

NOISE CONTROL IN MECHANICAL SYSTEMS

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Week:7

Lecture:32

Lecture 32: Passive noise control and acoustic materials

The slide features a white background with a blue header and footer. At the top left is the IIT Roorkee logo, followed by the text 'IIT ROORKEE'. In the center is the Swayam logo with the text 'FREE ONLINE EDUCATION swayam'. To the right is the NPTEL logo with the text 'NPTEL ONLINE CERTIFICATION COURSE'. The main title 'Noise Control in Mechanical Systems' is in a large, dark blue font, followed by 'Lecture 32' in a smaller blue font, and 'Passive Noise Control and Acoustic Materials' in a bold blue font. Below this is the name 'Dr. Sneha Singh' and her department 'Mechanical and Industrial Engineering Department'. At the bottom is a photograph of the IIT Roorkee building, a large white structure with a central dome and columns. A small number '1' is visible in the bottom right corner of the slide.

Hello and welcome to this course on noise control in mechanical systems with me, Professor Sneha Singh, from the Department of Mechanical and Industrial Engineering at IIT Roorkee. So, we have discussed some active noise control techniques. So far, we are dealing with the module on principles of noise control, and we have started discussing the various noise control strategies. We briefly discussed the ANC methods, but then we will

discuss in more detail the passive noise control techniques. So, this lecture is devoted to the discussion on the passive noise control techniques and then introduces the concept of acoustic materials.

Summary of previous lecture

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So, to begin with, this is the outline for this lecture: we introduce the passive noise control. And then, what do you mean by passive noise control? It is achieved mostly using some kind of materials. So, these materials are called acoustical materials, or simply you can also call them acoustic materials. You can call them by various names: acoustical materials, acoustic materials, or simply noise control materials. They all can be used synonymously to mean the same thing. So, we will see how these materials are classified, and then we will discuss what you mean by barriers, absorbers, and how to measure the performance of typical barriers in the purview of noise control.

Outline

- Introduction to Passive Noise Control
- Classification of acoustical materials / acoustic materials / Noise control materials
- Barriers ✓
- Absorbers ✓
- Performance indicators of Barriers



So, what is passive noise control? So, in ANC, you saw that we need an additional circuitry and an additional power source to create a new sound signal. So, we need to create a secondary source which is out of phase with the actual noise source to cancel the signal, but in the case of passive noise control, So, this refers to this broad set of noise control techniques where no external energy source is required. And no external sound source is being used. So, we do not use any external energy source, nor do we use any additional or external sound source, and yet we are able to control the existing noise. How do we do it? We use some materials to control it, okay. So, this you know, is used to control it.

Passive Noise Control

- **Passive Noise Control** are a broad set of noise control techniques where no external energy source or ^{N_s} sound source is used to control the existing noise.
- Noise control usually takes place by source, path or receiver modification.
- Most common techniques involve path modification, where acoustic materials are used to absorb or reflect back (block) the sound wave energy.

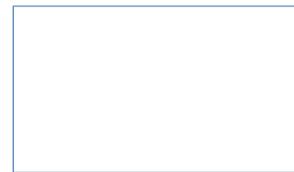


So, what do you mean by acoustic materials? You know, acoustic materials or noise control materials, these are the materials which are designed to reduce the noise by either controlling, redirecting, and/or manipulating the sound waves. So, any material which can manipulate the sound waves in a certain way and produce a certain effect becomes an acoustic material. So here, I would like to say that, for example, let us say we have an air medium and some noise source like me or any listener, any speaker who is speaking, and the sound waves are passing in the environment. If you introduce any medium which has a different characteristic impedance compared to the medium in which the sound waves are propagating, okay? So, in the acoustic fundamentals, we have seen that whenever there is a change in the characteristic impedance, then the waves undergo reflections, transmissions, and these kinds of things, you know, absorption. So, whenever this is introduced, the new medium is sort of trying to it is trying to change the propagation of the sound wave. So, it is trying to change how the sound waves are propagating initially. So, that medium itself now becomes an acoustic material. So, what you can say is that literally every material which has a slight, which has got a different impedance compared to the air medium, will act as an acoustic material. So, by that definition, almost every material that exists on this planet Earth is an acoustic material and can be used to control, redirect, or manipulate sound waves in certain ways. They do so by changing the usual propagation of the sound wave. So, whatever the free field propagation is, they change it

by introducing the phenomenon of reflection, transmission, and absorption when the sound waves hit those materials in their pathways.

Acoustic Materials

- **Acoustic materials** or **noise control materials** are the materials designed to reduce noise by controlling, re-directing, and/or manipulating sound waves.
- Noise control with such materials is typically achieved by controlling the reflection, transmission and absorption through these materials.



So, let us see. So, this is how they control it. Suppose you have an air medium in which sound waves are propagating, and you introduce a block of new material that has a different characteristic impedance than the air medium. Then the waves will undergo reflection, and some part of the waves will get reflected. The remaining part will enter the material, and while passing through the material, they can undergo some dissipation because every material can offer some resistance to the flow of sound waves. So, dissipation means that the sound energy gets used up as heat and this is how the attenuation of sound energy happens. So, some part of the energy is reflected, the remaining part passes through the material and undergoes some attenuation within the material because of the internal resistance faced in the material, and then whatever is remaining will come out from the other end of the material as the transmitted energy. This shows a typical interaction when sound waves hit a particular material lining. Okay, reflection happens, some dissipation happens, and then transmission happens. These

materials control They achieve the desired noise control by controlling what should be the reflection, what should be the transmission, and the dissipation. So, by controlling these three parameters, the materials are able to achieve various desired effects.

Acoustic Materials

The diagram illustrates the interaction of sound waves with a material lining. It shows a vertical layer of material between Medium 1 (on the left) and Medium 2 (on the right). An incident energy wave from Medium 1 strikes the material. This results in three energy paths: reflected energy back into Medium 1, transmitted energy into Medium 2, and dissipated energy within the material. A handwritten note in red ink states: "(Sound energy gets up as heat)".

- A material can control noise by **controlling the reflection, transmission and dissipation** of sound waves when they hit the material

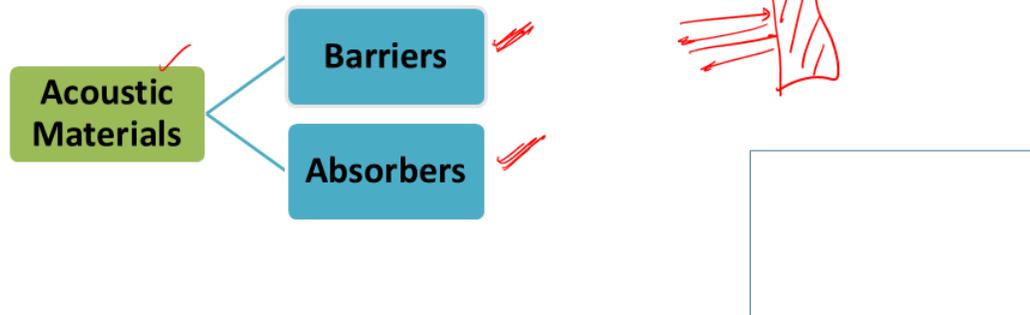
Interaction of sound waves with a material lining

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So, depending on how much energy they are able to reflect, dissipate, and transmit. So, these are the three things that happen whenever sound energy is incident on a piece of material, and depending on how much reflected energy is generated, how much dissipation is happening within the material, and lastly, how much transmission is happening out from the other end of the material. So, based on how much of all these three phenomena happen, the materials are classified. Some materials are classified. So, the broad categories for acoustic materials are barriers and absorbers, and we will discuss both of them one by one. So, what do you mean by barriers or simply sound barriers? So, the name itself means barrier. Barrier means something which is stopping something; it is a barrier, it's a hindrance to stop something. So, just by the name itself, you should think about something that is some hard material where whatever sound wave is hitting it is not able to pass, and it just has to go back with no other option. So, by the name itself, this is what comes to mind.

Classification of acoustic materials

- Depending on the desired intent of noise control, and on the extent of reflection, dissipation and transmission that a material achieves, acoustic materials are classified as:



So, let us see what these sound barriers are. Okay. So, here what happens is that in this typical interaction that occurs when the sound waves hit the surface of a barrier material, and this shows us the cross-sectional view of the interaction. So, what happens is this material is supposed to, suppose you want to, suppose you know your aim is that, here the noise source is located. Let us say this is your noise source, which is creating this sound wave energy, which is then incident on the material, and suppose your listener where you have to reduce the noise, is located here. So, you have the source here and the listener here. So, your target is that you do not care about. So, here you do not care about what the noise level at the source should be. It may be some machinery, but you want to protect the listeners from the noise of that machinery. So, the protection is literally desired at this particular location, not near the source, but near the listener. So, over at this part then, when this is your desired objective, whatever the noise source is, you do not care what the noise is. You do not want to reduce the noise level at the source itself. It could be some kind of machinery or plant. You are okay to have whatever noise level there, but then you have some listeners that are located near or slightly far away from that. Noise source, and at the listener, you would like to reduce the noise level. So, if only you know the noise reduction is supposed to be achieved here and not here, then you would use a barrier material, and what should that material do? It should be able to reflect more or dissipate more, but transmit less. So, they should minimize the transmission. So,

what is there? So, because you have to protect the listeners at this end from the effect of the. So, these listeners have to be protected. So, you want that the minimum amount of sound energy should pass through the material. So, that at this end you have very little sound. So, you can do that either by reflecting most of the sound, and even if the sound is reflecting, most of the sound is getting reflected, and whatever remains is passing through the material and getting dissipated in the material. So, these two components could be high, and this has to be minimum. So, that defines your material as a barrier material.

Sound Barriers

The diagram illustrates the interaction of sound waves with a material lining. It shows two media: Medium 1 on the left and Medium 2 on the right. A central 'Layer of material' separates them. Incident energy from Medium 1 is shown as a black arrow pointing towards the material. This energy is split into three paths: 'Reflected energy' (a red arrow pointing back into Medium 1), 'Dissipated energy' (a red arrow pointing into the material layer), and 'Transmitted energy' (a black arrow pointing into Medium 2). A 'Listener' is shown in Medium 2, with a red arrow pointing towards them from the transmitted energy. Handwritten red notes include 'Sona' near the incident energy, 'Listener' near the transmitted energy, and 'Cross-sectional view' pointing to the diagram. A red box highlights the 'Reflected energy' and 'Dissipated energy' paths.

- If noise control is desired primarily in medium 2:
 - Material should reflect more, dissipate more, transmit less.
 - Barriers come under this category.

Interaction of sound waves with a material lining

This shows a typical example. Suppose you know you have some machinery source here and some receiver is here, and you want to achieve the attenuation in this green zone, where you want to achieve the sound attenuation. Then, you can place a barrier material. It would mostly reflect the sound back towards the source, or it would scatter and diffract it in other directions. Whatever is remaining, it will try to dissipate it within the material itself. So, beyond the material at the other end, there is no transmission, and the listener is being protected. So, that is the main objective, which is to minimize the sound transmission. So, the better the barrier, the lesser should be the transmission. So, you know, if the barrier performance, you know, if the barrier is good, that means that we

have studied some terminology called the transmission coefficient, which is the magnitude of the transmitted wave by the incident wave. So, this should go down, right? Because there should be minimum transmission.

Sound Barriers

- These are the acoustic materials that block the sound waves incident on them. They do so by reflecting and dissipating more sounds, allowing minimum sound transmission through them to the other end.

The diagram illustrates the effect of a sound barrier. A sound source on the left emits waves that are reflected by a barrier. The area behind the barrier is labeled as the 'Shadow Zone', where a receiver is located. Labels include 'Reflected Waves', 'Propagating Waves', 'Source', 'Shadow Zone', and 'Receiver'. Handwritten green notes say 'Barrier ↑' and 'Transmission Coeff. ↓↓'. A source citation is provided: 'Source: Crocker, M. J. (ed.) (2007). "Introduction to principles of noise and vibration control" in Handbook of noise and vibration control. John Wiley & Sons.'

Barrier ↑ Transmission Coeff. ↓↓

Source: Crocker, M. J. (ed.) (2007). "Introduction to principles of noise and vibration control" in Handbook of noise and vibration control. John Wiley & Sons.

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Okay, so some of the typical sound barriers that we found are most of the structural kind of materials that we use to build buildings. You know, they are actually barrier materials, and they are made very consciously because, within the building, we would like to have quiet. We would not like to get disturbance from the outside noise sources. So, deliberately, barrier materials have been chosen since a long time ago to build the various walls, ceilings, and roofs of the building. So, whatever structural elements that you find in the building, such as concrete, hardwood, stone, and various such hard materials which have much higher impedance than air, they are sound barriers.

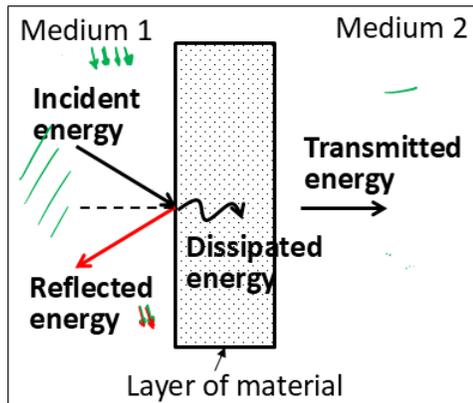
Sound Barriers

- Examples:
 - Concrete ✓
 - Hard wood ✓
 - Stone ✓
 - Any material with much high impedance than air



Then, the second type of material is absorber. Suppose you know what you desire is that you want to, for some reason, control the sound level. You want to bring down the sound levels here near the source, okay? And you do not care about what happens here, okay? This is not of your concern, but rather you would like to bring down the noise levels here itself. Then, the other way round, what should the material do? It should reduce the amount of reflection because you want to reduce the noise as much as possible in this zone, so near the source itself. So, either they should minimize the reflection. So, this component has to be minimized to reduce the sound levels here itself. So, those kinds of materials are called absorbers.

Sound Absorbers



- If noise control is desired primarily in medium 1:
 - Material should reflect less.
 - **Absorbers** come under this category.

Interaction of sound waves with a material lining

So, just like you know barriers, their main objective is to minimize the transmission. In the case of absorbers, their main objective is to minimize the reflection, okay. So, now what happens? So, basically, if they have to minimize reflection. So, what does it mean? So, if a material is present here and we are hoping that when the sound waves hit the material, the reflected waves are minimized as much as possible. So, how can that be achieved? That means that most of the sound waves hitting the material should be able to enter the material; that is a prime requirement. If they are not able to enter inside the material, which means that the material is hard and the waves are reflecting back. We do not want that; we do not want any reflection. So, we would like most of the sound waves that are hitting the material to pass through the material easily. So, the very first thing that they should do for minimizing the reflection is that they should allow the sound waves to enter inside it. So, by definition, any material that allows the sound waves to come inside it and does not reflect back becomes an absorber by definition itself. This is the only sufficient condition to define a sound absorber: any material that allows sound waves to enter inside it. Hence, it leads to minimal reflection, and it becomes an absorber. Now, what happens when the sound waves enter the material? It can be anything, but the material should be able to allow the sound waves to enter the absorber. So, once they enter the material or the absorber, they can either get dissipated within the material itself. So, these are some optional things that can happen. They may either get dissipated within

the material itself, such that not only is the reflection minimized, but the transmission also goes down. So, this is already being minimized, but the transmission can also go down if you increase the dissipative part within the material. So, this is optional. This does not define an absorber. Basically, it should be able to just minimize the reflection; that is the sufficient condition for an absorber. After entering the material, it can either get dissipated to minimize the transmission as well, or it can simply enter and pass to the other end without any dissipation. Even then, that material would be classified as an absorber. So, now think about the various kinds of materials we have that we call absorbers. For example, there are porous materials that have a lot of holes inside them. So, when the sound waves hit, it is not a hard material, but it is a material with a lot of holes. So, it allows the waves to enter the material. For example, foam, such as open-cell polyurethane foam, has a lot of pores that are exposed to the sound waves. When the sound waves hit, these pores allow them to enter inside the material. So, it becomes an absorber. In the same way, these kinds of various fibers, the loose fibrous materials like glass wool, will also allow the sound waves to enter and that would become an absorber. Then, various kinds of natural woven fibers. So over here, for example, the kind of clothing that I am wearing over here. You can see that if you look at your clothing, it is made up of a lot of woven fabrics with woven fibers and it has a lot of holes inside it. Suppose, for example, if you do an experiment at home, you just take a sheet of metal and you pour water over it or a sheet of metal container and you pour water over it, the water will not drip down from the material because it's a hard material. In the same way, instead of taking that metal container, you just take a piece of cloth. And you pass the water over the piece of cloth container, will it hold the water? No, the water will drip down from the piece of cloth because it is not rigid. It has a lot of holes and spaces through which the water can pass through. And sound wave is what? It is the propagation of air. So, if the water is passing through the material, most definitely the air can very easily pass through that cloth material. So, that is also a porous that is also becoming an absorber because it has a lot of spaces through which the air can pass through and the sound waves can pass through. So that becomes, you know, an absorber in itself. Now imagine that you have got this building, and you just have everywhere, you know, it is closed completely from the barriers. The roof, ceilings, and the walls, and then you have a window that is open. That open window itself, suppose I am speaking anything by the walls, are not going to allow my sound waves to pass to the other end. You know, most of it will be reflected back, but whatever sound waves reach the open window, will the window stop them from reflecting back? No, the windows will just simply allow all the

waves to pass through. So, that window itself will then become an absorber. By definition of it.

Sound Absorbers

- These are the acoustic materials that absorb the sound waves incident on them, i.e. they minimize the reflection of sound waves incident on them. *sufficient condition*
- They allow sound waves to enter the material, then it may get dissipated within the material such that transmission is also minimized, or the sound waves may pass to the other end without much dissipation. *(optional)*
- Examples:
 - Polyurethane foam ✓
 - Glass wool ✓
 - Natural woven fibres (cotton, jute, etc.) ✓
 - Open window in a wall ✓



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So, what are the ways in which we can measure the performance of these sound barriers? So, we discussed, you know, briefly what a sound barrier is and then what a sound absorber is. We defined and gave some examples. Now, let us see how we measure the performance of these materials. We first start with sound barriers. So, some of the performance indicators we use are sound transmission loss, sound transmission class, insertion loss, and noise reduction. Let us look at them one by one.

Performance of sound barriers

- Performance indicators:

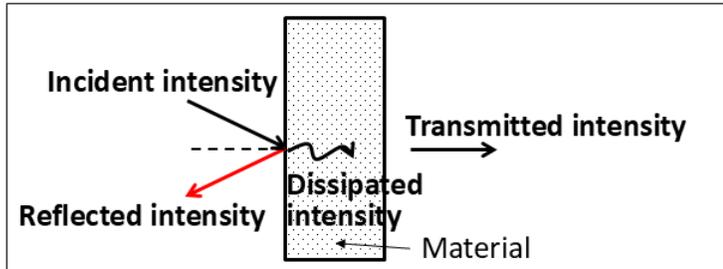
- Sound Transmission Loss ✓ → $TL(f)$ *Not a single value metric*
- Sound Transmission Class ✓
- Insertion Loss ✓ → $IL(f)$
- Noise Reduction ✓ → $NR(f)$



So, what is sound transmission loss, which in this lecture series from now on I will also call it just transmission loss because we are dealing with noise control? So, transmission loss by definition means by default you can assume it to mean that this is sound transmission loss. So, this is the acronym that will be used because we will be solving a lot of questions where we will use this acronym. So, how is it defined? Suppose this is a typical interaction that is happening with a material. So, here when the sound waves hit the material, the transmission loss through the material is defined as the difference between the incident sound energy level and the transmitted sound energy level when the sound waves hit the material. So, whenever the sound waves are hitting the material, some part is getting reflected, and then after dissipation, some part is transmitting from the other end of the material. So, the difference between the incident sound intensity level and the transmitted sound intensity level. So, let us derive a formulation for this.

Transmission Loss

- **Transmission loss (TL)** of a material is the difference between the incident sound intensity level and transmitted sound intensity level when the sound waves hit that material.



So, by definition, TL is what? It is

$$10 \log_{10} \left(\frac{I_{\text{in}}}{I_{\text{ref}}} \right)$$

so, it is the difference between the sound intensity level which is being incident on the material and the sound intensity level which is being transmitted from the material, okay.

So,

$$10 \log_{10} \left(\frac{I_{\text{in}}}{I_{\text{ref}}} \right)$$

because this is the incident intensity and then the sound intensity level. So,



$$10 \log_{10} \left(\frac{I_{tr}}{I_{ref}} \right)$$

where this is the incident sound intensity and this is the transmitted sound intensity. Then by the properties of log, when you combine the two terms together, you ultimately end up with this term. This cancels out. So, you ultimately get

$$10 \log_{10} \left(\frac{I_{in}}{I_{tr}} \right)$$

okay. Now, you know that the intensity transmission coefficient τ in our very, you know, module on the acoustic fundamentals, we had defined it as the ratio of the intensity of the transmitted wave and the intensity of the incident wave. So, the term inside it is nothing but 1 by τ . So, this becomes our formulation of transmission loss $10 \log_{10}$ and within that you have 1 by τ . It is a very important formulation which I would recommend you if you are in the field of noise control and if you are, you know, listening to these lectures, please take a note of this equation. It will be used in a lot of places because transmission loss is a very important matrix which we use for most of the materials. So, it is a very important equation. So, suppose you know here this is how the transmission loss is happening through some kind of material.

Transmission Loss

- By definition:

$$TL = 10 \log_{10} \left(\frac{I_{in}}{I_{ref}} \right) - 10 \log_{10} \left(\frac{I_{tr}}{I_{ref}} \right) = 10 \log_{10} \left(\frac{I_{in}}{I_{ref}} \times \frac{I_{ref}}{I_{tr}} \right)$$

$$TL = 10 \log_{10} \left(\frac{I_{in}}{I_{tr}} \right) \quad \text{So, } TL = 10 \log_{10} \left(\frac{1}{\tau} \right)$$

I_{in} = incident sound intensity ✓
 I_{ref} = reference sound intensity ✓
 I_{tr} = transmitted sound intensity
 τ = intensity transmission coefficient

$\tau = \frac{I_{tr}}{I_{in}}$

Now, suppose you have some wall where it is made up of various materials. So, for example, here where I am delivering the lecture itself, what I can see is, you know, the walls are here, the bottom place is covered with, you know, wooden kind of covering and then there are some, you know, tiles which are holey in nature. So, a lot of, you know, the walls are having a lot of different compositions. So, the wall may not be uniform throughout. Suppose this is your wall, and the waves are incident on this wall, and you want to see its, you know, transmission loss or how well it is performing as a barrier. So, you have it composed of different parts having different composition. So, to calculate the effective transmission loss of this composite wall, you use this formulation, okay? TL is given by

$$\mathbf{TL} = \mathbf{10 \log_{10} \left(\frac{1}{\bar{\tau}} \right)}$$

So, this becomes 10 log 10 of 1 by $\bar{\tau}$, where $\bar{\tau}$ is what? It is the average, you can say, or you can call it as, let us not call it as an average, you can just say it is an effective transmission coefficient. So, the net transmission coefficient for this composite wall is given by the summation of $S_i \tau_i$, which is the summation of the individual transmission coefficient of each, you know, each component multiplied by the surface area of that component, and after that, the total surface area you are dividing it by. So, let us say, for example, suppose the tau for this particular material was 0.8. This was 0.9, sorry, 0.8 would be a very high transmission for a barrier material. So, let me give you low values. Suppose the τ of this material was 0.1, for this one it was 0.01, for this material it was 0.04, and for this it was 0, or let us say 0.05, okay. Is the tau, then the net transmission loss through this wall you would calculate as

$$\mathbf{TL_{eff} = 10 \log_{10} \left(\frac{1}{\bar{\tau}} \right) ; \bar{\tau} = \frac{\sum_{i=1}^n S_i \tau_i}{\sum_{i=1}^n S_i}}$$

where $\bar{\tau}$ you will first find, which would be you sum up the area. So, whatever is the area, let us say, you know, this area is, let us say, you know, 1 meter square, 1 meter square, this is 1.5 meter square. This area is total, you know, approximately, you know, 1.513-meter square, and this is 1.5-meter square, okay. So, the area of the various individual

components is given. So, you can simply multiply the area with the corresponding transmission coefficient like this and then So, the τ for this is 0.04, and then like this, and then divide by the total area, which is 1 plus 1.5 plus 3 plus 1.5, and you would be getting your net effective $\bar{\tau}$.

Transmission Loss of a Composite Material

- If a wall is made of different materials, then effective transmission loss by the wall is:

$$TL_{eff} = 10 \log_{10} \left(\frac{1}{\bar{\tau}} \right) ; \bar{\tau} = \frac{\sum_{i=1}^n S_i \tau_i}{\sum_{i=1}^n S_i}$$

τ_{eff}

S_i = surface area of material i
 τ_i = transmission intensity coefficient of material i

$TL_{eff} = 10 \log_{10} \left(\frac{1}{\bar{\tau}} \right) ; \bar{\tau} = \frac{(1 \times 0.1 + 1.5 \times 0.01 + 3 \times 0.04 + 1.5 \times 0.05)}{(1 + 1.5 + 3 + 1.5)}$

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Okay, now the second performance indicator is noise reduction. So, what does it mean? It means it is the difference between the sound pressure level just before passing the barrier material and just after passing the barrier material. So, let us say this is our material which is placed. You place a microphone at some standard distance. You cannot place it too close to the material because, as we know, for any measurement, we need to maintain a certain distance; otherwise, we will be in the near field, okay. So, in order to avoid the near field effect, we will keep it at a certain distance. So, usually, what noise control engineers do is they take a standard distance of 1 meter. So, 1 meter before the barrier material and then that exact same 1-meter distance after the barrier material, they have two microphones. So, they measure the sound level just before entering the material and then the sound level just after passing through it, and the difference between these two levels gives you the noise reduction. In terms of, there is a derivation also there, which

we are not discussing in this course, but directly giving you the formulation. So, noise reduction in terms of the transmission loss of this material is the

$$NR = L_{p1} - L_{p2} = TL + 10 \log_{10} \bar{\alpha}$$

What is $\bar{\alpha}$? It is the average sound absorption coefficient of the material. We know that the sound absorption coefficient is

$$\alpha = 1 - |r|^2$$

More about the sound absorption coefficient I will discuss when we study about the sound absorbers. So, this is one metric to define the barrier performance. So, obviously, if a material is a good barrier, the transmission loss has to be high, okay. In the same way, if the material is a good barrier, then the noise reduction has to be high. So, the higher the value of these metrics, the better the barrier material is.

Noise Reduction

- Noise reduction (NR) is the difference between the sound pressure level before and after passing through a barrier material.

$NR = L_{p1} - L_{p2} = TL + 10 \log_{10} \bar{\alpha}$

$\alpha = \text{sound absorption coefficient of the material}$ $\alpha = 1 - |r|^2$

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The third kind of metric that we will discuss is the insertion loss. So, what is the insertion loss of a material? It is defined as Let us say this is our point of interest where our listener is located and the source is playing. So, once the material is not there, in that situation, what was your SPL when there was no barrier material? And then, when the barrier material got installed, what was the SPL? The difference between the two will give you the insertion loss. So, basically,

$$IL = SPL_{\text{without barrier}} - SPL_{\text{with barrier}}$$

So, here in this case, it is

$$IL = SPL_1 - SPL_2$$

So, again, the better the barrier, the higher the insertion loss should be. So, that is how we will have these three barrier materials.

Insertion Loss

- **Insertion Loss (IL)** of a material is the difference in sound pressure levels at the receiver point without and with the material.

$$IL = SPL_{\text{without barrier}} - SPL_{\text{with barrier}}$$

$IL = SPL_1 - SPL_2$


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Now, I would like to tell you, before I close this lecture, that all three of these metrics here, this TL is actually a function of the frequency. So, I can call this as transmission loss is a function of frequency; it is not a single value, rather it is a function of the frequency. The sound insertion loss, again, is not a single value, but rather a function of frequency, and noise reduction, which is this one, is also a function of the frequency. So, these are not a single value matrix. They are all, you know, functions of the frequencies. Now, we have only one matrix remaining, that is sound transmission class, which we will discuss in the next class.

Performance of sound barriers

- Performance indicators:

- Sound Transmission Loss ✓ → $TL(f)$ *Not a single value metric*
- Sound Transmission Class ✓
- Insertion Loss ✓ → $IL(f)$
- Noise Reduction ✓ → $NR(f)$



So, for the time being, thank you for listening.

Thank You

