NOISE CONTROL IN MECHANICAL SYSTEMS

Prof. Sneha Singh

Department of Mechanical and Industrial Engineering

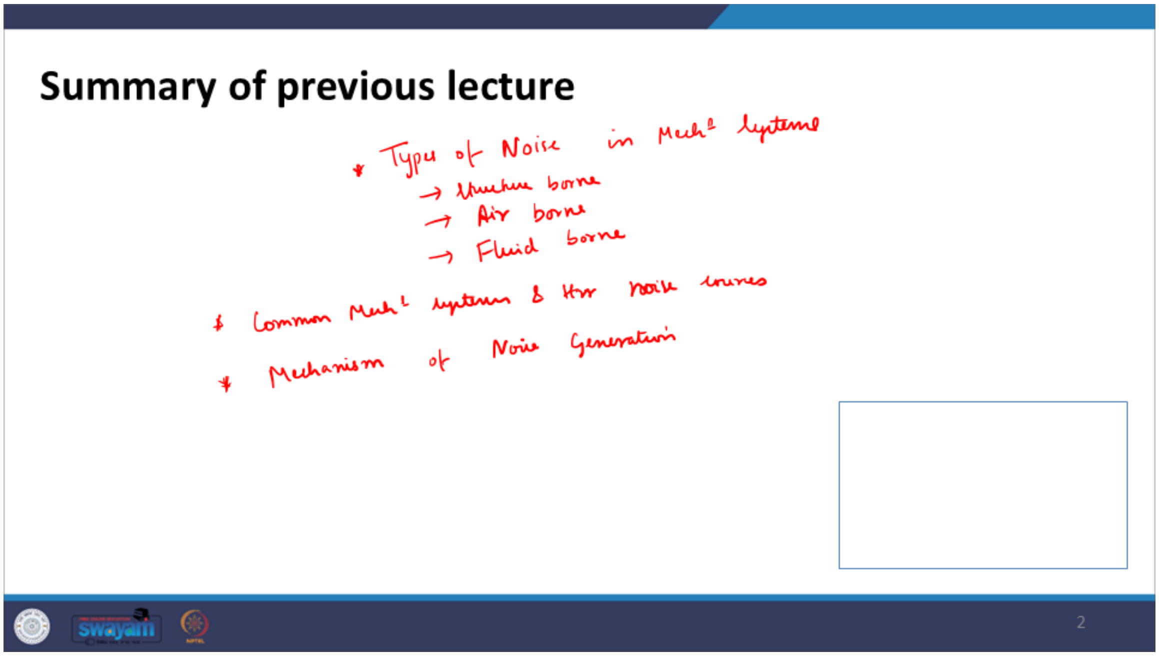
IIT Roorkee

Week:11

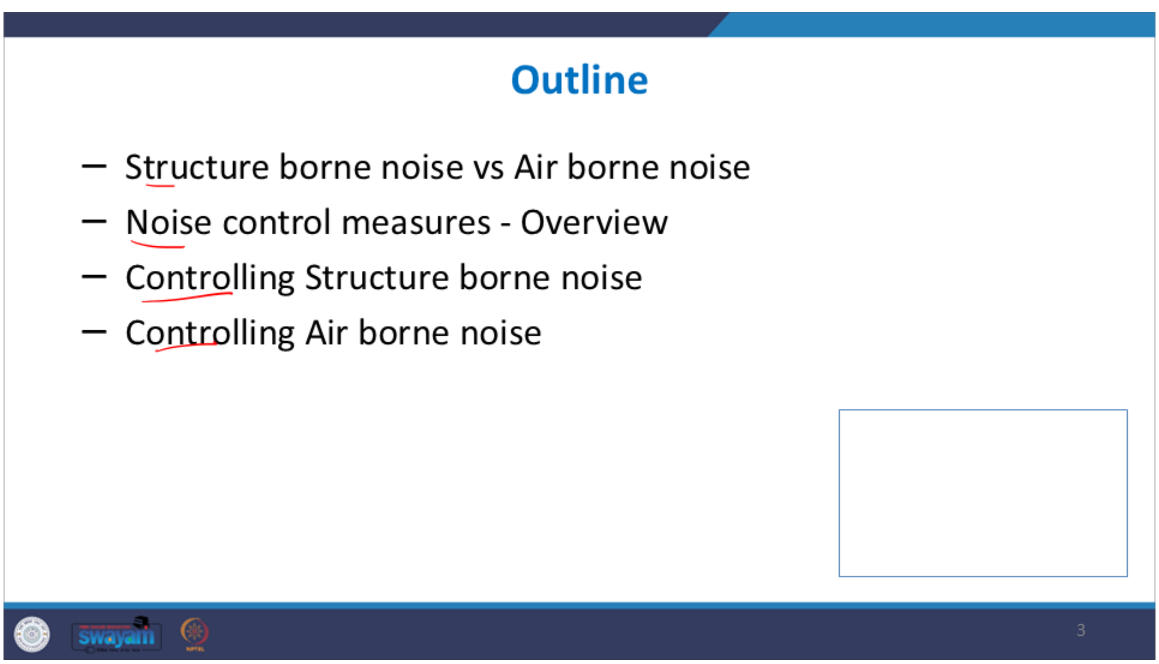
Lecture:055

Lecture 055: Noise in Mechanical Systems 3

Hello and welcome back to this lecture series on noise control in mechanical systems with myself, Professor Sneha Singh from IIT Roorkee. We have begun our module on noise in mechanical systems, and so far, what we have discussed is we have studied about the types of noise typically found in mechanical systems. You have like the structure-borne, air-borne, and fluid-borne, these kinds of typical noise types available, and then what are the types of noise in some of the common mechanical systems and their noise sources. Such as the noise sources in an engine, in rotational machinery, in fans and compressors, what are the typical phenomena through which the noise is created, and what kind of noise is present, what is the frequency and the temporal content of these noise sources within the mechanical systems and mechanical subcomponents. And then we have also discussed the mechanism of noise generation in these various mechanical devices.



in this lecture, we will study about the structure-borne noise and air-borne noise in more detail because these are the two most common categorizations of the types of noise that are available in mechanical systems, and each of them has a different means of propagating and spreading, and therefore, they need different types of noise control techniques. we will discuss these things.



Noise in Mechanical Systems

Types of Noise:

- **Structure-borne noise**

  Noise that travels through solid structures, typically originating from mechanical vibrations within the system.

- **Airborne noise**

  Noise that propagates through the air, typically generated by the movement of machinery, fans, or fluid flow.

- **Fluid-borne noise**

  Noise due to the flow of fluids (liquids or gases) through a system, such as in pipes, valves, and ducts.

4

In this lecture, quickly to recap, the types of noise present in mechanical systems can be divided based on how they propagate, and we have the structure-borne noise, air-borne noise, and the fluid-borne noise. Let us study out of these, these two are one of the most common forms of noise propagation in mechanical systems, and then we have the fluid borne as well, but the mechanism of fluid-borne noise is more complicated and is kept out of the scope of this particular lecture series.

Structure Borne Noise

- **Definition:** The waves which propagates through solid material like wall, floor, or a body of machine. It moves in within structures (as flexural vibrations) up to certain threshold then it start radiating in surrounding fluid media as an audible noise.
- **Origin:** It originally start at mechanical impact, vibration of motor, turbine, pump or any other mechanical devices which are in contact with the structure.
- **Example:**
  - Mechanical Impact : Hammering at distance of connected surface can create vibration throughout the structure.
  - Vibration : Imbalanced mass from rotating shaft create vibration and that can pass to all connected structure.

5

Let us see the structure-borne noise. What is the definition here? These are the sound waves which propagate through the solid material, material of the wall, floor, or any kind of body of the machinery. And it moves within these structures in the form of typically fractional vibrations.

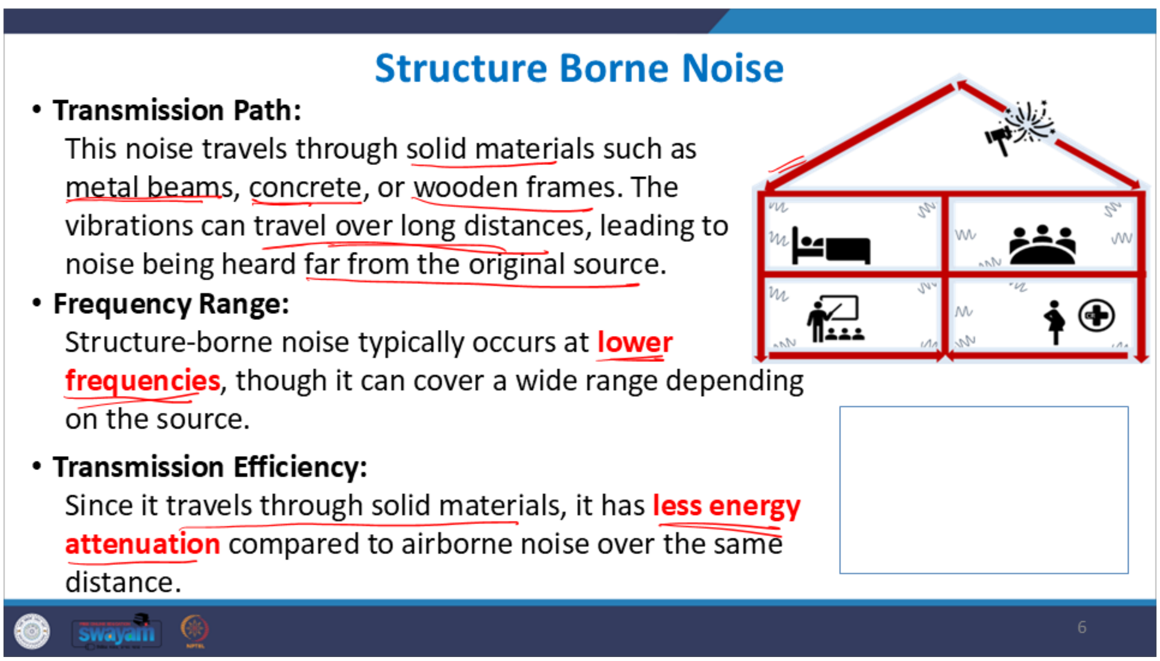
Let us say this was some kind of source attached to a long plate or a mount, and this created the noise. This noise propagated in the form of vibrations of this plate, the flexural vibrations, and then later you have a receiver here, and from here it radiated outwards and reached the listener. We have already studied the radiation phenomenon and how plates or solid structures can radiate longitudinal sound waves based on the flexural waves created in their structure. Here what happens is the waves typically propagate through the solid structure in the form of flexural vibrations or other forms of vibrations, and then after a certain threshold, they start radiating outwards into the surrounding acoustic medium or the fluid media, and then it can be heard by the listeners as audible noise.

What are the typical origins of structure-borne noise in mechanical systems? It can start, let us say, in the form of a mechanical impact or the vibration of a motor mounted on some kind of solid structure. Then the turbine that might be mounted on some solid structure, or any kind of machinery kept on the ground or in contact with some solid structure or frame, if it starts to vibrate and create noise, that vibration comes into contact with the mount or the stand of the machinery, and through those mounts and stands, It propagates as structure-borne noise. In the same way, if machinery is kept on a hard floor, then most of the noise coming out of the machinery is going to radiate through the ground or the hard floor on which it is kept in the form of structure-borne noise.

So basically, anything where solid structures come in contact, and when noise is created, it finds a pathway in terms of the solid structures to travel through. Mechanical impact, hammering at a distance on connected surfaces, can create vibrations throughout the structure, and imbalanced masses from a rotating shaft can again create vibrations. If that shaft is connected through a bearing to other parts of machinery or some other solid structures in the machinery, then that same vibrational noise will pass in the form of vibration through the various interconnected structures and propagate. One typical observation you will see is, suppose you have a speaker at your home—just a simple observation. If you are playing the speaker through the air, just hanging on some cables, and then you drop that speaker on a hard floor and play the same speaker, you will hear a much louder sound when the speaker is on the hard floor. Why?

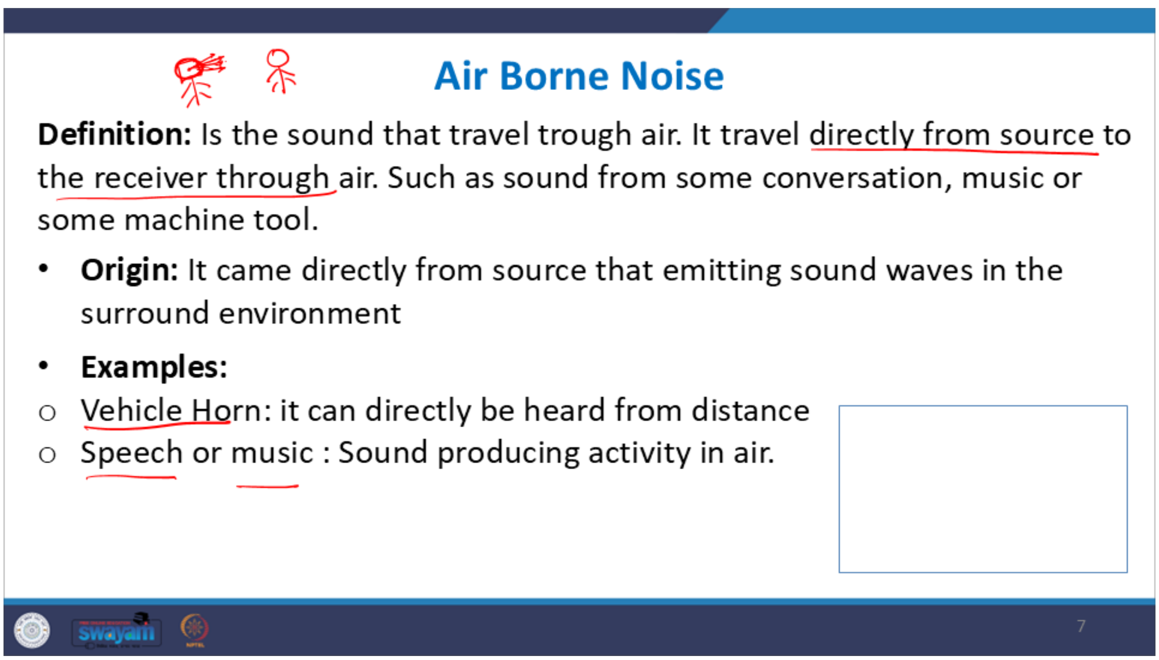
Because when that same speaker is hanging on the cable in the air, whatever noise is being created due to the movement of the diaphragm of the speaker that is directly radiating into the air, so this is an airborne noise. But when that same speaker is coming in contact with the heart floor or some kind of heart surface where it is kept, then the vibration of that speaker has another means of propagating. Whether it is the hard floor or the hard surface on which the speaker is kept, the noise created will then pass on as the vibrations in that hard surface and now will have structure borne noise as well in comparison to the airborne noise.

As you will see the structure borne noise, they usually have more problems in attenuating. They don't attenuate so easily over distance and compared to the airborne noise they have less attenuation over distance. So, in this case when the speaker is kept on a hard surface some part of the noise is propagating as structure borne noise, and it is not attenuating and it is much louder to hear.

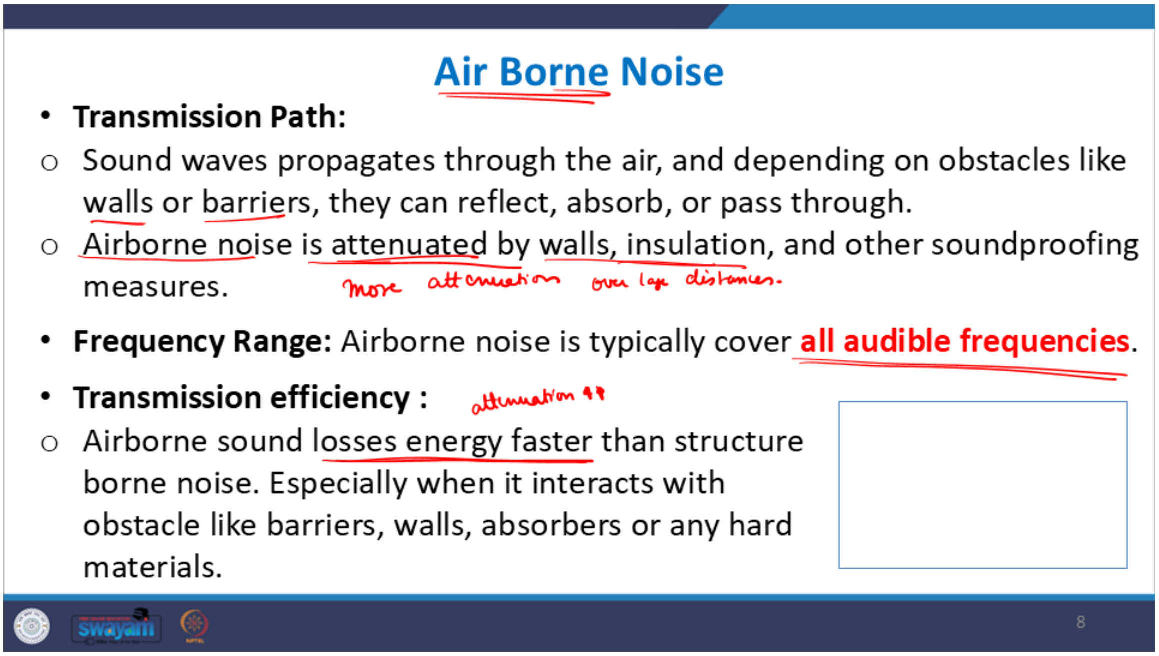


What are the transmission paths of this structure borne noise? Any kind of solid structure you can think of like the mechanical system. Suppose some kind of building is there, then the concrete beams, the beams and the frames of the building or kind of structure and they can travel over very long distances, and they can be heard very far away from the original source. They suffer less attenuation, there is less energy attenuation, and they can travel over very long distances through these interconnecting structures and even if the noise is produced much farther away but because they are getting these interconnected structures to pass through, they can be heard much louder even at longer distances. They are more dangerous in terms of noise.

The frequency content now, typically, the kind of structural elements we use in mechanical systems or even in civil structures. Most of the engineering materials have their natural frequency, or the parts that we deal with, the natural frequency is usually at the lower end. The structure-borne noise typically propagates through the structures at lower frequencies. that becomes a typical content which is the lower frequencies, and then it can cover a wide range depending on the source, but mostly it is on the lower frequency end. And as I told you, the transmission efficiency, because it travels through the solid structures, usually there is much less energy attenuation compared to the airborne. They can be heard much louder even at further distances.



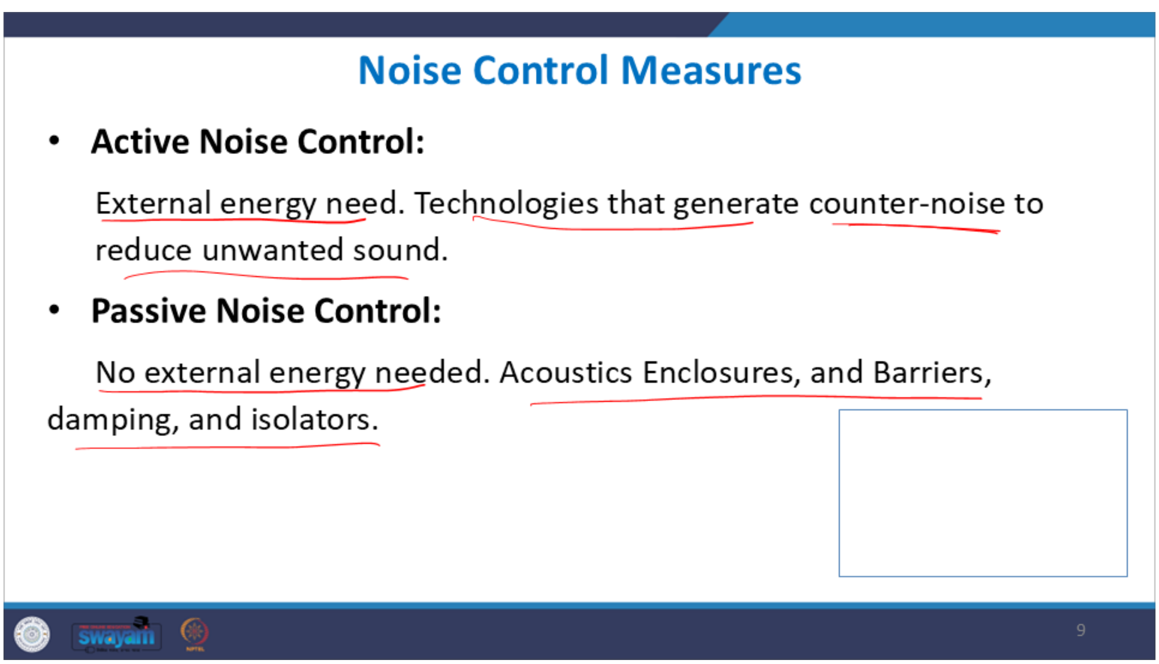
Let us see the airborne noise in comparison to the structure of the borne. Again, what happens here? In the previous case, you had some noise source which found some pathway through the structures and propagated by means of vibrations in the structure, and finally, after a certain point or after a certain threshold, it radiated outwards into the air and was heard by the listener. The structural elements were one of the major paths through which the sound wave was propagating.



But in the airborne, whatever your noise source is, let us say you have some noise source. Let us say we have a typical example of a person speaking, and then there is another listener. for example, I am speaking to you. the person is speaking and is creating these speech signals; they are radiating directly into the air. There is no structural pathway here; directly from the source, they are radiating. Directly from the source, they are going into the fluid acoustic medium and radiating forward as longitudinal acoustic waves. So, that becomes your airborne sound.

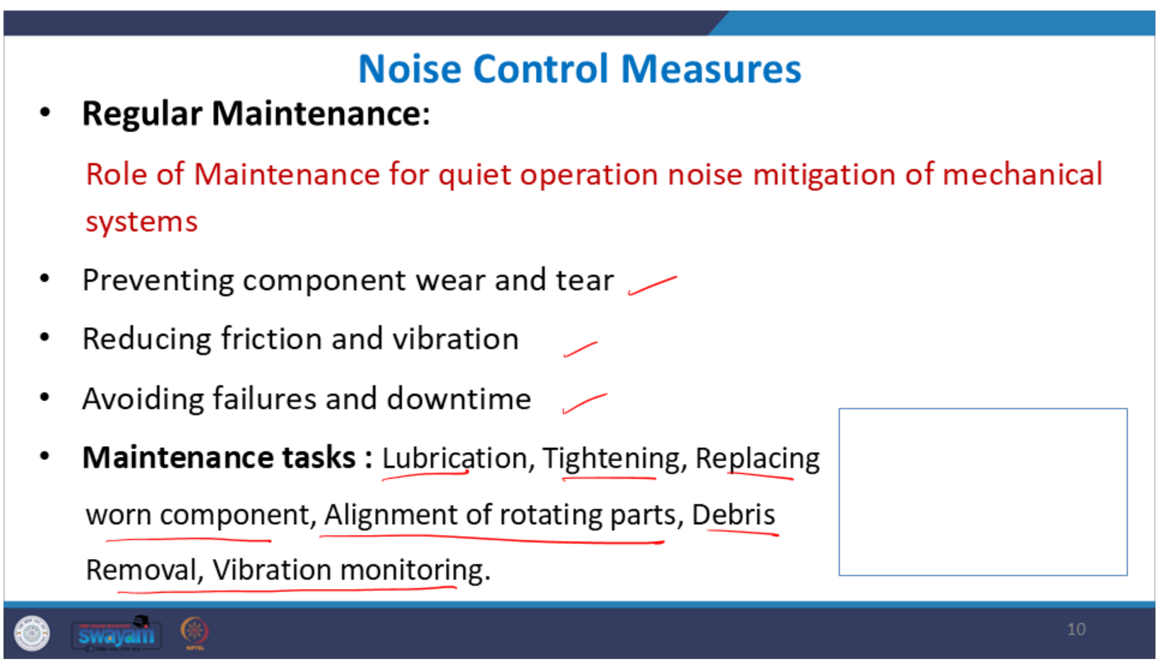
Directly from the source they are all almost all part of the sound that is created from the source is directly going into the air and then it is being received by the receiver and there is not significant involvement of structural elements in the pathway. For example, the conversations you have, if somebody is playing the guitar, once again, that is an airborne sound. Some of the machine tools are creating the sound which is propagating outwards in the air. Usually what happens is that it comes directly from the source into the surrounding environment. like the vehicle horns the speech the music etc all of this are example of airborne noise so what is the transmission path here obviously the transmission path here is the fluid acoustic medium the most common being the air or the atmosphere that we live in so air is one of the most common medium through which these sound waves are propagating so what happens when the sound waves they are propagating through the air there could be various obstacles on their pathway they can find some obstacles like walls barriers and other such materials which might be able to reflect absorb or transmit a portion of the sound waves that are incident and hence these airborne sound waves they get attenuated because in our surroundings in our atmosphere and in our environment whenever, there is a noise source and the sound waves are propagating, they are going to encounter various kind of materials and obstructions in the pathway it could be in the form of some object that might be present some person might be standing there could be walls or the buildings the trees anything that is present in the atmosphere will be able to reflect and deflect some form of the sound waves and hence because of this the attenuation keeps happening over distances and not just the presence of these objects which are in the atmosphere even the air itself has its own resistance. If I am speaking, there is an air resistance and slowly over long distances it is going to attenuate the sound waves. In comparison to structure bond, the airborne noise will definitely face a lot more opposition and a lot more kind of obstruction compared to structure bond and hence it will be attenuated more.

There will be more attenuation in general to the airborne noise over large distances and the frequency content for structure bone was typically low frequencies but here it is in all the audible frequencies that you can imagine you have the airborne noise. The transmission efficiency obviously the energy is lost much faster. as I told you again the attenuation suffered by the airborne noise is much more compared to structure bone because the sound wave gets to interact with a lot of things in the pathway. The barriers, walls, absorbers and a lot of other things.



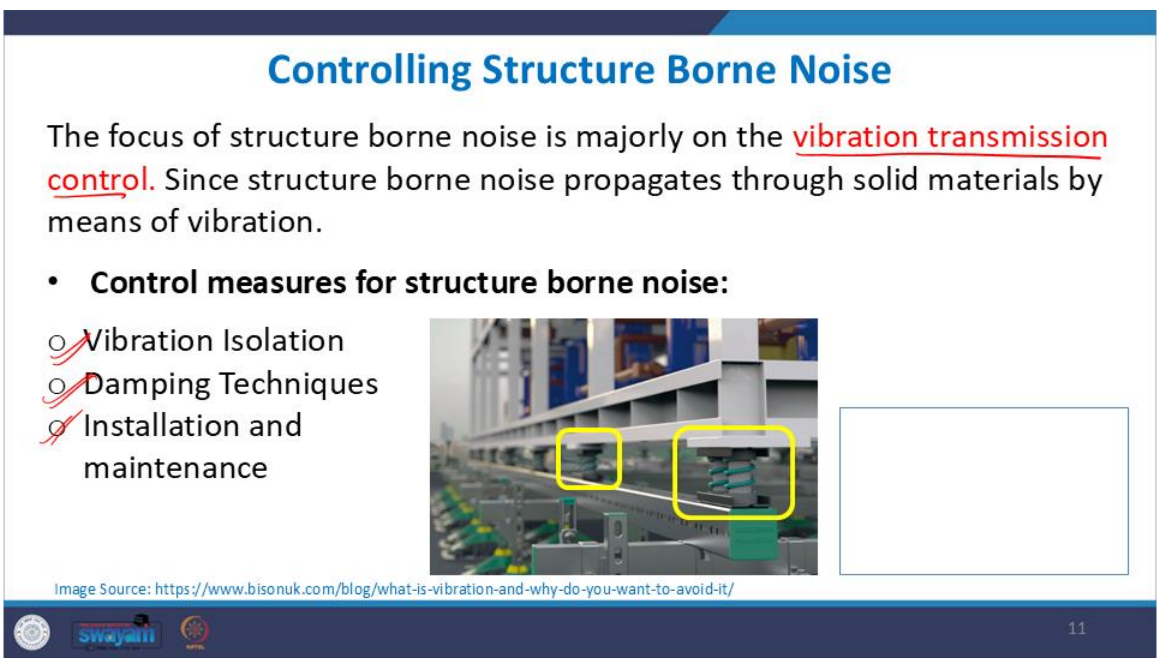
Let us see how to control these two different types of noise: the structure-borne and the air-borne, and in the typical module on noise control and the principles of noise control. I have told you that if you want to control the noise, you can do that using the source-path-receiver model, which means that you modify the source, which is the most efficient. Effective method: you simply change the source or redesign your source so that it ends up creating less noise. Otherwise, if you do not have that option—the machinery has been installed and now you are going there as a noise control engineer— then changing the machinery, if that is not an option, you will modify the pathway.

And finally, you can modify the receiver, which means you can give some earplugs or mufflers to the receiver or enclose the receiver and isolate the receiver from the source. But path modification then becomes one of the most common methods, and in the path modification, structure-borne has a different pathway and the air-borne has a different pathway. So, the control measures will then change because they have different kinds of transmission paths and different transmission strategies. Let us quickly recap the overview of how noise control is done. It could be active or passive. Active is when external energy is needed, and there are technologies through which you create an anti-phase noise to reduce your unwanted sound, and then passive technologies where no external energy is needed—some acoustic enclosures, barriers, dampers, or isolators. Some passive materials and devices are used to attenuate the noise.



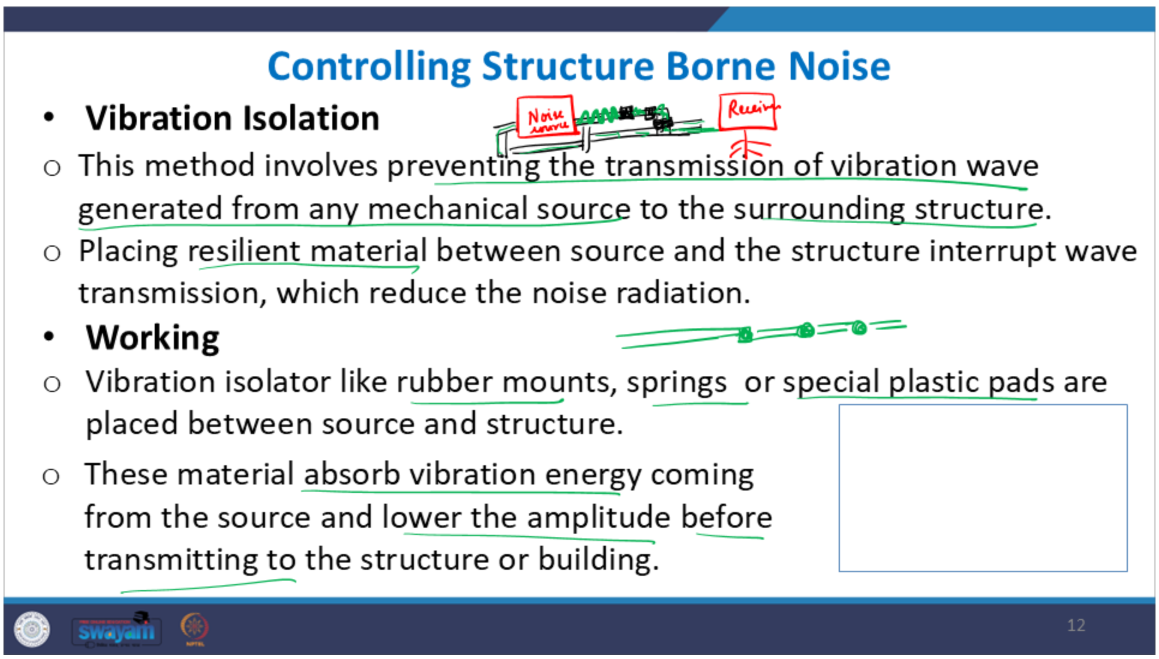
And for any mechanical system, the role of maintenance becomes very important because if the machinery is brand new or is in very good condition—properly lubricated and properly fixed and installed with no loose ends—it will run much more smoothly. There will be much less unwanted vibrations, there will be less unbalanced forces, and therefore, there will be less noise created.

The best way would be to have regular maintenance of the machinery in order to ensure its quiet operation by preventing component wear and tear, reducing friction and vibrations, avoiding failures and downtimes, and always making sure that in the plant or on the site where these machinery or mechanical systems have been installed, you have proper condition monitoring and regular maintenance checks. And the lubrication, the tightening, replacing of the worn-out components, adjusting the alignment of the misaligned parts, debris removal, monitoring of the excess vibration levels—all this, if they are done, then the machinery is going to function smoothly and it will create less noise. I had already told you, like in the previous lectures, that the smoother the function of any machinery or any kind of mechanical system, the less obstruction or the less resistance they face to their smooth operation, the less would be the noise, and the more resistance or the more obstruction they face to their smooth functioning, the more noise is going to be created.



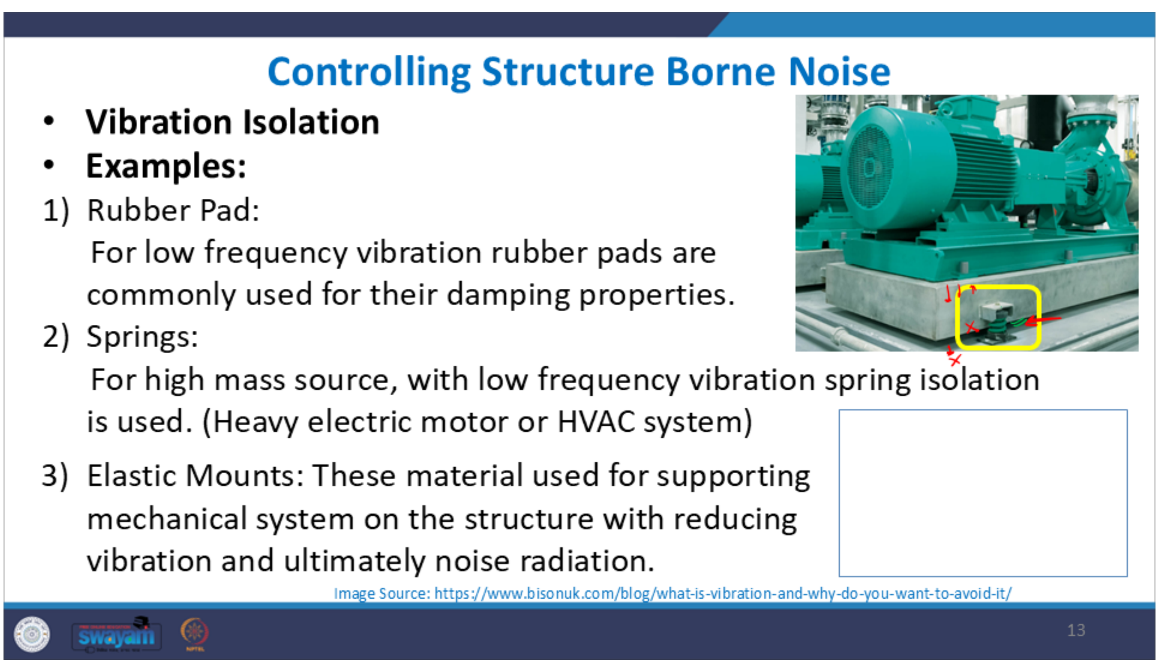
With this overview of the typical noise control strategy for mechanical systems, let us see the differences in controlling structure-borne noise and airborne noise. Airborne noise.

When we are talking about structure-borne noise, it propagates through, as I told you, that as a noise control engineer, if you cannot modify the source, then you have to modify the pathway. In the case of structure-borne noise, the pathways are these. Structural solid elements, and it propagates as vibrations through these structural elements. The main noise control strategy would be to control this vibration transmission through these interconnecting pathways. Whatever the structural path the noise is taking, you have to control the vibration transmission through various measures like vibration isolators, which could be used and installed. The major pathway of the noise between the noise source and the listener involves damping techniques, installation, and maintenance. Let's quickly have a look at these strategies one by one.

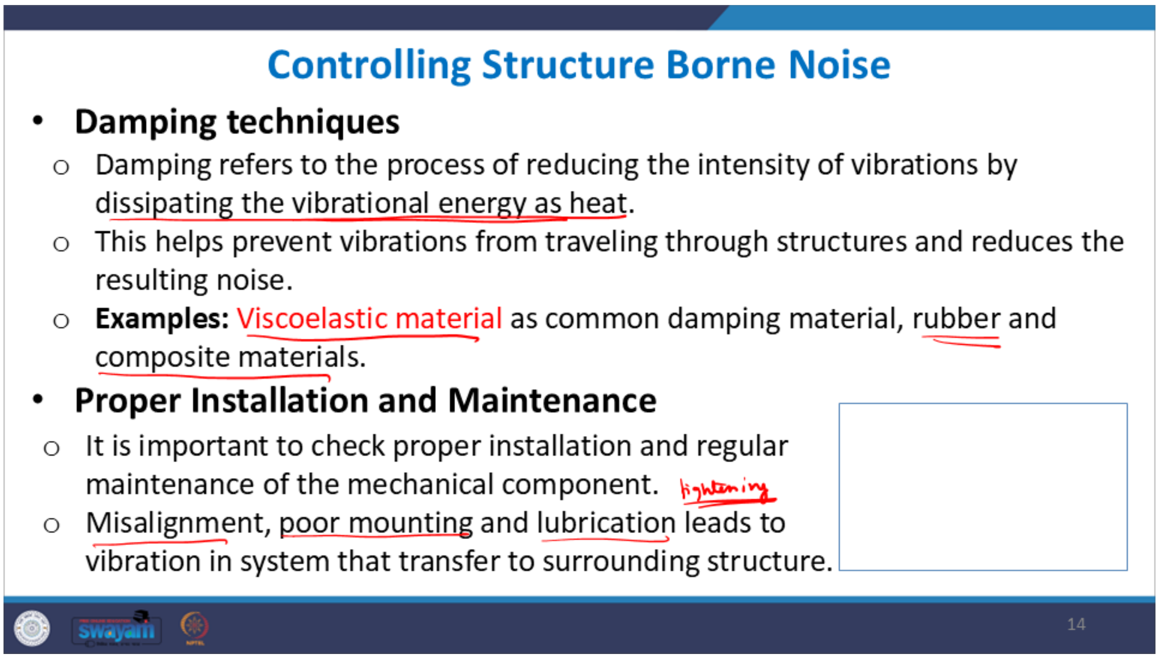


The first one is vibration isolation. What you do here is isolation, meaning that from the schematic, I can show you this is your noise.

Source, the source that is creating the noise, and this is, let us say, your receiver who is going to receive it. You have some pathways. It could be in the form of the mounts of the machinery, the frames and stands, or any other structural elements present between the noise source and the receiver. Your major noise source is propagating through these pathways. It is propagating as structure-borne noise. What you would do is modify this pathway. The principle of vibration isolation, or philosophy, is that you change the pathway so that it can isolate or stop the transmission from the source to the receiver. So whatever vibrations were going this way, suppose some kind of isolating devices you have installed in the pathway, what they will do is isolate the vibrations. Whatever vibrations were traveling, they will damp out, then damp more, and by the time they reach this end, they would flatten out. You isolate the vibration between the source and the receiver. Preventing the transmission of the vibration waves generated from the source to the surrounding structure through which it might propagate. How can you do that? You usually place resilient materials. Because they don't transmit vibration very well. Whatever structure surrounds your source, you can make it with materials that are known to be more vibration resilient. The materials which are known to dampen vibrations are not very good conductors of vibrations, if you can say. Just like we have thermal insulators or electrical insulators, we can think of these vibration isolators as a kind of vibration insulator. These are materials which will sort of reduce the flow of vibrations. They are very resilient, and they do not conduct vibration very easily. that kind of material you can use. For example, some composite materials are known to be more vibration-resilient compared to metals. And all of this can help in interrupting or stopping the transmission. Then, you can redesign your structural path. You can install some of these, mass-spring systems or isolators, such as rubber mounts, springs, and special plastic pads between the source and the structure. Whatever let us say this is your structure, you can have these isolating elements in the structure. You can sort of break the pathway by installing, at regular intervals, these breaks, such as rubber mounts, springs, or plastic pads. It will break the path of the vibration. What these materials do is absorb the vibration energy and lower the amplitude before transmitting it to the other end of the structure.



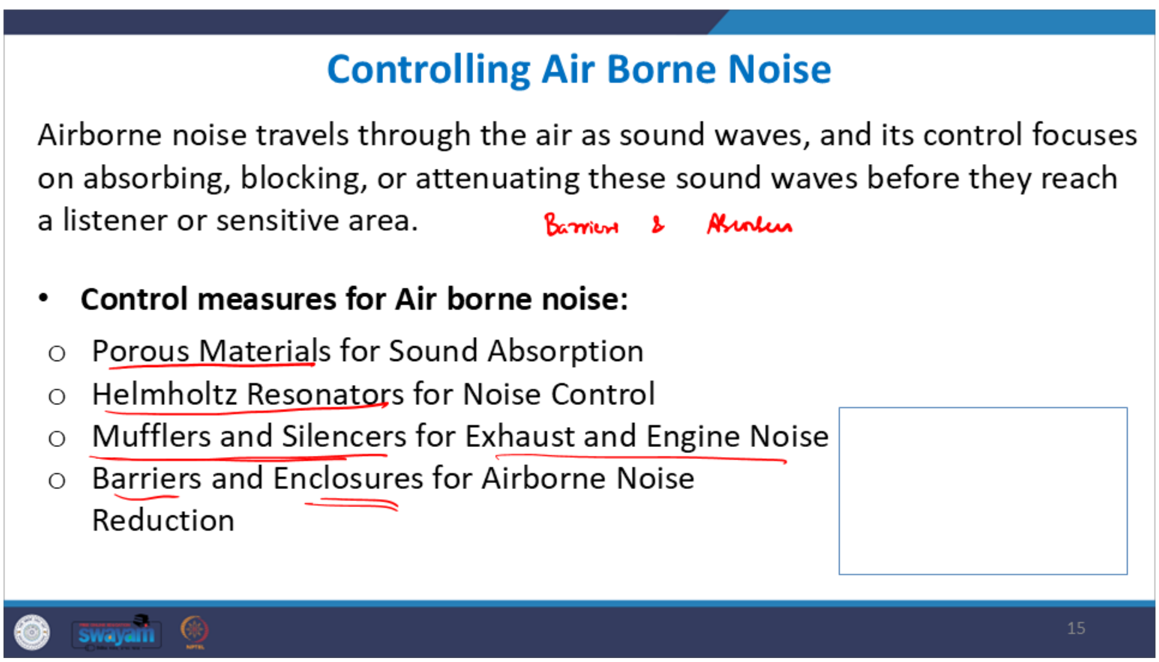
This shows some examples. Here, we have machinery directly installed on the ground, but at the connection points, these spring-type vibration isolators have been placed. The main purpose is that if vibrations are generated here, they would not propagate over here. They would be blocked by this and will not go there. From the machinery to the ground structure. Rubber pads, springs, various kinds of elastic mounts are also available, and all of these are known to stop the flow of vibration.



Now, the other technique is damping. Just like we have vibration isolation, the other one is damping of the vibration. There is a difference between isolation and damping. What isolation means is stopping the transmission of the vibration waves. You can have these isolation devices along the pathway, and they can stop the transmission of the vibration waves. But damping means a method through which the vibrational energy can be dissipated in the form of heat. Some kind of frictional elements—you can think of, some kind of means, some kind of frictional devices. If the vibration is passing through them, then due to the friction faced, the vibrational energy is converted into heat energy and is dissipated into the atmosphere, leading to the loss of energy.

So, they typically dissipate the vibration energy as heat energy. And in that process, they help in reducing the vibrations, pass on through the structure. Typically the viscoelastic materials are one of the most common damping materials used. For example, the various kind of rubbers and composite materials, they tend to be better damping material. They tend to dissipate.

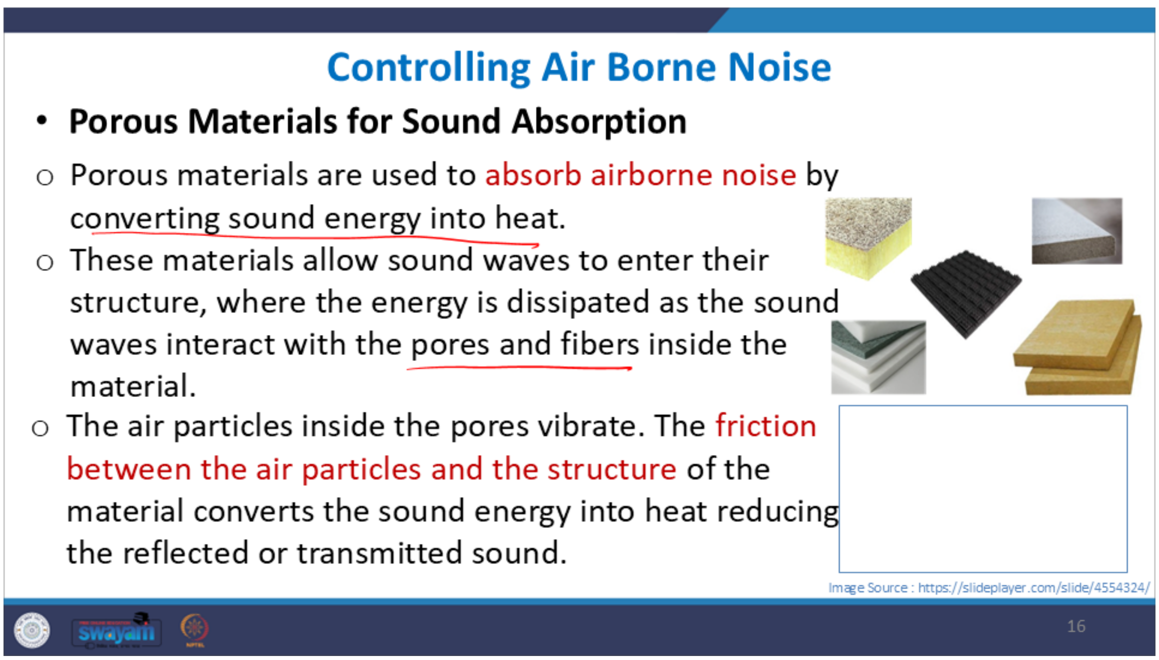
They sort of can be thought of as more resistance material. More resistive to the flow of vibration and they convert the vibrational energy into friction and heat. These kinds of materials can be used which are damp materials. A difference that needs to be understood here is that isolation is simply stopping the waves and damping is converting it into heat energy. The third major form of technique is proper installation and maintenance as already told any part just think of it, as an observer. Suppose you have machinery just go near it and you can see suppose some part is vibrating. There is most likely it is a loose part which is not properly fixed and it is able to vibrate suppose you could tighten that part using a screw even in any kind of machinery which is old and worn out and a lot of vibration is happening on some parts if you just go and tighten those parts with proper screws or fix these parts properly. Then suddenly the vibration is going to go down a lot that installation and maintenance again plays a very important role in reducing the vibrations, proper mounting, proper reducing of the misalignments, lubrications, proper fixing and tightening of the materials, making sure that there is no loose ends etcetera all of this can help in, reducing vibration.



Now, how do we control the airborne noise? Airborne noise typically travels through the air as sound waves, and an entire module was already dedicated in this lecture series on noise control. We studied various passive noise control devices, such as barriers, absorbers, and within the absorbers, we studied porous materials, Helmholtz resonators, barriers, and enclosures—these kinds of devices. all of that was a means of controlling airborne noise. We have already discussed in depth how to control airborne noise.

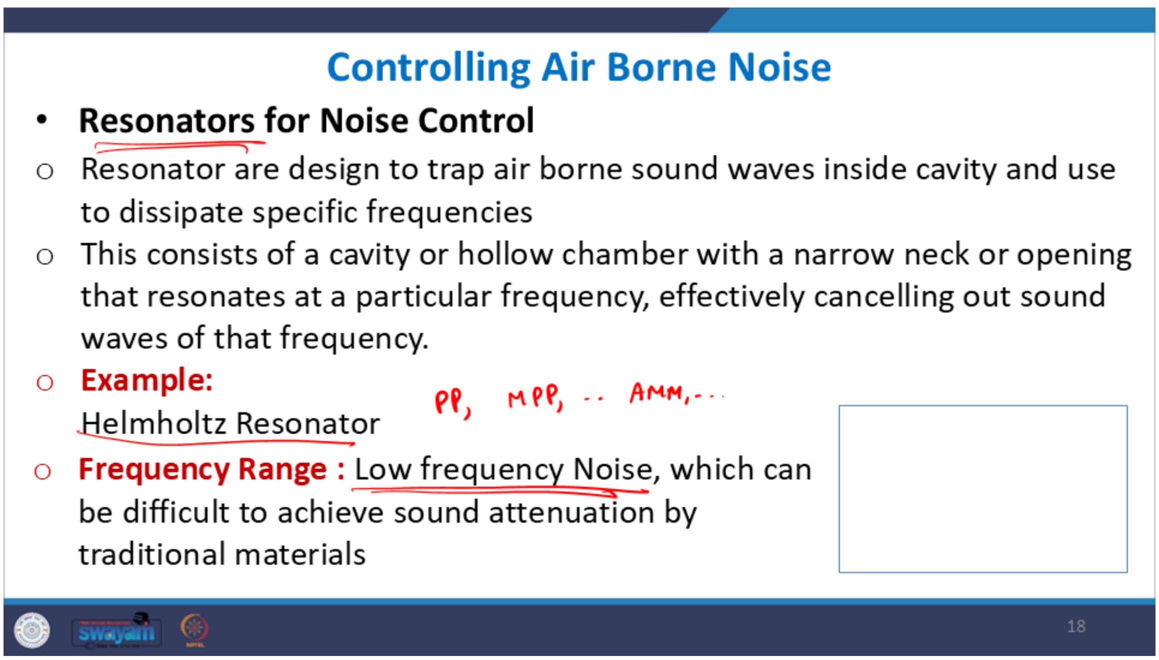
What do you do? Since sound waves travel through the air, you install structures that act as obstructions to the flow of sound waves. These structures could either be barriers that reflect sound waves or absorb and convert sound energy into heat. We have seen various kinds of absorbers, such as porous materials, Helmholtz resonators, acoustic metamaterials, perforated panels, and micro-perforated panels. All of these are resonance-based sound absorbers.

Similarly, barriers and enclosures are all methods of controlling airborne noise. For example, exhaust and engine noise can be reduced by installing mufflers and silencers, literally in every tailpipe of a vehicle.



What are these porous materials? Again, they convert sound energy into heat by dissipating heat. Why? Because the sound wave faces more obstructions through the various pores and the fibers within these kinds of materials, which convert these sound waves into heat. We have discussed in detail these porous materials and their method of operation. This can be referred to in the previous lectures. What has been observed is that these porous materials are more effective in high and mid-frequency noise control. Some of the most common porous materials include fiberglass, which is among the most widely used industrial porous materials. It is very widely used in industries and most building applications for soundproofing purposes. These days, even foams—such as open-cell foams—are used. When you look in the market commercially, you can find open-cell, closed-cell, and other types. But open-cell foams are the ones that would be handy because they act as absorbers. They allow the sound waves to enter inside and get dissipated. The open-cell foams. They are usually used in appliances and machinery.

Mineral wool is also being used a lot these days in walls, ceilings, and floors to absorb sound and improve the insulation of buildings and indoor spaces. In room acoustics, they are used for offices, studios, and auditoriums in the form of acoustic panels, baffles, and ceiling tiles. The enclosures are mostly used in industrial plants for enclosing machinery or equipment.



Then, resonators are obviously being used, especially because these porous materials are more commonly used to control high and mid-frequency noise.

For targeted low-frequency noise control, resonators are being used. It could be a Helmholtz resonator, a perforated panel, a micro-perforated panel, or an acoustic metamaterial. All of these are means of controlling low-frequency noise. They use the resonance phenomenon and are able to achieve sound wave attenuation.

Controlling Air Borne Noise

- **Resonators for Noise Control**
  - **Applications:**

perforated panel, Helmholtz resonators, - - expansion chambers.

1) **Automotive Exhaust system :** Helmholtz resonators are commonly used in vehicle exhaust systems to reduce engine noise, especially low-frequency rumble.
2) **Enclosure:** Machines or equipment producing noise can be enclosed in structures lined with porous materials.
3) **Acoustics Barriers :** Barrier material using resonator for air borne low frequency noise control.
   Example : Local Resonance Sonic Cystal Acoustic Barrier

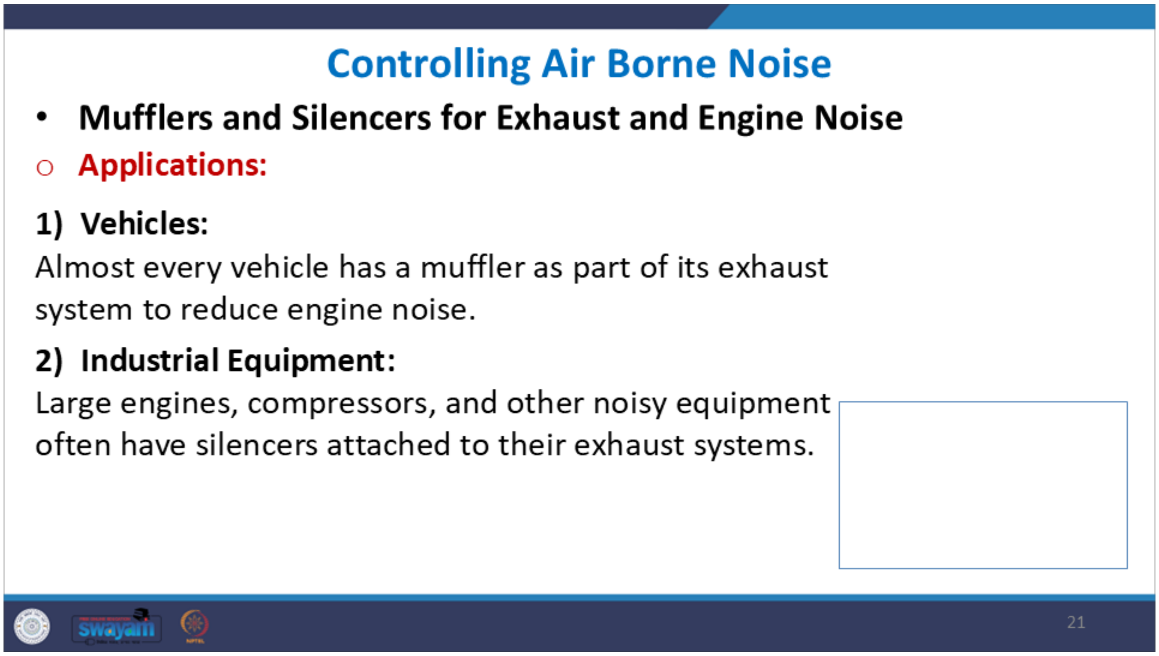
Image Source: https://www.thirdgen.org/forums/exhaust/626475-helmholtz-resonators

They are now being applied these days even in automotive exhaust systems where you have silencers. In the silencer, you can find perforated panels, Helmholtz resonators, and various kinds of expansion chambers. These act as resonators. Typically, these are used in automotive exhaust systems. Even in some newly designed enclosures, they are being incorporated, and in some newly designed acoustic barriers, we are now incorporating these resonator-based solutions. These are the new technologies that are emerging, like the local resonance sonic crystal acoustic barrier that is now being used.

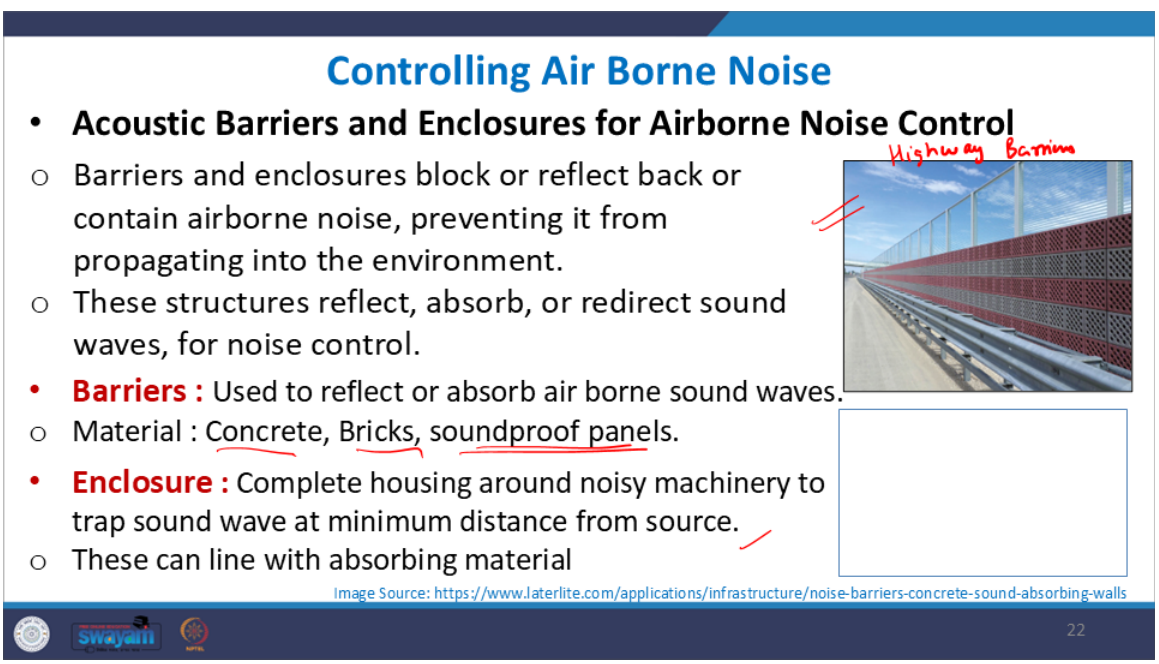
Controlling Air Borne Noise

- **Mufflers and Silencers for Exhaust and Engine Noise**
  - Mufflers **(silencers)** are devices used to reduce the noise produced by the exhaust of engines, particularly in vehicles and machinery.
  - They work by either absorbing sound, reflecting it, or interfering with it to reduce its intensity before it exits the exhaust system.
  - Mufflers typically use a combination of chambers, baffles, and perforated tubes to reflect and cancel out sound waves.
  - As the exhaust gases pass through the muffler, the sound waves are broken up and their intensity is reduced.

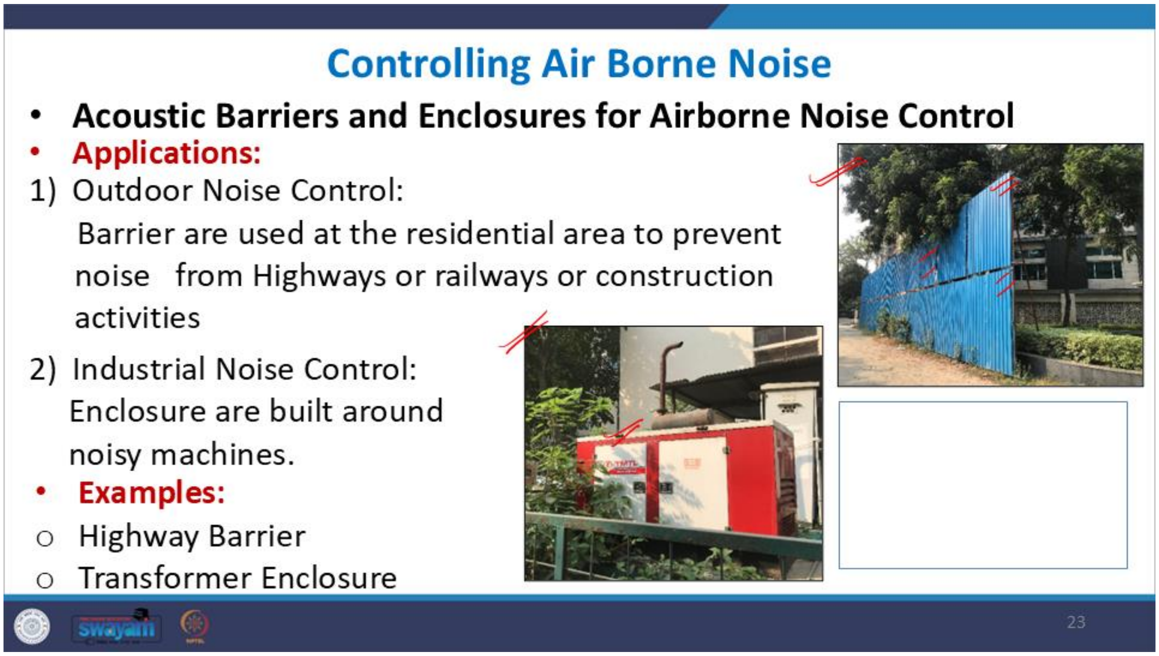
The mufflers and silencers, as already mentioned, are used in the exhaust and the engine. You can see them, and they have various kinds of compartments with perforations. The perforations help in the thermo-viscous losses, and then we have the Helmholtz cavity, which also helps with resonance-based sound absorption.



They are applied in vehicles and industrial equipment wherever we make use of the exhaust and the engine.

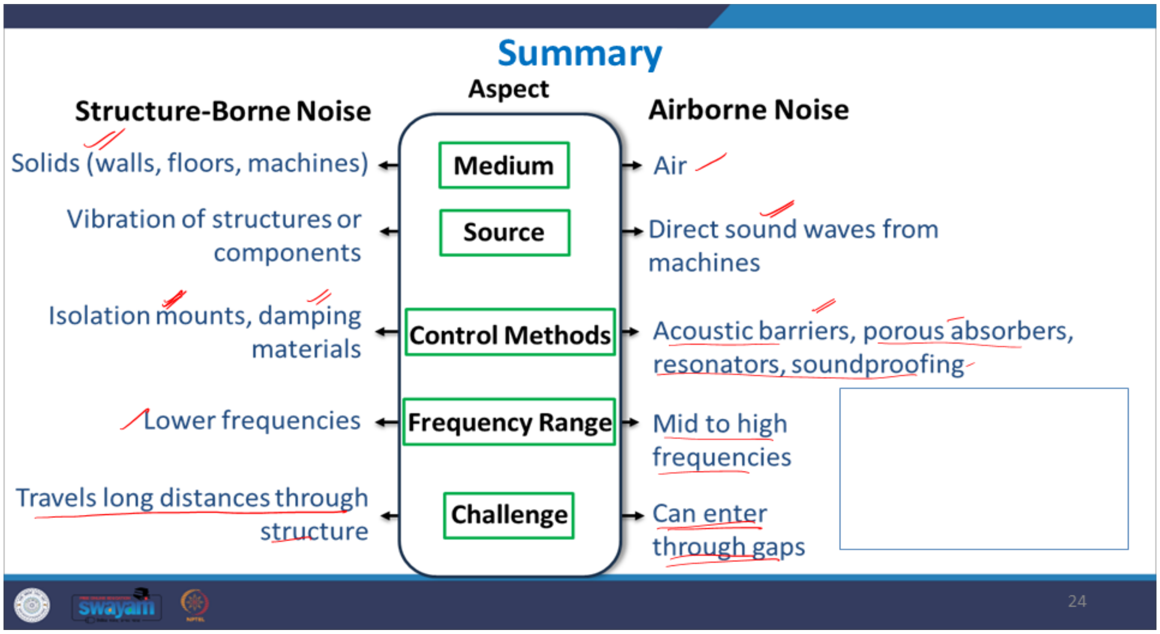


The acoustic barriers and enclosures are used for airborne noise control. These are made of concrete, bricks, or other kinds of soundproof materials. Barriers are there, especially on highways. These highway barriers are there. And even if there are barriers at the construction sites or enclosures in the construction sites.



These are the images taken from around the campus of IIT Roorkee, where you can see that. These barriers are installed wherever construction is happening so that they can contain the noise within the construction site and prevent it from propagating outside to other residential and quieter areas. In the same way, the transformer rooms are always enclosed, completely using these enclosures, and all of these are methods of controlling airborne noise.

This is a quick summary of what has been taught in this lecture, which could be used as a go-to guide for any noise control engineer. For structure-borne noise, the medium is these solid structures: walls, floors, and machinery parts; for airborne noise, it is air. The source is usually the vibration of the structures or the components. But here, the source is that the sound waves are directly radiating from whatever machinery or person is present. In the control methods.



We basically have isolation. We try to stop the vibration from propagating through. We can either isolate it or damp it. And then, in the control methods here, we can install obstructions in the pathway. In the air, we could have barriers, enclosures, resonators, and various other soundproofing materials. And the frequency range here is lower, while here we have mid to high frequencies in the airborne case.

The challenge is that it travels over long distances with much less attenuation and is much harder to control. And here, the challenge is that even a small gap in your enclosure—or even a small gap—and it will propagate through. Things need to be properly sealed here. With this, I would like to close the lecture. Thank you for listening.