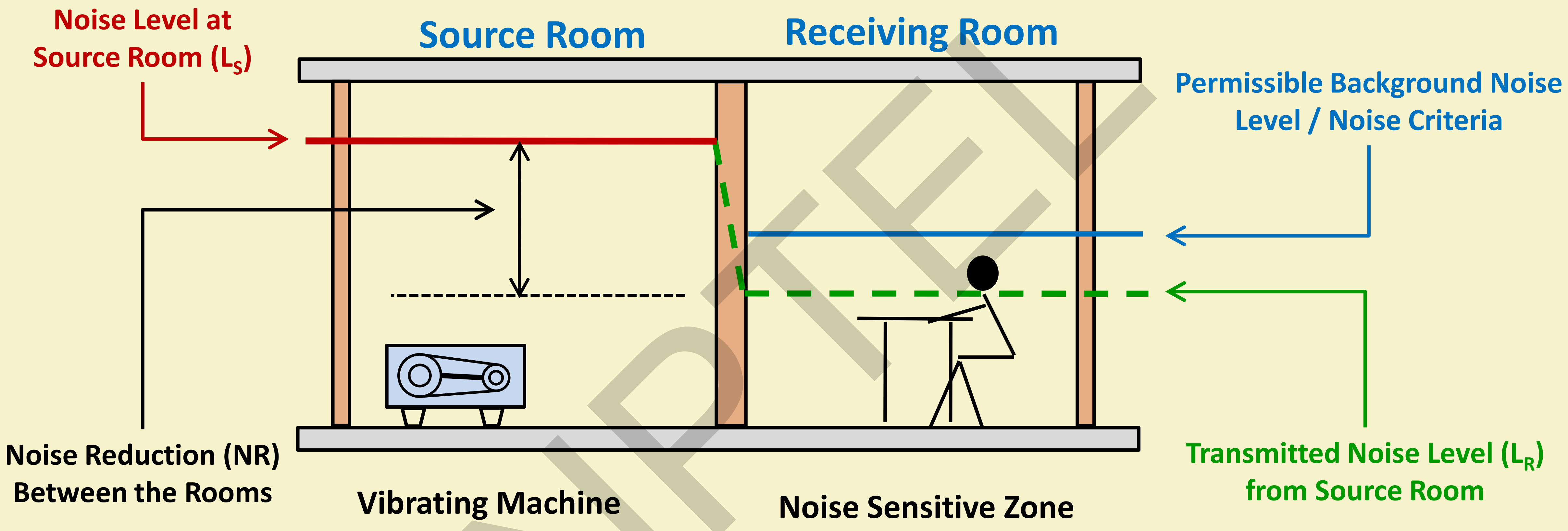
Type of Space	Noise Criteria	Equivalent dB
Recording Studio, Concert Hall	NC-15 to NC-20	25 to 30
Bedroom, Hospital, Apartment, Hotels	NC-20 to NC-30	30 to 40
Auditorium, Theater, Music Practice room	NC-20 to NC-30	30 to 40
Private office, Conference room, Library, Class room	NC-30 to NC-35	40 to 45
Office, Hotel Reception, Retail shop, Cafeterias, Restaurants, Gymnasium	NC-35 to NC-40	45 to 50
Laboratory, Workspace, Corridor, Equipment room	NC-40 to NC-45	50 to 55
Kitchen, Laundry, Industrial Shop, Machine room	NC-45 to NC-55	55 to 65

There are alternate contours have been also proposed. The major four different types of noise curves are:

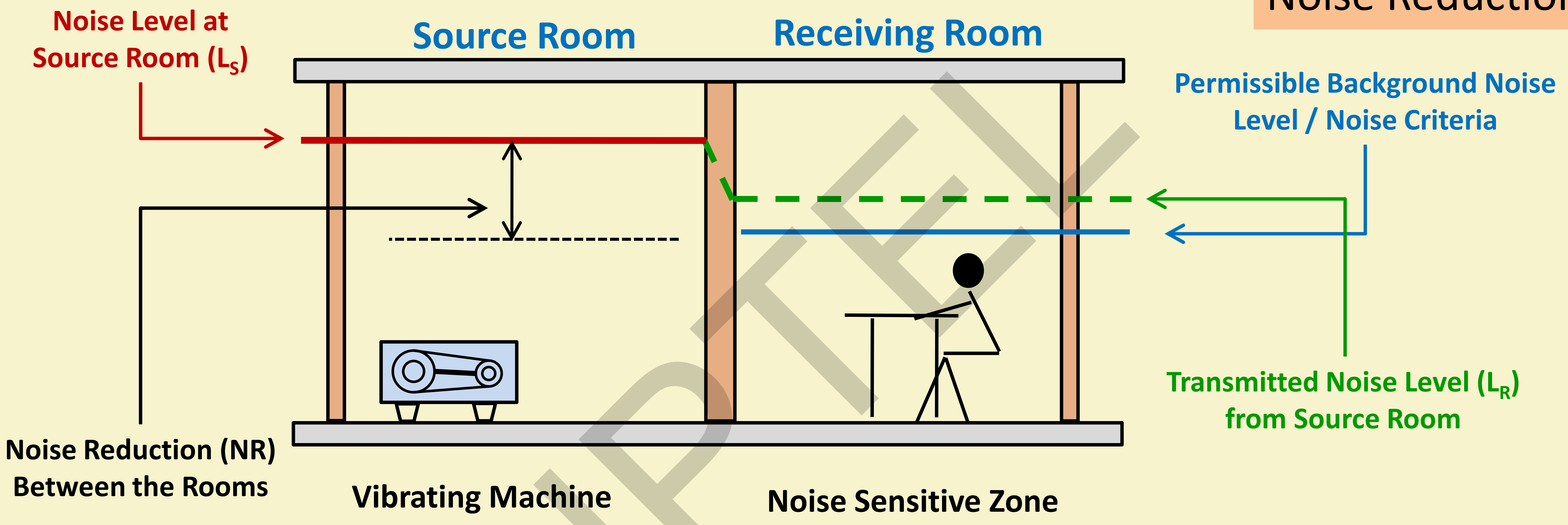
- **Noise Criterion Curves (NC)**
- **Noise Rating Curves (NR)**
- **Preferred Noise Criterion Curves (PNC)**
- **Room Criteria Curves (RC)**

the NC criteria remain the most widely accepted.

Noise Reduction



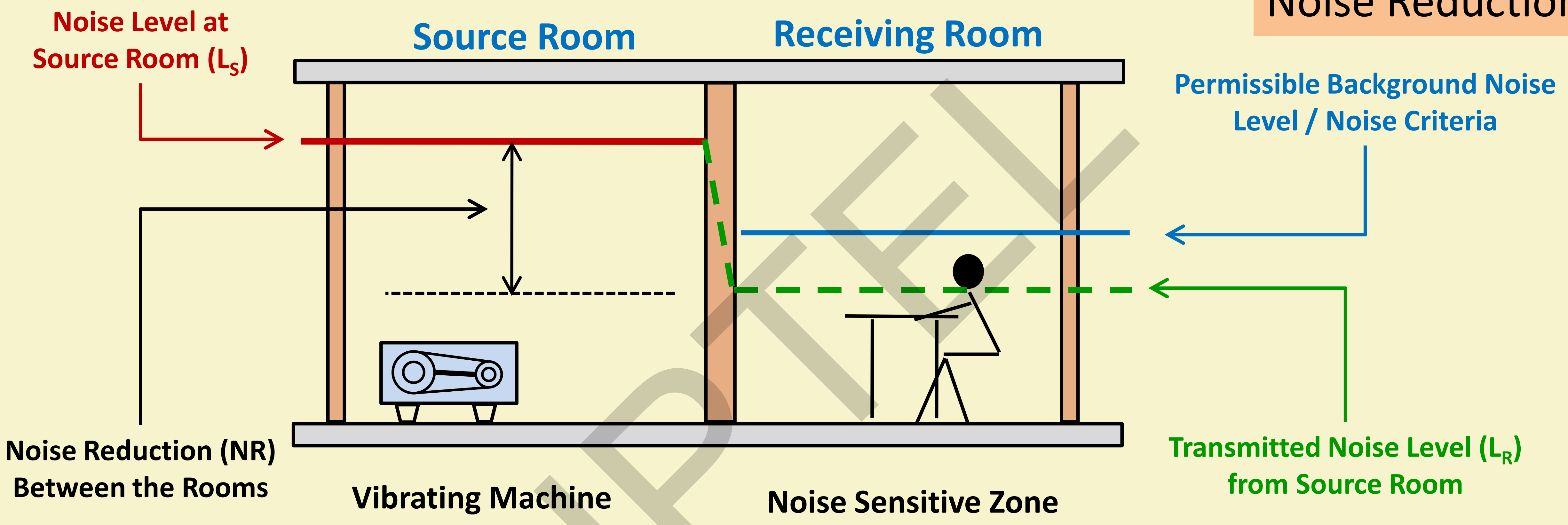
Noise Reduction



Transmitted Noise at receiving room (L_R) is higher than specific Noise Criteria of the space

Not Desirable

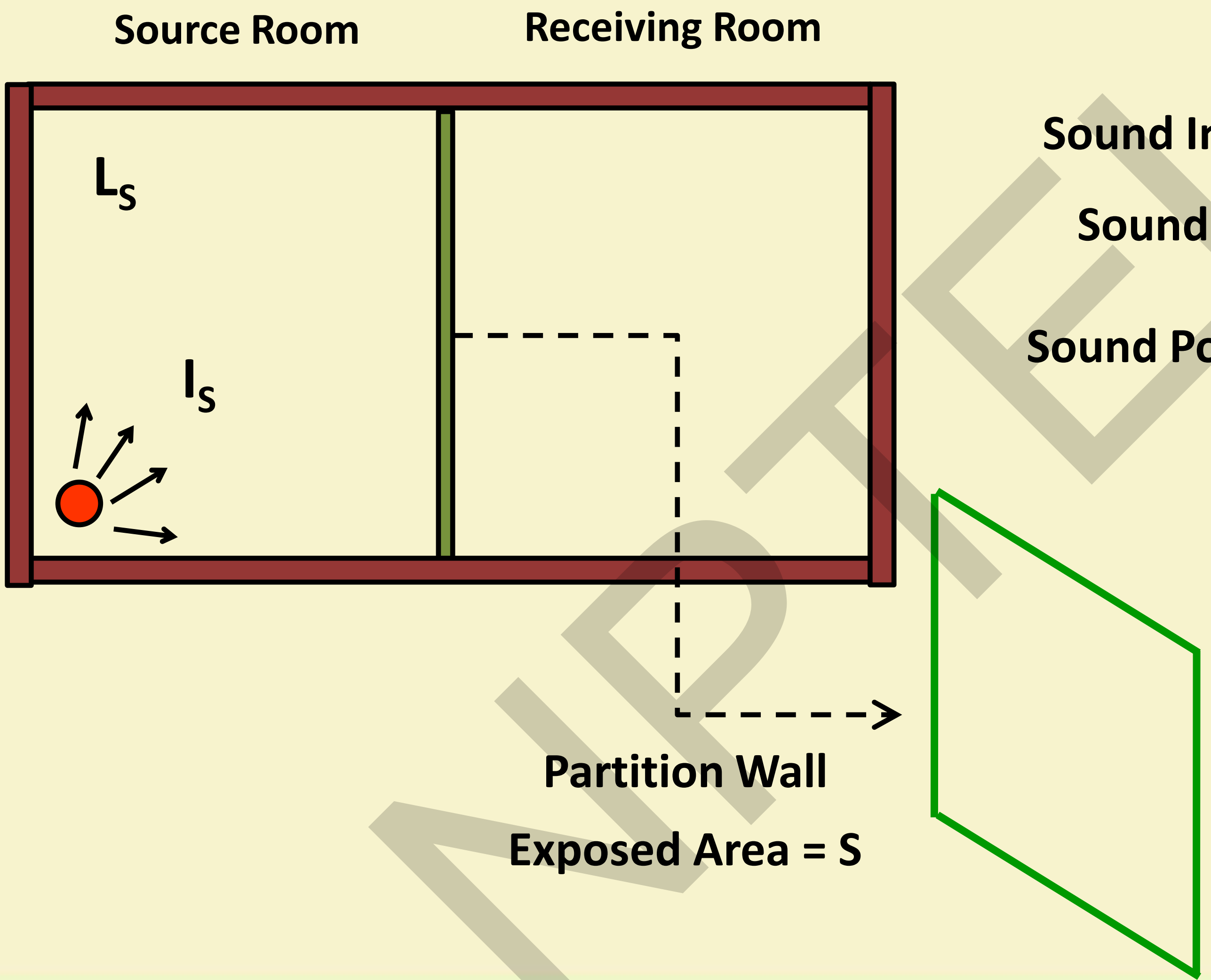
Noise Reduction



Transmitted Noise at receiving room (L_R) is lower than specific Noise Criteria of the space

Desirable

Noise Reduction



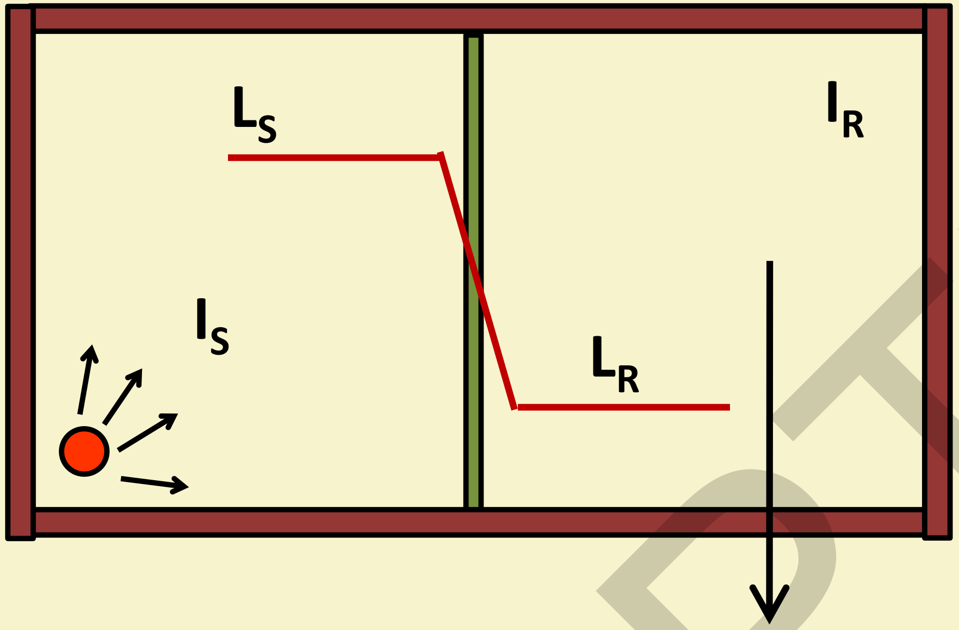
Sound Intensity Level at Source Room = L_S

Sound Intensity at Source Room = I_S

Sound Power incident at Partition wall = W_S

$$W_s = I_s \times S$$

Noise Reduction



Sound Intensity Level at Receiving Room = L_R

Sound Intensity at Receiving Room = I_R

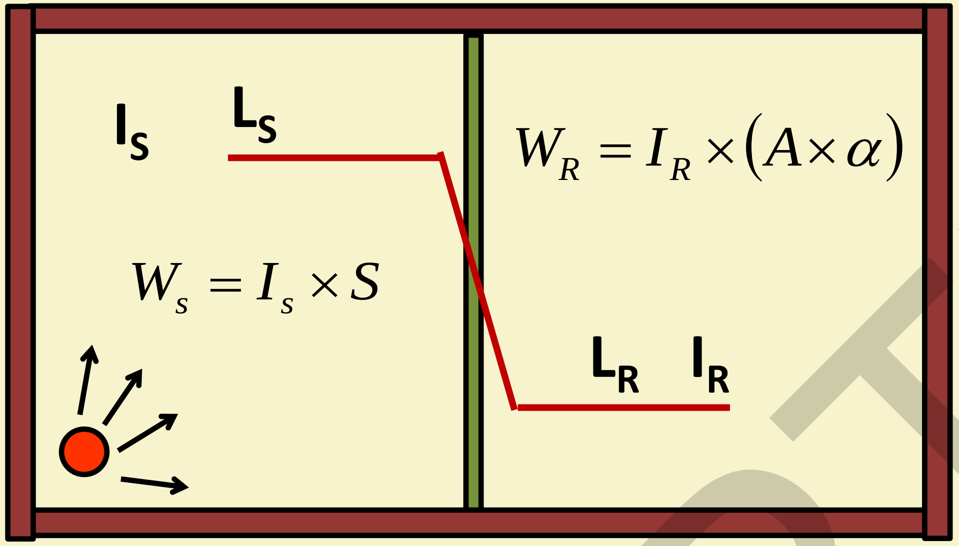
Sound Power at Receiving Room = W_R

$$W_R = I_R \times (A \times \alpha)$$

At Receiving Room: Sound Power = (Sound Intensity) X (Total Absorption)

Total Absorption = Individual Surface Area of the Interior Surfaces (A) X Sound Absorption Coefficient of respective Surface (α)

Noise Reduction



Sound Power at Source Room = W_S

Sound Power at Receiving Room = W_R

By Definition **Transmission Coefficient**

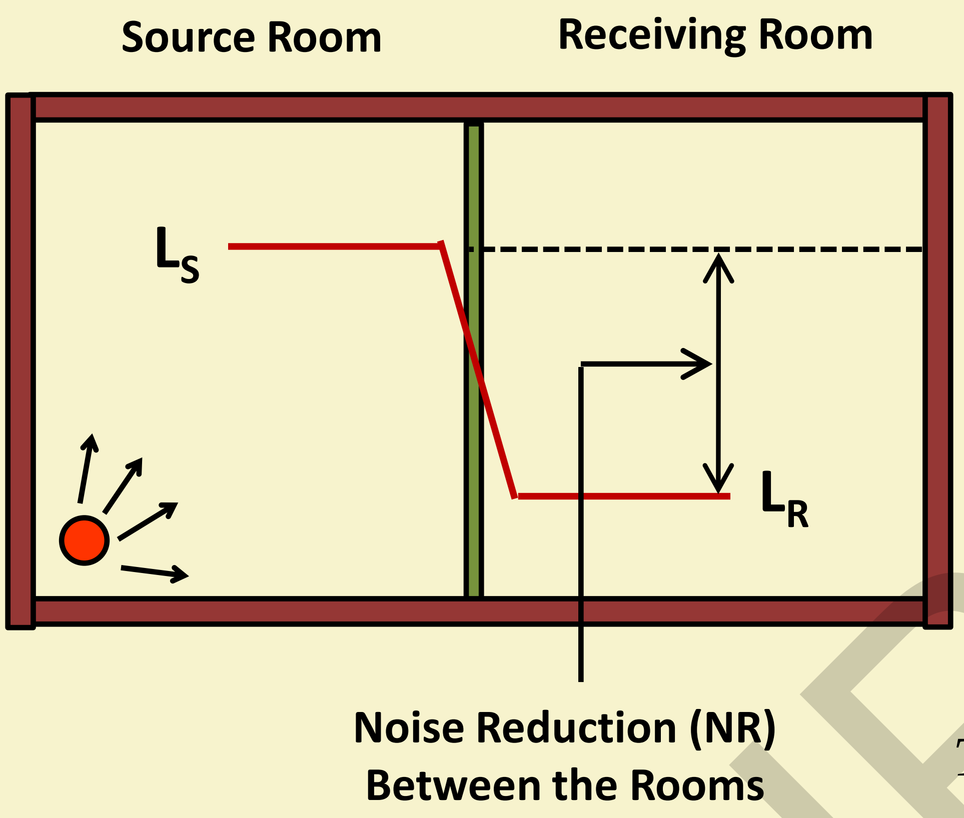
$$\tau = \frac{W_R}{W_s} = \frac{I_R \times (A \times \alpha)}{I_s \times S}$$

$$\frac{1}{\tau} = \frac{W_s}{W_R} = \frac{I_s \times S}{I_R \times (A \times \alpha)}$$

By Definition **Transmission Loss** is

$$TL = 10\log\frac{1}{\tau} = 10\log\left(\frac{W_s}{W_R}\right) = 10\log\left[\frac{I_s \times S}{I_R \times (A \times \alpha)}\right]$$

Noise Reduction



$$TL = 10\log\left[\frac{I_s \times S}{I_R \times (A \times \alpha)}\right]$$

$$TL = 10\log\frac{I_s}{I_R} + 10\log\frac{S}{A\alpha}$$

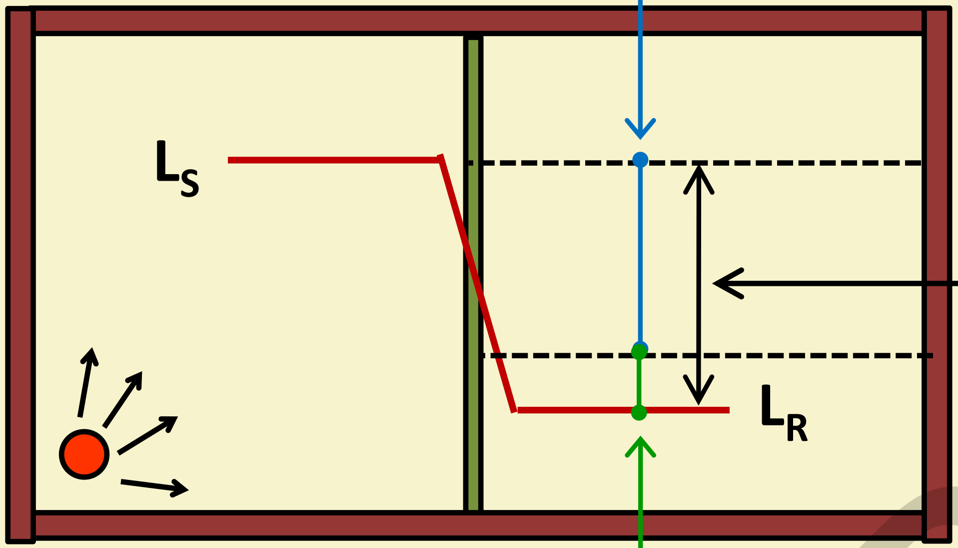
$$TL = 10\log\frac{I_s}{I_{ref}} - 10\log\frac{I_R}{I_{ref}} - 10\log\frac{A\alpha}{S}$$

$$TL = L_s - L_R - 10\log\frac{A\alpha}{S} \Rightarrow L_s - L_R = TL + 10\log\frac{A\alpha}{S}$$

$$\boxed{NR = TL + 10\log\frac{A\alpha}{S}}$$

Noise Reduction

Transmission Loss of the Partition Wall



Noise Reduction (NR) Between the Rooms

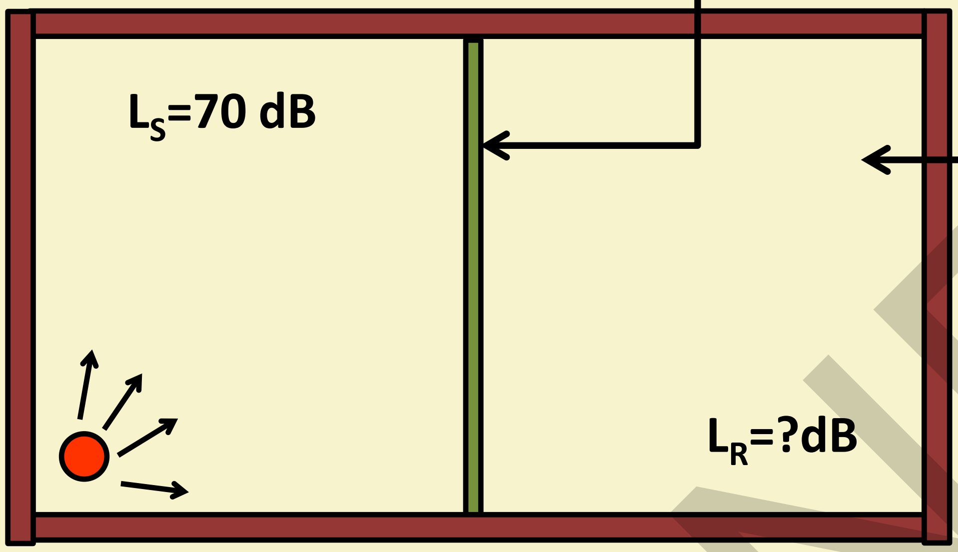
$$NR = TL + 10\log\frac{A\alpha}{S}$$

Total Sound absorption of Receiving Room (Aα)

Exposed surface Area of the Partition Wall towards the Source Room (S)

Noise Level at Source Room = 70 dB

Partition Wall Details:
Wall: Area 32 m^2 TL = 30 Db
Window: Area 8 m^2 TL = 40 dB



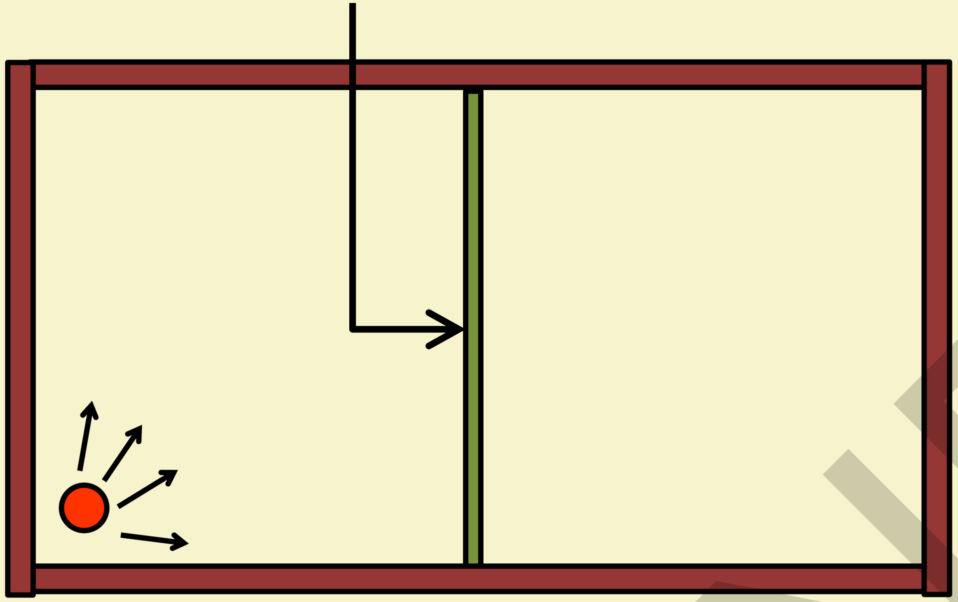
Receiving Room Details:
Size: 10m X 7m X 4m (Height)
Sound Absorption Coefficient (α) value of:
Wall = 0.5, Ceiling = 0.65, Floor = 0.02

Calculation of Transmission Loss of Partition Wall:

Partition Wall Details:

Wall: Area 32 m² TL = 30 dB

Window: Area 8 m² TL = 40 dB



$$\tau = 10^{-\left(\frac{TL}{10}\right)} \Rightarrow \tau_{wall} = 10^{-3}, \quad \tau_{window} = 10^{-4}$$

$$\tau_{avg} = \frac{32\times10^{-3} + 8\times10^{-4}}{40} = \frac{0.032 + 0.0008}{40} = 8.2\times10^{-4}$$

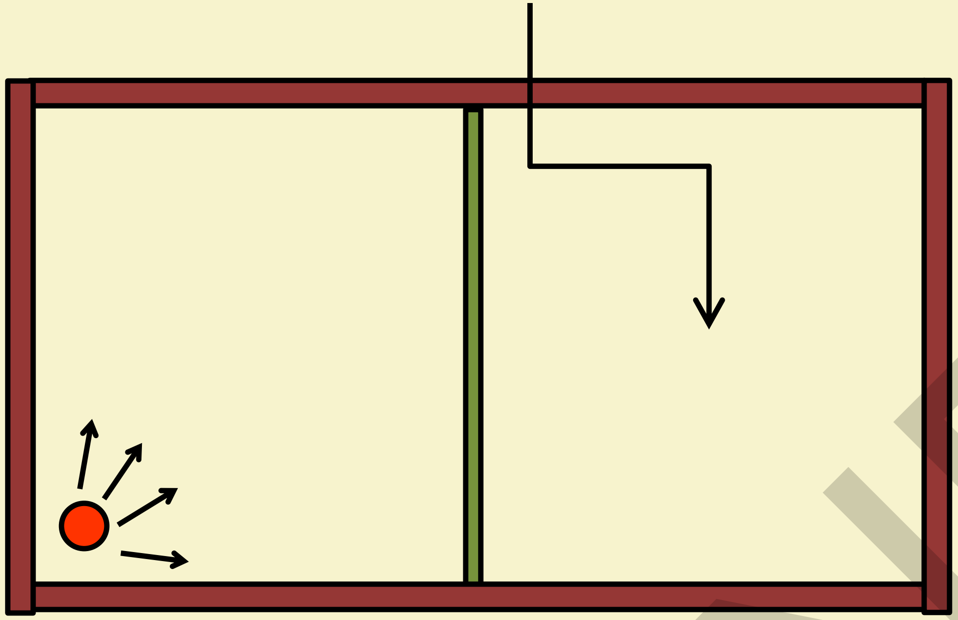
$$TL_{avg} = 10\log\frac{1}{\tau_{avg}} = 10\log\frac{1}{8.2\times10^{-4}} = 30.86 = 31\,\text{dB}$$

Receiving Room Details:

Size: 10m X 7m X 4m (Height)

Sound Absorption Coefficient (α) value of:

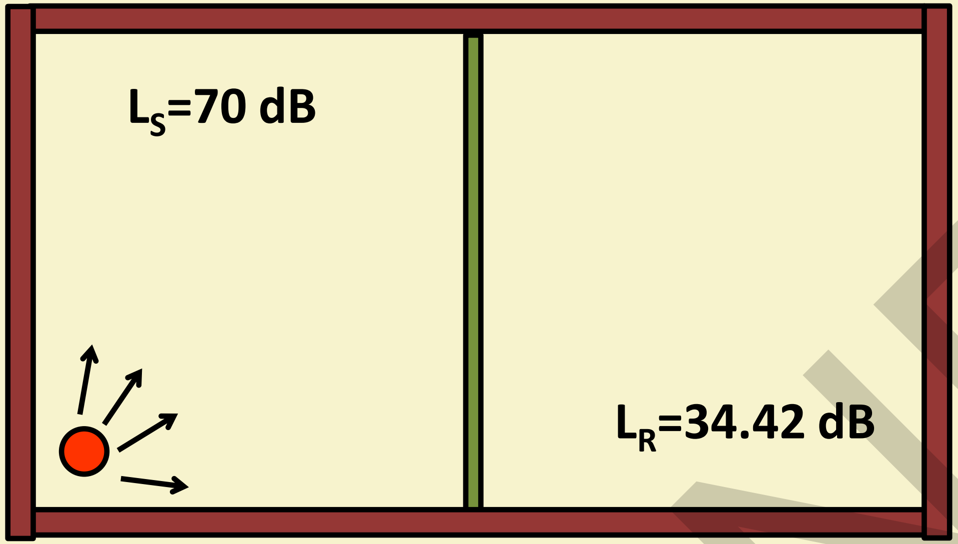
Wall = 0.5, Ceiling = 0.65, Floor = 0.02



Calculation of Total Absorption in the Receiving Room:

Item	Area	α	A Xα
Wall	2X(10+7)X4=136	0.5	68
Ceiling	10X7 = 70	0.65	45.5
Flooring	10X7 = 70	0.02	1.4
		Total Absorption (Aα)	**114.9**

Calculation of SIL in the Receiving Room:



$$L_s - L_R = TL + 10\log\frac{A\alpha}{S}$$

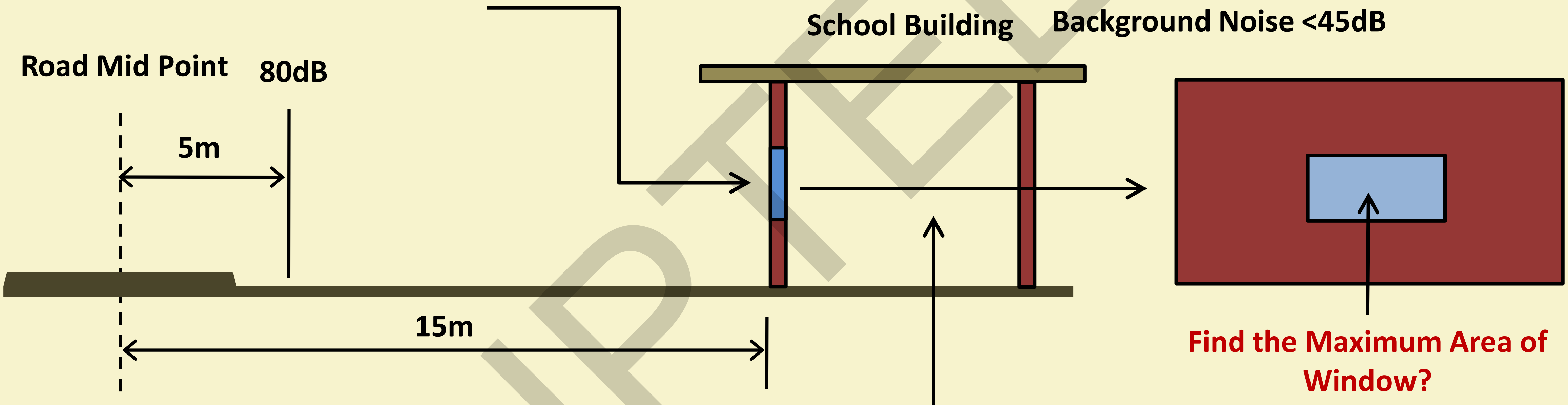
$$\Rightarrow\ 70 - L_R = 31 + 10\log\frac{114.9}{40}$$

$$\Rightarrow\ 70 - L_R = 31 + 4.58 = 35.58$$

$$\Rightarrow\ L_R = (70 - 35.58) = 34.42\,\text{dB}$$

Noise Reduction

Partition Wall Details:
Wall dimension exposed to Road: 10mX3m
Wall: TL = 60 dB
Window: TL = 15 dB

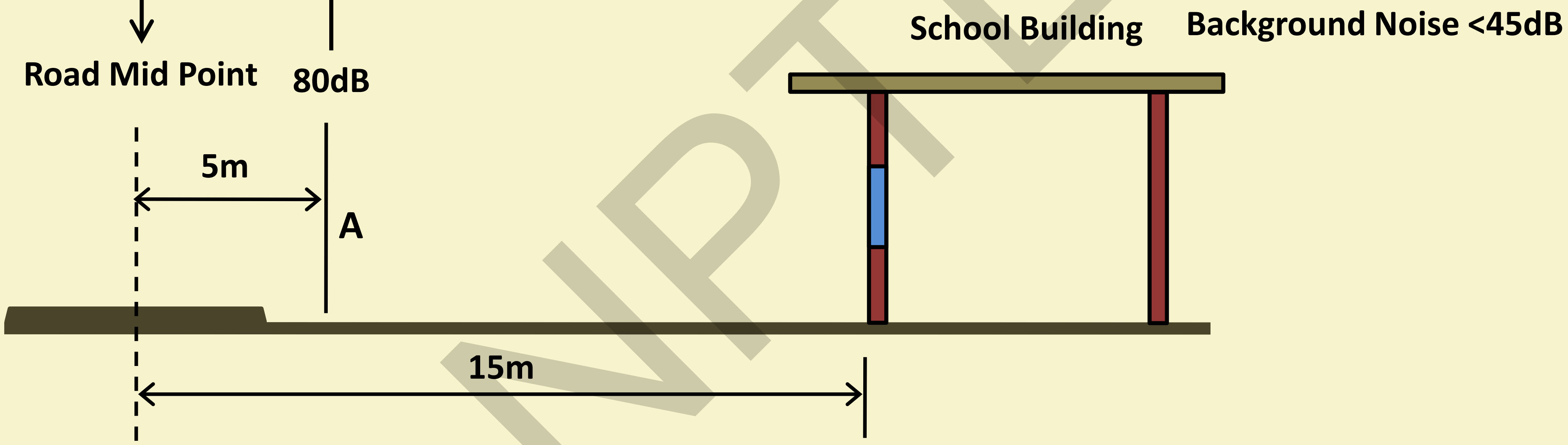


Class Room Details:
Size: 10m X 6m X 3m (Height)
Average Sound Absorption Coefficient (α) of all surfaces is 0.3

Noise Reduction

$$L_A = 10\log\frac{I_A}{I_{ref}} = 80\ \text{dB} \;\Rightarrow\; I_A = 10^{-12}\times 10^{8} = 10^{-4}\ \text{w/m}^2$$

$$\text{Power of Sound Source} = I_A \times 4\pi R_A^2 = 10^{-4}\times 4\pi\times(5)^2 = 0.031415\ \text{watt}$$

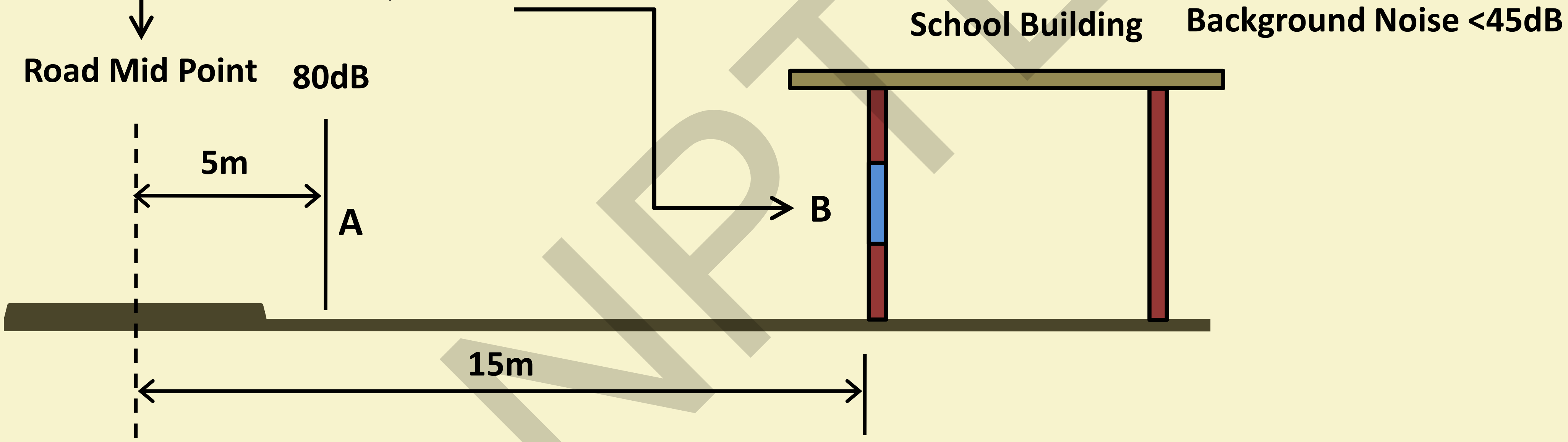


Noise Reduction

$$\text{Power of Sound Source} = I_A \times 4\pi R_A^2 = 10^{-4} \times 4\pi \times (5)^2 = 0.031415 \text{ watt}$$

$$I_B = \frac{W}{4\pi R_B^2} = \frac{0.031415}{4\pi \times (15)^2} = 1.11\times10^{-5} .\text{w/m}^2$$

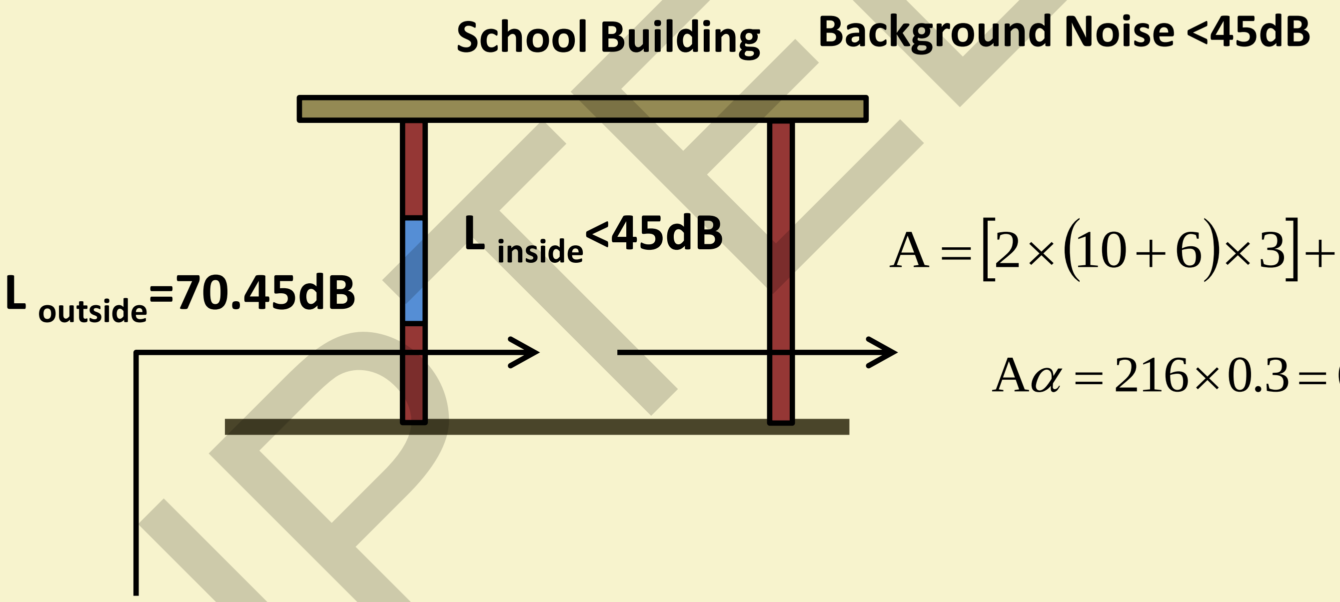
$$L_B = 10\log\frac{I_B}{I_{ref}} = 10\log\frac{1.11\times10^{-5}}{10^{-12}} = 70.45\,\text{dB}$$



Noise Reduction

$$NR = \text{Sound level due to Sourse} - \text{Desire Sound Level at Indoor}$$

$$NR = 70.45 - 45 = 25.45\,\text{dB}$$



$$A = [2\times(10+6)\times 3] + 2\times(10\times 6) = 216\,\text{m}^2$$

$$A\alpha = 216\times 0.3 = 64.8\,\text{m}^2\ \text{Sabin}$$

Class Room Details:

Size: 10m X 6m X 3m (Height)

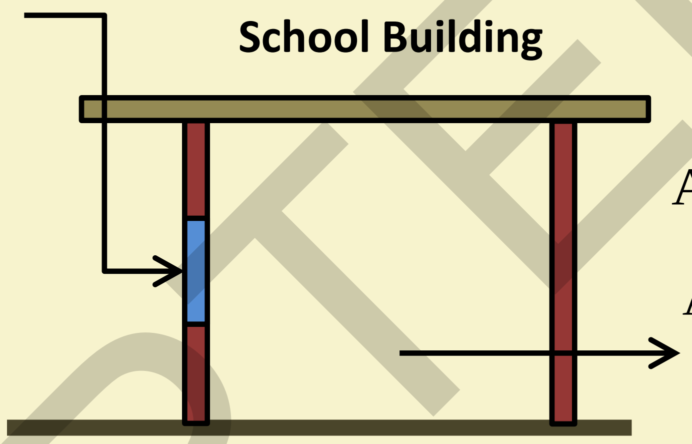
Average Sound Absorption Coefficient (α) of all surfaces is 0.3

Noise Reduction

$$\text{NR} = \text{Sound level due to Sourse} - \text{Desire Sound Level at Indoor}$$

$$\text{NR} = 70.45 - 45 = 25.45\,\text{dB}$$

Partition Wall Details:
Wall dimension exposed to Road: 10mX3m



$$\text{S} = (10 \times 3) = 30\,\text{m}^2$$

$$A = [2 \times (10 + 6) \times 3] + 2 \times (10 \times 6) = 216\,\text{m}^2$$

$$A\alpha = 216 \times 0.3 = 64.8\,\text{m}^2 \text{ Sabin}$$

$$\Downarrow$$

$$NR = TL + 10\log\frac{A\alpha}{S}$$

$$\Downarrow$$

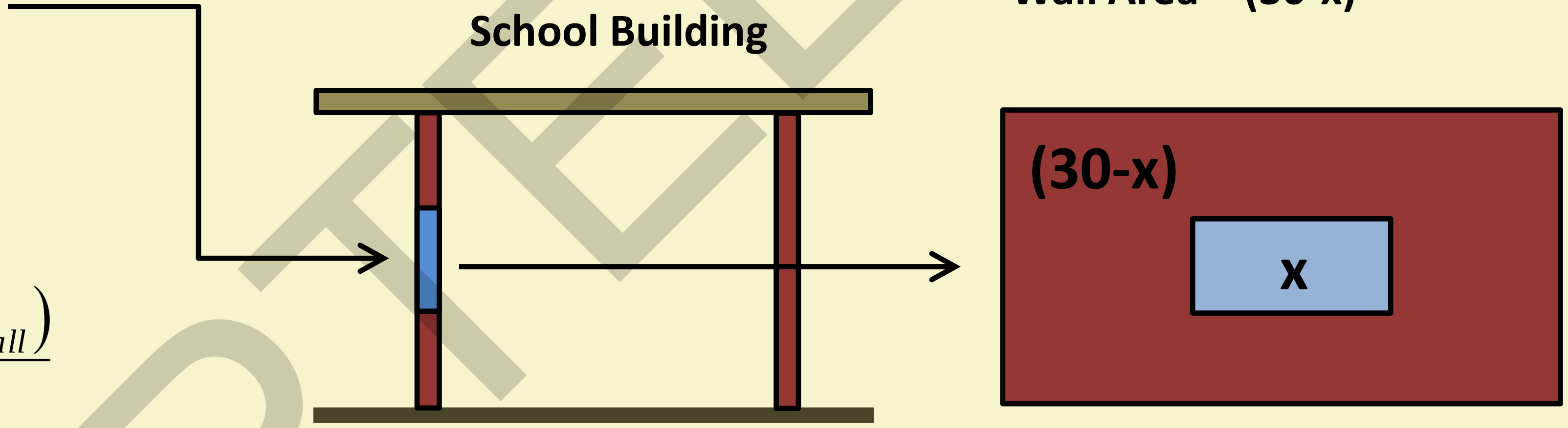
$$25.45 = TL + 10\log\frac{64.8}{30} \Rightarrow 25.45 = TL + 3.34 \Rightarrow TL = 25.45 - 3.34 = 22.11\,dB$$

Noise Reduction

$$\tau_{wall} = 10^{-6}$$
$$\tau_{window} = 10^{-1.5}$$

Partition Wall Details:
Wall dimension exposed to Road: 10mX3m
Wall: TL = 60 dB
Window: TL = 15 dB

Let the Window area be 'x'
Wall Area = (30-x)



$$\tau_{avg} = \frac{\sum_{i=1}^{n} \tau_i \times A_i}{\sum_{i=1}^{n} A_i}$$

$$\tau_{avg} = \frac{(\tau_{Window} \times A_{Window}) + (\tau_{Wall} \times A_{Wall})}{(A_{Window} + A_{Wall})}$$

$$\frac{(10^{-1.5} \times x) + (10^{-6} \times (30 - x))}{(30)} = 10^{-2.211}$$

Solving, $x = 5.09\,\mathrm{m}^2$

So, Window Area should me 5m² Maximum

Home Work

Outline the relation among: Noise Criteria, Transmission Loss & Noise Reduction

If the total absorption of the receiving room is gets doubled, what will be the change in the Noise Reduction (NR in dB)? Assume rest all other parameters remain unchanged.

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1. **Acoustics in the Built Environment**, Duncan Templeton, Architectural Press; 2nd Edition
2. **Architectural Acoustics Illustrated,** Michael Ermann, wiley, 2015
3. **Architectural Acoustics,** Marshall Long, El Sevier, Academic Press,
4. **Mechanical and Electrical Equipment for Buildings**, Walter T. Grondzik, Alison G. Kwok, Benjamin Stein and John S. Reynolds, John Wiley & Sons, Inc. (11th Edition) [Part-IV]

End of Lecture 32: Air Borne Sound Transmission -II

Architectural Acoustics

Lecture 33: Air Borne Sound Transmission-III

Dr. Shankha Pratim Bhattacharya

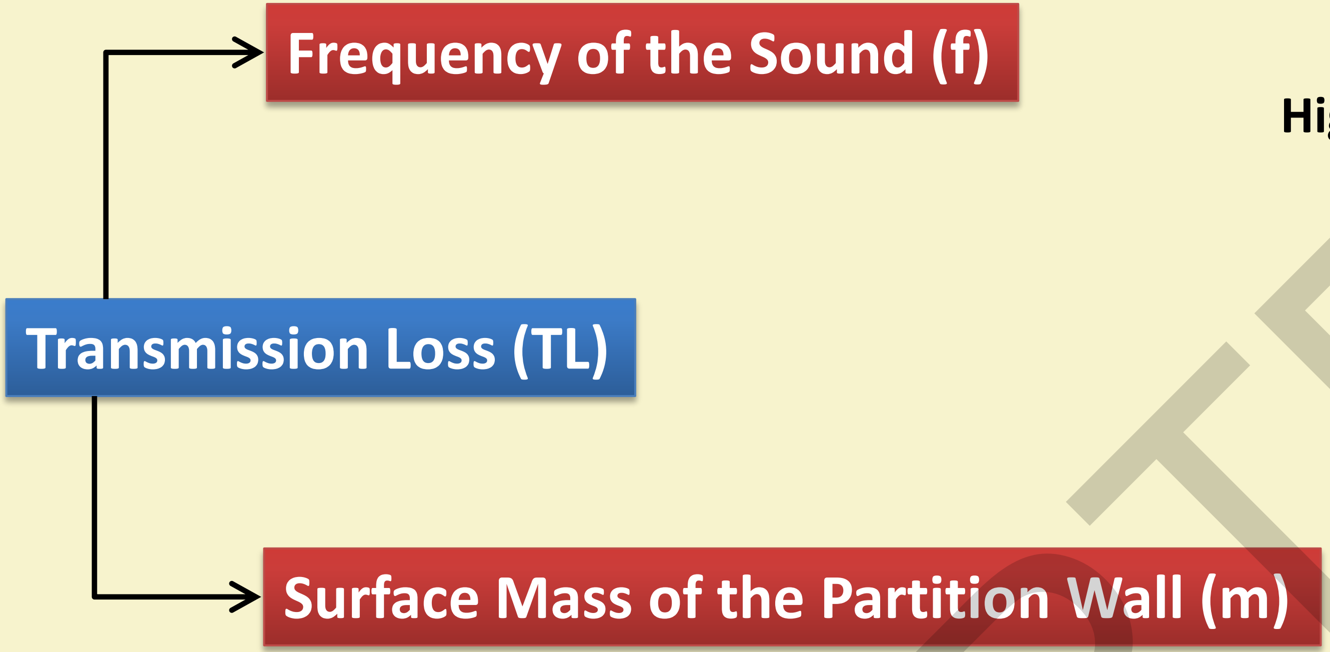
Department of Architecture & Regional Planning

Learning Objectives

Describe the Coincidence Effect on the Transmission loss of a partition wall

Establish the methodology to evaluate the STC value of a partition wall

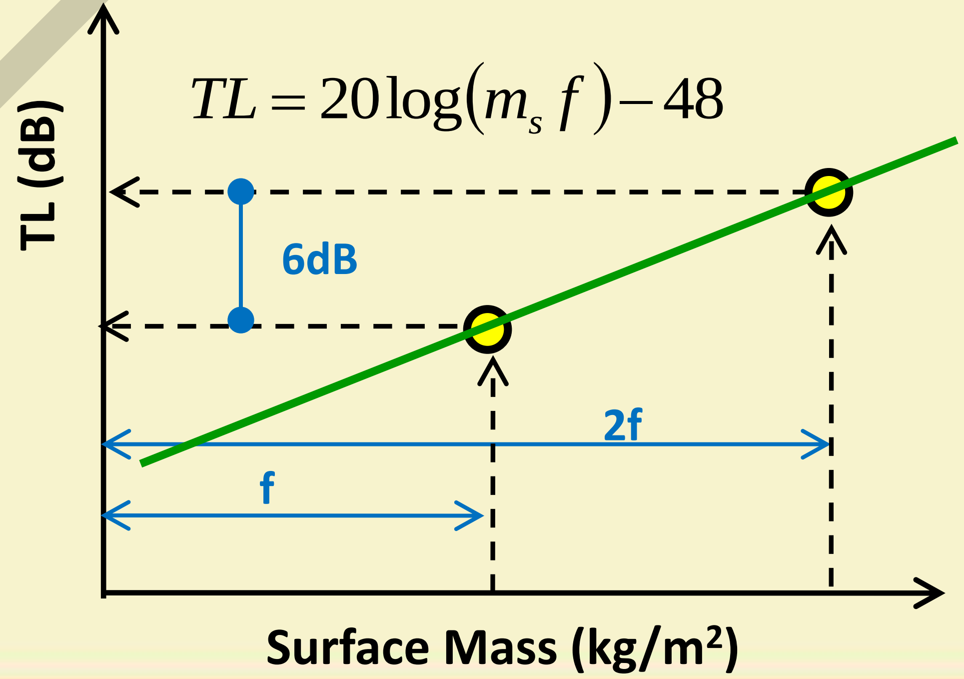
Frequency and TL



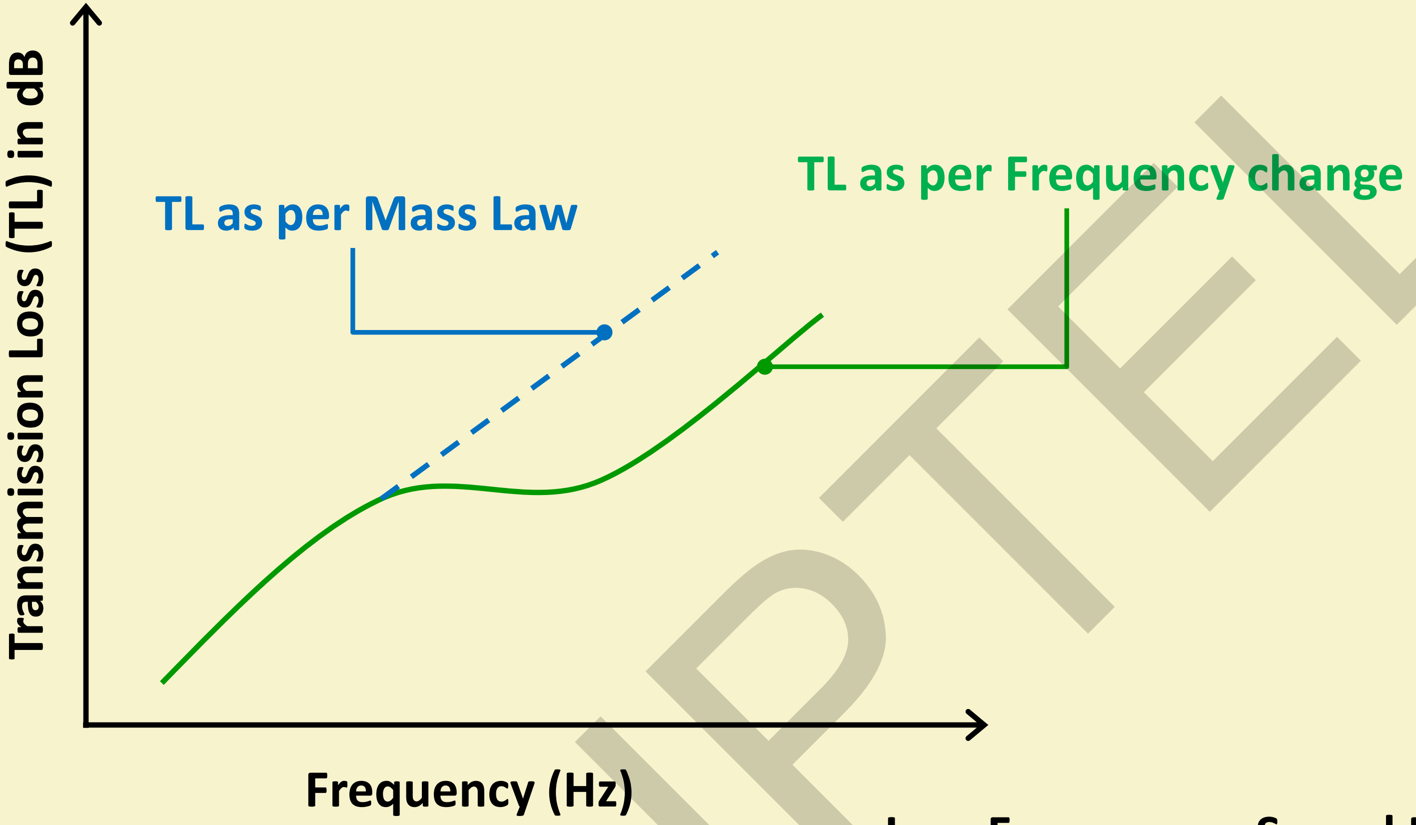
Higher the Frequency ….. Higher Transmission Loss

Per Octave ….

Only 6dB increment of Transmission Loss



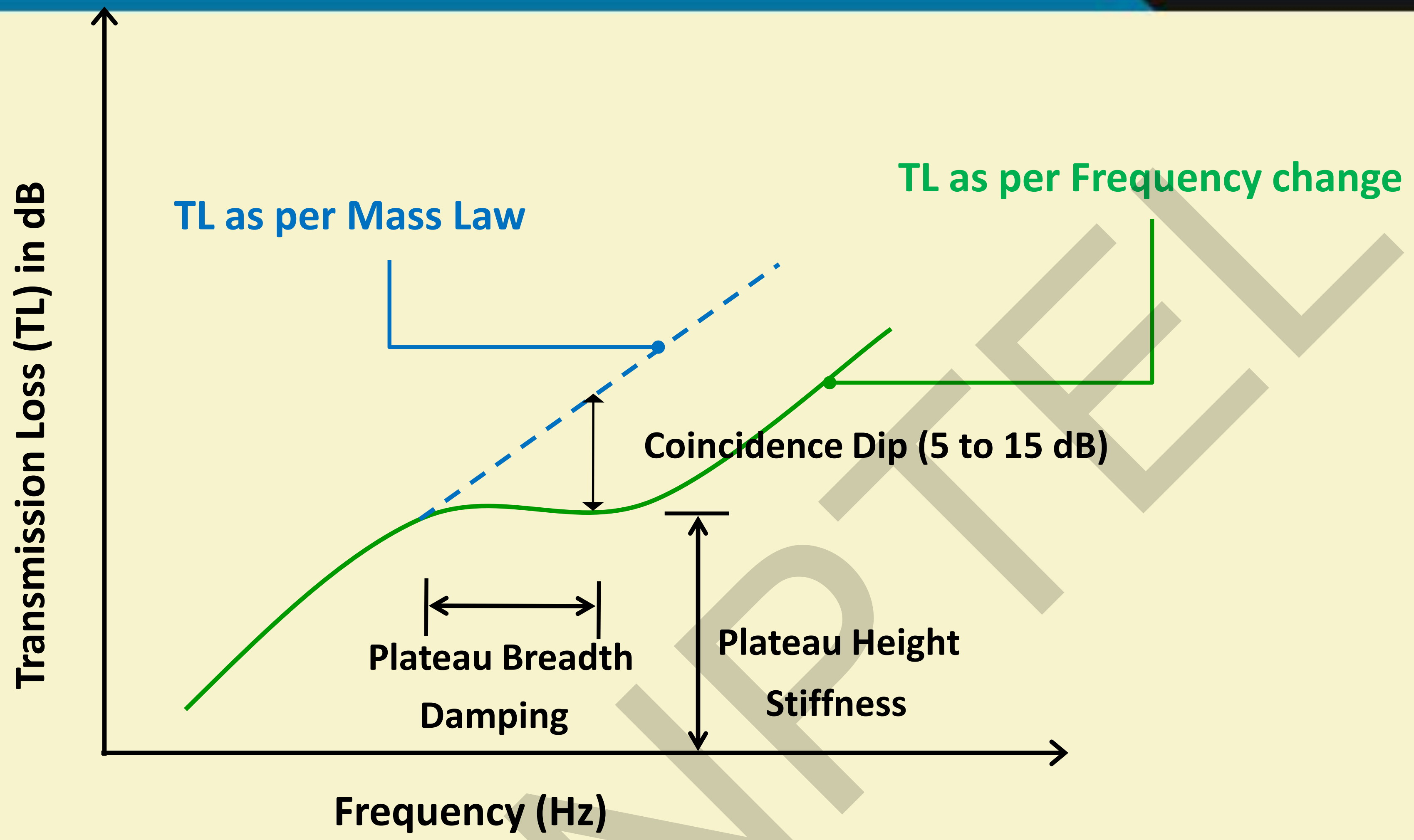
Frequency and TL



Low Frequency : Sound Energy pass through: Low TL

High Frequency : More Sound Energy isolation: High TL

Frequency and TL

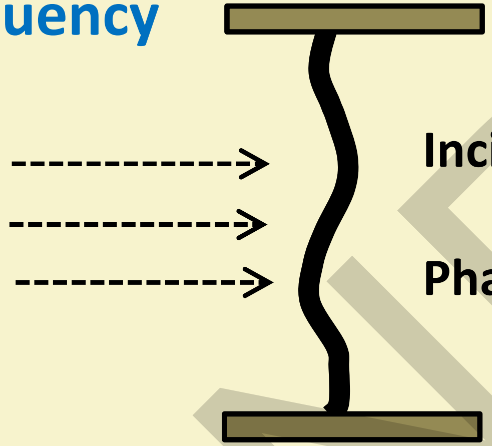


At the critical frequency the phase of incident sound waves corresponds to or coincides with the phase vibration (shear wave) of the barrier in such a way as to pass a large portion of the incident energy. This is called Coincidence Effect

Critical Frequency

Coincidence Effect

Incident Sound Wave



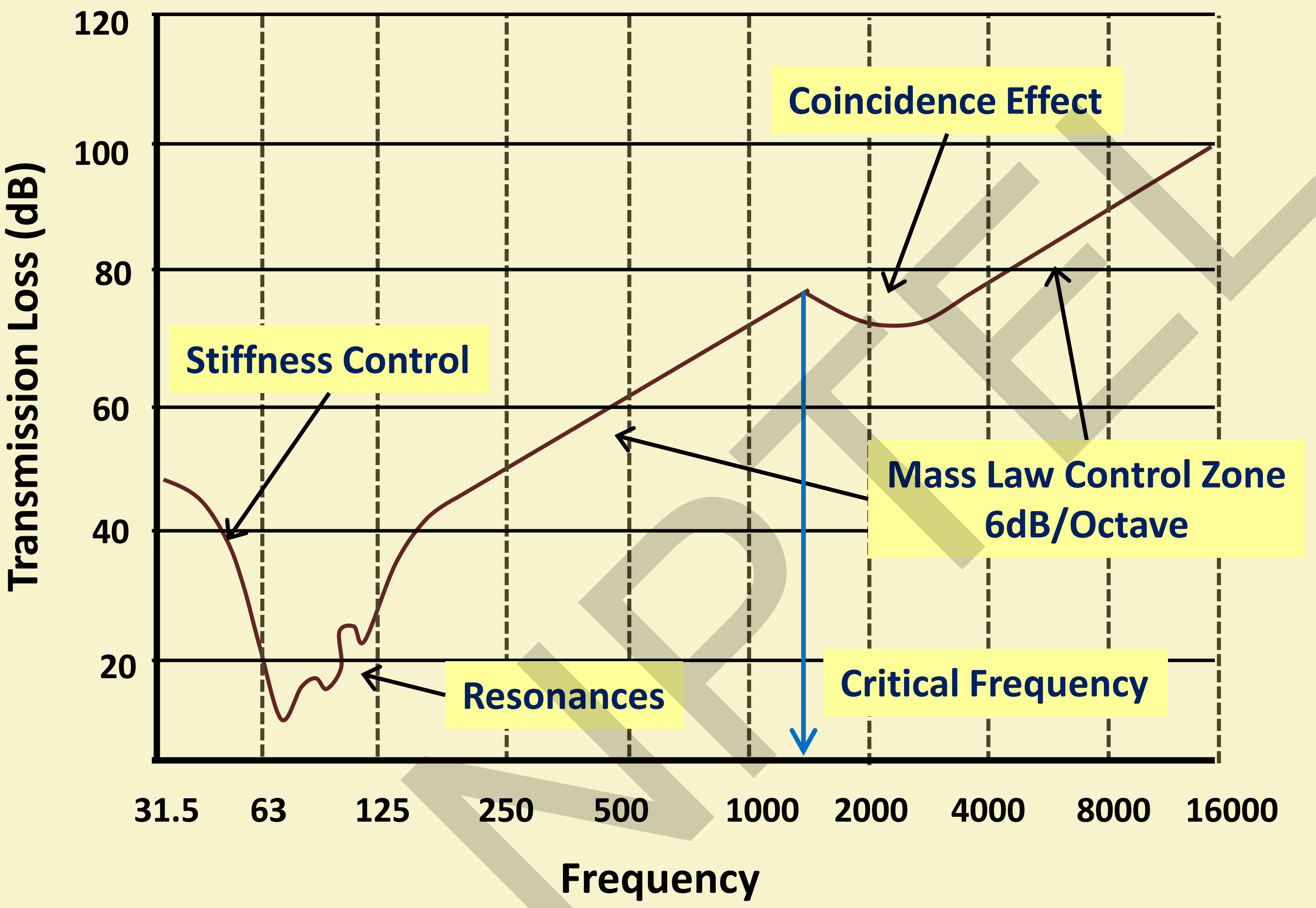
Incident Sound Wave Frequency

=

Phase of Partition Wall Vibration

Vibration of Partition Wall

Coincidence Effect



STC

A **single-number average Transmission Loss** is necessary to designate a given partition wall to describe a sound barrier characteristics.

Theoretically, such averages can be **misleading**, since they **ignore** the variation of transmission loss for the entire **range of frequencies**.

But still a **common methodology** and establish a **single number Transmission Loss** is needed for general understanding and specification for a partition wall.

A system of standard contours was developed in the United States called **sound transmission class (STC) contours**.

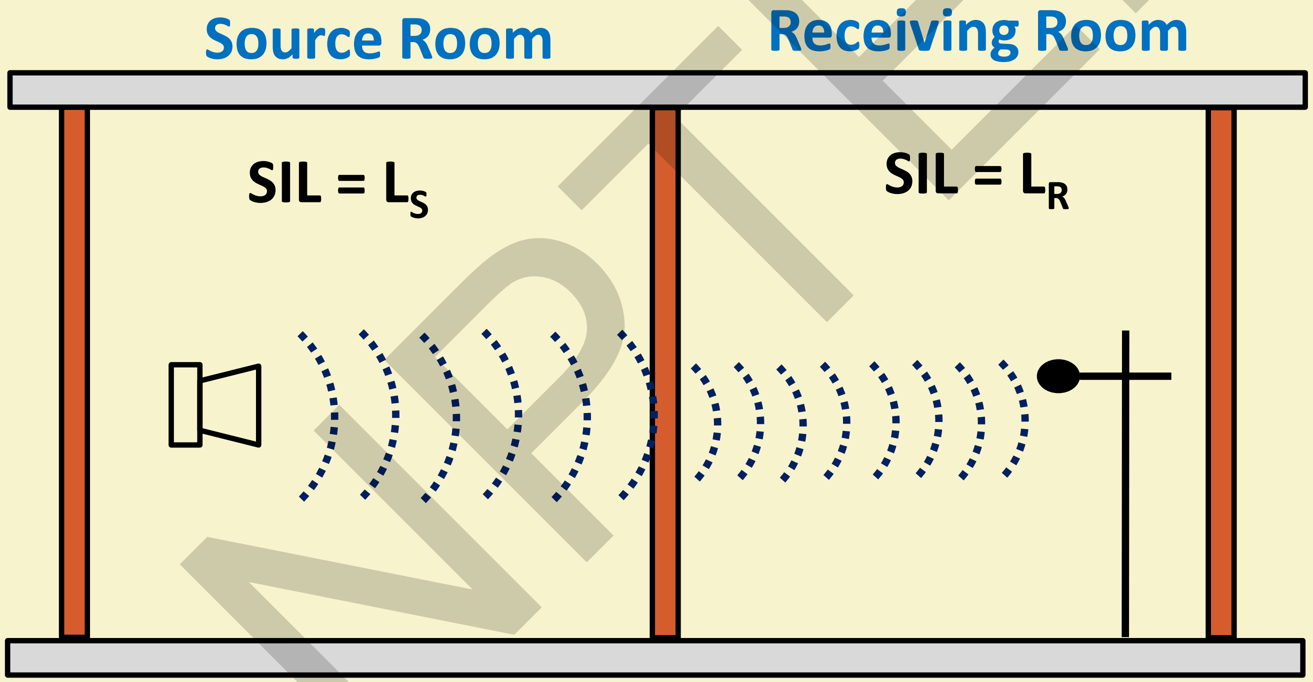
Steps to find STC

1. Laboratory test to find the TL of a particular wall for a specific frequency
2. Find the TL for a specific one-third Octave band of frequencies (125Hz to 4000Hz, total 16 frequencies)
3. Plot Frequency vs. TL graph
4. Overlay the STC Contour based on the averaging and gradual decreasing the TL value over frequency
5. Get the Single number Sound Transmission Class (STC) value of wall

Steps to find STC

1 Laboratory test to find the TL of a particular wall for a specific frequency

Use Noise Reduction (NR) formula to calculate TL for various Frequencies $$TL = L_s - L_R - 10\log\frac{A\alpha}{S}$$



2

Find the TL for a specific one-third Octave band of frequencies (125Hz to 4000Hz, total 16 frequencies)

Steps to find STC

STC Calculation Table

Sl No	frequency	TL (Actual)
1	125	
2	160	
3	200	
4	250	
5	315	
6	400	
7	500	
8	630	

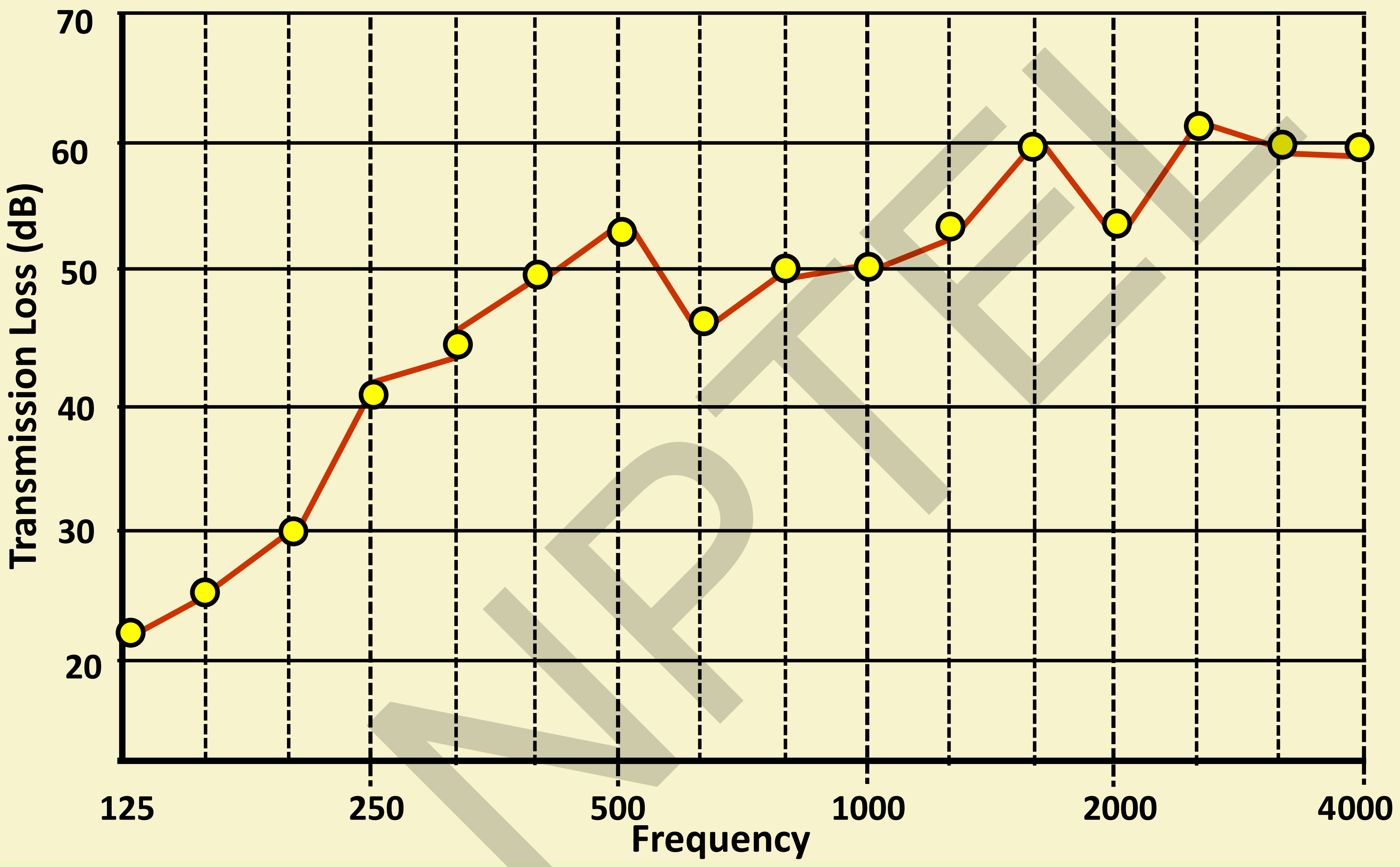
STC Calculation Table

Sl No	frequency	TL (Actual)
9	800	
10	1000	
11	1250	
12	1600	
13	2000	
14	2500	
15	3150	
16	4000	

Test the partition wall in a given specific acoustical environment and obtain the TL values for all 16 one-third octave band frequencies from 125 Hz to 4000 Hz.

3 Plot Frequency vs. TL graph

Steps to find STC



4

Overlay the STC Contour based on the averaging and gradual decreasing the TL value over frequency

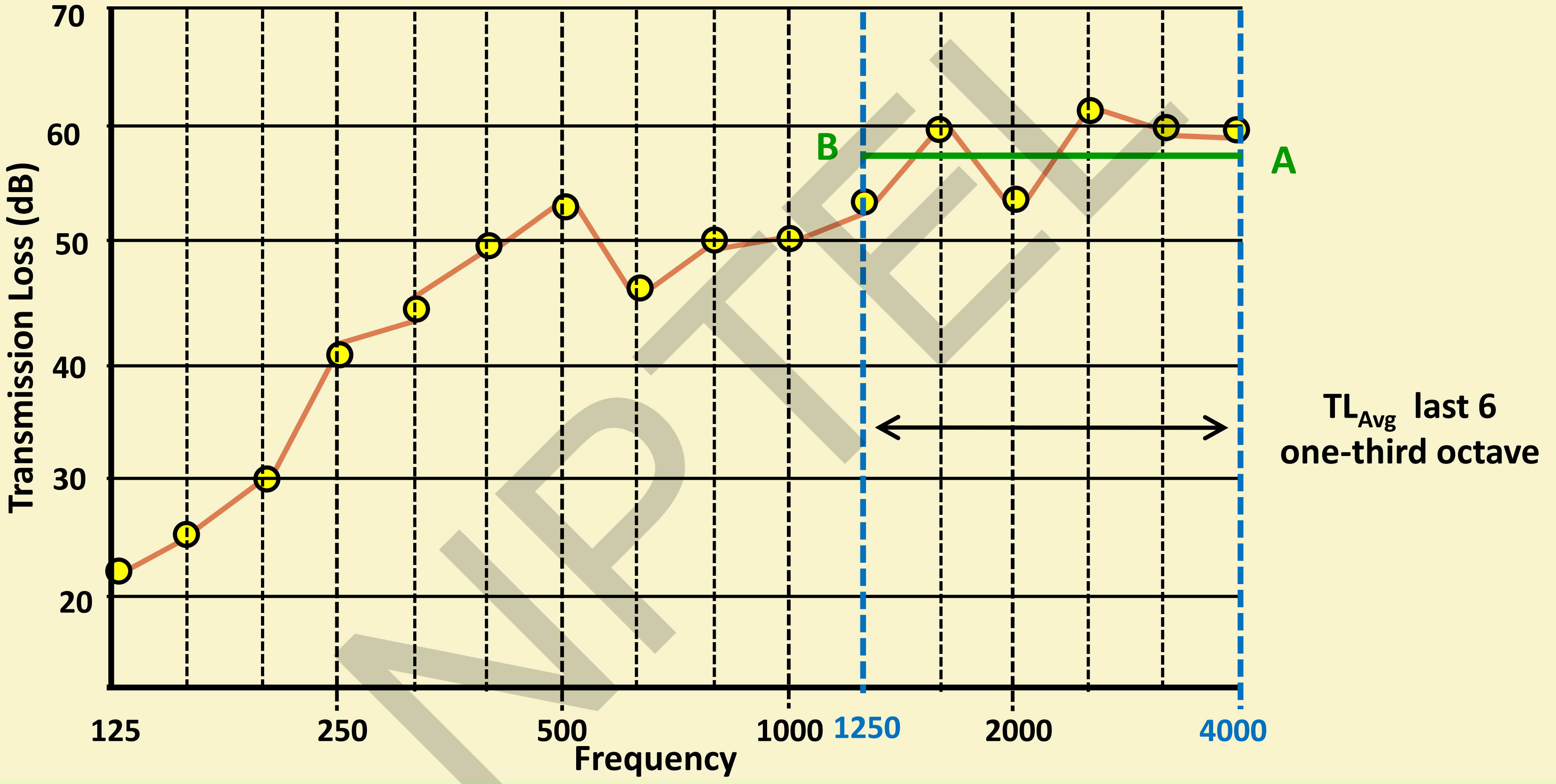
Steps to find STC

Draw a STC Contour (for the first trial) and superimpose with the previous plot. The STC contour can be arrived by following steps:

4a) Calculate the average TL value for the last 6 one-third octave band frequencies, i.e. 1250 to 4000 Hz

4b) Draw a straight line (parallel to X-axis) having TL equal to the average TL value of the previous step. Draw this line AB from Frequency 4000 to 1250 Hz.

Steps to find STC



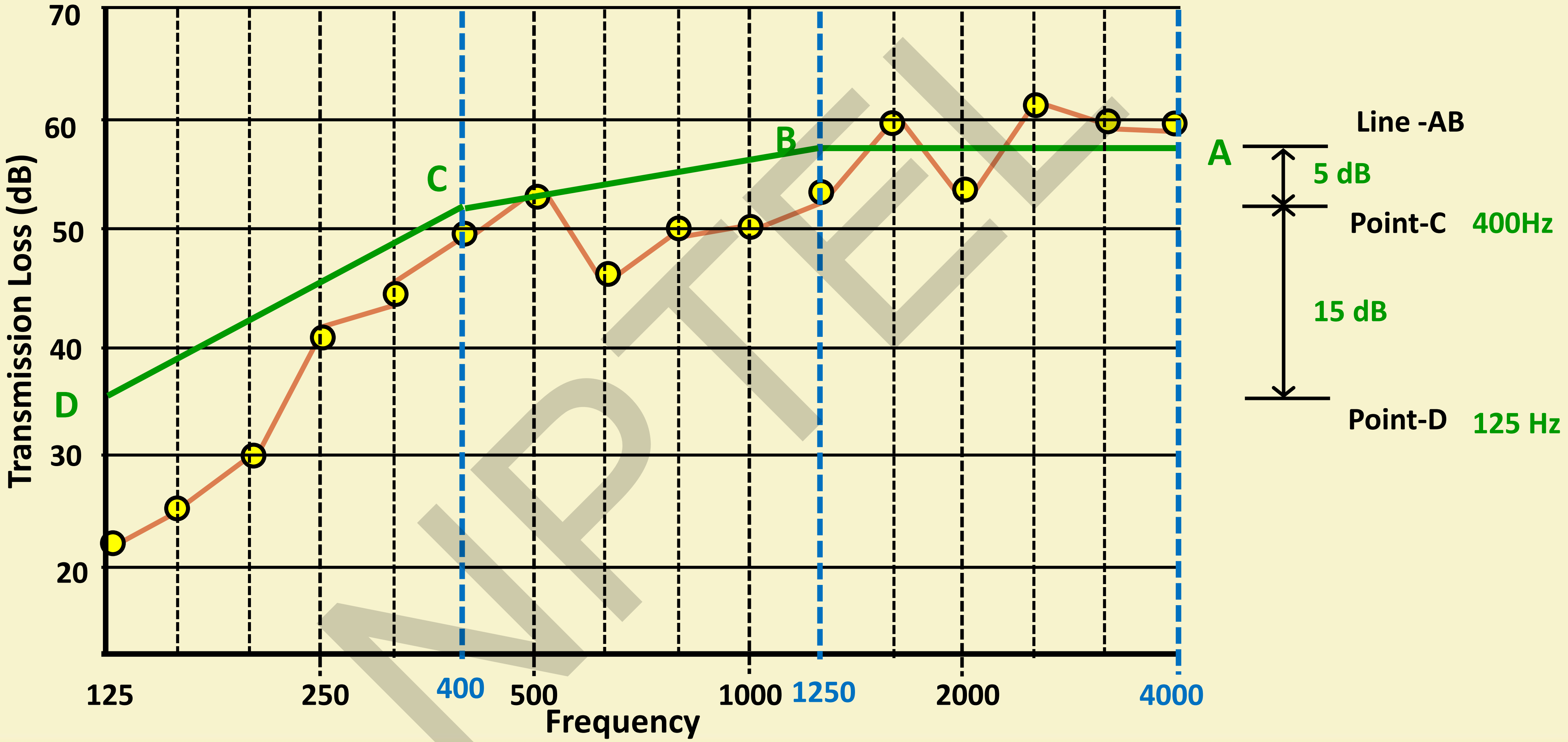
4 Overlay the STC Contour based on the averaging and gradual decreasing the TL value over frequency

4c) Plot the point 'C' over 400Hz frequency, 5dB below the AB line. Join BC. The line segment BC is inclined and having 1 dB reduction per one-third octave band frequency.

4d) Plot the point D over 125Hz frequency, 15 dB below the point C and join CD. The line segment CD is also inclined and having 3 dB reduction per one-third octave band frequency.

4e) The line ABCD is the STC contour for the first trial.

Steps to find STC



5 **Get the Single number Sound Transmission Class (STC) value of wall**

Steps to find STC

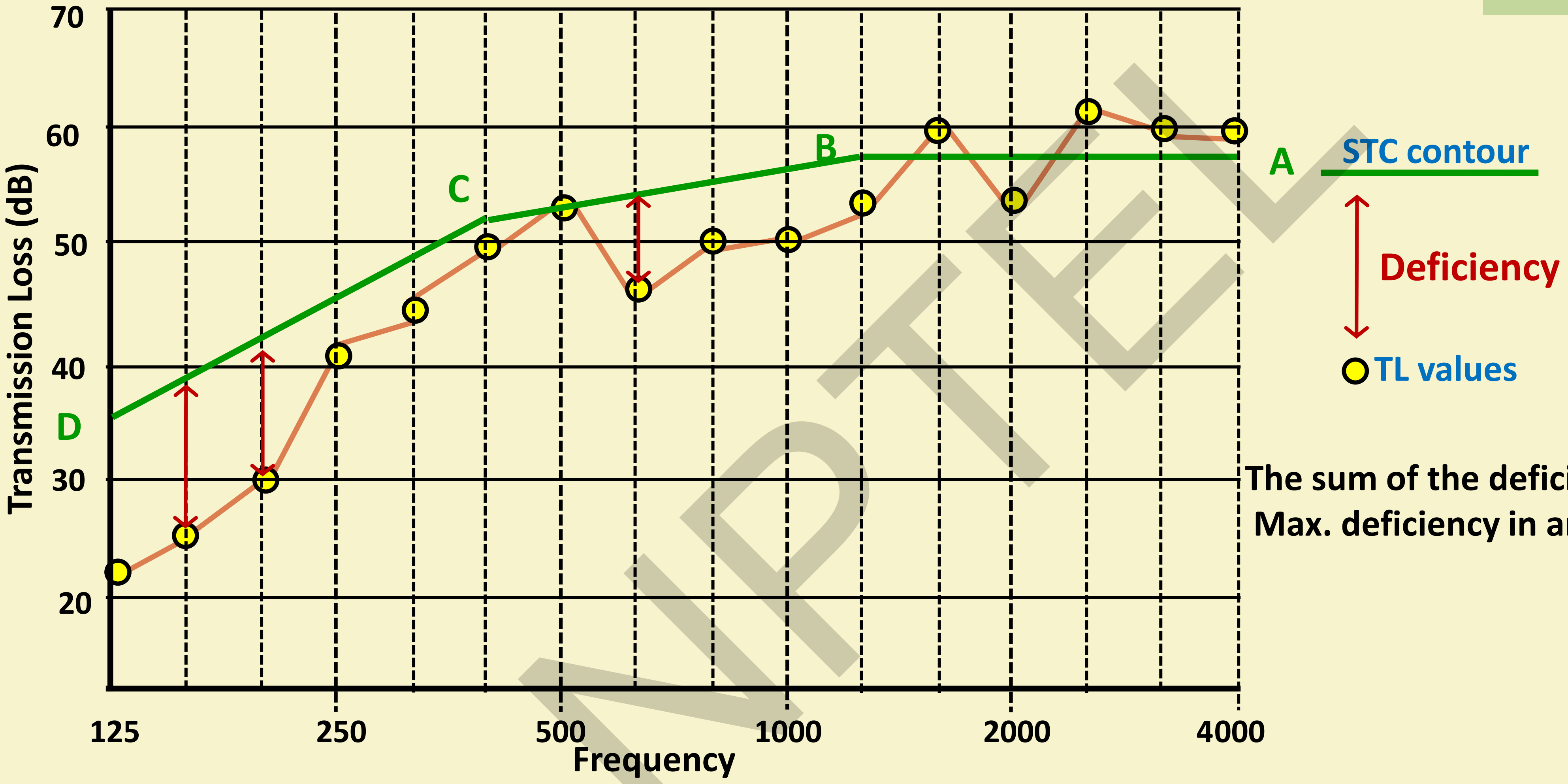
5a) Identify frequencies having the magnitude of the deficiency. the magnitude of the deficiency is the difference between the STC contour and TL values for that band frequency. No credit is given for TL data above the contour.

5b) Sum the deficiencies and identify the maximum deficiency. Check the following two criteria:

i. The sum of the deficiencies is less than or equal to 32 dB, and

ii. The maximum deficiency in any one band does not exceed 8 dB.

Steps to find STC



The sum of the deficiencies =<32 dB

Max. deficiency in any one band =<8 dB

5 Get the Single number Sound Transmission Class (STC) value of wall

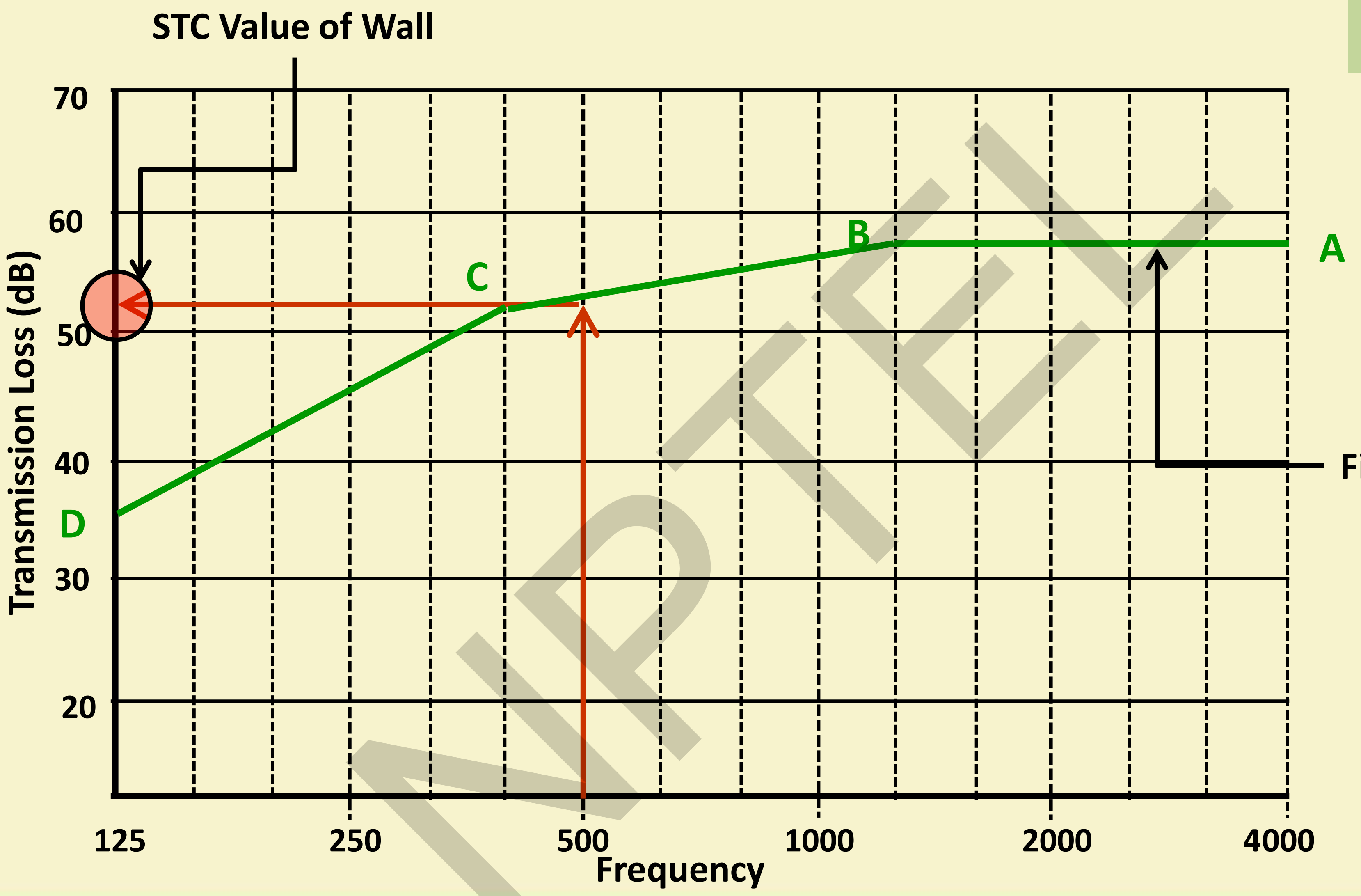
5c) There may be two following situations:

i. If the criteria satisfy, Increase the trial STC contour by 1-dB and carry out the steps 5a & 5b

ii. If the criteria do not satisfy, decrease the trial STC contour by 1-dB and carry out the steps 5a & 5b

5d) Stop at final STC contour. The resulting TL value at 500 Hz on the final STC contour represents the STC value of the partition wall.

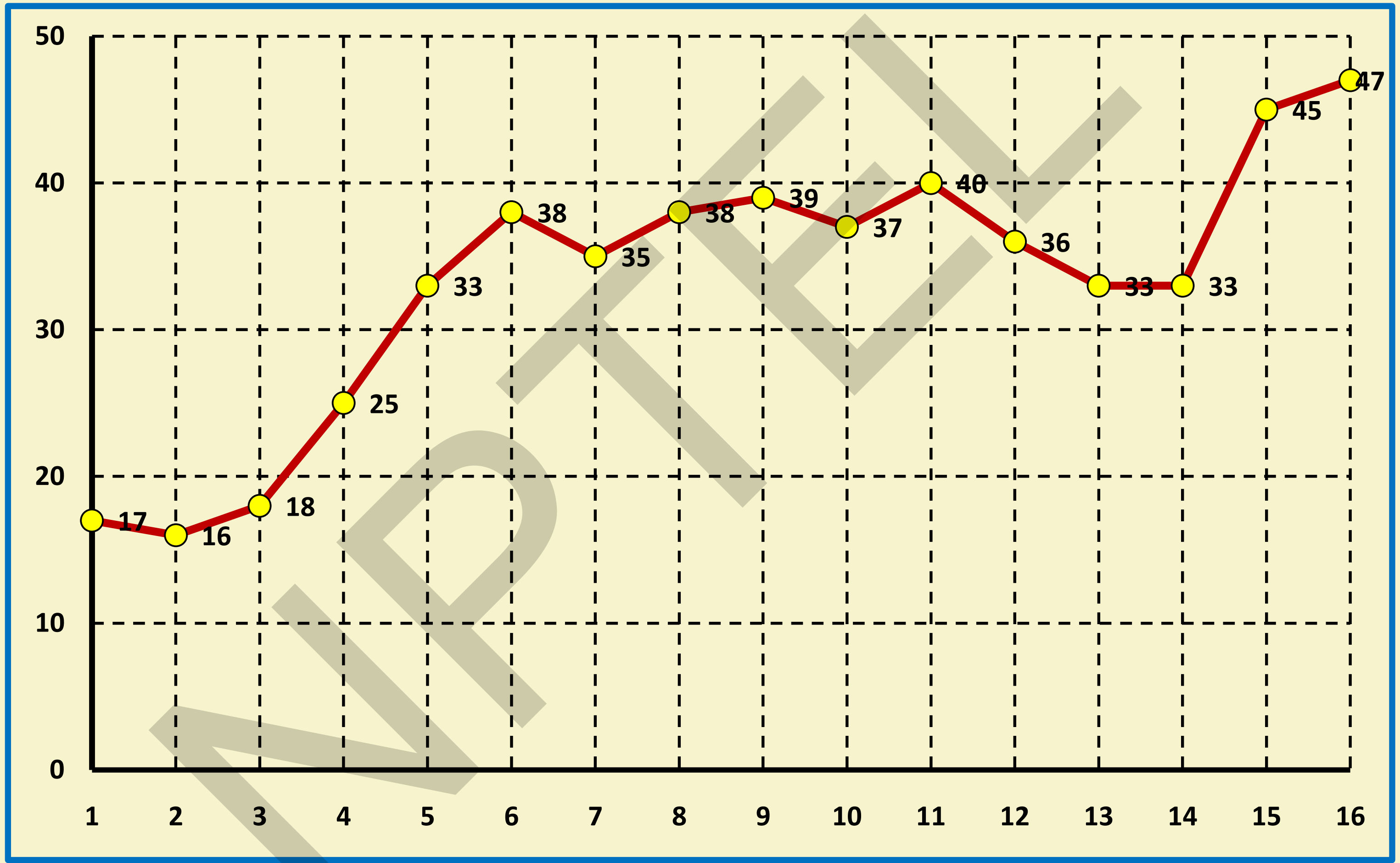
Steps to find STC



Example to find STC

f	TL (Actual)
125	17
160	16
200	18
250	25
315	33
400	38
500	35
630	38
800	39
1000	37
1250	40
1600	36
2000	33
2500	33
3150	45
4000	47

Following Transmission Loss (TL) values are obtained from a laboratory test of certain partition wall



Example to find STC

STC Contour for First Trial

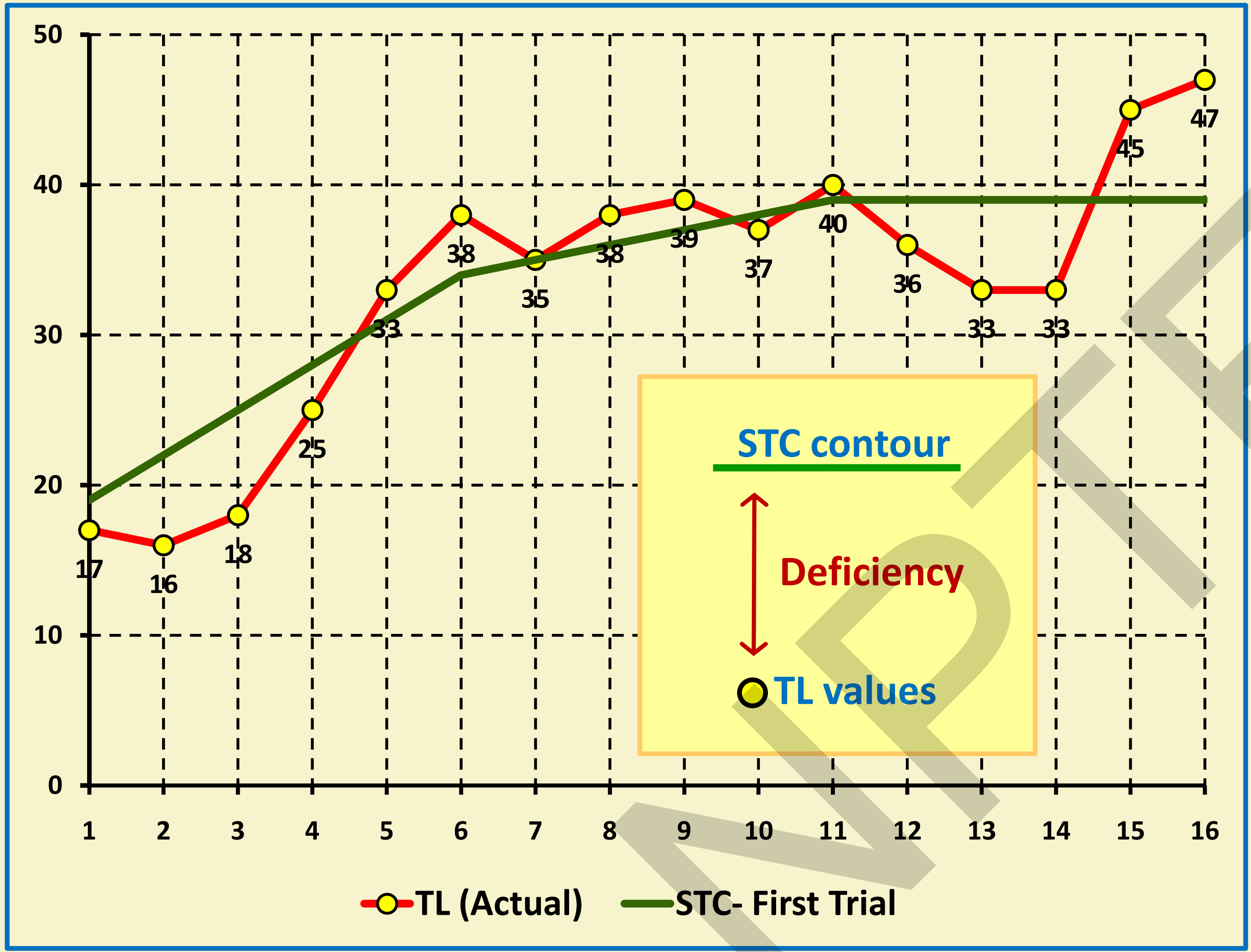
f	TL (Actual)	STC- First Trial
125	17	19
160	16	22
200	18	25
250	25	28
315	33	31
400	38	34
500	35	35
630	38	36
800	39	37
1000	37	38
1250	40	39
1600	36	39
2000	33	39
2500	33	39
3150	45	39
4000	47	39

At 125 Hz, the TL value decrease by 15 dB from the earlier value i.e. 19 dB (34-15)
3-dB decrease per one-third octave

At 400 Hz, the TL value decrease by 5 dB from the average value i.e. 34 dB (39-5)
1-dB decrease per one-third octave

Average of Last Six TL value is 39 dB

Example to find STC



First Trial STC Contour and TL Plot

f	TL (Actual)	STC- First Trial	Difference(First Trial)
125	17	19	**-2**
160	16	22	**-6**
200	18	25	**-7**
250	25	28	**-3**
315	33	31	2
400	38	34	4
500	35	35	0
630	38	36	2
800	39	37	2
1000	37	38	**-1**
1250	40	39	1
1600	36	39	**-3**
2000	33	39	**-6**
2500	33	39	**-6**
3150	45	39	6
4000	47	39	8

Example to find STC

f	TL (Actual)	STC- First Trial	Difference (First Trial)
125	17	19	**-2**
160	16	22	**-6**
200	18	25	**-7**
250	25	28	**-3**
315	33	31	2
400	38	34	4
500	35	35	0
630	38	36	2
800	39	37	2
1000	37	38	**-1**
1250	40	39	1
1600	36	39	**-3**
2000	33	39	**-6**
2500	33	39	**-6**
3150	45	39	6
4000	47	39	8

Check the following two criteria

The sum of the deficiencies is less than or equal to 32 dB

The maximum deficiency in any one band does not exceed 8 dB

First Trial:

Sum of the deficiencies: -34 dB

Maximum deficiency : -7 dB

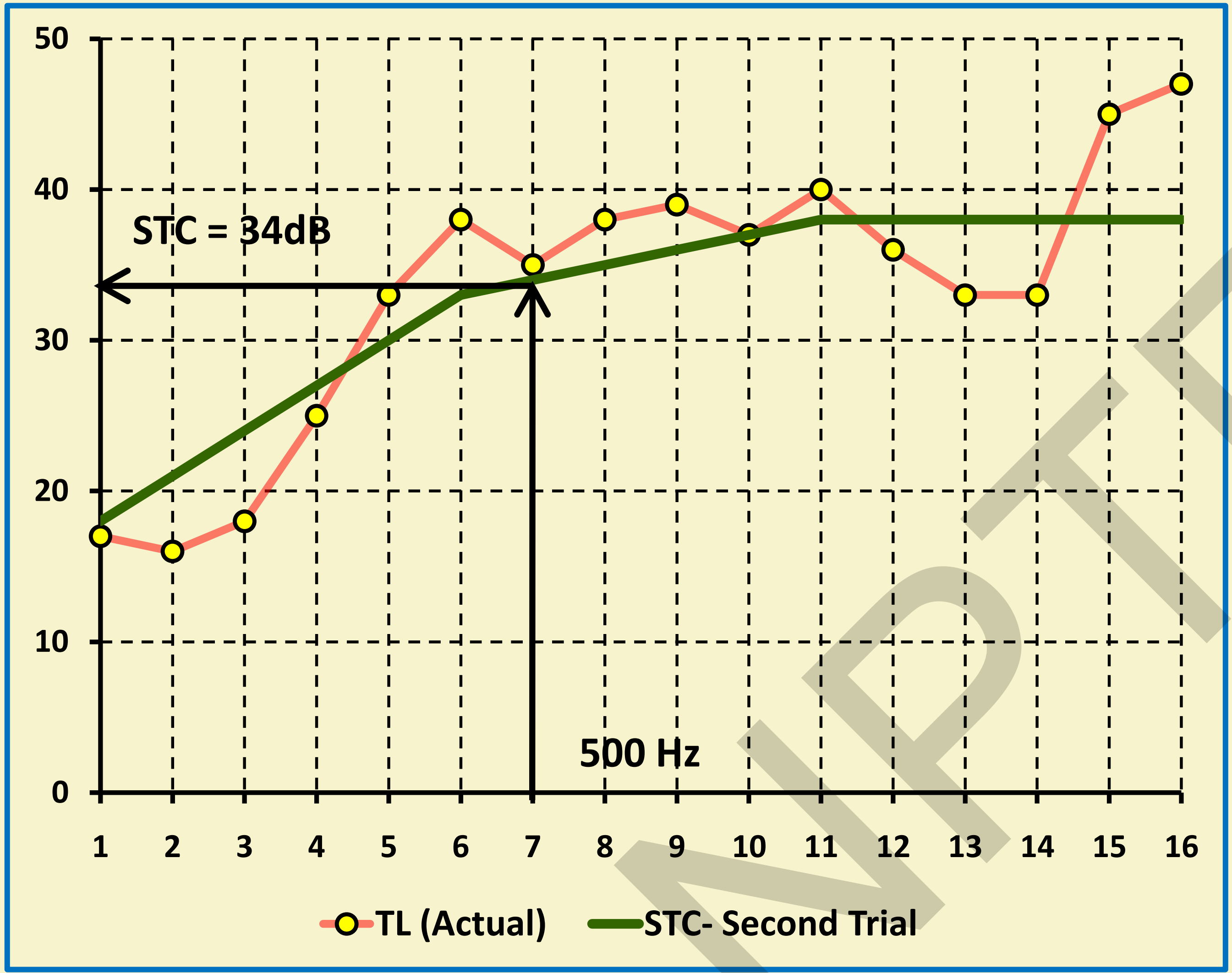
So, Next Trial is required with decrease the STC Contour by 1-dB

Example to find STC

f	TL (Actual)	STC First Trial	Difference (First Trial)	STC Second Trial	Difference (Second Trial)
125	17	19	-2	**18**	**-1**
160	16	22	-6	**21**	**-5**
200	18	25	-7	**24**	**-6**
250	25	28	-3	**27**	**-2**
315	33	31	2	**30**	3
400	38	34	4	**33**	5
500	35	35	0	**34**	1
630	38	36	2	**35**	3
800	39	37	2	**36**	3
1000	37	38	-1	**37**	0
1250	40	39	1	**38**	2
1600	36	39	-3	**38**	**-2**
2000	33	39	-6	**38**	**-5**
2500	33	39	-6	**38**	**-5**
3150	45	39	6	**38**	7
4000	47	39	8	**38**	9
Total Deficiency			**-34**		**-26**
Maximum Deficiency			**-7**		**-6**

Second Trial STC Contour will be the set for the partition wall

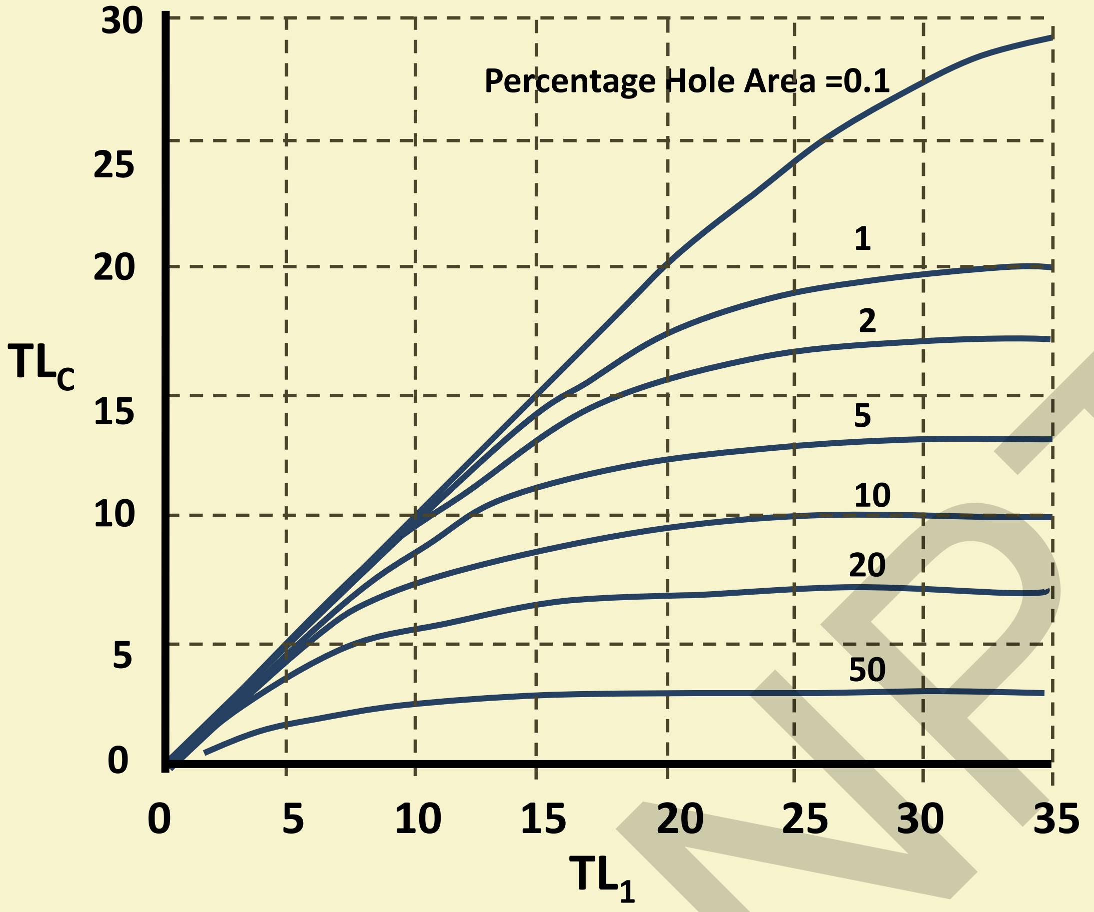
Both the criteria satisfies

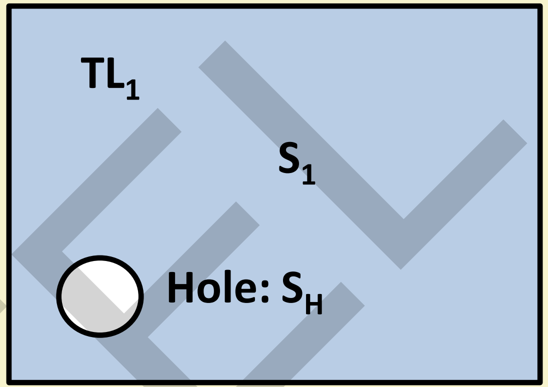


Example to find STC

Sound Transmission Class of the Partition Wall is 34 dB

Hole in the Wall





Transmission Loss of Partition wall without hole: TL_1

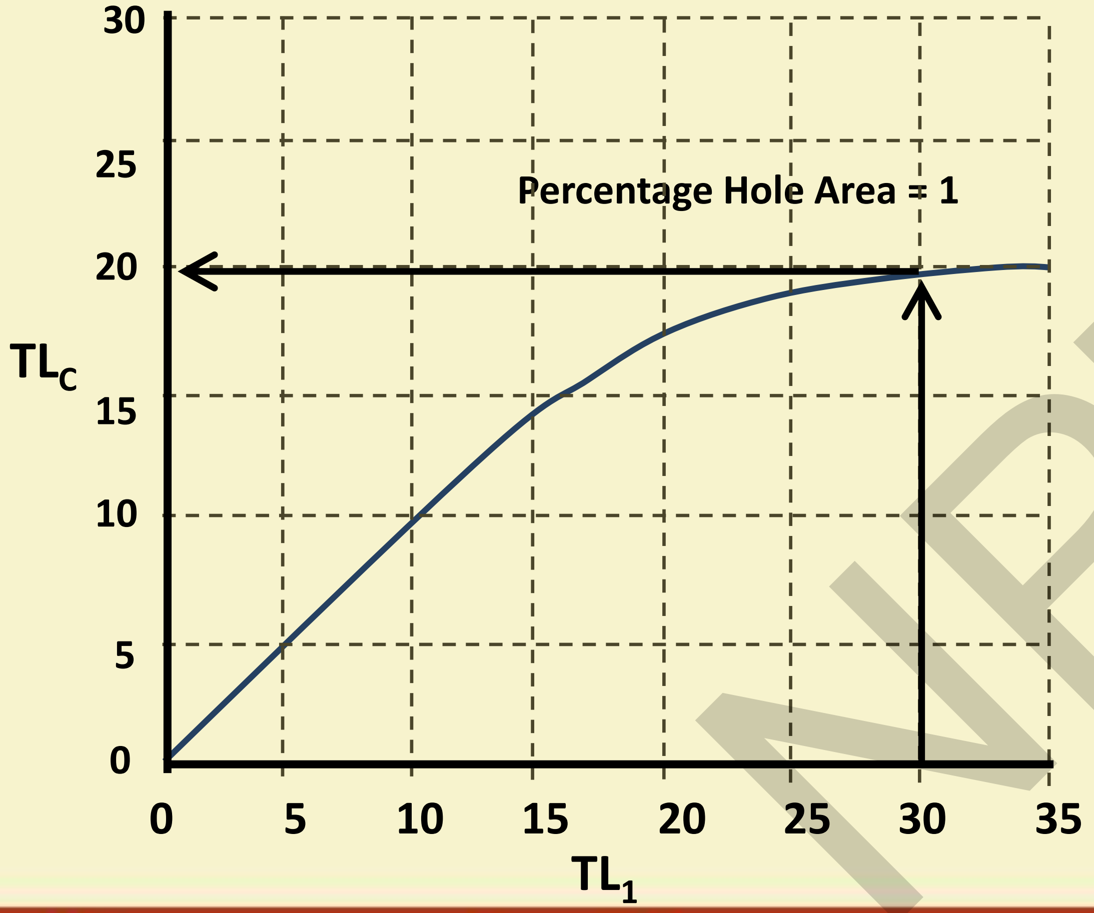
Total Area of Wall: S_1 Area of hole: S_H

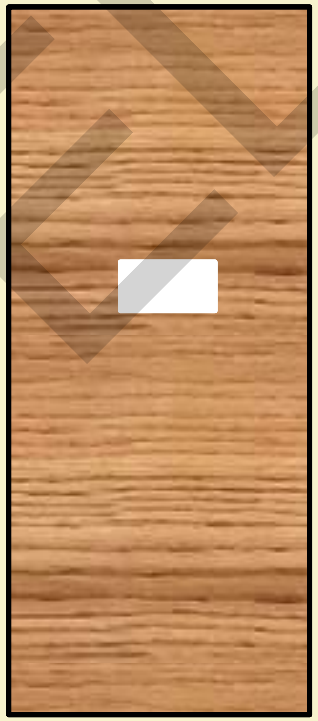
Percentage Hole area: $(S_H / S_1)X100$

Combine Transmission Loss: TL_C

Hole in the Wall

Size of the door = 2m X 1m
Transmission Loss of the Door = 30dB
Size of the Hole = 20cm X 10 cm





Total Area of Wall: $S_1 = 2\ m^2$

Transmission Loss of Partition wall without hole: TL_1 hole = 30dB

Area of hole: S_H Area = 200 cm^2

Percentage Hole area: $(S_H / S_1)X100 = (200 / 20000)X100 = 1\%$

Combine Transmission Loss: TL_C =20dB

- The surface mass of the partition wall has to be established as reasonable maximum.
- Double leaf partition wall is better than the single leave.
- The air gap between two leaves may be filled with sound absorptive blanket to further improve the transmission loss.

- The proper stiffener arrangement within the partition wall should be ensure.
- Fixing the partition wall with wall, ceiling and flooring should be proper to minimize coincident effect.
- Noise leaks within and perimeter edges of the wall should be carefully avoided.

Home Work

What is the significance of STC value?

If the average TL value of last six one third frequency of a partition wall is 35, what could be its STC value, if all criteria is full filled

Bibliography

1. **Acoustics in the Built Environment**, Duncan Templeton, Architectural Press; 2nd Edition
2. **Architectural Acoustics Illustrated,** Michael Ermann, wiley, 2015
3. **Architectural Acoustics,** Marshall Long, El Sevier, Academic Press,
4. **Mechanical and Electrical Equipment for Buildings**, Walter T. Grondzik, Alison G. Kwok, Benjamin Stein and John S. Reynolds, John Wiley & Sons, Inc. (11th Edition) [Part-IV]

End of Lecture 33: Air Borne Sound Transmission -III

IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Architectural Acoustics

Lecture 34: Structure Borne Sound Transmission-I

Dr. Shankha Pratim Bhattacharya

Department of Architecture & Regional Planning

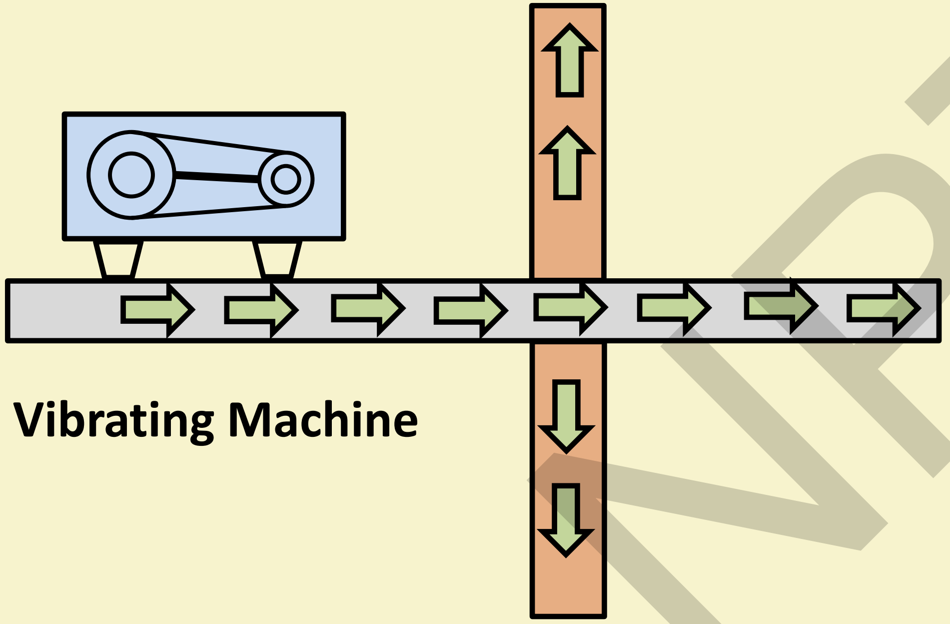
Learning Objective

Develop the fundamentals of Structure borne sound transmission

Explain the parameters that control the structure borne sound transmission

Definition

Structure-borne sound results from any vibration source or from an impact. It is transmitted through solid structural parts of the building such as floor, beam, column, wall, pipe, duct.



Sources of Structure borne Sound in Building

Source

Pumps: Reciprocating and Centrifugal

Compressors: AHU, Cooling Tower

Electrical: Motor, Generator, Transformer, UPS

Workshops: Shop Floors Machines

Moving Machines: Elevator, Gantry Grader

Structural Effect

- Differential Settlement/ Total foundation failure
- Propagation of existing cracks / Hairline cracks will be wider
- Fatigue load will creates serviceability problems

Acoustical Effect

- Annoying noise to occupants
- Noise may interfere with precision instruments
- Vibration noise induces High blood pressure, headache, gastric problems, deafness

Vibration Isolation

Vibration Isolation

Active Vibration Isolation

The modification is made in the vibrating machines to control the vibration amplitude

Passive Vibration Isolation

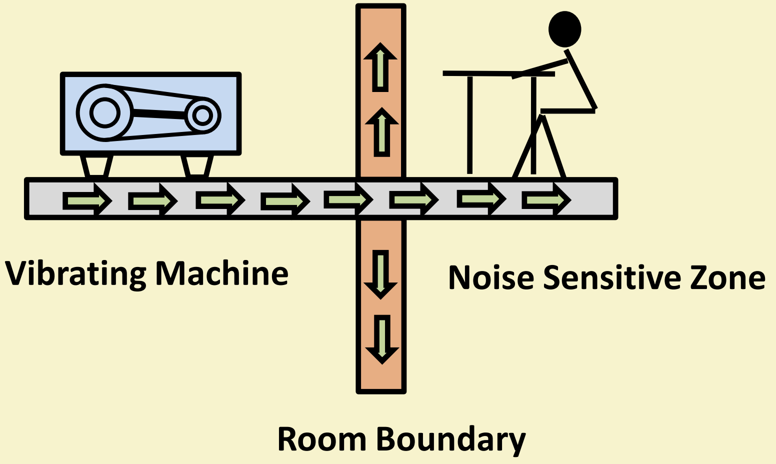
The vibration is isolated from the vibrating machines and control the amplitude during propagation

Passive Vibration Isolation

A vibration problem can be read as **Source – Path – Receiver model**

Source: A mechanical vibration or fluid flow disturbance, generated internally by the machine

Path: The structural or airborne path by which the disturbance is transmitted to the receiver



Receiver: The responding system of the noise, may be termed as noise sensitive space

Vibration Solutions - Source

- Relocate the machine on as rigid a foundation and as far as possible from potential receivers
- Replace machine with a higher quality or different type of machine that is quieter
- Change the operating speed to avoid coinciding with structural resonances
- Use active vibration control and absorber

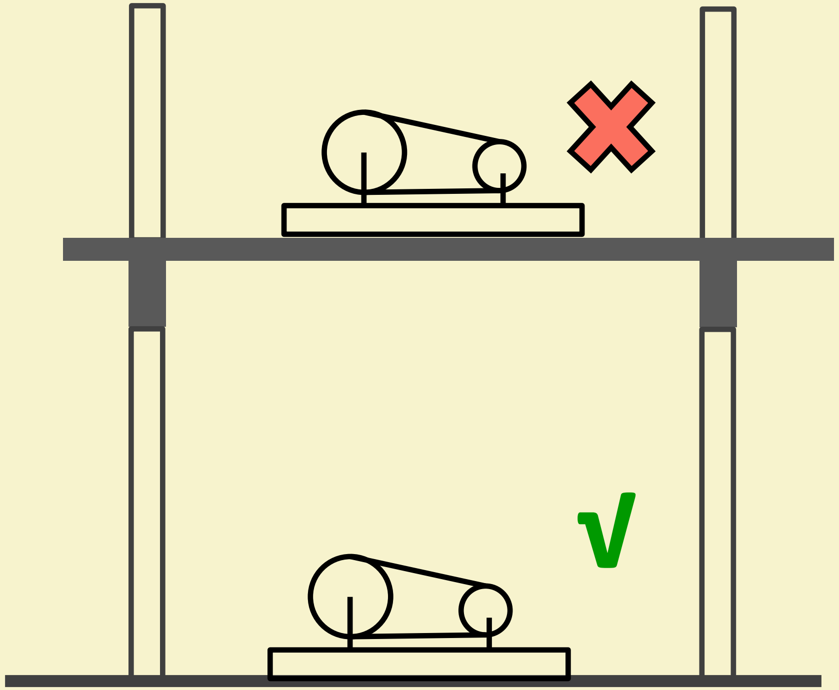
Vibration Solutions - Path

- Minimizing the vibration transmission by installation of isolator springs and/or inertia blocks.
- Structural Discontinuity

Vibration Solutions – Receiver

- Adding structural damping in the receiving zone to minimise the effect of vibration
- Isolate the receiver from the vibration propagation path

Position and Placement



Any vibrating machine should be placed in the Ground Floor

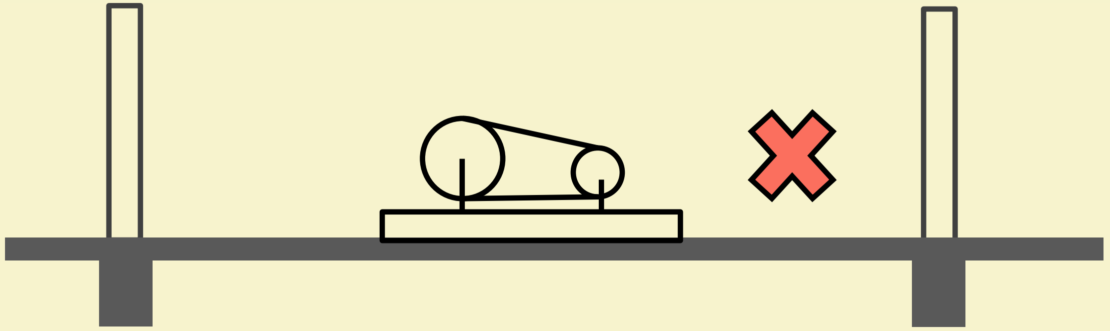
The transmission of the structure borne sound with be high, as overall support and stiffness is missing

Adjacent rooms and the room just below will be effected

The continuous ground support will decrease the transmission of the structure borne sound

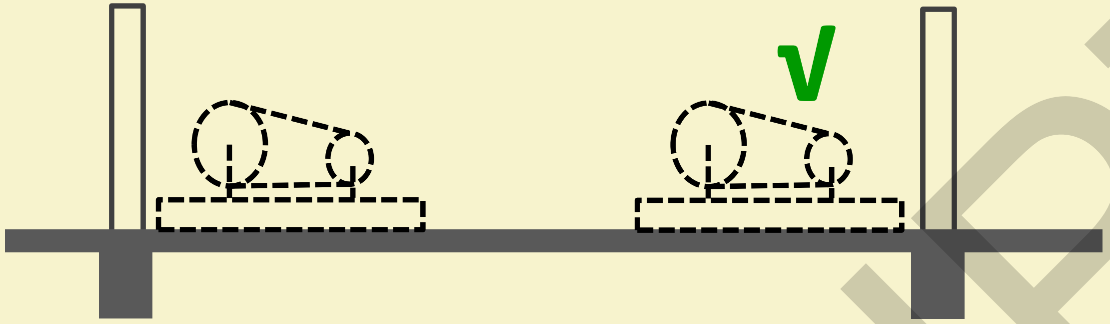
Adjacent rooms will be effected

Position and Placement



Any vibrating machine should be placed near the floor beams and columns. Not at the mid slab portion.

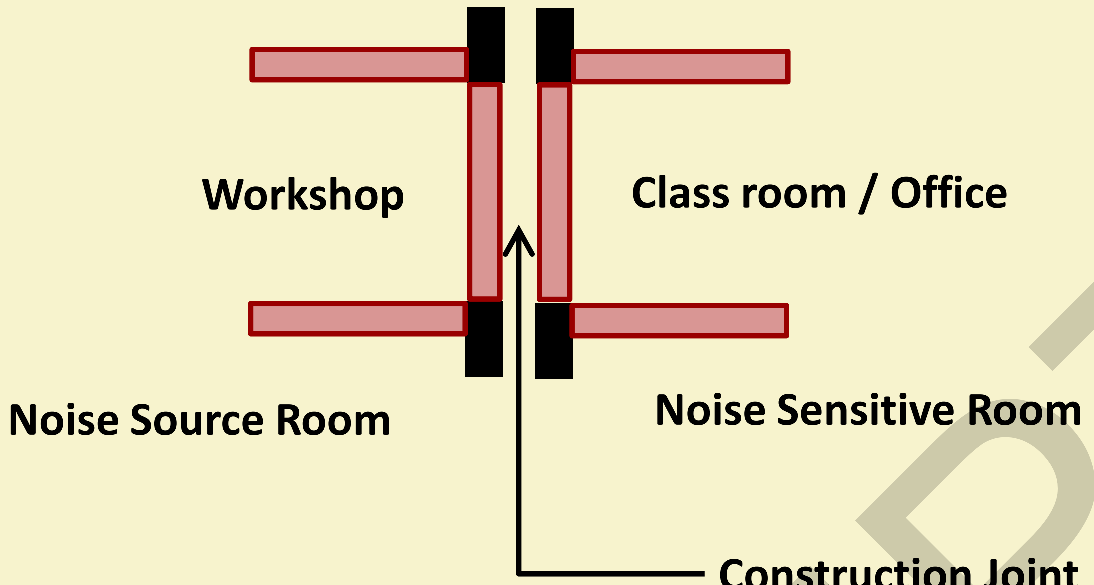
Machine at mid slab produces high structure borne sound as the stiffness beneath is comparatively low

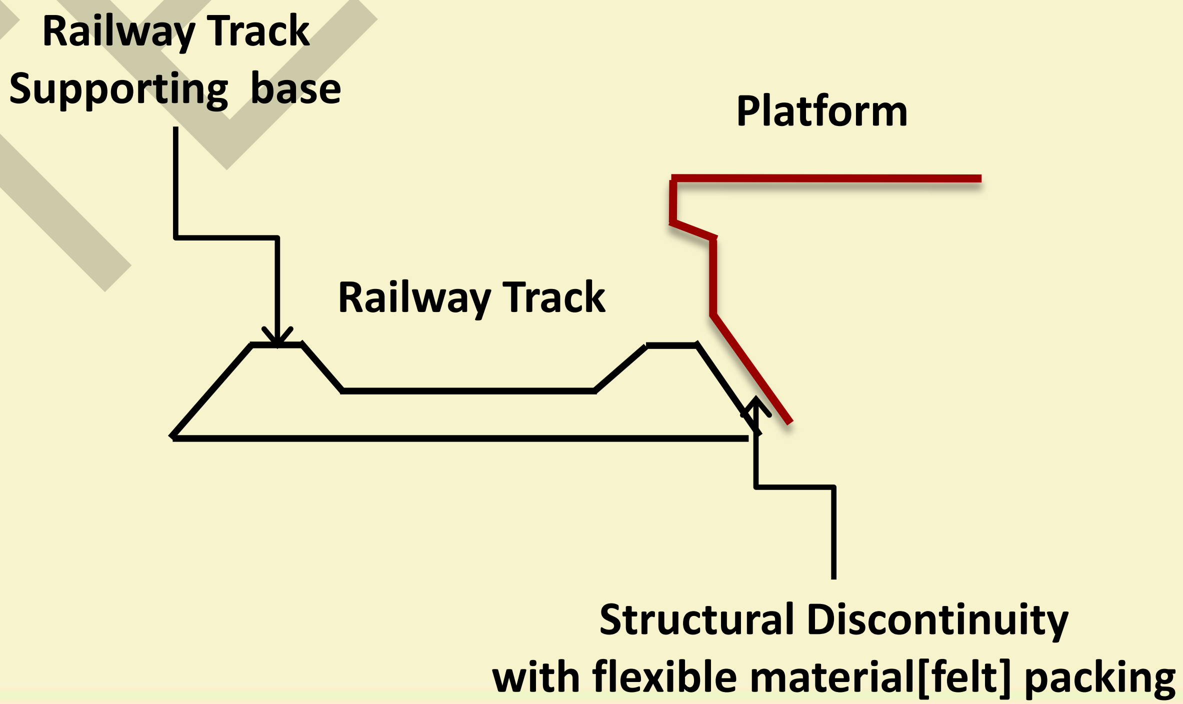


Due to presence of column and beam and high relative stiffness the machine produces low structure borne sound near end slab and support portion

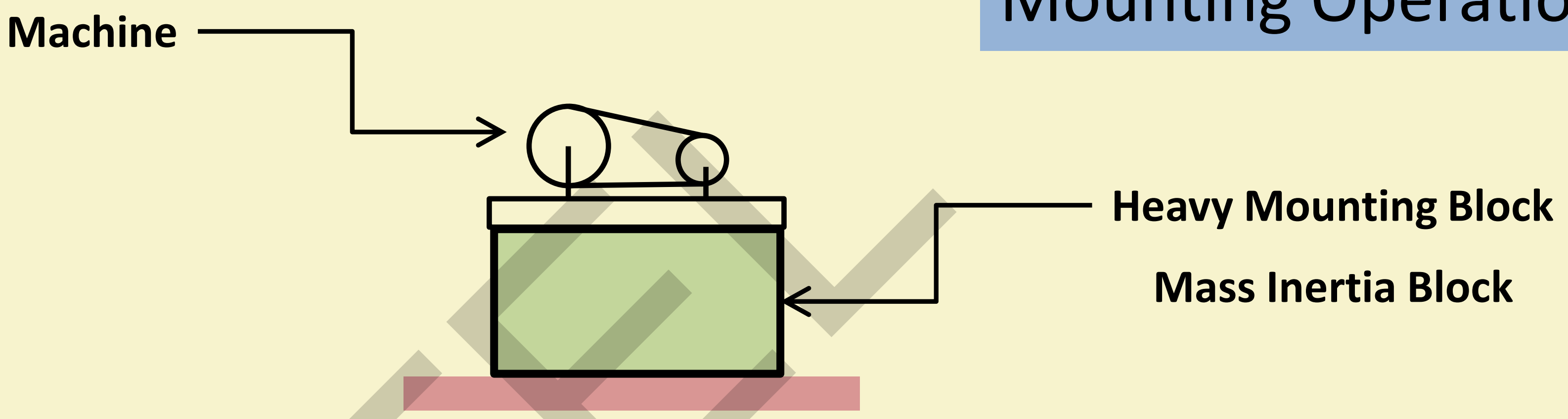
Structural Discontinuity

Structural discontinuity in the form of construction joints will stop propagation of structure borne sound

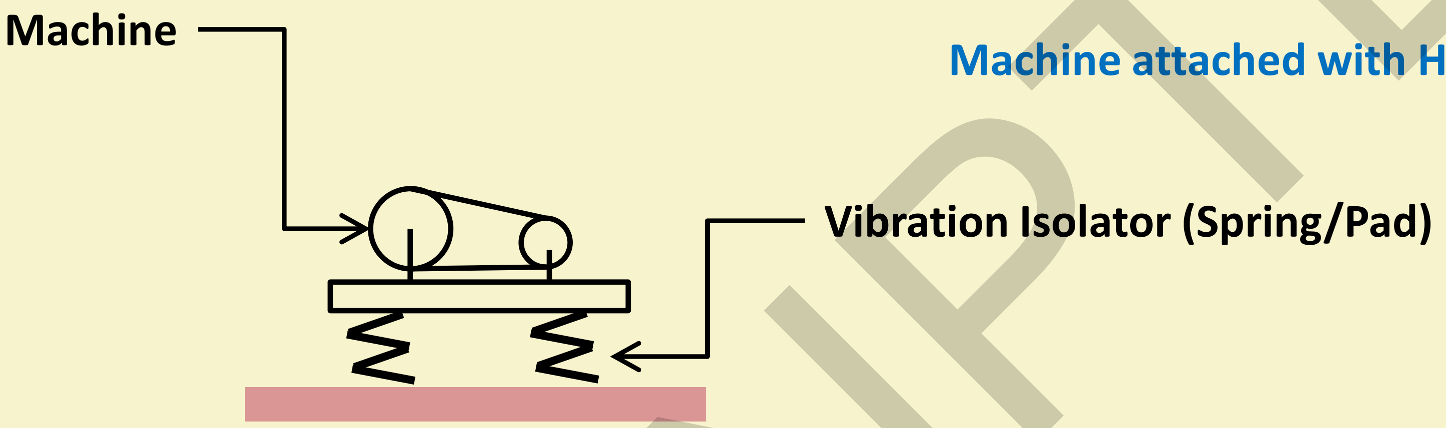




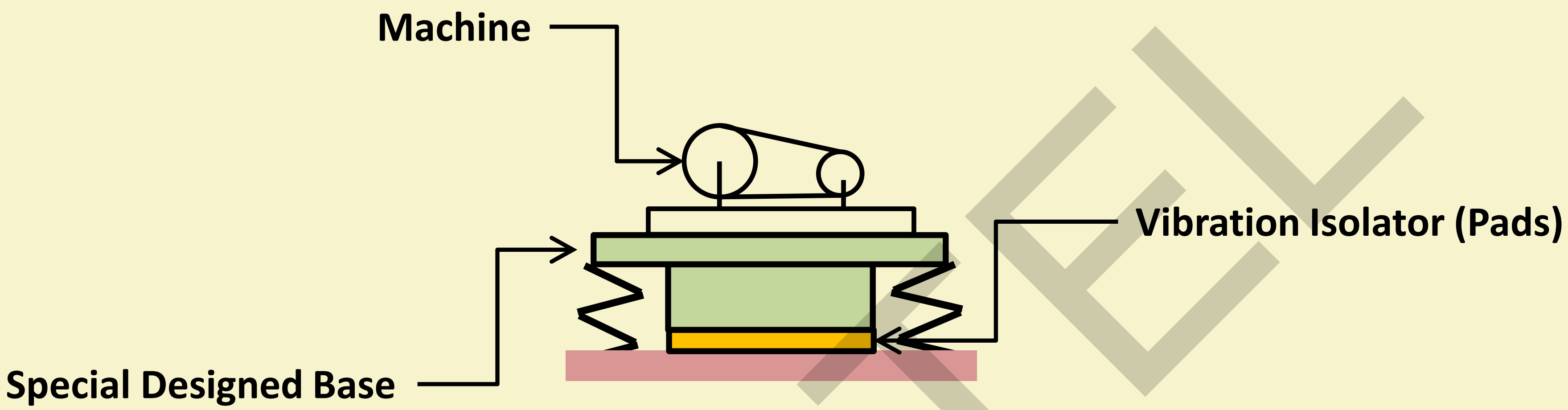
Mounting Operation



Machine attached with HEAVY MOUNTED MASS



Machine mounted directly with VIBRATION ISOLATING SYSTEM
[mechanical damper or flexible padding]



Machine attached with SPECIAL DESIGN BASE FRAME

Mounting Operation

Free undamped Vibration

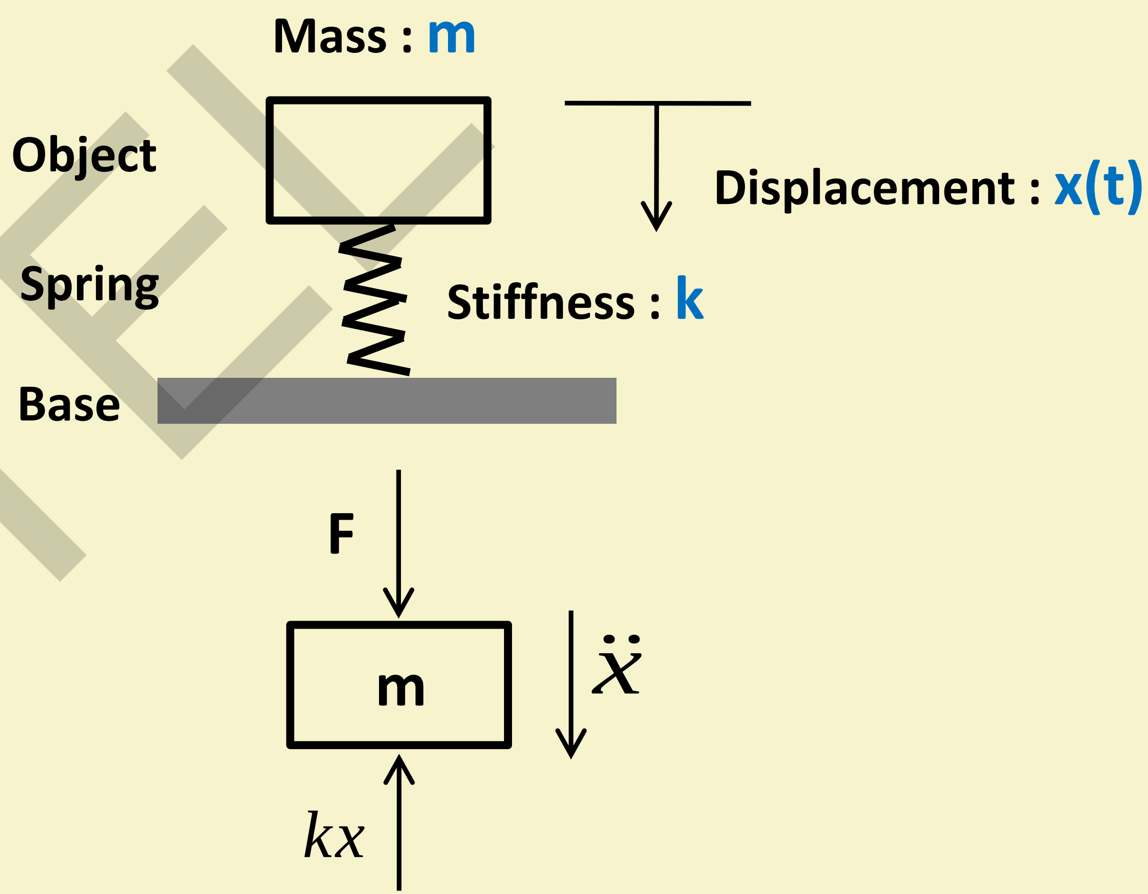
Free undamped Vibration (SDOF)

$$F - kx = m\ddot{x}$$

$$\Rightarrow m\ddot{x} + kx = 0$$

Solution of this partial differential equation is given by:

$$x(t) = Ae^{i\left(\sqrt{\frac{k}{m}}\right)t} + Be^{-i\left(\sqrt{\frac{k}{m}}\right)t}$$



Free undamped Vibration

$$x(t) = Ae^{i\left(\sqrt{\frac{k}{m}}\right)t} + Be^{-i\left(\sqrt{\frac{k}{m}}\right)t}$$

The radical term in the exponent is define as the circular natural frequency *of* vibration of the system:

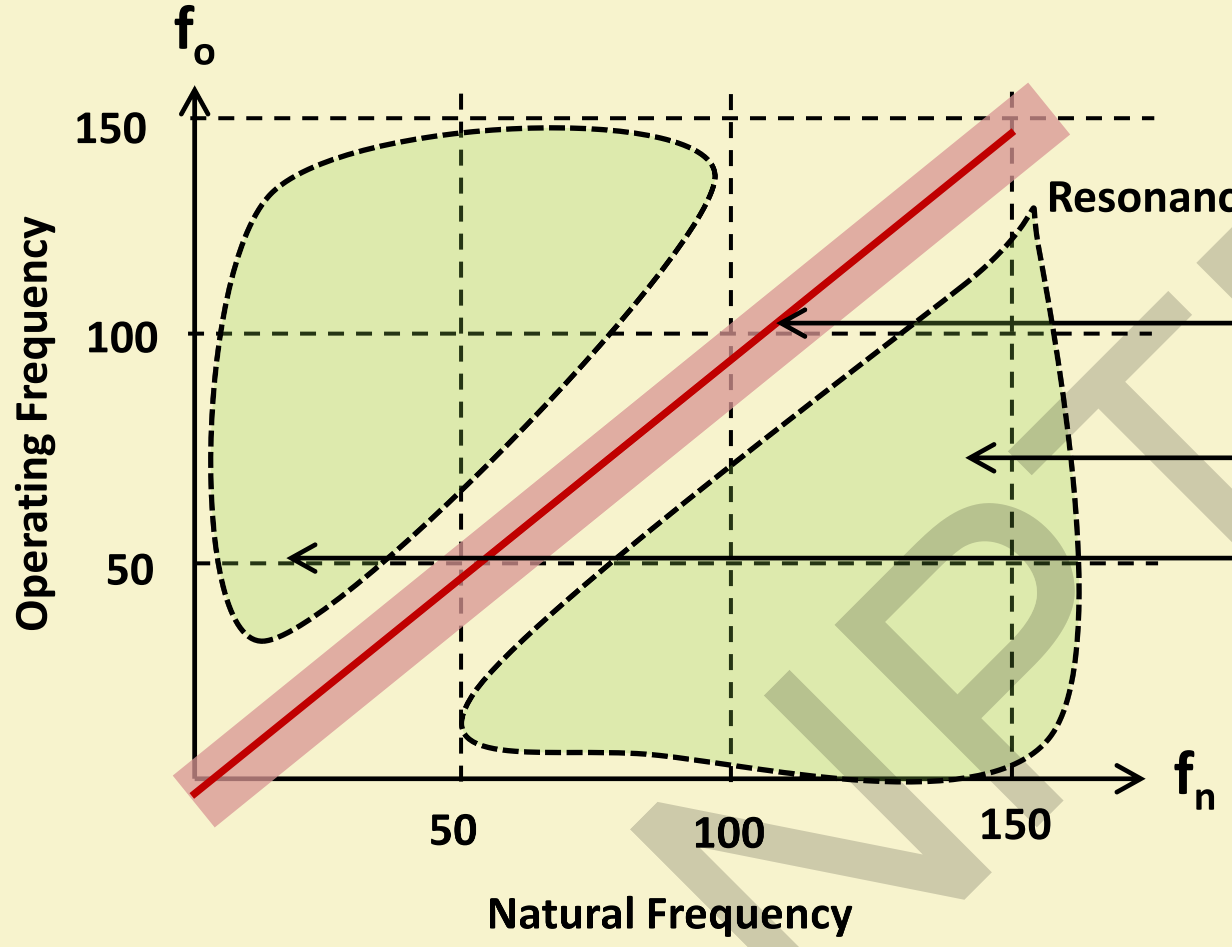
$$\omega_n = \sqrt{\frac{k}{m}}$$

The natural frequency and natural time period of the system are expressed as by:

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

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

Free undamped Vibration



Operating Frequency = Natural Frequency

Resonance ……High rate of Structure borne sound transmission

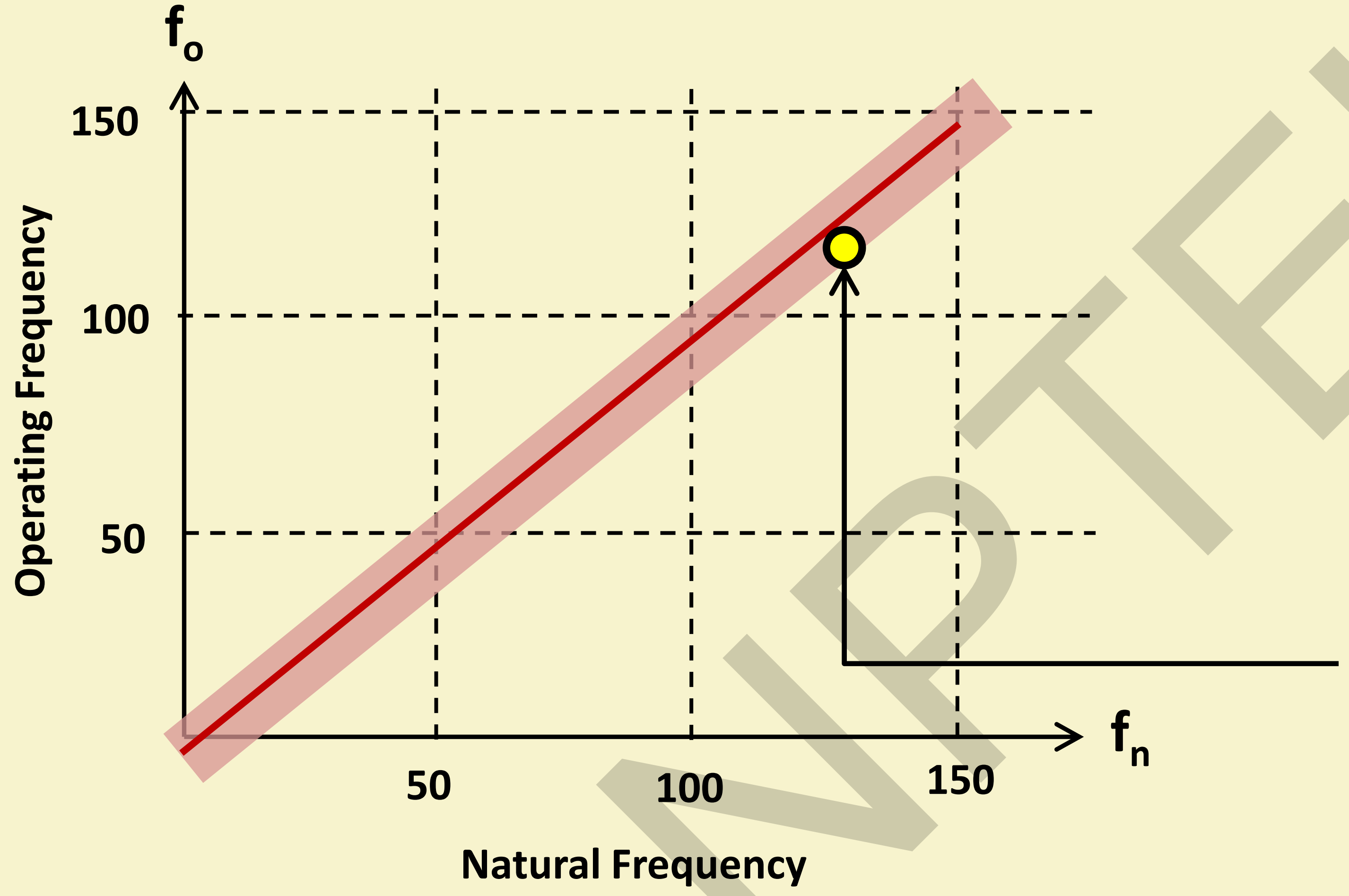
Operating Frequency >> Natural Frequency

Or

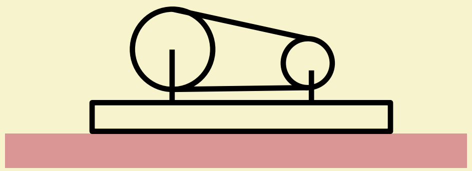
Operating Frequency << Natural Frequency

Low rate of Structure borne sound transmission

Free undamped Vibration

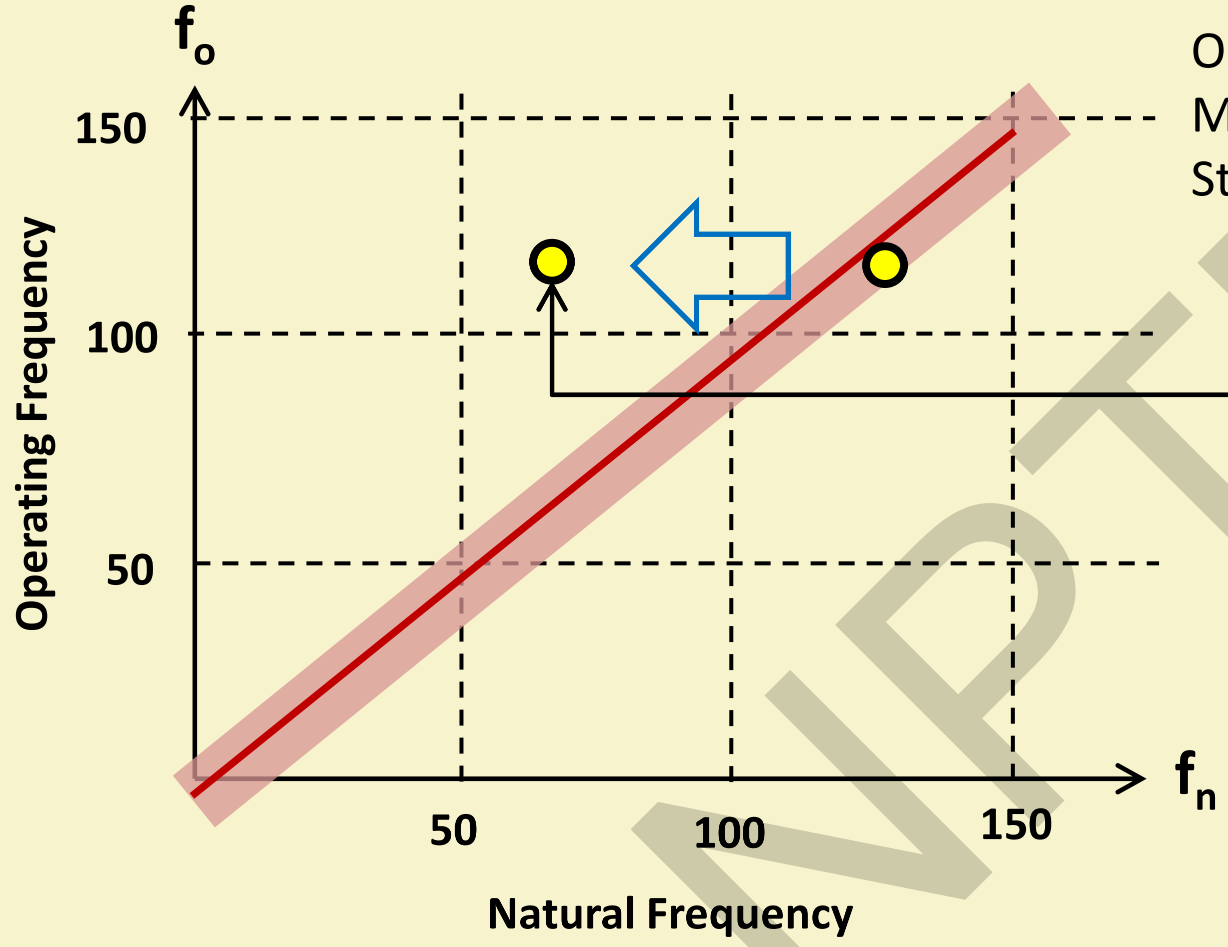


Operating Frequency: **120 Hz**
Mass of the Machine: **15kg**
Stiffness of the Machine: **10^4 kN-m**



$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{10^4 \times 10^3}{15}} = 130 \text{ Hz}$$

Free undamped Vibration

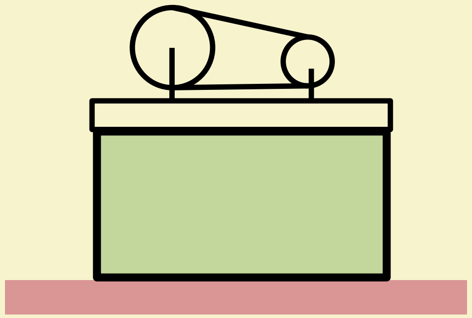


Operating Frequency: 120 Hz

Mass of the Machine + base mount block: (15+45)=60kg

Stiffness of the Machine: 10^4 kN-m

$$f_n = \frac{1}{2\pi}\sqrt{\frac{10^4 \times 10^3}{60}} = 65\,\text{Hz}$$



Free undamped Vibration

A thin metal sheet of **0.5 mm thickness** (mild steel , **density 7800 kg/m^3**) is a part of a machine and having fundamental **natural frequency of 1000 Hz**.

The expected operating frequency is also very neat to the 1000 Hz.
As both the natural and operating frequency matches, the thin sheet is **expected to have a resonance** and produce noise

It is decided to increase the mass of the thin metal sheet by application of **special pai**nt (density **1200 kg/m^3**), so that the fundamental natural frequency become **900 Hz**

Compute the thickness of the paint need to be apply to control the resonance and noise

Free undamped Vibration

Fundamental Natural Frequency is given by: $$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Relation between Natural Frequency and Mass: $$\frac{f_1}{f_2} = \sqrt{\frac{m_2}{m_1}}$$

Mass of per sq.mt of thin sheet is: $$\mathrm{m}_1 = \left(1\times1\times\frac{0.5}{1000}\right)\times7800 = 3.9\,\mathrm{kg}$$

The modified Mass of the sheet: $$\sqrt{\frac{m_2}{m_1}} = \frac{1000}{900} = 1.11 \qquad \mathrm{m}_2 = (1.11)^2\times3.9 = 4.8\,\mathrm{kg}$$

Mass to be increase by painting: $\Delta m = (m_2 - m_1) = (3.9 - 4.8) = 0.9\,kg$

Let the thickness of the paint to be applied is 't'

Then, $\Delta m = \left(1 \times 1 \times \frac{t}{1000}\right) \times 1200 = 0.9\,kg$

Solving, $t = 0.75\,mm$

Home Work

Outline the types of passive vibration isolation techniques

If the stiffness of a machine is reduces to half and mass gets doubled. What will be the change of its natural frequency?

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1. **Acoustics in the Built Environment**, Duncan Templeton, Architectural Press; 2^{nd} Edition

2. **Architectural Acoustics Illustrated,** Michael Ermann, wiley, 2015

3. **Architectural Acoustics,** Marshall Long, El Sevier, Academic Press,

4. **Mechanical and Electrical Equipment for Buildings**, Walter T. Grondzik, Alison G. Kwok, Benjamin Stein and John S. Reynolds, John Wiley & Sons, Inc. (11^{th} Edition) [Part-IV]

End of Lecture 34: Structure Borne Sound Transmission -I

Architectural Acoustics

Lecture 35: Structure Borne Sound Transmission-II

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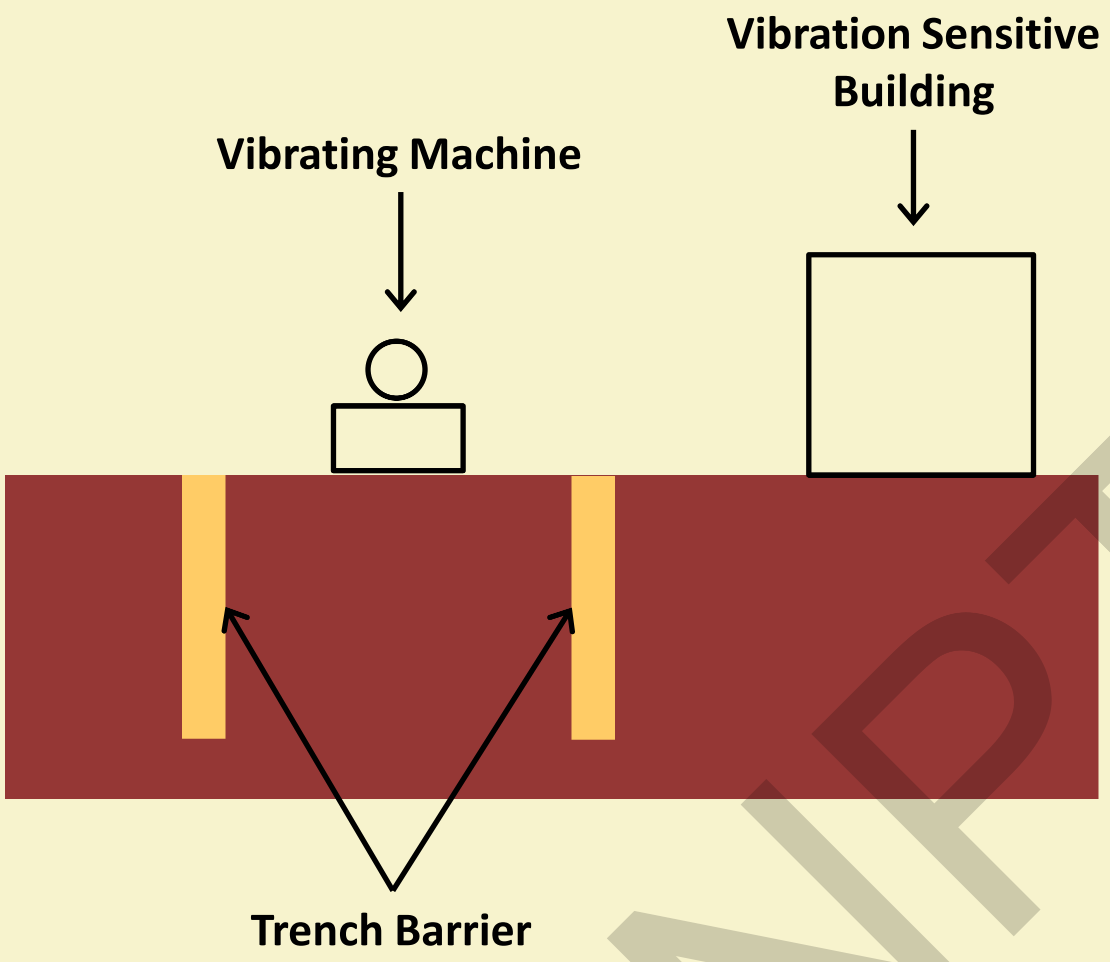
Department of Architecture & Regional Planning

Learning Objective

Relate the mass – stiffness – damping regarding the vibration transmission

Discuss the ‘Impact Insulation’

Trench Barrier



Trench Barrier

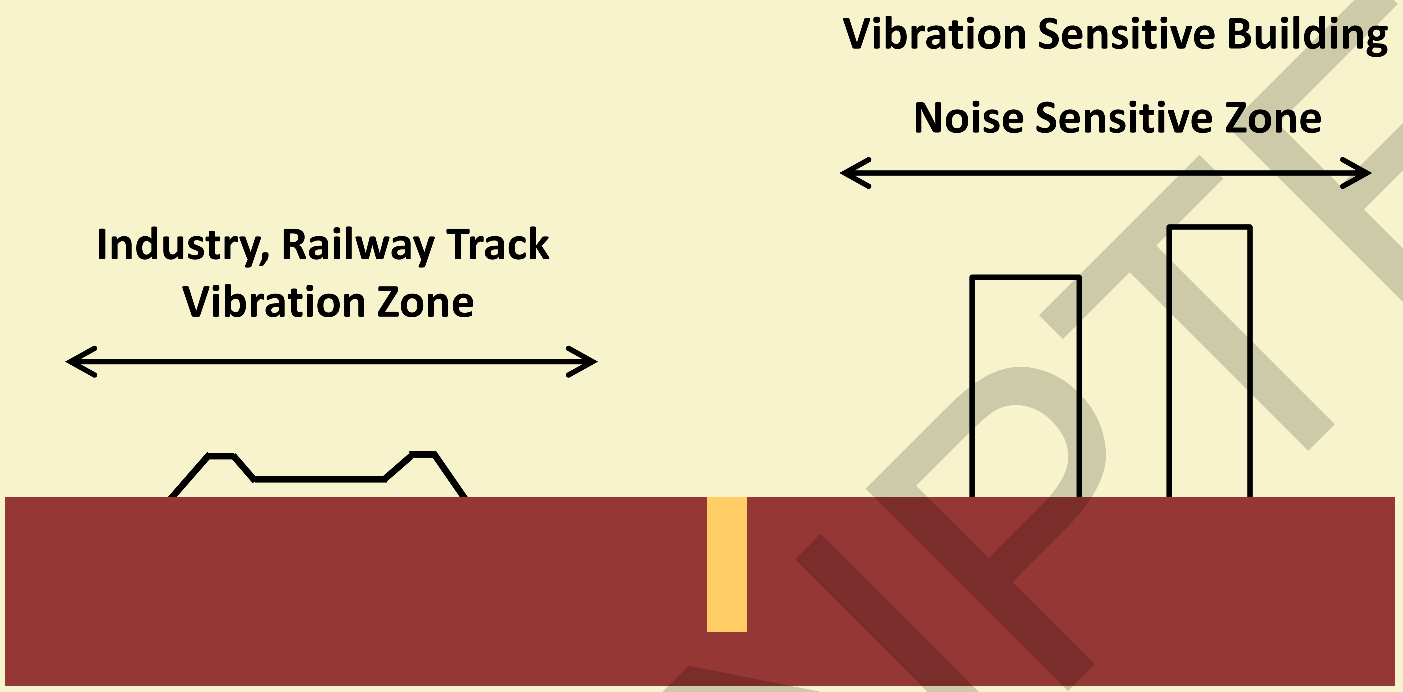
Fine / Medium Sand

Depth: 1.0 – 2.5m Width: 0.5 times Depth

Felt Layer

Depth: 1.0 – 1.5m Width: 0.3m

Trench Barrier



Trench Barrier

Wooden Barrier (3cm Thick)

Or

Metallic Barrier (0.5-1.5 cm Thick)

Free damped Vibration

Free damped Vibration (SDOF)

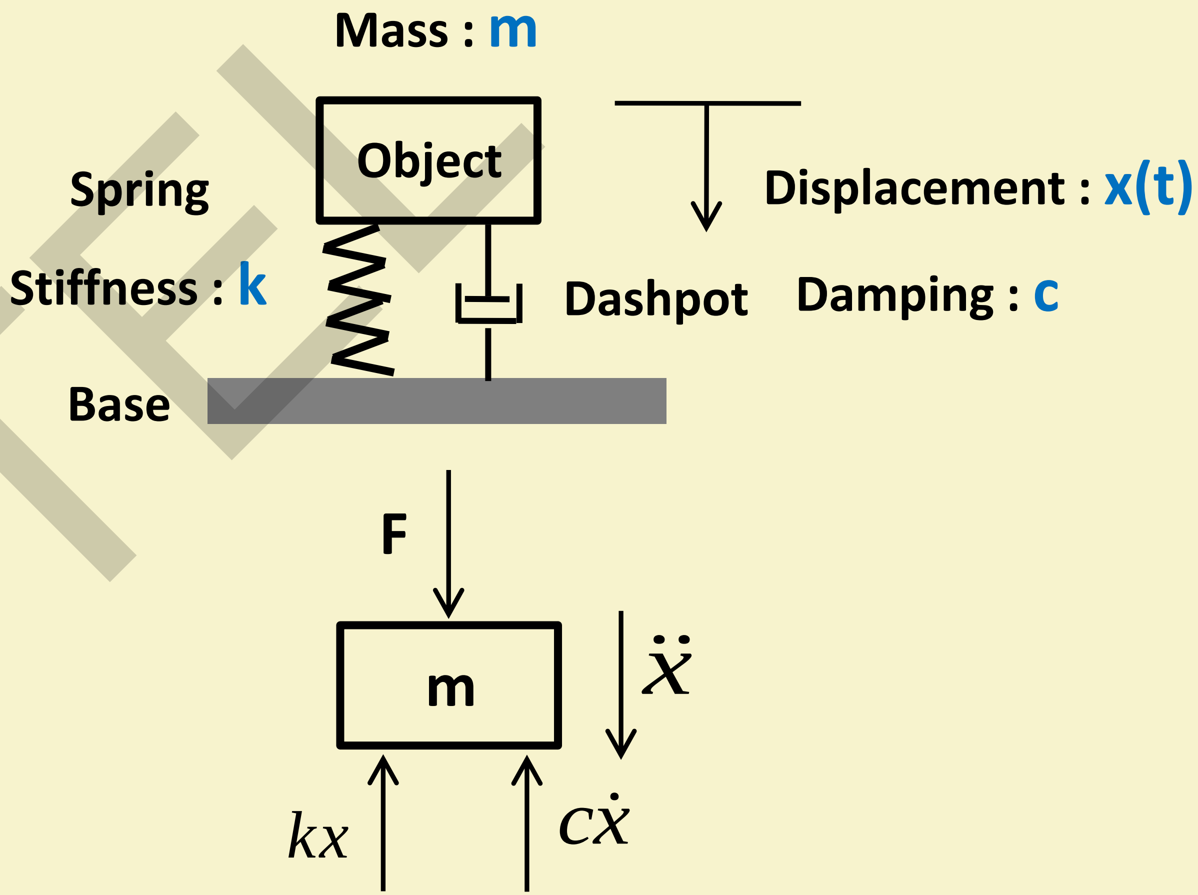
$$F - kx - c\dot{x} = m\ddot{x}$$

$$\Rightarrow \quad m\ddot{x} + kx + c\dot{x} = 0$$

Solution of this partial differential equation is given by:

$$x(t) = Ae^{r_1 t} + Be^{r_2 t}$$

Where, $$r = -\frac{c}{2m} \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{k}{m}}$$



$$x(t) = Ae^{r_1 t} + Be^{r_2 t} \qquad r = -\frac{c}{2m} \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{k}{m}}$$

The critical value of damping is define such that the term inside the radical equals 0:

$$c_{cri} = 2\sqrt{km}$$

The fraction of actual damping and critical damping is called Damping Factor

$$\xi = \frac{c}{c_{cri}}$$

$\xi < 1, (c < c_{cri})$ **Under Damping**

$\xi = 1, (c = c_{cri})$ **Critical Damping**

$\xi > 1, (c > c_{cri})$ **Over Damping**

Transmissibility Ratio

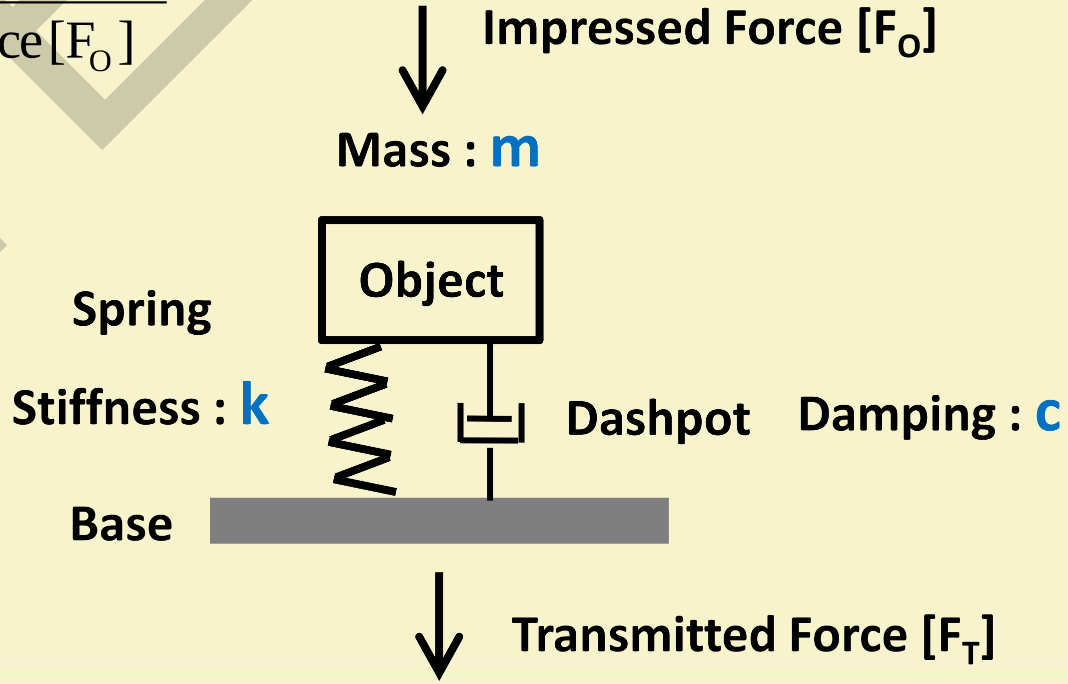
Transmissibility Ratio defines as the ratio between the transmitted force [F_T], and Impressed force [F_O]. Higher the TR vibration and structure borne sound propagation also will be more.

$$TR = \frac{\text{Transmitted Force}\,[F_T]}{\text{Impressed Force}\,[F_O]}$$

Transmissibility Ratio [TR]

FACTORS

- **Natural Frequency of Machine [f_n]**
- **Operating Frequency of Machine [f_o]**
- **Damping Factor [ξ]**



Transmissibility Ratio

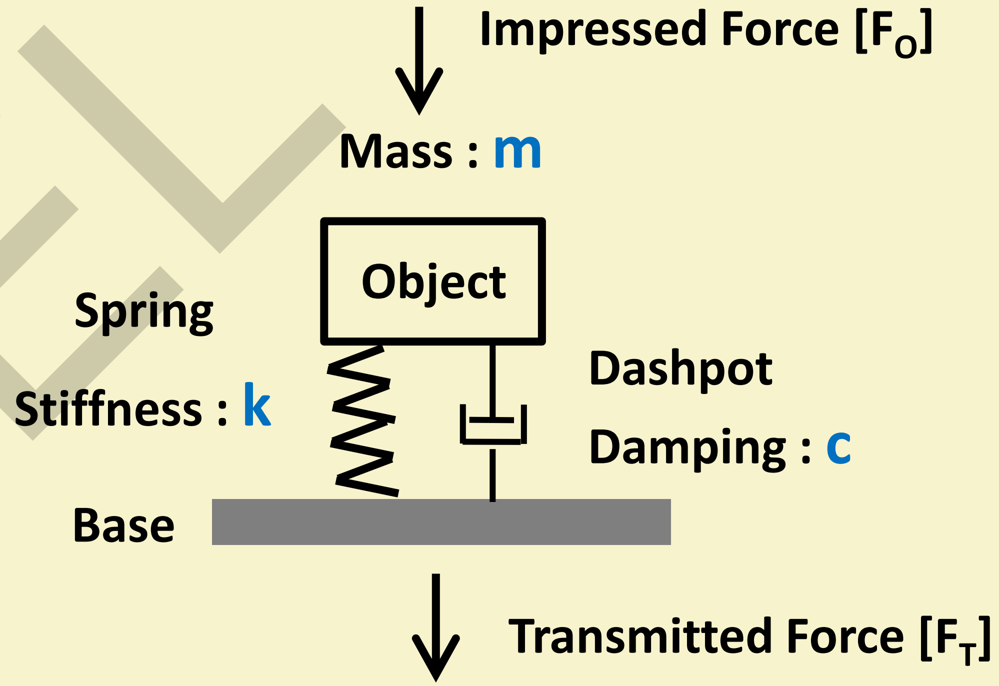
Natural Frequency of Machine [f_n]

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

Where, f_n is the natural frequency [in Hz]
'k' is the Stiffness expressed in kg/m and
'm' is the mass of the system in kg

Transmissibility Ratio [TR]

$$TR = \frac{\sqrt{1+\left(2\xi\dfrac{f_o}{f_n}\right)^2}}{\sqrt{\left[1-\left(\dfrac{f_o}{f_n}\right)^2\right]^2+\left(2\xi\dfrac{f_o}{f_n}\right)^2}}$$



Where, f_o and fn are the operating and natural frequency of the system expressed in Hz.
ξ is the Damping Ratio.

Transmissibility Ratio

Let **R** be the **Frequency Ratio**

$$R = \frac{\text{Operating Frequency } (f_o)}{\text{Natural Frequency } (f_n)}$$

$$TR = \frac{\sqrt{1 + \left(2\xi \frac{f_o}{f_n}\right)^2}}{\sqrt{\left[1 - \left(\frac{f_o}{f_n}\right)^2\right]^2 + \left(2\xi \frac{f_o}{f_n}\right)^2}} \Rightarrow TR = \frac{\sqrt{1 + (2\xi R)^2}}{\sqrt{\left[1 - R^2\right]^2 + (2\xi R)^2}}$$

Fullest Damping ξ = 1.0

50% Damping ξ = 0.5

No Damping case ξ=0

Transmissibility Ratio

$$TR = \frac{\sqrt{1+(2\xi R)^2}}{\sqrt{\left[1-R^2\right]^2+(2\xi R)^2}}$$

No Damping case ξ=0 $\qquad \xi = 0 \Rightarrow TR = \dfrac{1}{1-R^2}$

50% Damping ξ = 0.5 $\qquad \xi = 0.5 \Rightarrow TR = \dfrac{\sqrt{1+(R)^2}}{\sqrt{\left[1-R^2\right]^2+(R)^2}}$

Fullest Damping ξ = 1.0 $\qquad \xi = 1.0 \Rightarrow TR = \dfrac{\sqrt{1+4R^2}}{\sqrt{\left[1-R^2\right]^2+4R^2}}$

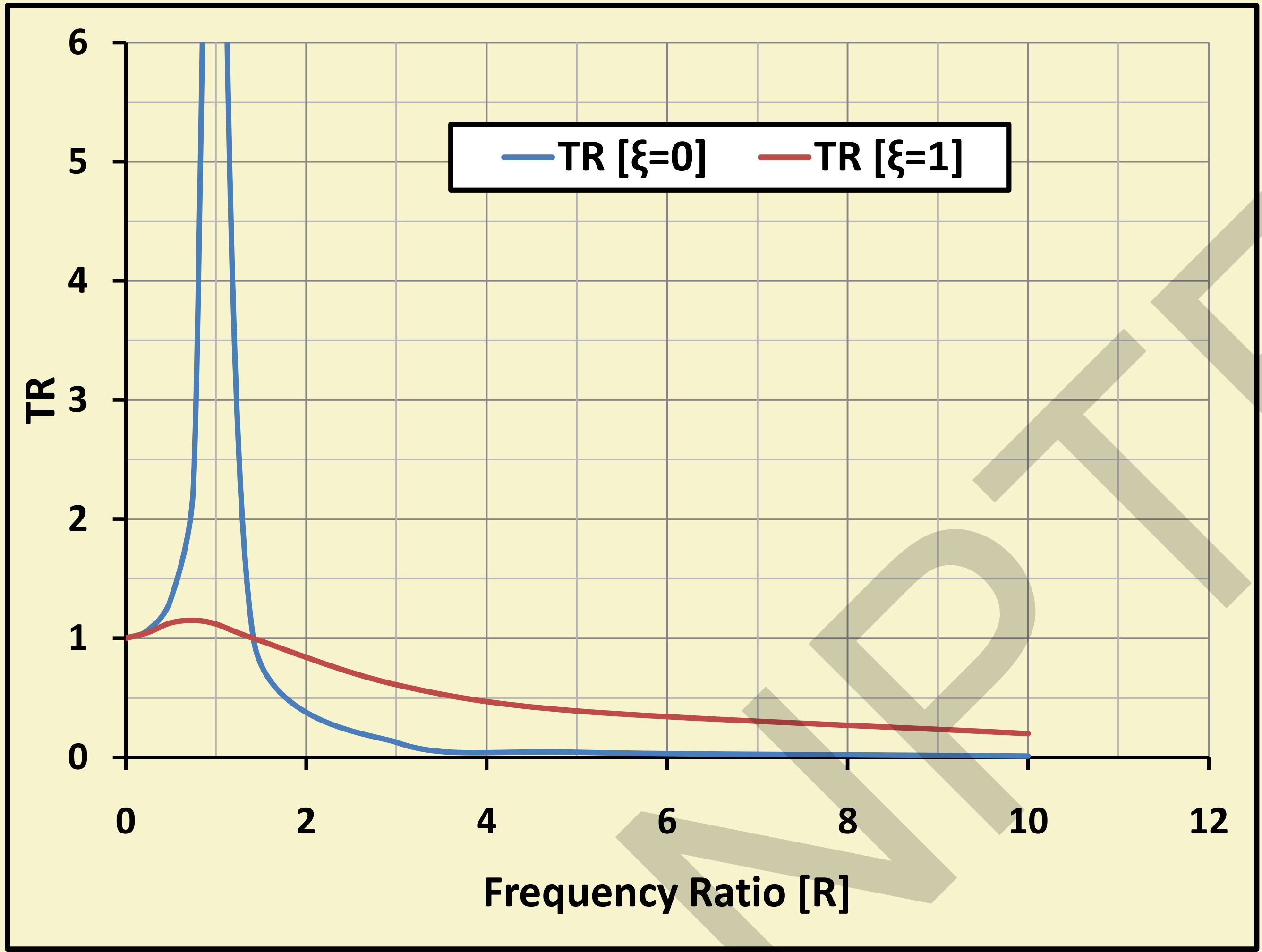
Transmissibility Ratio

No Damping case ξ=0 $\xi = 0$ ⇨ $$TR = \frac{1}{1-R^2}$$

R	0	0.25	0.5	0.75	1	1.414	3	5	10
TR [ξ=0]	1	1.07	1.33	2.28	Inf	1	0.125	0.042	0.01
TR [ξ=1]	1	1.05	1.13	1.15	1.12	1	0.61	0.39	0.2

Fullest Damping ξ = 1.0 $\xi = 1.0$ ⇨ $$TR = \frac{\sqrt{1+4R^2}}{\sqrt{\left[1-R^2\right]^2 + 4R^2}}$$

Transmissibility Ratio



R	TR [ξ=0]	TR [ξ=1]
0	1	1
0.25	1.07	1.05
0.5	1.33	1.13
0.75	2.28	1.15
1	inf	1.12
1.414	1	1
3	0.125	0.61
5	0.042	0.39
10	0.01	0.2

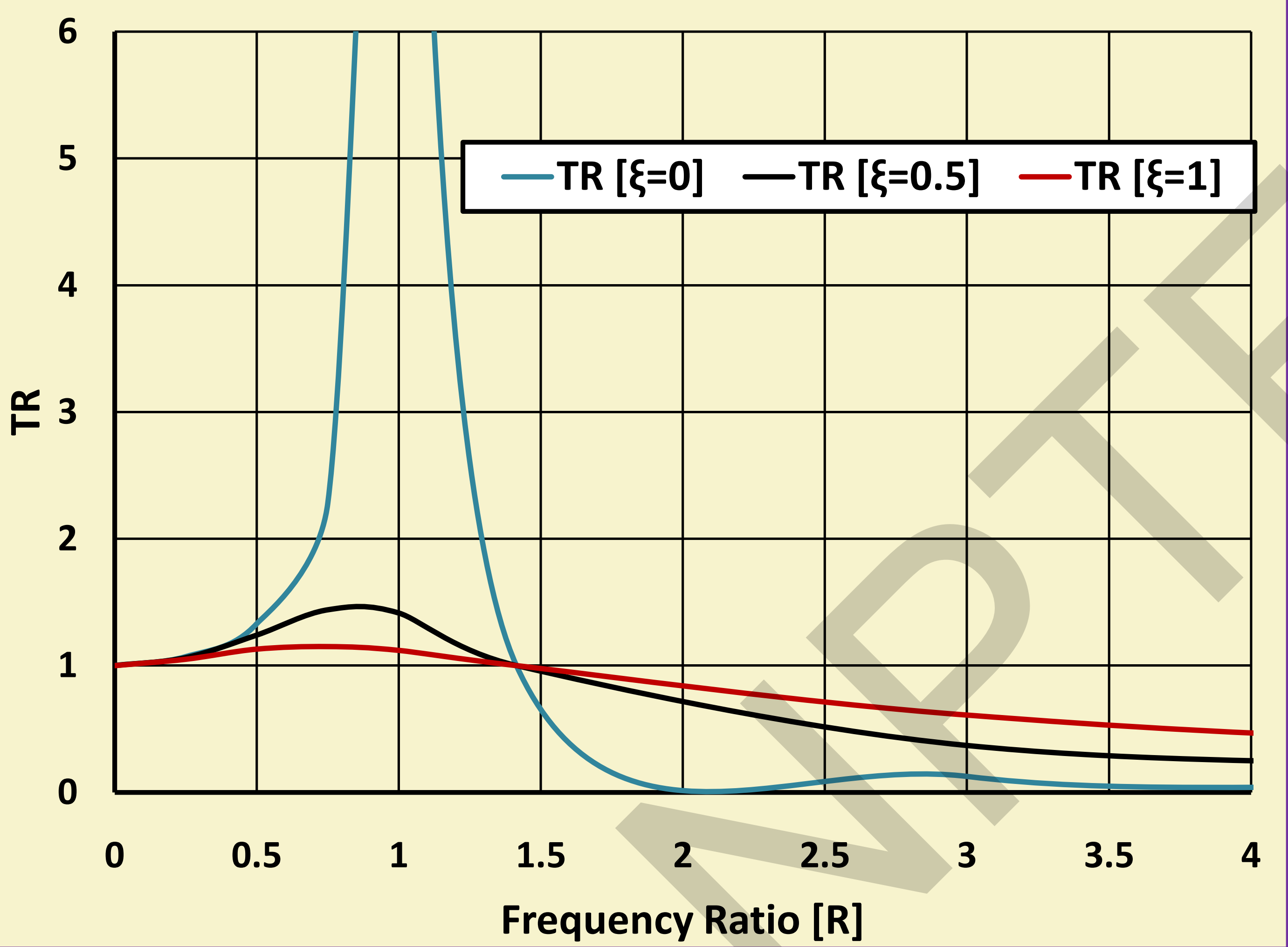
Transmissibility Ratio

50% Damping ξ = 0.5

$\xi = 0.5 \Rightarrow TR = \dfrac{\sqrt{1+(R)^2}}{\sqrt{\left[1-R^2\right]^2+(R)^2}}$

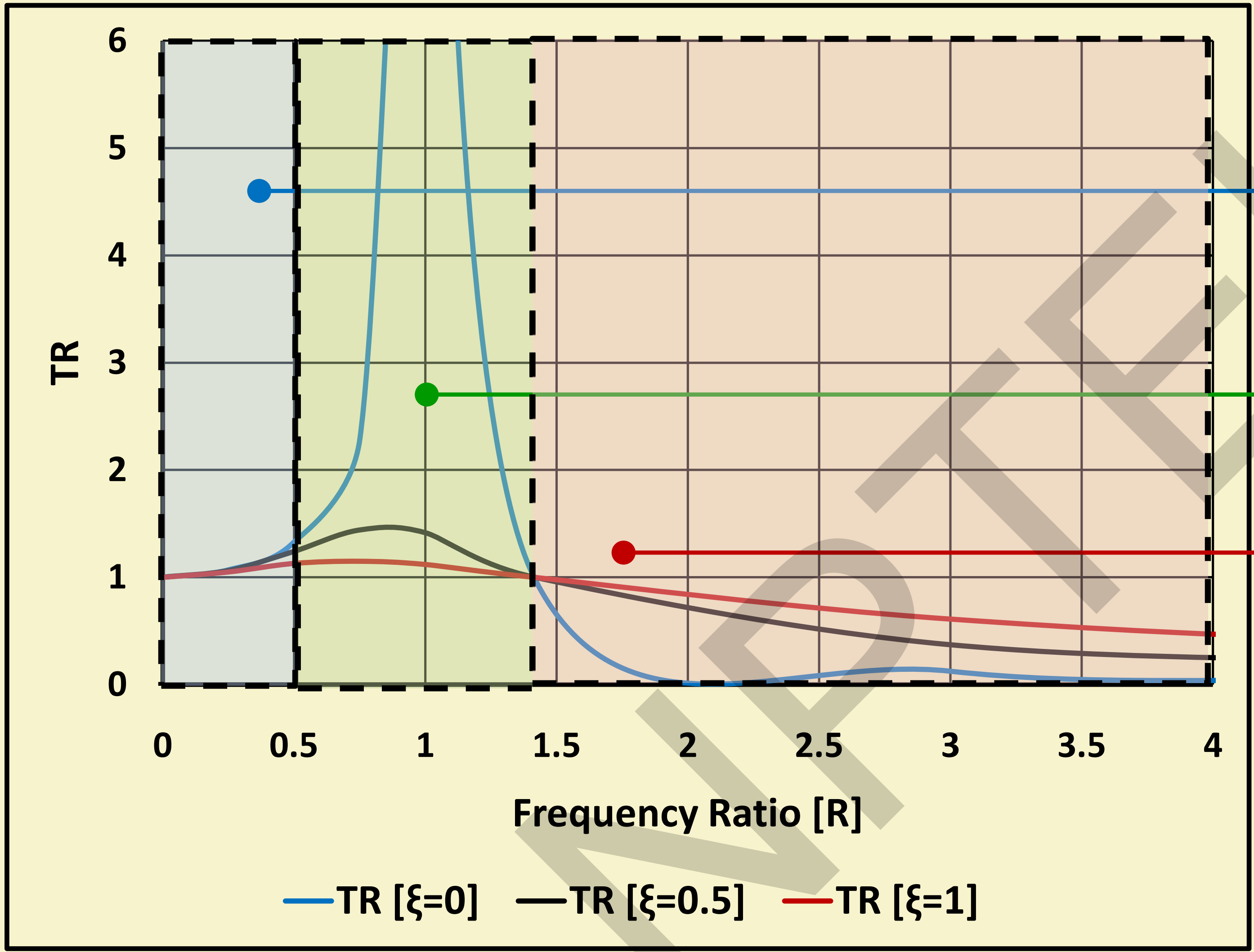
R	**0**	**0.25**	**0.5**	**0.75**	**1**	**1.414**	**3**	**5**	**10**
TR [ξ=0.5]	1	1.06	1.24	1.44	1.41	1.00	0.37	0.21	0.10

Transmissibility Ratio



R	TR [ξ=0]	TR [ξ=0.5]	TR [ξ=1]
0	1	1	1
0.25	1.07	1.06	1.05
0.5	1.33	1.24	1.13
0.75	2.28	1.44	1.15
1	inf	1.41	1.12
1.414	1	1.00	1
3	0.125	0.37	0.61
5	0.042	0.21	0.39
10	0.01	0.10	0.2

Transmissibility Ratio



0<R<0.5:
Use of Damper is uneconomical

0.5<R<1.414:
Use of Damper is Highly Necessary

R>1.414:
Use of Damper is Prohibited

Control of Impact Noise

Cushion the Impact

Resilient cushioning materials in common use are floor tile of rubber and cork, or carpeting on pads, in ascending order of impact insulation.

Float the Floor

Since the key to elimination of structure-borne sound is isolation, separating the impacted floor from the structural floor by a resilient element is extremely effective. This element can be rubber or mineral wool pads, or blankets, or special spring metal sleepers.

Suspend the Ceiling—and Use an Absorber in the Cavity

The most disturbing noise is that radiated down from the ceiling. A flexibly suspended ceiling with an acoustic absorbent layer suspended in it can be very effective if not flanked by paths leading into the walls and from there reradiating into the space below. It is imperative that the entire floor slab above be decoupled from the walls below by resilient separators.

Isolate all Piping

All rigid structures such as piping must be isolated so as not to form a flanking path, and penetrations must be caulked with resilient sealant so as not to constitute an air-sound leakage path.

IIC

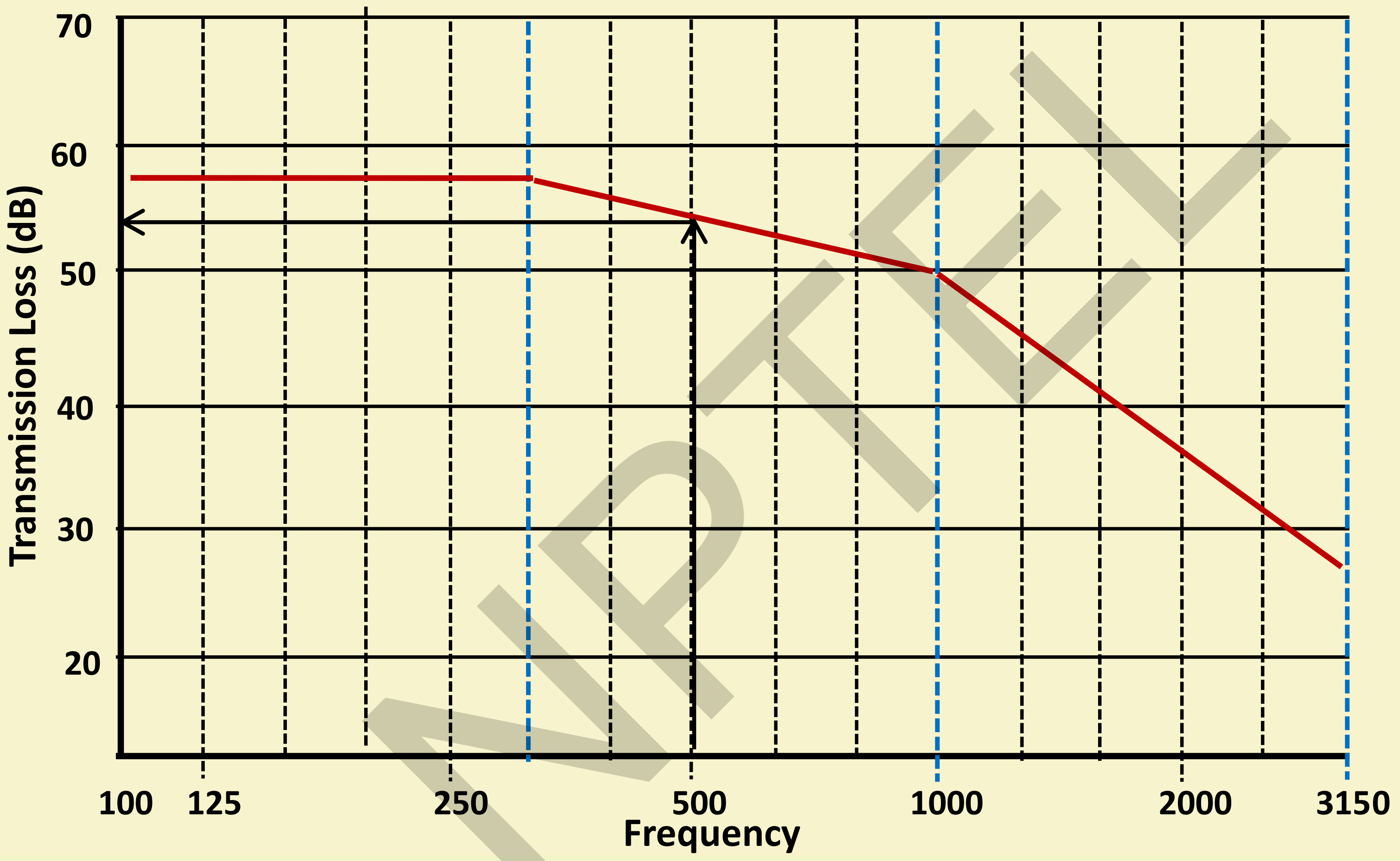
Impact Insulation Class (IIC) is a **rating system** to describe the sound insulation quality of floor of ceiling against the **impact borne sound**.

The IIC number is an **indicatory number**, roughly represent the **reduction in decibels** when one side of the partition tapped by the testing machine.

This classification covers the determination of a single figure rating that can be used for comparing floor-ceiling assemblies for general building design purposes. The rating is called impact insulation class (IIC).

The test frequency bands are a series of **one third octaves 100 to 3150 Hz.**

IIC

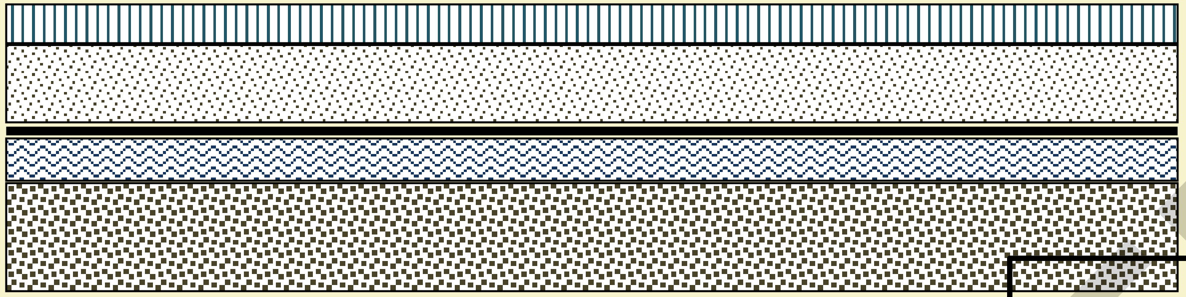


70
60
50
40
30
20
Transmission Loss (dB)
100
125
250
500
1000
2000
3150
Frequency

IIC

Type of Flooring	IIC
Ceramic Tiles, Marble Floor	28
Vinyl Flooring	35-40
Hard Wooden Flooring	30-35
Concrete with Mineral Fiber Floating Floor	60-65
Carpet	75-85

Floating Floor



Floor Finish

75 mm Screed Concrete

Waterproofing Membrane

Resilient Blanket Layer (25-35mm)

Structural RCC Slab

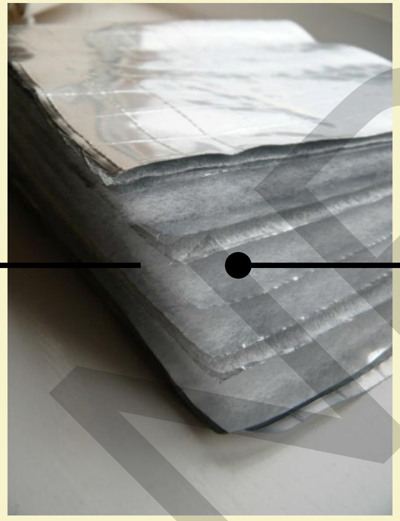
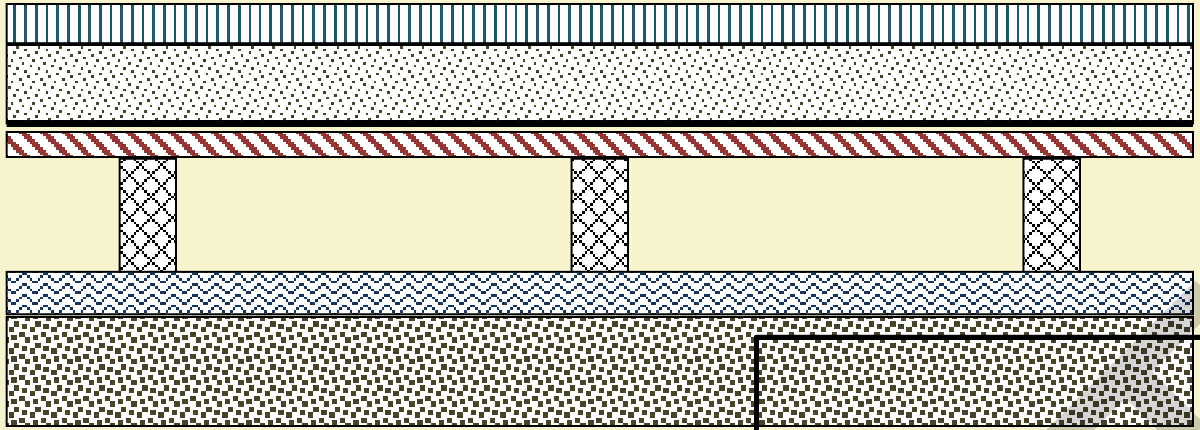


Photo Source: (i) Australasian Insulation Supplies Pty Ltd & (ii) https://www.eboss.co.nz

Floating Floor



Floor Finish

75 mm Screed Concrete

Waterproofing Membrane

12mm Ply Wood

50X50 mm Wooden Runner

Resilient Blanket Layer (25mm)

Structural RCC Slab

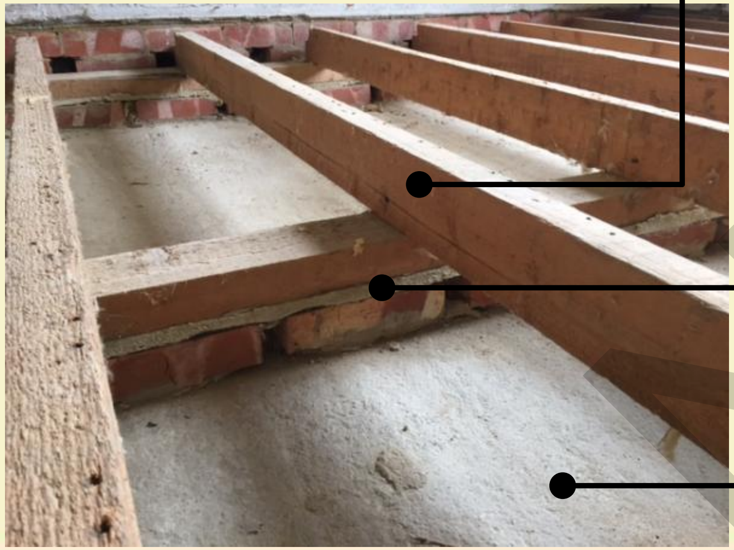


Photo Source: http://www.greenbuildingforum.co.uk

Home Work

State the methodology and steps involves to Impact Insulation Rating of a floor

If a machine having stiffness of 10^5 N-m and mass 10 kg. The operating frequency is 75 Hz. Do you recommend a damping to control the mechanical vibration? Justify your statement.

Bibliography

1. **Acoustics in the Built Environment**, Duncan Templeton, Architectural Press; 2nd Edition

2. **Architectural Acoustics Illustrated,** Michael Ermann, wiley, 2015

3. **Architectural Acoustics,** Marshall Long, El Sevier, Academic Press,

4. **Mechanical and Electrical Equipment for Buildings**, Walter T. Grondzik, Alison G. Kwok, Benjamin Stein and John S. Reynolds, John Wiley & Sons, Inc. (11th Edition) [Part-IV]

End of Lecture 35: Structure Borne Sound Transmission -II