NOISE CONTROL IN MECHANICAL SYSTEMS

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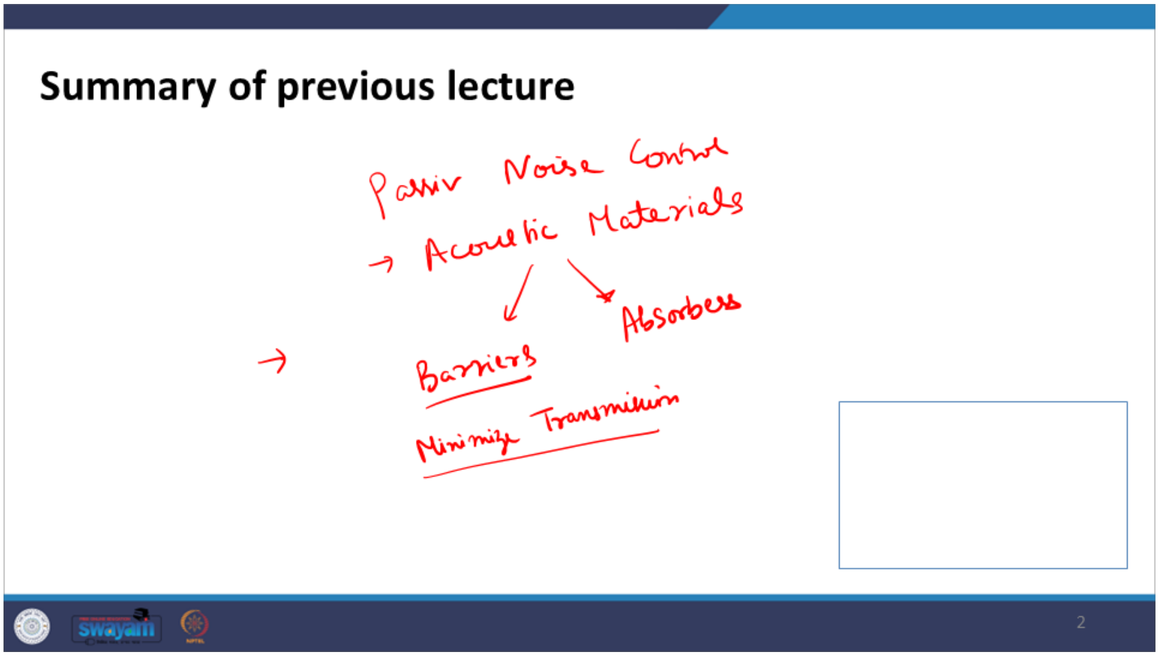
Week:7

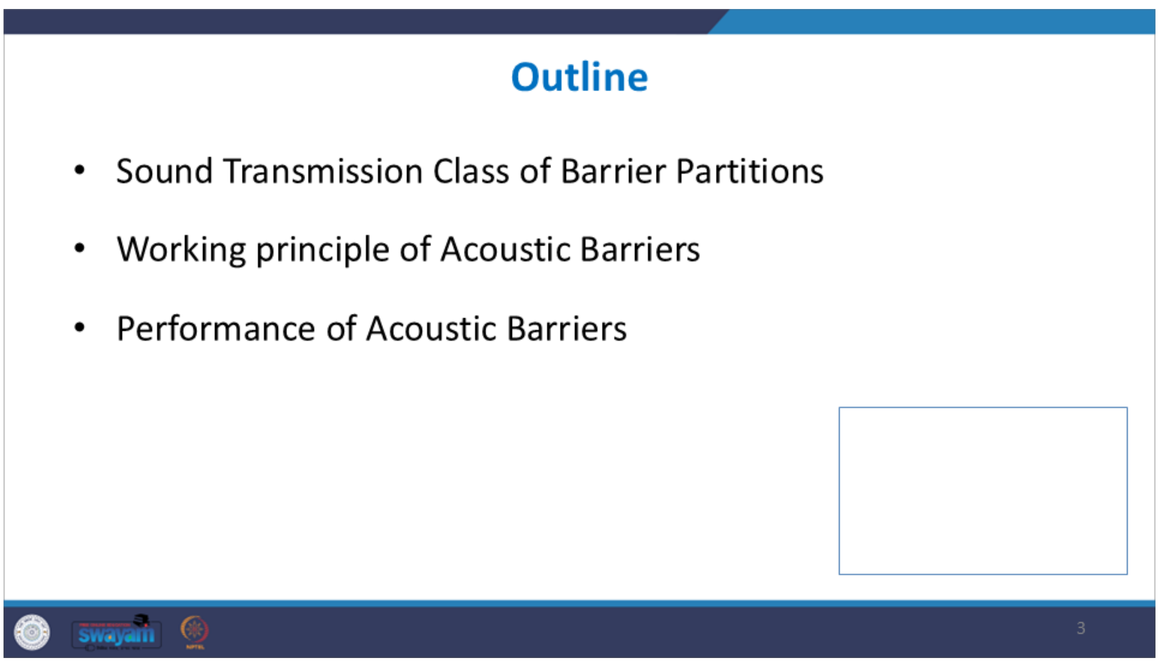
Lecture:033

Lecture 033: Sound barriers

Hello and welcome to this lecture on sound barriers in the course on noise control in mechanical systems. So here in this lecture, we have started the discussions on passive noise control. We are now focusing on passive noise control. We have studied the concept of acoustic materials, or the materials typically used to control or manipulate sound waves, and how they can be used for passive noise control. A broad classification of these acoustic materials includes barriers and absorbers.

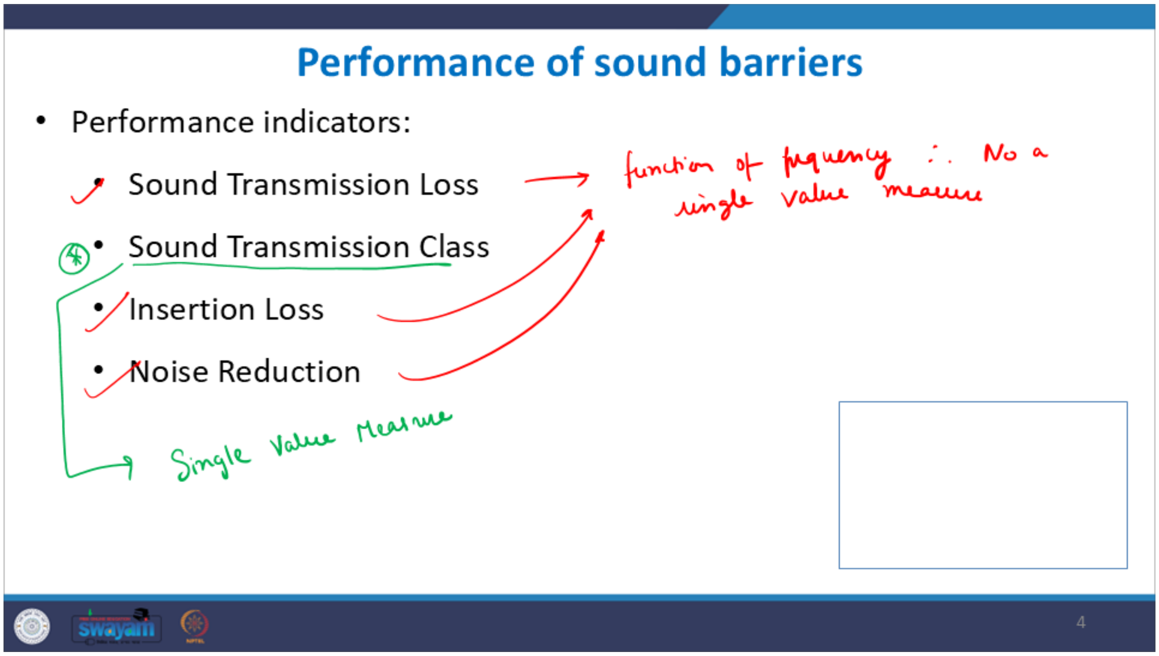
Barriers are materials that minimize sound transmission through them. We have already discussed sound barriers and their typical performance measures. Today, we will discuss another performance measure: the sound transmission class assigned to various barrier partitions.





Then, we will study the working principle of a typical acoustic barrier and the mathematical formulation of its performance in a particular setup.

To quickly summarize, the performance of sound barriers can be evaluated using various measures.

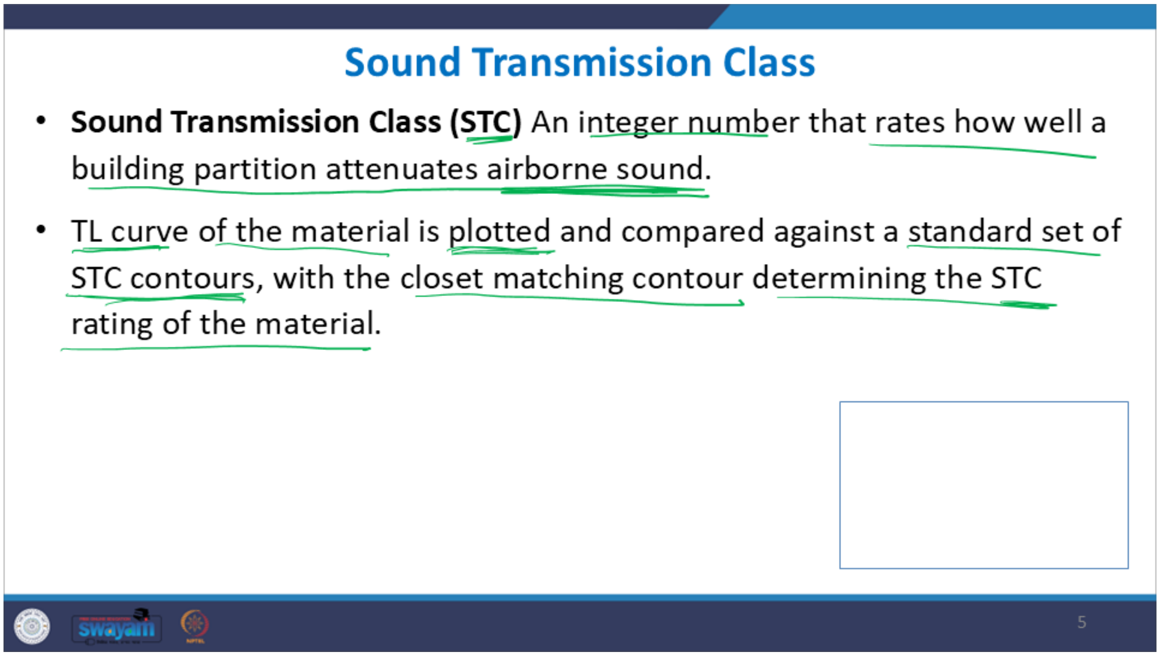


These include sound transmission loss, insertion loss, and noise reduction. All of these are not single values but are functions of frequency. They are not single-value measures. Since they are functions of frequency, they are not single-value measures. Today, we will discuss the fourth type of performance measure: the sound transmission class, which is a single-value measure.

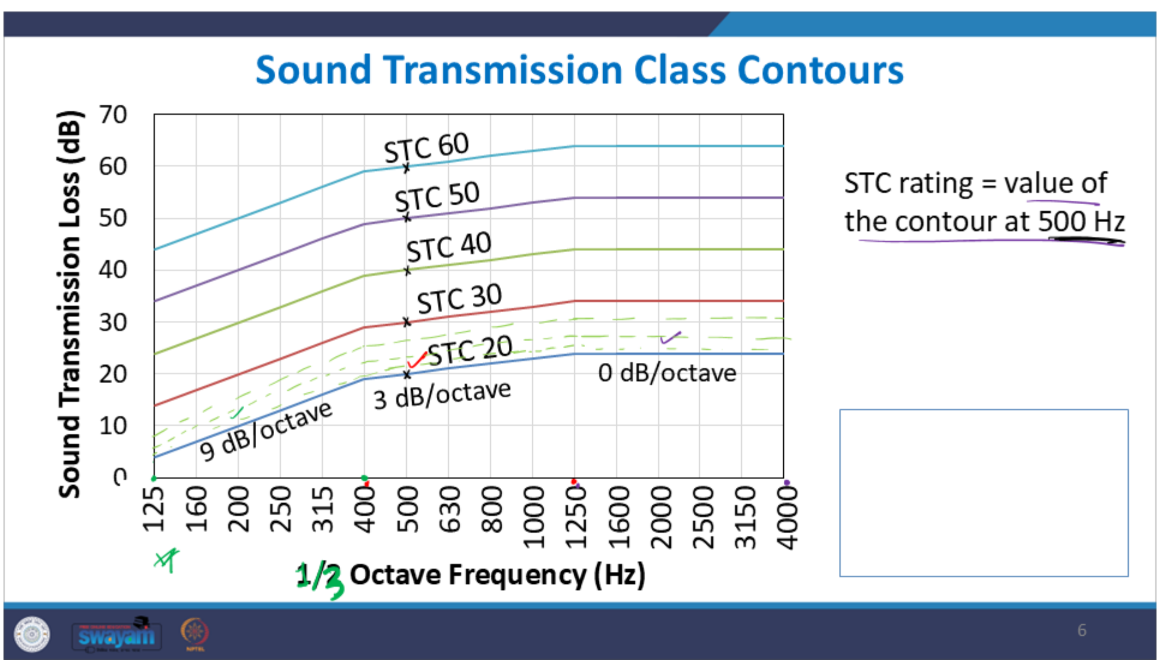
Based on how the one-third octave spectrum is obtained when the sound wave passes through this one kind of partition, and the transmission loss spectrum is what we get. We can compare it to some reference contours to finally get a single value, which gives you the sound transmission class of that particular barrier partition.

Let us see sound transmission class, or STC. It is an integer number that rates how well a building partition attenuates airborne sound. Here, just remember that it is typically used to find out how it attenuates or reduces airborne sound; the structural sound is not taken into consideration here.

The TL curve of the material—so what happens is, you first obtain the transmission loss of that particular partition wall and find out how much the transmission loss. From that particular material, you plot it in the octave spectrum against the frequency.

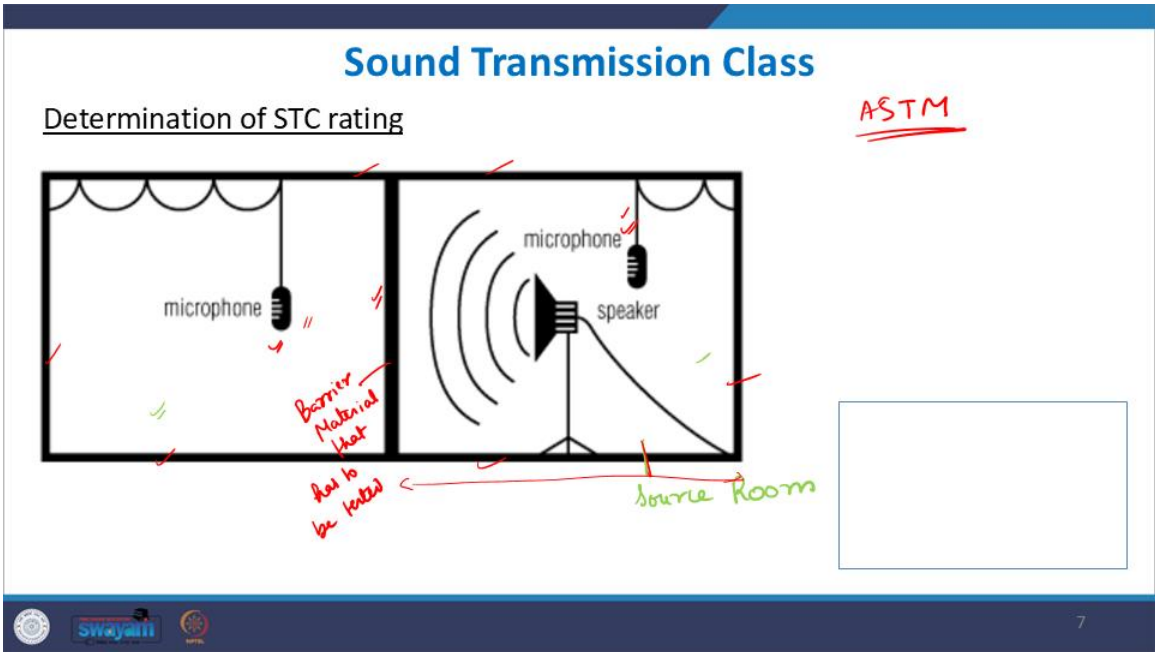


Then, just like we had the noise criteria curves—NC, NR, RC, and NCB curves—where a set of standard contours were there, the octave spectrum of a space was compared against these standard contours, and a single-number rating was given. In the same way, the TL curve is obtained. And then, it is compared with some standard set of sound transmission class contours. These are the standard contours, and the closest matching contour will determine the STC rating of that particular building material. This shows the family of the STC curves. Here, the curve has a standard shape.

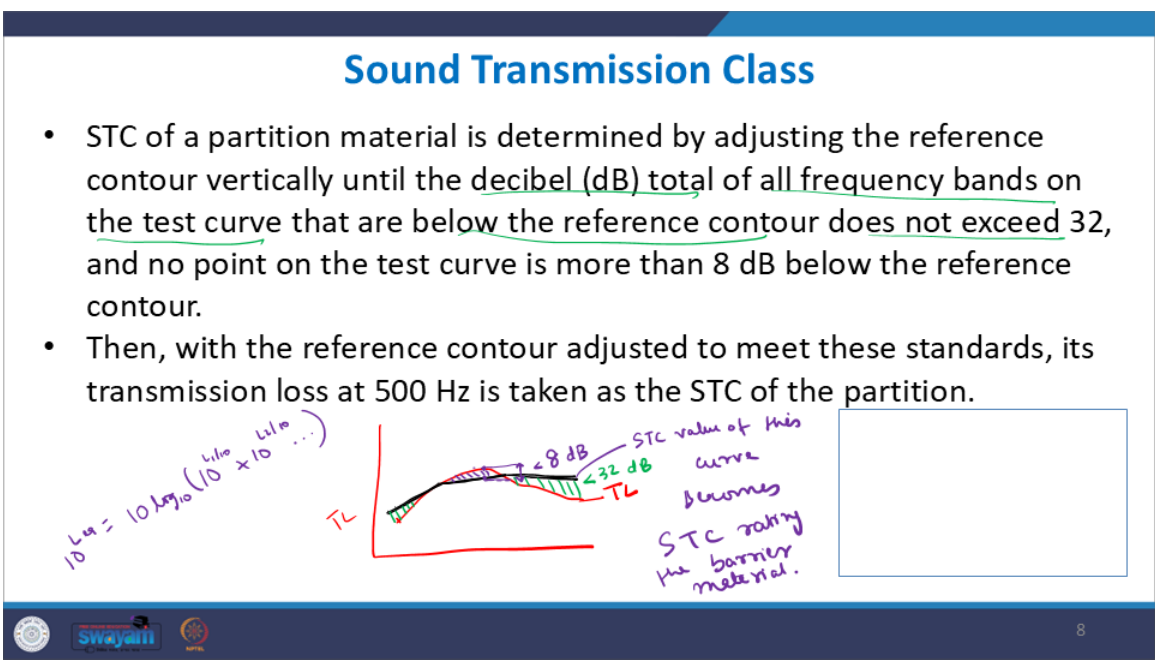


The first part of the curve starts from, the one-third octave spectrum over here. In the one-third octave spectrum, starting from the middle frequency of 125 Hz. To about 400 Hz, the curve follows a slope of 9 decibels per octave, and in that slope, you have a straight-line curve. It is a straight line with a slope of 9 decibels per octave in this region. Then, from 400 Hz till 1250 Hz, the curve follows again a straight line with a slope of 3 decibels per octave. And then, followed by that, from 1250 to 4000 Hz, the curve becomes a flat line; the slope becomes 0 decibels per octave. All the curves they will have the same shape, one sloping, one steep line 9 dB per octave followed by the 3 dB per octave and then a flat line in the 3 frequency regions and what is the, so these are the reference STC contours or STC curves. And, the value associated with the difference curve is the value where that contour is crossing the 500 Hz octave frequency so over here you can see, this particular curve here it is exactly at 500 the value of the value of the STC is 20. We give it a value of STC 20. Then the same curve, 9 dB per octave, 3 dB per octave and 0 dB per octave these lines you plot one by one you can plot it and wherever value it achieves at 500 Hz becomes that STC number. Here you can see 30 decibels and then here this curve 40 dB is the value at 500 Hz. It is assigned STC 40 and so on STC 50 and 60 and so on, and in the middle of them as in you can have infinite number of STC contours so you can have the STC 21 following the same pattern, STC 22 following the same pattern which means the same slopes in the same defined frequency regions and so on. There can be many such STC curves, all of them following the same kind of slopes in the predefined frequency region and whatever value comes based on these shapes at the 500 Hz becomes its STC number. I hope with this description it is clear what it how to obtain the standard STC curves. You simply draw a line from 125 to 400 and the slope of the line should be 9 dB per octave followed by a line from 500 to 1250 with a slope of 3 dB per octave and so on. And you can keep drawing such lines at any point. Infinite such lines which are a family of the STC curves.

Now how do you now determine the sound transmission class typical class of a material or a partition. It is usually used to, sort of characterize and rate a partition wall in a building. Let us say you have got one room where you have a microphone and another room. This is called the source room. In this room, you have this reference source, which is generating your noise, and then you have a partition. You have some standard dimensions. You can refer to the ASTM standards for finding out how the STC or the sound transmission class is determined. You have a room which is a source room where you play the noise source, and you have a speaker here, and then a partition wall, and then the other room. All the other walls are made of the same material. Which is supposedly acoustically hard, and only this one is the barrier material that has to be tested—this wall here that has to be tested.



And then you have a microphone here to measure, so that the sound intensity level is measured here before the material. And you have the sound intensity level here, and based on the two measurements, you can find out the transmission loss due to this particular partition.



Once you obtain the transmission loss by testing a particular partition in this manner, you pass the sound waves, you measure the sound pressure level before, and the sound pressure level after passing through the material, and compare those values to get the transmission loss. Then after that, what you do is, let us say, you obtain a particular transmission loss curve. This is your transmission loss curve for the tested material. And now, that there are various such standard STC contours like this. You start from the STC 0 value, and you keep going up till you reach a contour. Suppose I reach finally this contour. So, till you reach a contour where what happens is that this condition is satisfied that finally, the total decibel of all the frequency bands in the test curve that are below the reference contour they should not exceed 32. Let us say finally, you start drawing these various curves and what you get is let me get to a single contour just to show you.

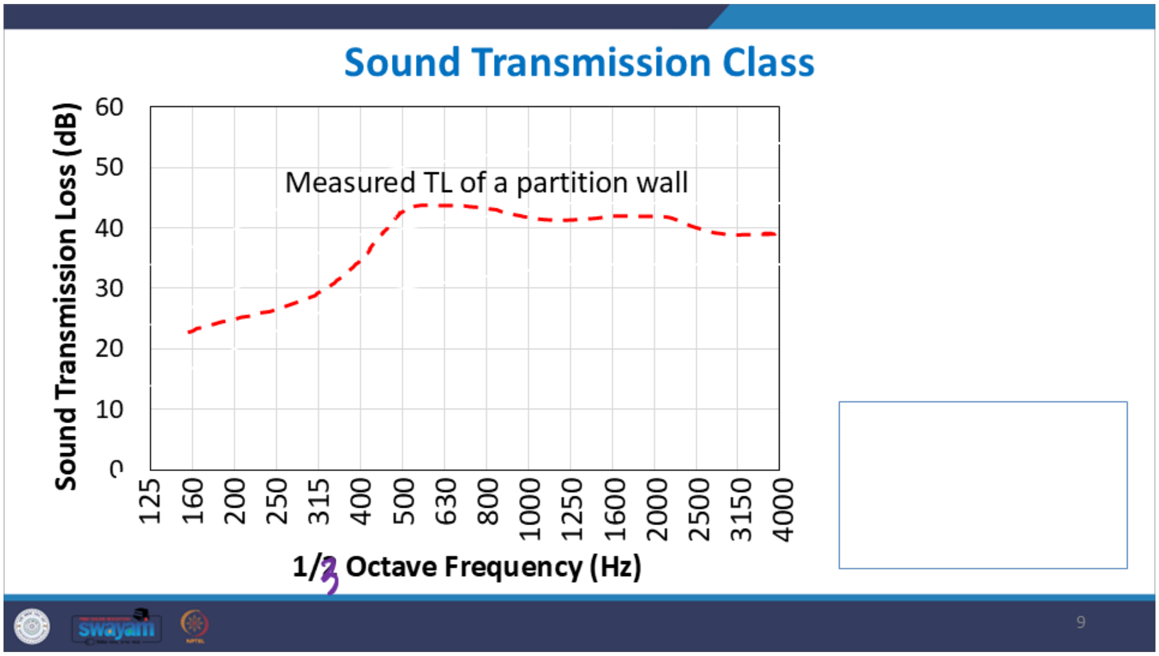
Let us say you started drawing the various contours and you finally, reached one reference contour where this is your reference contour. Here what should happen is the total dB of all the frequency bands in the reference spectrum that are below it. These areas over here which are below it. I think it is better to draw a different reference spectrum that makes it more believable. let me draw once again the TL spectrum of a material and suppose you start, drawing the various STL contours, and you go up from STC 0 and you go up in steps and finally you reach one particular contour where suppose it see it looks like this. Let us say and the very first contour where this condition gets satisfied that the net decibel total below it is less than 32 dB and the net decibels above it the total you sum up these dB's decibel combination is something like this

$$10^{Leq} = 10 \log_{10}\left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} \ldots\right)$$

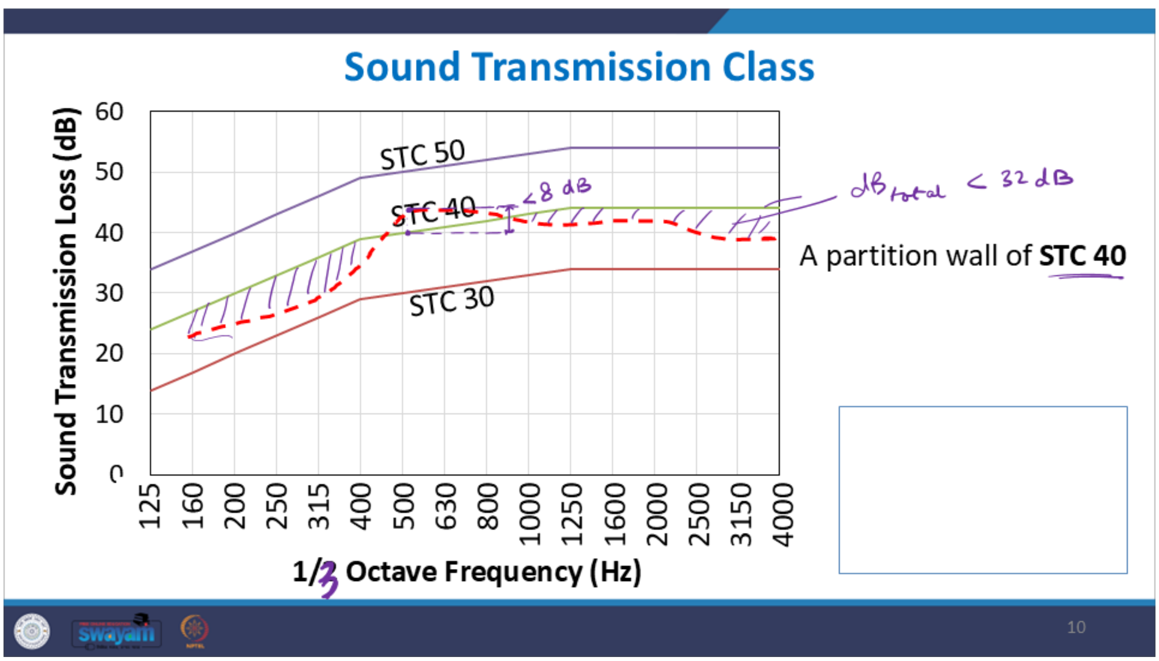
this is how you combine the decibels so when you combine the decibels the total decibels that are below must not be must not exceed 32 and those above and no point on the test curve and no point that is above so the maximum value of this difference the point that is above should not be less than 8 dB. The maximum point on the test curve which is above the reference STC contour this value here it should not exceed 8 decibels and all the points that are below they should be smaller than 32 decibels.

The very first curve that achieves this condition then becomes then that STC value the STC value of this curve. Becomes the STC rating of the barrier material that you are testing.

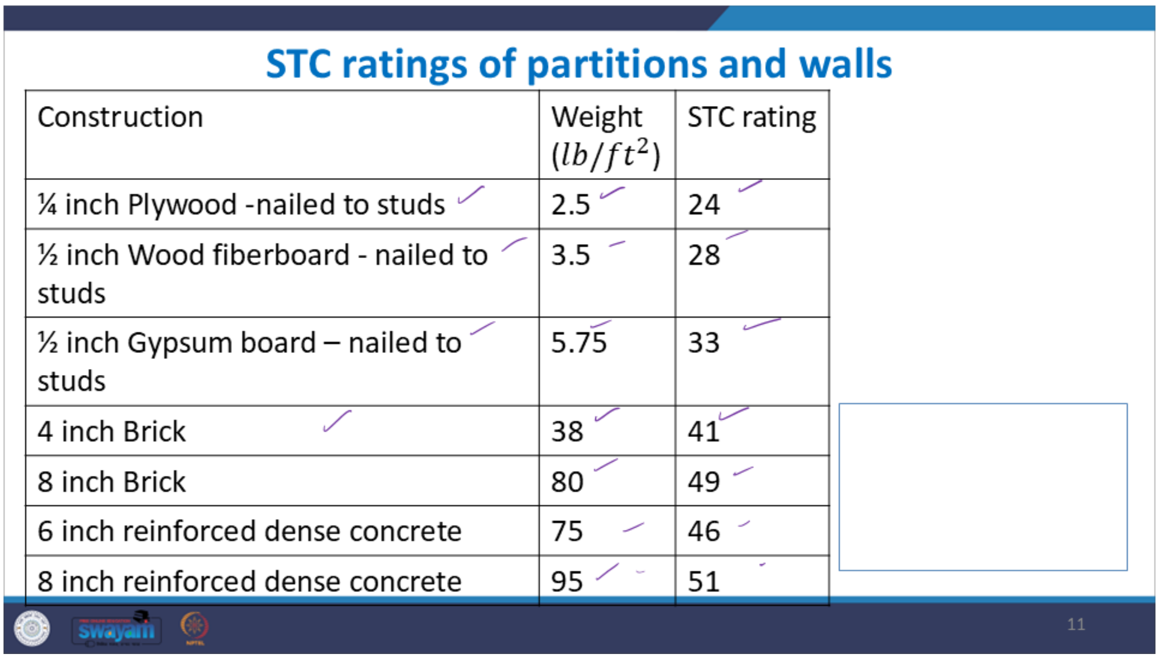
Let us see for example, this is the measured transmission loss of a partition wall where, this kind of a typical test environment has been used and this is the measured transmission loss.



Now, you can start by, drawing the various, STCs from STC 0, STC 5, 10, 15 like that various kind,



and let us say at a certain point here STC 20 the net values here, the dB total which is for the curve, the dB total of all the frequency bands on the test curve that are below the reference contour which are these values. The dB total of all these things should be smaller than 32 decibels and this is the highest value which is above the reference contour the difference between them is less than 8 dB. The closest curve that you get becomes your STC 40. The very first curve that satisfies this again this is one third octave frequency. This is how you assign the STC 40 to this particular partition wall.



STC ratings of partitions and walls

Construction	Weight (lb/ft^2)	STC rating
¼ inch Plywood -nailed to studs	2.5	24
½ inch Wood fiberboard - nailed to studs	3.5	28
½ inch Gypsum board – nailed to studs	5.75	33
4 inch Brick	38	41
8 inch Brick	80	49
6 inch reinforced dense concrete	75	46
8 inch reinforced dense concrete	95	51

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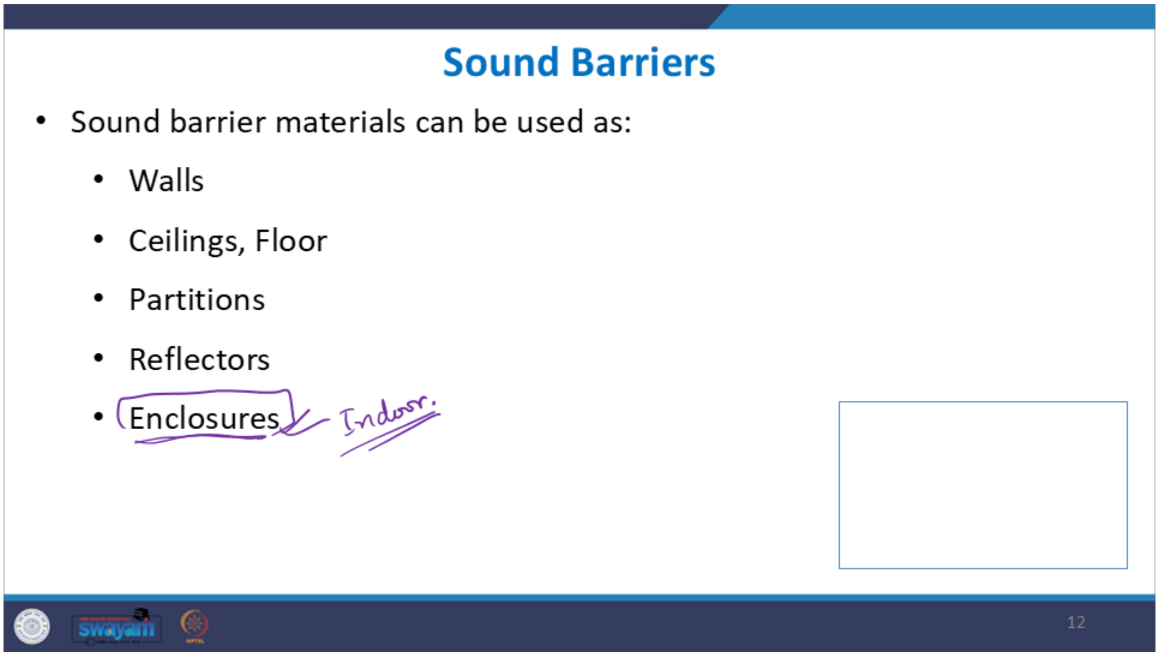
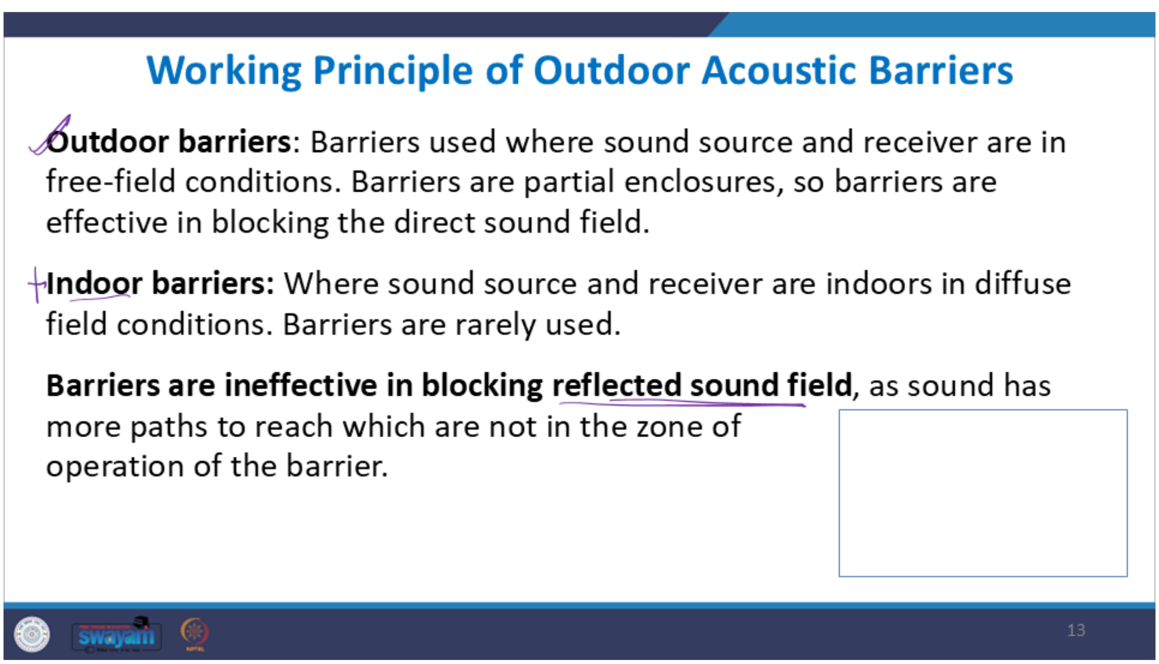
Some of the STC, recommended I will just say, this is the STC not recommended, but the measured STC ratings of different partitions and walls. Now, just remember that when you are using a particular material, the transmission loss achieved at the material depends on a lot of properties. It depends on what material you are using. And at the same time what are the dimensions of the wall, what is the thickness, length and the breadth of the wall and how the wall is mounted, what are the end conditions or support conditions of that wall. whenever the STC rating of a particular partition or wall is given then the material used to make it is specified. Then, the thickness is also specified, as well as how it is mounted or what its boundary conditions at the edges are also specified, and that completely defines your particular partition, which then becomes your STC rating. These are the various things you can look at. It can be found in books. And so on. You get the material, which has a specific density, thickness, and the way it is mounted, and you obtain the STC rating.

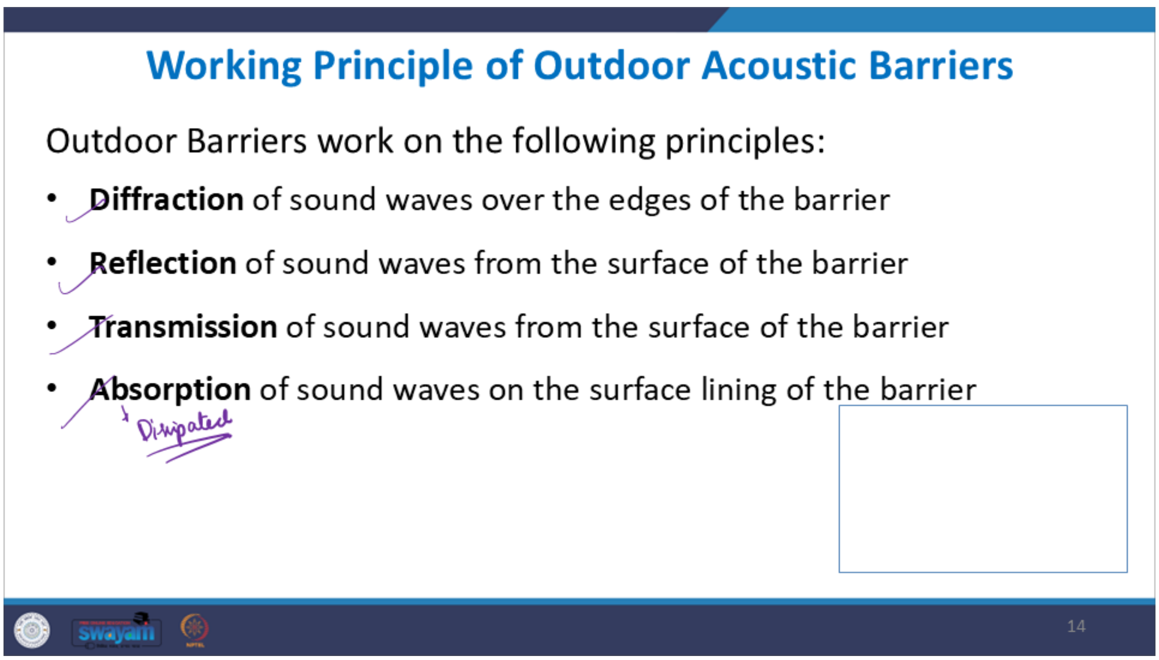
You have the STC tables available. Any noise control engineer can buy a handbook on noise, vibration, and control. In these handbooks, these standard tables are always available.



As a designer, you can choose the best STC partition for your building, sound barrier materials can be used for many things. They can be used to make walls, ceilings, floors, and various partitions in buildings. They can also be used as acoustic reflectors in pathways for some experiments, and they can be used as enclosures.

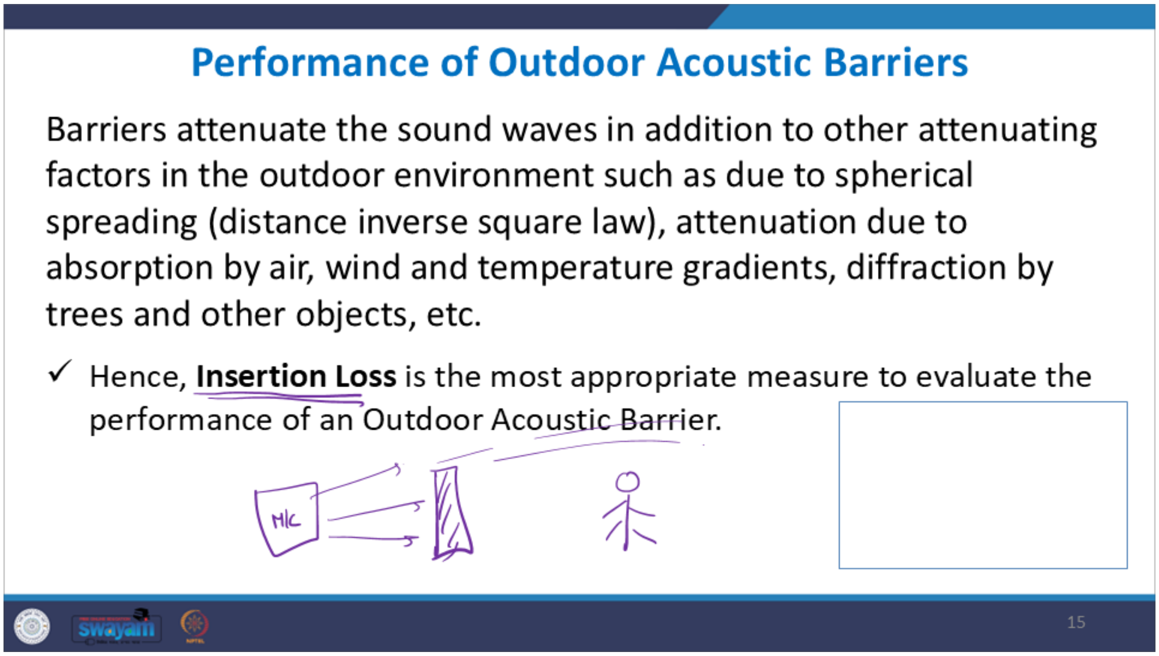


Let us see the working principle of outdoor acoustic barriers. Whenever barriers are used indoors. The barriers are effective in reflecting back and blocking the direct sound field. But if it is a highly reverberant environment with many sound paths through which sound can reach the receiver then, in that diffuse field environment, the performance of the barrier essentially reduces because it is a partial barrier. Therefore, more barriers are usually used in the outdoor environment and not in the indoor environments. In the indoor environments, we use the enclosures, In the indoor environments, they can be used, but barriers are usually used in the outdoor environments. Because they are ineffective in blocking these reflected sound fields when there are an infinite number of paths through which the sound wave can reach the listener.



What is the working principle of these outdoor acoustic barriers? First is the diffraction of the sound waves that happens over the edges of the barriers, then the reflection of the sound waves from the surface of the barrier, the transmission of the sound waves from the surface of the barrier, and the absorption of the sound waves on the surface lining.

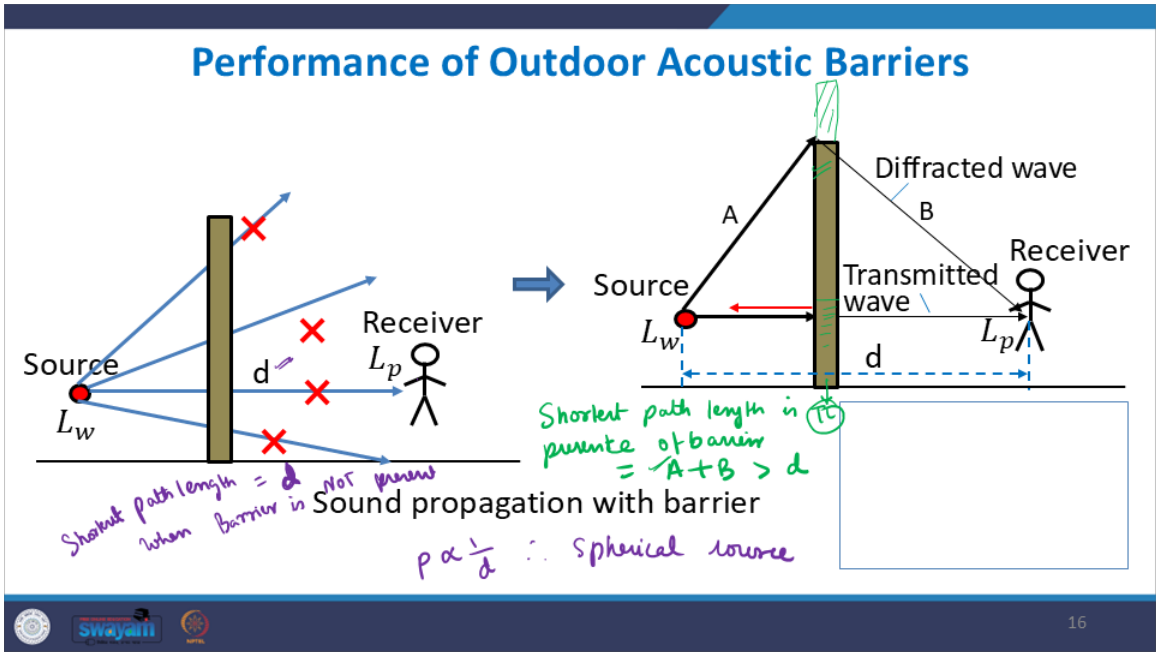
The sound waves are hitting and they are diffracting back from the edges, they are reflecting back from the surface, and then whatever is remaining gets transmitted. Then, some part of it gets absorbed and dissipated, I would say, while passing through the material of the barrier. Let us see how the performance of an outdoor acoustic barrier is evaluated. Typically, a barrier is placed in an outdoor environment.



Let us say this is your receiver, this is some noise source machinery, and you want to block its pathway using this barrier. This is how the sound is moving so that you can create some shadow zone. In the outdoor environment there are various things such as, when the sound wave is propagating, if it is a point source, it is propagating at a spherical wavefront. Then, with the distance, anyways, the sound is spreading, and following the inverse square law. Attenuation happens due to the absorption within the air itself, then the wind and the temperature gradient conditions can vary from time to time. Diffraction can happen from various things like trees and other objects that might be present. There are so many things outdoors, it is not a controlled environment, and there are so many things that can lead to, absorption or attenuation of sound. How do you evaluate just the performance of the barrier when there are so many other things that are distorting the sound wave?

The best measure that could be used is the insertion loss. You first measure that without the barrier. This was the typical sound levels at the listener in the presence of all these other effects as well. But then the barrier is added, and this is the reduced sound pressure level at the receiver. Here from this, you can directly get the sole contribution of the barrier in that setup. This shows, typically a receiver.

You have some source which is generating the sound waves, and whatever they are going to reach the receivers, but they have been blocked by the barrier. Any of the direct sounds that were about to reach.

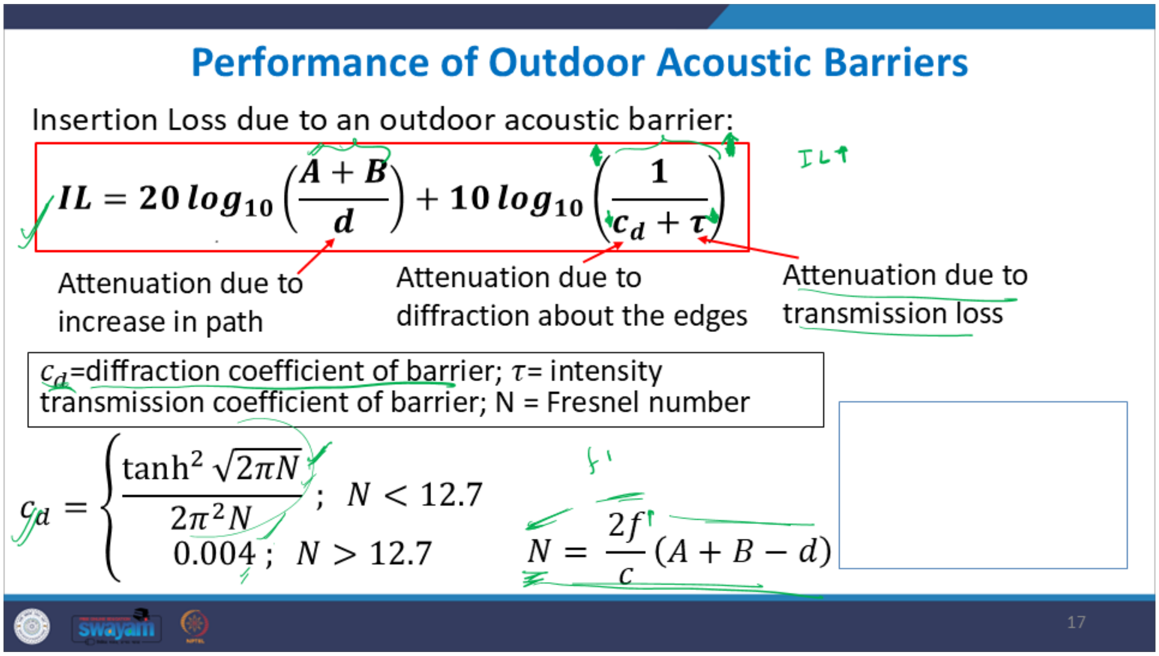


Let us say this is the receiver's ear, a sound in the absence of a barrier would have reached the receiver following a path of length. Here the path length is equal to ‘d’ when the barrier is not present.

When the barrier is not present, the shortest path length taken by the sound wave would be ‘d’, and given that it is a spherical sound wave, with the increase in the distance, the overall pressure is going to go down, following the inverse square law, which means that the pressure would be inversely proportional to the distance for a spherical source.

$$P \propto \frac{1}{d}$$

If the shortest path length was ‘d’ if the barrier was absent, but now that the barrier has been installed, what happens is that now the sound at ‘d’ is not being received; rather, the direct sound that is reaching the receiver is the shortest route taken by that direct sound wave, which is A plus B. The new shortest path length, I would add the word 'shortest'. this is the shortest path length in the absence of the barrier, which is ‘d’. The shortest path length in the presence of the barrier over here it is installed in the ground. Is now A plus B, which is definitely much greater than ‘d’. The path length is increased. That is why some attenuation is happening because of that. There is some attenuation because, the increase in the path length of the direct sound that is reaching the listener, as well as, anything that is going there, it is suffering some attenuation through the material itself. there is some loss due to the transmission loss of the material itself.



Overall, the derivation is again not in the course, directly we come to the mathematical formulation. The insertion loss for an outdoor acoustic barrier it is given by

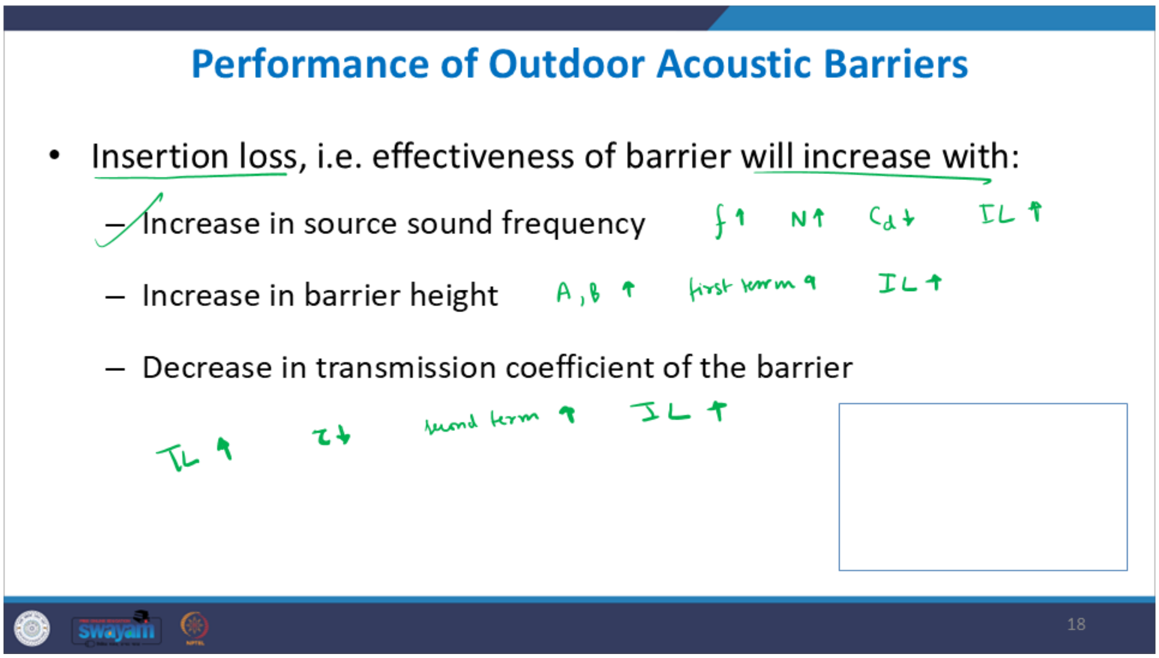
$$IL = 20\, log_{10}\left(\frac{A+B}{d}\right) + 10\, log_{10}\left(\frac{1}{c_d+\tau}\right)$$

Here what are these various quantities? The insertion loss the first kind of loss happens because of the increase in the path length. Here A plus B is the new shortest path length where the sound is directly reaching without being blocked by any material and previously it was not A plus B but it was rather a shorter path length 'd' so,

$$\frac{A+B}{d},$$

this is the attenuation due to the increase in the path and then there are some attenuations due to the diffraction that is happening around the edges and that is given by a diffraction coefficient of the barrier which is a function given by this. It is a function of the frequency. This is called as the Fresnel number. All of these derivations have been long derived and are not within the course.

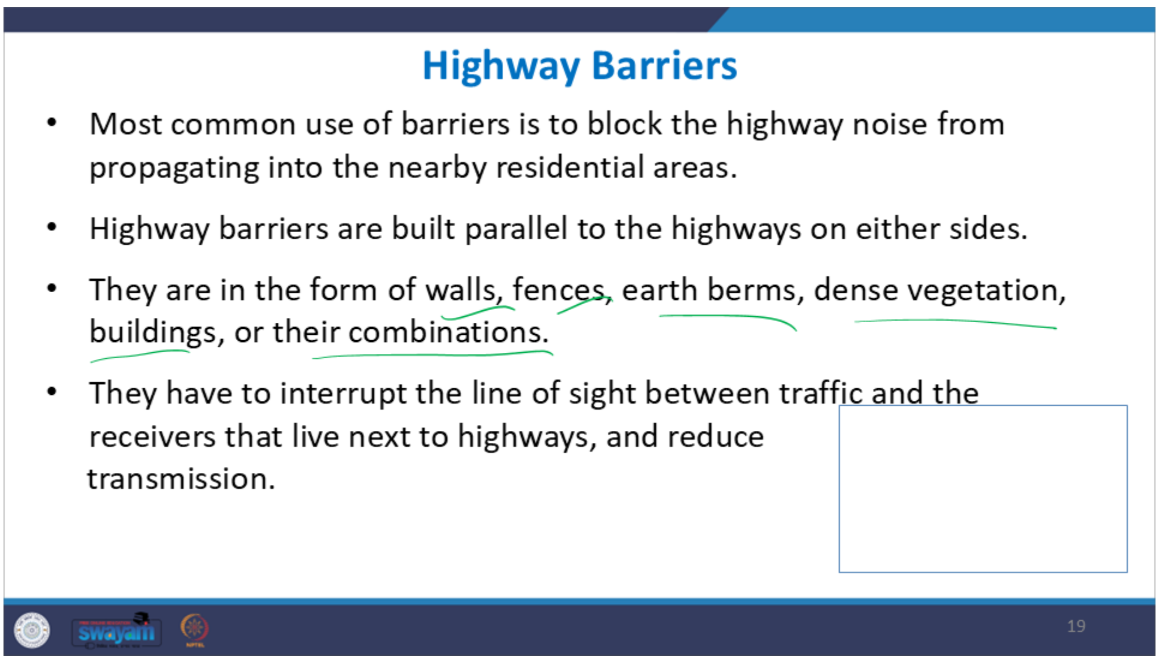
Here n is the Fresnel number and whenever, the n value is smaller than this at lower frequencies this is the, kind of the diffraction coefficient and at higher frequencies beyond a certain value it becomes a constant of 0.004. And then there is also some attenuation due to the transmission loss within the material due to the presence of the material itself. That also is accounted for here using this tau factor. These various factors come together to give you the net insertion loss. Again, these are some of the equations that noise control engineers should definitely remember.



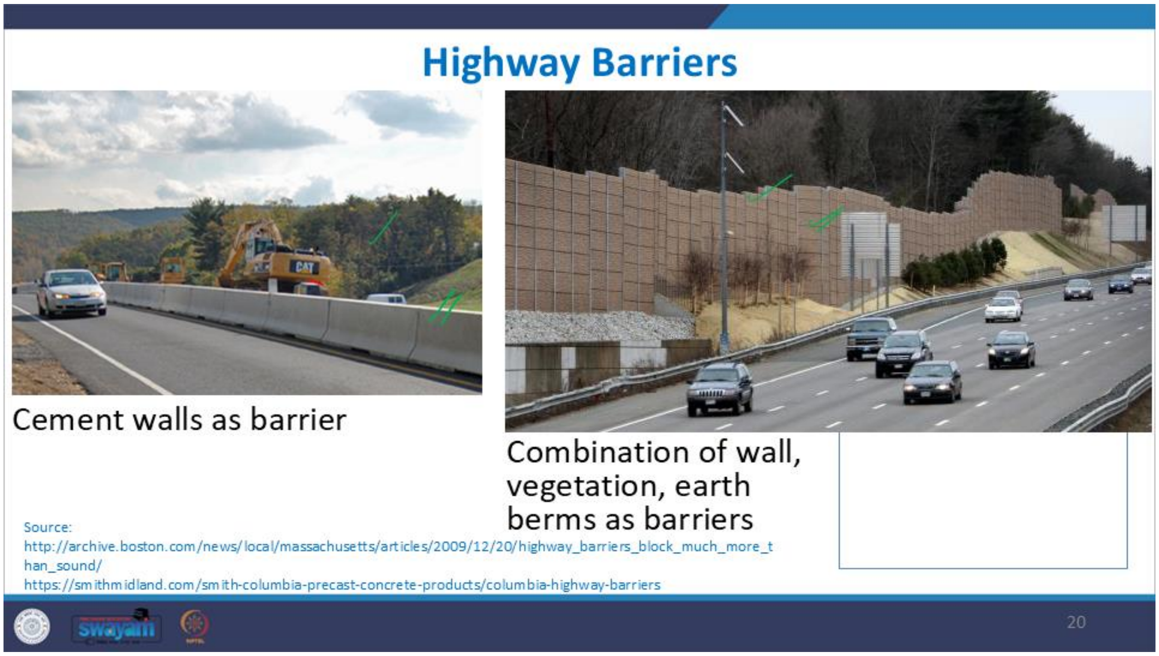
From these equations, what you see is that See, if this quantity supposes everything else is fixed. A and B, they are dependent on the dimensions of the barrier. If you increase the height of the barrier, both A and B are going to go up. A much larger path difference will result. Therefore, this quantity will increase, and hence the overall insertion loss is going to go up. The higher the height of the barrier, the greater the insertion loss will be. Similarly, if you are using a material with a higher transmission loss? If the transmission loss is increasing, which means tau is decreasing, and hence this value is increasing. IL is also increasing. With the increase in the transmission loss of the material, the insertion loss also increases. With the increase in the height of the barrier, this quantity increases. The insertion loss increases, and with the frequency also because at lower frequencies this number is small. At higher frequencies, it increases, therefore, at higher frequencies.

The other way around. at higher frequencies, this value is going to decrease, this is going to increase, and hence the overall insertion loss is going to go up.

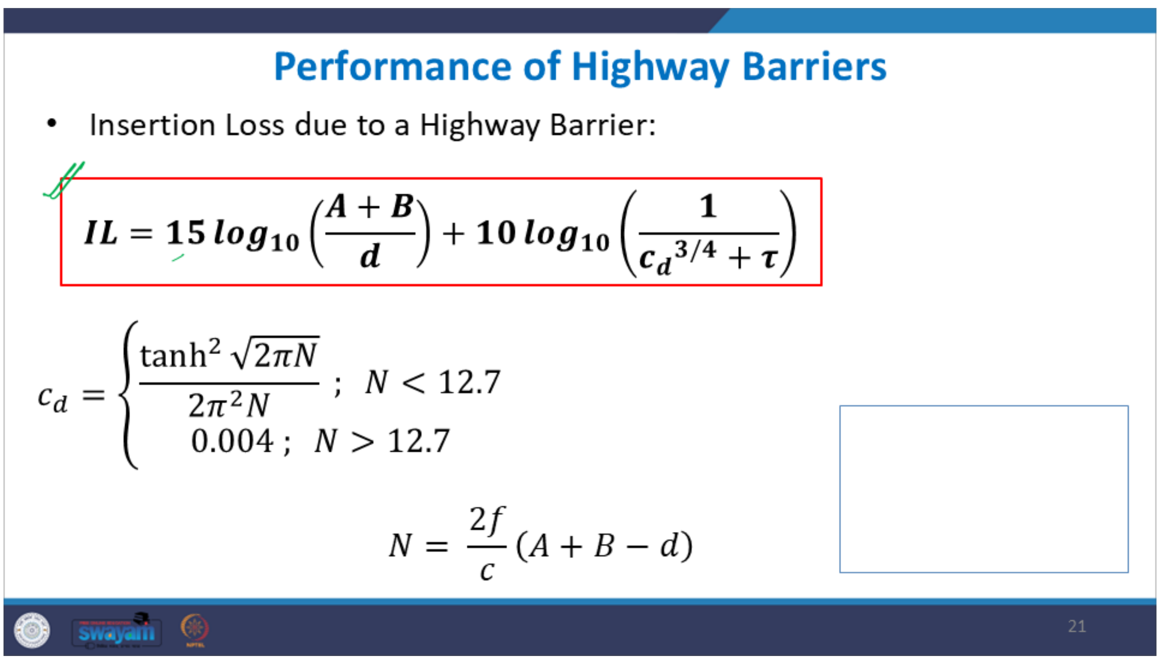
Basically, insertion loss will increase with increase in the sound source frequency because with the increase in f, then the Fresnel number n increases and the diffraction coefficient for, smaller frequency is given by this, sine thing and then for larger frequency, this c_d value, it is a fixed small value for higher frequencies, but for larger frequencies it is a much higher number. the c_d overall goes down and when the c_d goes down then this second kind of term increases in value, the overall I L increases when the barrier height increases A and B increase and therefore, the first term increases, in the transmission loss calculation. The overall transmission loss increases and when transmission coefficient decreases again the second term it will increase. When the T L is increasing the τ will decrease second term will increase. Overall, the insertion loss is going to increase.



Now usually, the barriers one of the most common applications of outdoor barriers is in the use of highways where, they are installed next to the highways to block the sound sounds from, propagating further into the nearby, market areas and the residential areas. These can be in the form of cement walls fences earth bumps, dense vegetations buildings or various such combinations. you can see, along the highways, these kind of even the trees and the plantations, the cemented, barriers and all these kinds of various kind of complicated barriers as well.



They are there to block the sound waves.



And for this typical highway barrier, this is an empirically derived relationship that in the highway barrier, the insertion loss is given by this formulation. Small change from the general outdoor acoustic barrier.

With this, I would like to conclude this lecture. Thank you for listening.

Thank You