NOISE CONTROL IN MECHANICAL SYSTEMS

Prof. Sneha Singh

Department of Mechanical and Industrial Engineering

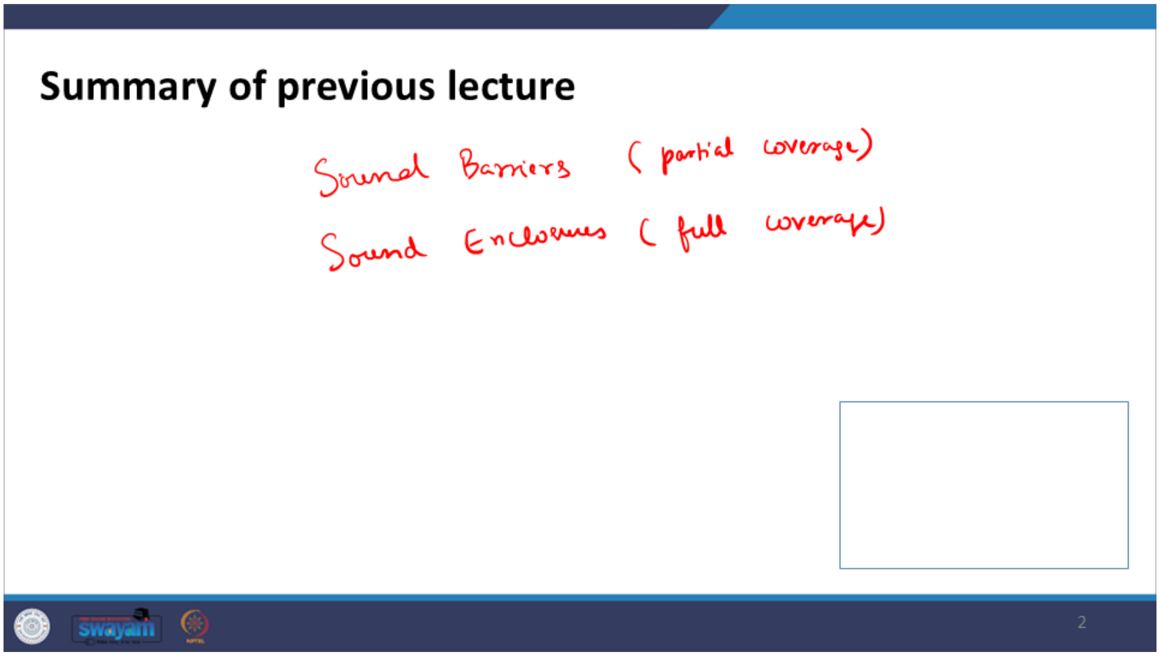
IIT Roorkee

Week: 7

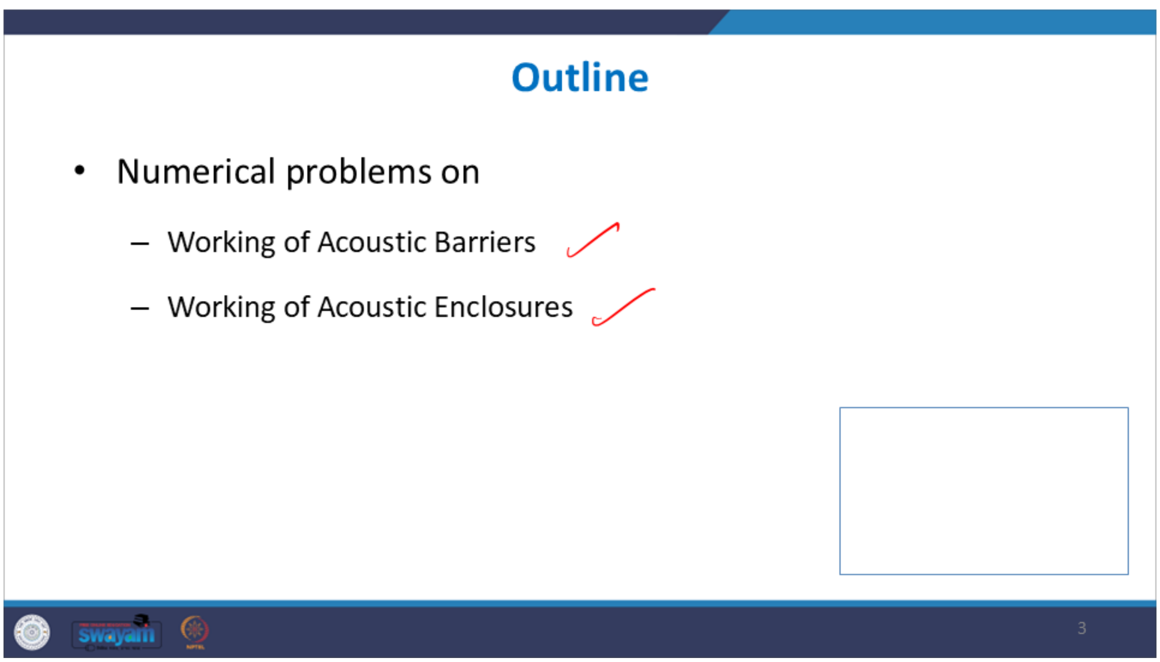
Lecture: 35

Lecture 35: Sound barriers and enclosures: Numerical

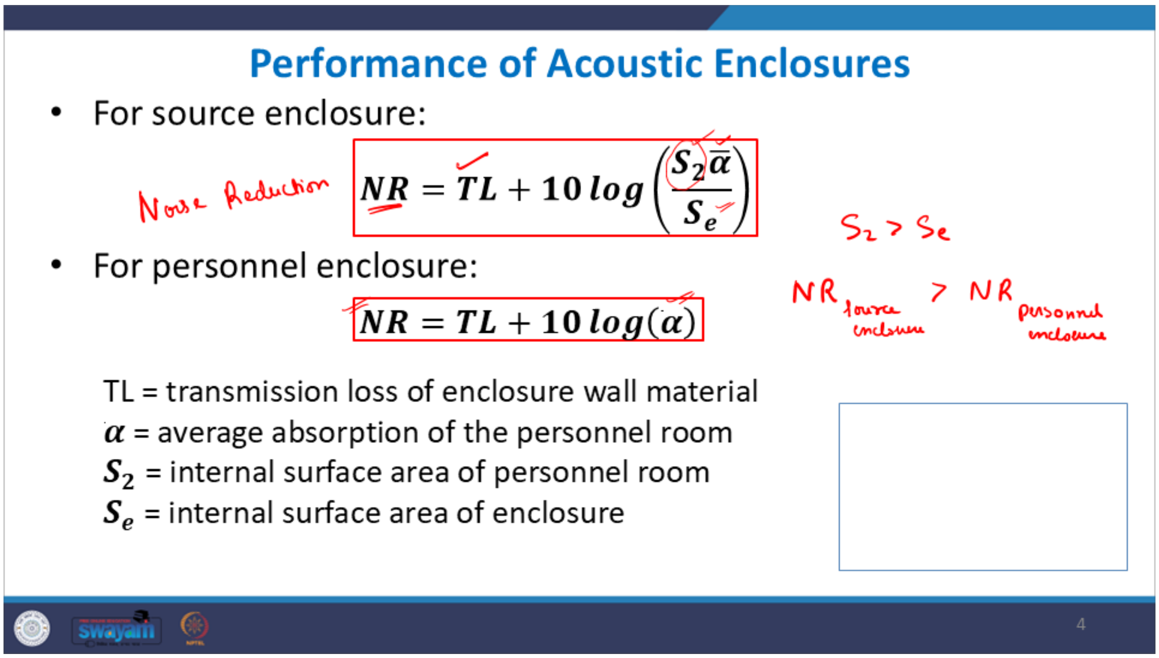
Hello and welcome to, you know, this series on noise control in mechanical systems with me, Professor Sneha Singh from IIT, Roorkee. So, you know, in the previous lectures, we have done our discussions on, you know, sound barriers and sound enclosures where this is like provides partial coverage to listener. And this provides full coverage to the listener against some noise sources. And they both are made of materials which have high transmission loss and are supposed to block the sound waves from transmitting to the other end.



So, today we will solve some numerical problems based on the working of acoustic barriers and acoustic enclosures.



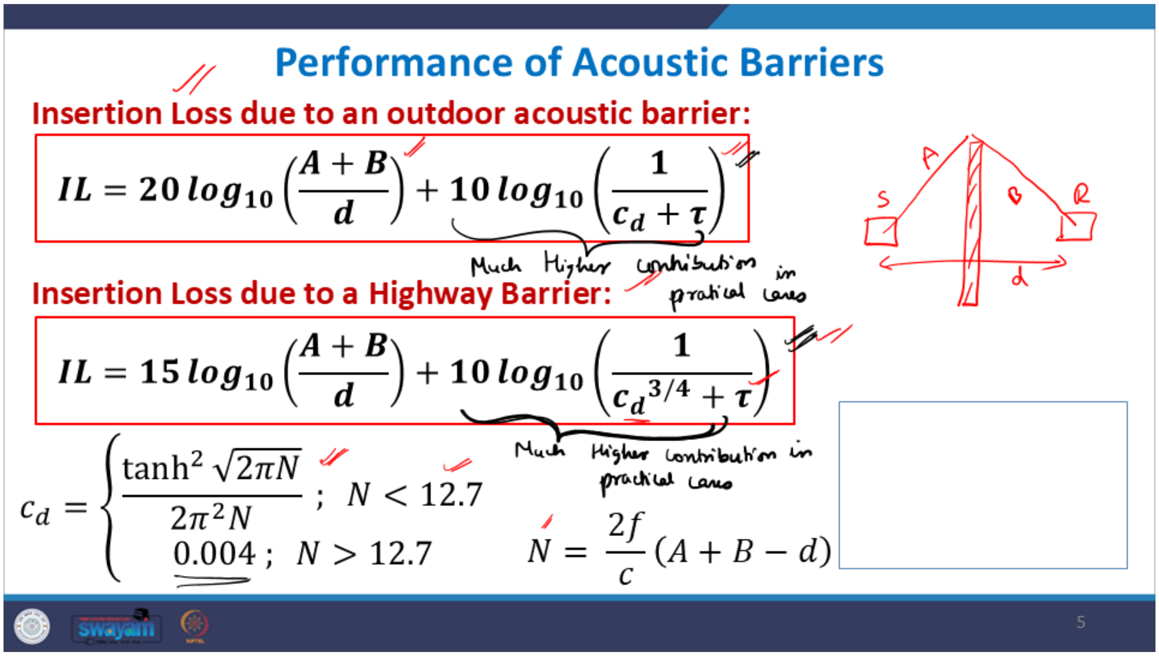
Ok so, in order to solve the problem, I will quickly recap you know the mathematical formulations of you know the performance by an acoustic enclosure. So, for acoustic enclosure, noise reduction is used as you know the performance measure and when the enclosure is, uhh Built in order to enclose the source then that becomes a source enclosure and this is the noise reduction formula which is the transmission loss of the material used for making enclosure plus 10 log 10 of the total surface area of the personal room.



$$NR = TL + 10\log\left(\frac{S_2\bar{\alpha}}{S_e}\right)$$

$$NR = TL + 10\log(\bar{\alpha})$$

multiplied by the average absorption coefficient of that room divided by the total surface area of enclosure and for personal enclosure the noise reduction is given by transmission loss of that material which is used for building the enclosure plus 10 log of simply alpha bar. And hence because S2 is always greater than Se therefore the noise reduction of the source would be greater than the noise reduction of the enclosure personal enclosure barrier. So, noise reduction of the source enclosure of everything same when provided all other conditions are same and the same enclosure when used on the noise on the source will provide a greater noise reduction compared to when it is used to cover the personal. Ok because S2 will always be greater than Se and hence this value would be higher than 1 and this term is going to increase compared to this term.



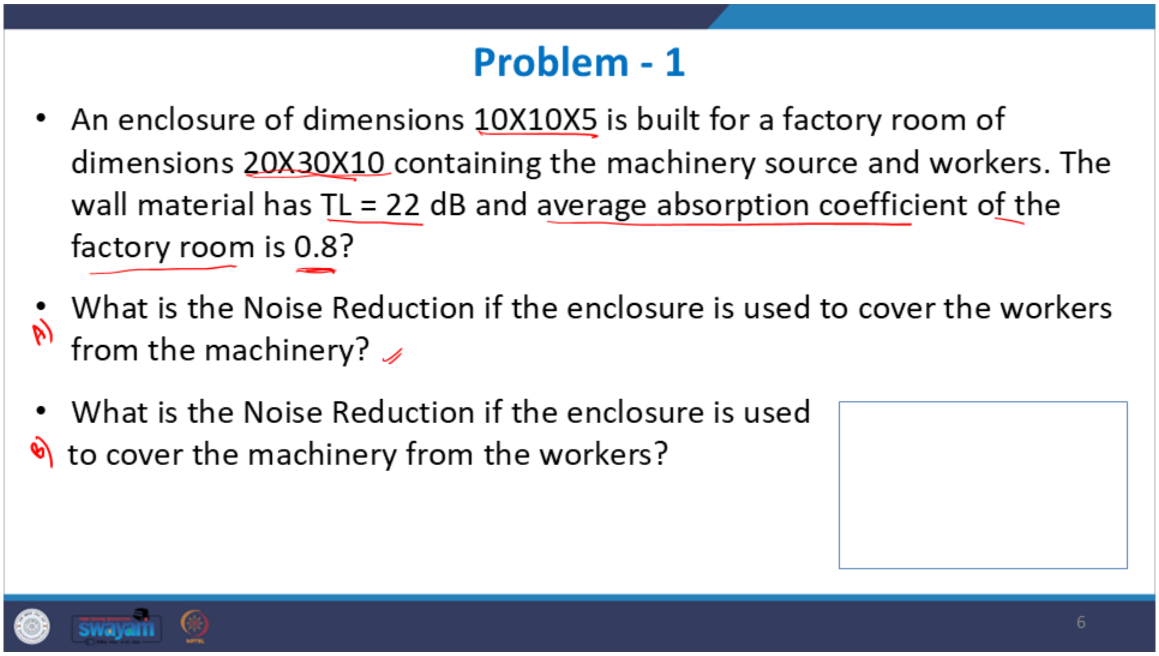
Then the performance of acoustic barriers, they are measured using the insertion loss and for a typical outdoor acoustic barrier, this is the big formulation for the acoustic barrier, insertion loss and for a highway barrier there is slight tweaking to the above formulation to give us this.

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

$$IL = 15\log_{10}\left(\frac{A+B}{d}\right) + 10\log_{10}\left(\frac{1}{{c_d}^{3/4}+\tau}\right)$$

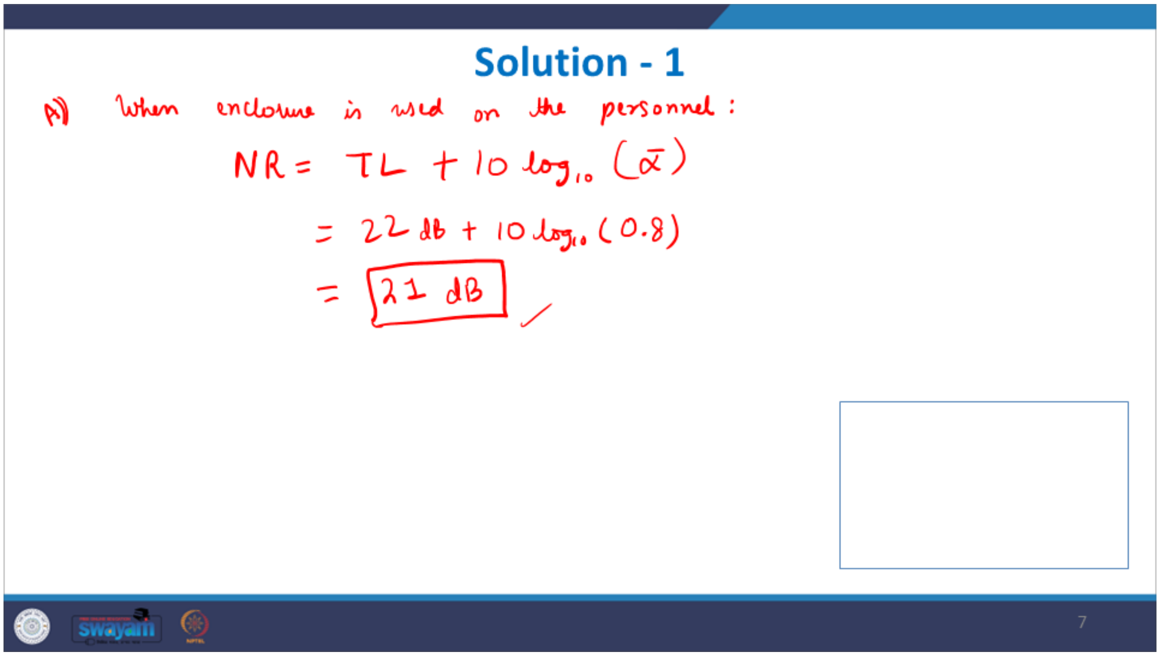
$$c_d = \frac{\tanh^2\sqrt{2\pi N}}{2\pi N^2}$$

where you know this is the diffraction coefficient given by this mathematical function where this being the Fresnel number and this tau is the transmission intensity coefficient of the material that is being used to construct that barrier and A plus B gives you the total path once the barrier is installed and d gives you the to the path length the shortest path length between the source and the receiver without the barrier a plus b being the shortest path length with the barriers. So, if suppose this is your source, this is your receiver and you have some barrier in between them, then this is your d and this becomes your A and this becomes your B.



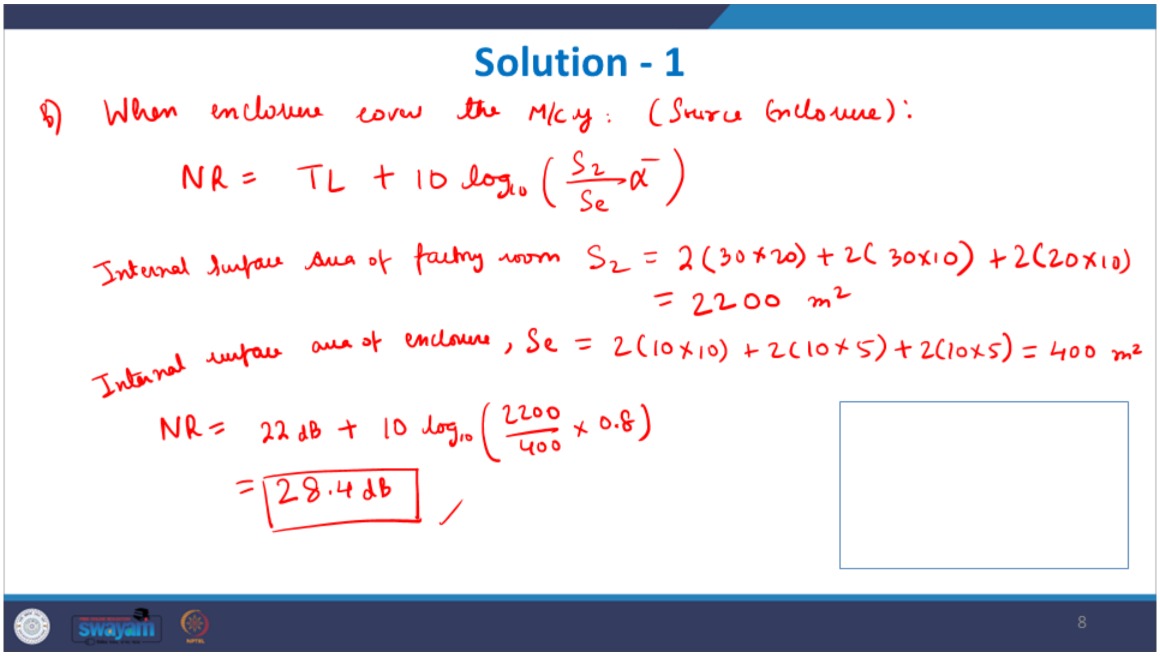
So, let us solve you know the very first problem and enclosure of dimensions is built for a factory room with the dimensions as given here and it contains the machinery source as well as the workers working inside that you know factory room and the wall material of the enclosure has a transmission loss of 22 decibels and the average absorption coefficient of the factory room is given to be 0.8. So, there are two you know cases let us say case A and case B. What is the noise reduction if the enclosure is used to cover the workers from the machinery? So we have built the enclosure of a particular material and we are going to install it in this factory room.

So first we use it on the personnels or the workers and we enclose them in this enclosure and find out the noise reduction. Then we use the same enclosure and put it on the machineries. And then we find out the noise reduction so hopefully in the part B there should be higher noise reduction because now we are using it on the source



so, let's start with the first case okay case A when enclosure is used on the person or on the workers and it is enclosing the workers Then for this condition the noise reduction is given by this formulation. So simply this is given to us as 22 decibels and this is alpha bar is 0.8 for the factory room which is the room where the enclosure the workers are working. And this, if you calculate, it comes out to be 21 dB. So, this is our answer for the very first case.

Let us now see case B, when the enclosure covers the machinery. Okay, it is used, so it becomes a source enclosure. In that case, the noise reduction is given by okay, here S2 is the surface area, you know, the internal surface area



of the factory room because that is the room where, you know, the personnel are located. That is our S2, and we can find this out from the dimensions of the room. So, these are the dimensions of the room okay, 20 by 30 by 10. So, the internal surface area, you know, you can find it out. You know, this is the surface area. It will become the surface area of that cuboidal room. So, it will simply be—we have two surfaces of 30 by 20, plus two surfaces of 30 by 10, plus two surfaces of 20 by 10. So, all the six surfaces of the cuboidal room we have obtained. So, the total surface area in square meters would come out to be 2200 in the SI unit. So, if the unit is not given, you can take it as the SI unit. Now, we find out the internal surface area of the enclosure, and the dimension of the enclosure again is given to us. It is this 10 by 10 by 5. So again, using the same formulation, we have

which gives us 400 square meters. So now, let us use it to find out the noise reduction of this case in the above formula. Okay, if you do that, what you obtain is overall So, the noise reduction increases when the same enclosure is used to cover up the machinery rather than to cover up the personnel. OK. Okay, let us move on to the very next question. The noise level in a reverberant factory room is 85 decibels.

Problem - 2

- Noise level in a reverberant factory room is 85 dB without any enclosure. What will be the noise level in the room after the machinery is enclosed by a material with $\tau = 0.04$. Given that the surface area of the factory room is 25 m^2, surface area of enclosure is 10 m^2. The factory room is covered with a material of $\alpha = 0.86$.

without any enclosure so we have a factory room environment closed so reverberant conditions are used then we use an enclosure and 85 decibels is when no enclosure is there what will be the noise level in the same room after the machinery gets enclosed by a material with tau as this and the surface area of the factory room is this. surface area of the enclosure is this and the factory room is covered with a material of alpha as 0.86 so here what we are doing is we are installing an enclosure to cover the machinery so we will use the performance of source enclosure so here it is the case of source enclosure.

Solution - 2

It is the case of Source Enclosure:

$$NR = SPL_{w/o\ en.} - SPL_{with,\ en} = TL + 10\log_{10}\left(\frac{S_2\bar{\alpha}}{S_e}\right)$$

$$= 10\log_{10}\left(\frac{1}{\tau}\right) + 10\log_{10}\left(\frac{25}{10}\times 0.86\right) \quad (\tau = 0.04)$$

$$= 14\ dB + 3.3\ dB$$

$$= 17.3\ dB = SPL_{w/o\ en} - SPL_{with,\ en}$$

$$\Rightarrow 17.3\ dB = 85\ dB - SPL_{with,\ en.}$$

$$SPL_{with,\ enclosure} = 85 - 17.3 = \boxed{67.7\ dB}$$

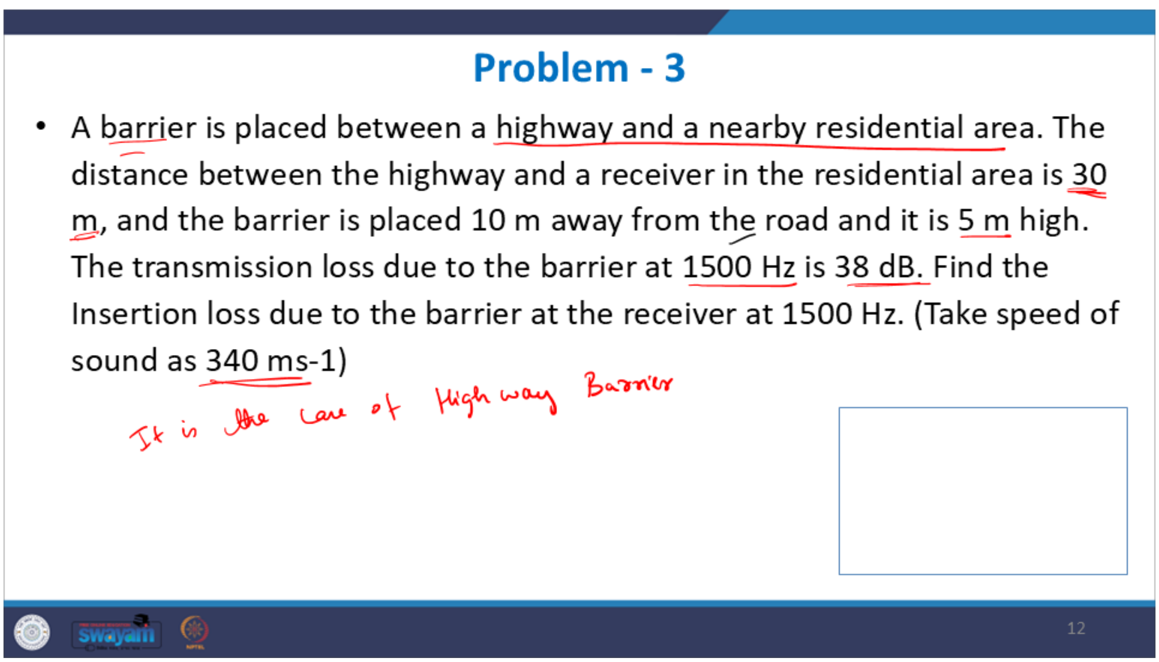
So, the net noise reduction which means that the SPL without enclosure minus the SPL with enclosure is given by this formulation.

$$NR = SPL_{w/o\ enc} - SPL_{with,en} = TL + 10\log\left(\frac{S_2\bar{\alpha}}{S_e}\right)$$

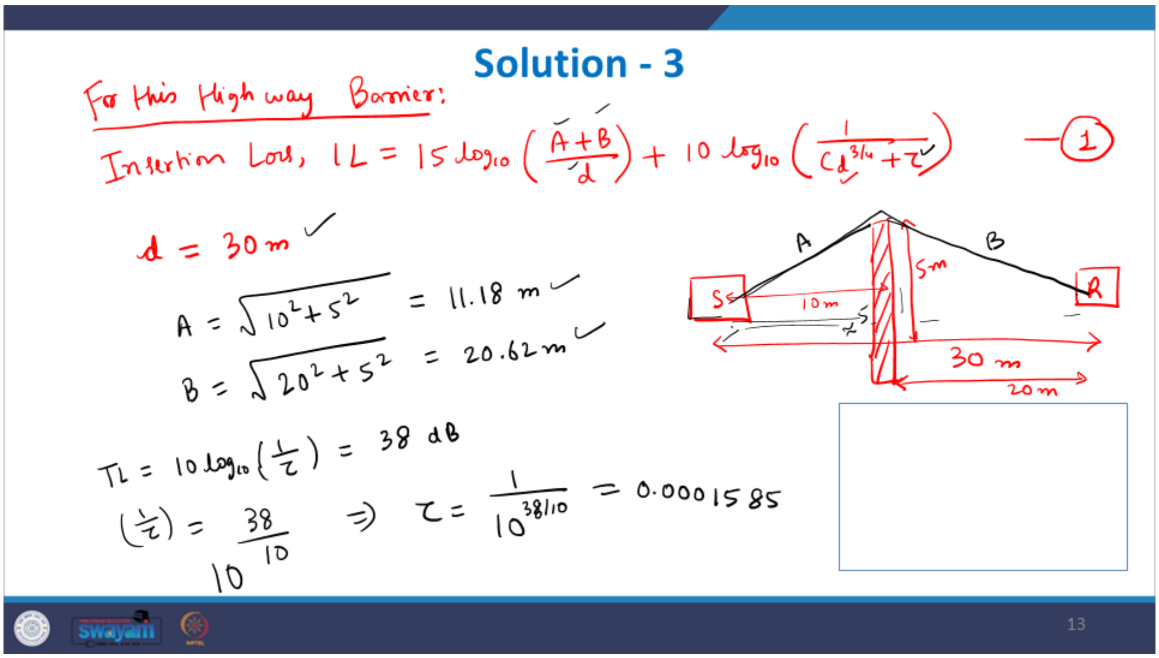
Okay all these values are given. We first calculate the transmission loss which is 10 log 10 of 1 by tau plus this whole thing here. The 25 meter square and 10 meter square are given as the respective surface areas and the alpha bar is 0.86

and here this is 0.04. if you put it here so what you will get is so 17.3 decibels is the net reduction in the noise which is the SPL without enclosure minus SPL with enclosure and now the without enclosure SPL is given to us as 85 decibels And this is not known. So, this is what we have to find. What will be the new SPL with enclosure?

This should be. So, this becomes our answer for what has been asked: the new noise level in the room. So, the noise level reduces from 85 to 67.7 decibels. Okay, Let us go to problem 3.



So, here this is the case of a barrier placed between a highway and a nearby residential area. So, automatically, what is this barrier? It is the case of a highway barrier, so we will use the highway barrier formulation. The distance between the highway and the receiver is given to be 30 meters; this becomes RD. The barrier is placed 10 meters away from the road. and it is 5 meters high. The transmission loss due to the material of the barrier at this particular frequency is 38 decibels, and the insertion loss you have to find out. When the barrier is installed, what will be the insertion loss? You can take this as the speed of sound. So, let's see here. We know that for this highway barrier, we have to find the insertion loss.



Okay. It's given by this formulation. Each of these quantities we will first find out separately. So, let us label it as equation 1, and we need to find out all of these things from the information provided. So, d is the shortest distance between the source, which is the highway road, and the receiver, which is that residential area, and the direct distance between the two.

So, it is said that the area is 30 meters between, say, that is the distance between the two. So, the distance when there is no barrier becomes 30 meters. So, let us say this is our highway road, which is the source. We have some barrier. And we have a receiver.

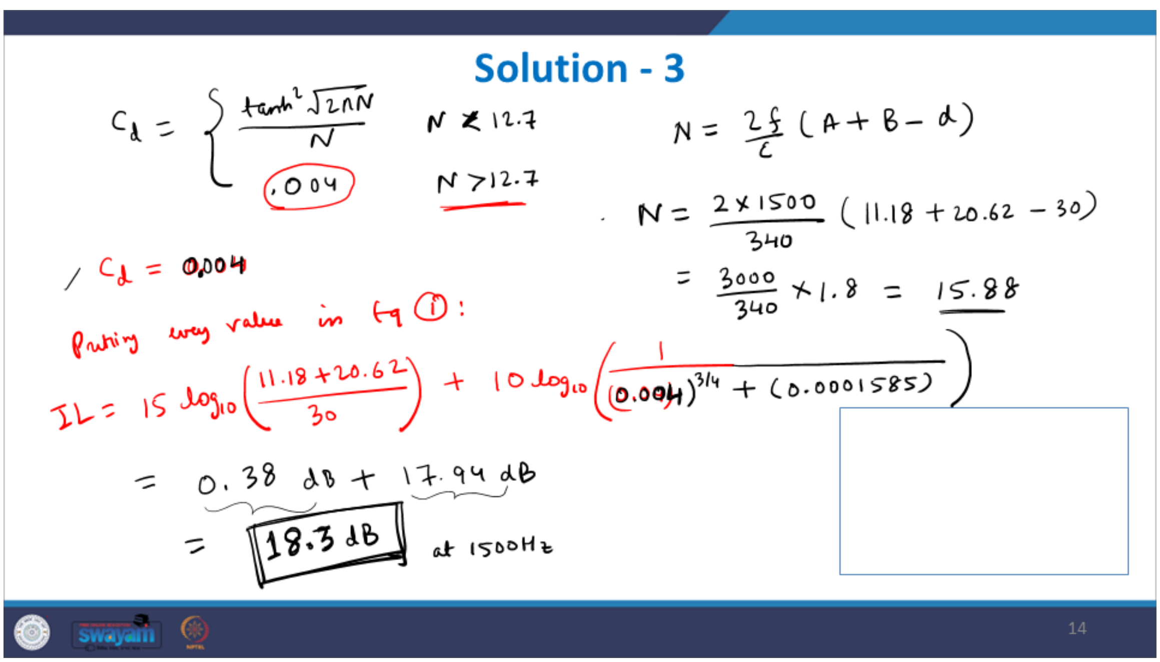
Okay. And the distance between the two is given as 30 meters, and the barrier has been installed 10 meters away from the road, which is the source, and it is 5 meters high. So, given that, let us assume that this is 5 meters, and the source and the receiver are very close to the ground. So, what we have here is that because the height is not given, this is given to us as 10 meters. So, automatically, this thing will become 20 meters. Okay, and this height is given to us as 5 meters above the ground. So, we have to find A plus B, the new pathway. Okay, this one. Okay, this is your A and B. So, you can use the Pythagoras theorem. You know A, and this height, if you take as approximately 5, then we have one triangle. A will come out to be the square root of 10 squared plus 5 squared. Okay, so the value comes out to be close to 11.818 meters.

B, when you take The value comes out to be close to 20.62 meters, okay. Given that, you know, this source to here is 10 meters, and this is 5 meters, so you simply use the Pythagoras theorem on the two triangles, okay? So, we have found this, this, and this. Now, let us find out what the diffraction coefficient in tau is.

Let us first find out tau; it is easier to find. The transmission loss might be given to us; it is given as 3800 at the frequency of interest. So, we know that TL is what? It is 10 log10 of 1 by tau, and this is given to you as 38 dB. So, now tau you have to find out as a number.

So, 1 by tau, if you do it like this, take it 38 by 10 into 10 to the power, right? Just solving it. So, tau will become 1 divided by 10 to the power of 38 by 10. So, simple solving of this algebraic equation.

So, what you end up with is the value, Okay? There is no sort of unit to this. It is a fractional quantity. Then, let us find out the diffraction coefficient.



So, now, we have found this. The remaining unknown is Cd. And to find that, we first need to find the Fresnel number, okay, because Cd is given by this formulation. It will have a value of this whenever n is greater, sorry, smaller than 12.7.

And when it will simply have a value of 0.04 when n becomes greater than 12.7, and where what is n here? This is the Fresnel number. This is its formula. So here, the frequency of interest is 1500, so f becomes 1500. A, B, and d we have already found here, so let's input these quantities to find the Fresnel number. This we take as the speed of sound in the air. So, if you solve this, I think this is the number that you get. Now, this here is the case of n being greater than 12.7.

Therefore, this should be our diffraction coefficient value for this case. So, now we have found the last unknown. Let us put all of these into the first equation. So,

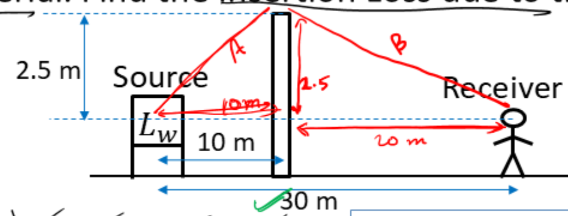
and we will get the insertion loss Sorry, so this should be 0.0004. Here, let me make this correction. Okay, so if you go here, let us go and refer back to our formula. So, yes, it is 0.0004.

So, that is what we use. Okay. Okay. This entire thing, if you solve it, you know, hopefully this is what you should get. The first term comes out to be close to this much.

The second term comes out to be close to this much and the overall insertion loss for this highway barrier is 18.3 decibels. Okay, so that is what we had to find. Fine, okay. And this is at 1500 Hertz. As the frequencies change, your N is going to change, hence your Cd will change, and the value is also going to change. So, insertion loss is a function of frequency. At this particular frequency, this is the value which we are getting. Okay, so the last problem for this particular lecture is we have a barrier. And here, it is not a highway barrier. You can see it is a machinery source.

Problem - 4

- A barrier is placed between a transformer machinery and the personnel. Table gives the sound power spectrum of machinery and TL of the barrier material. Find the Insertion Loss due to this Barrier installation.



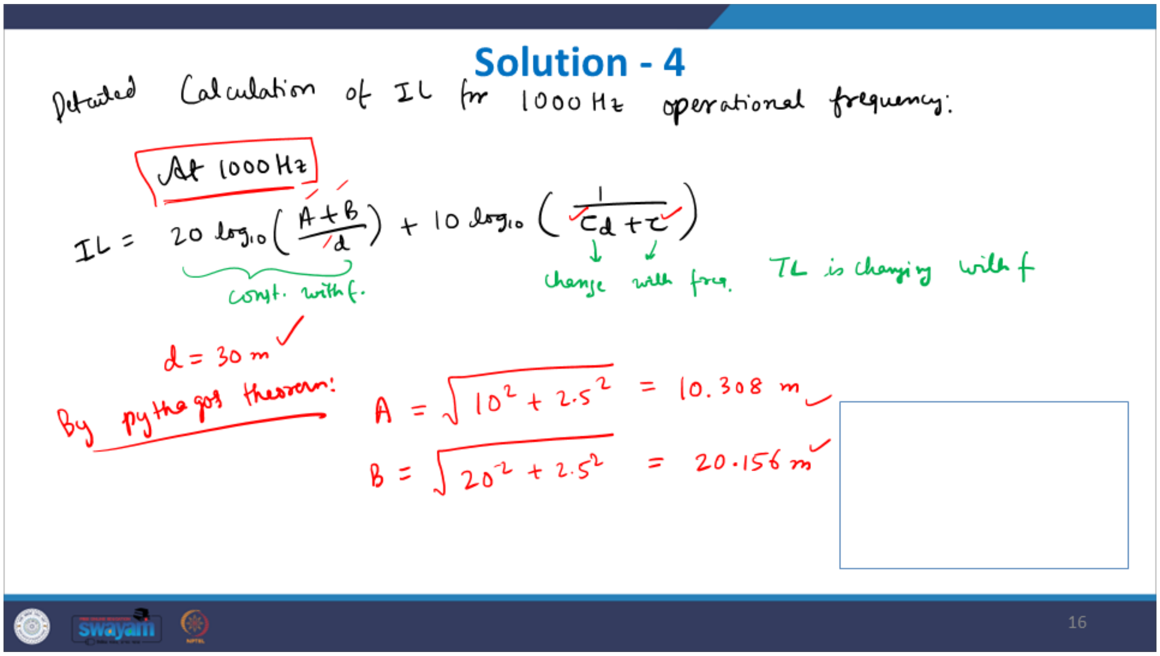
f (Hz)	63	125	250	500	1k	2k	4k	8k
L_w (dB)	112	116	110	106	106	100	95	90
TL (dB)	36	38	38	38	38	44	50	56

Some transformer machinery is being used. And the barrier is placed between that machinery source and the personnel working. Okay. And it is an outdoor environment. And the sound power spectrum of the machinery at the different frequencies is given.

At the same time, the transmission loss of the barrier material is given to you. You have to find out the insertion loss due to this barrier installation. So, now we know that insertion loss is a function of frequency. So, at different frequencies, it will have different values. Okay.

So, you have the table you can use the table and find out the insertion loss at each of the given frequencies like this. So, for this just for demonstration purposes I will solve for the case of 1000 Hertz and in the same way you can follow and do it for every frequency. So, in the in that formulation other values will be the same when you calculate the insertion loss only the Cd which is the diffraction coefficient will change with the change in the frequency because of the change in n. So, you will keep all other values same. You will keep changing Cd based on what frequency it is operating and accordingly you will get a particular insertion loss value.

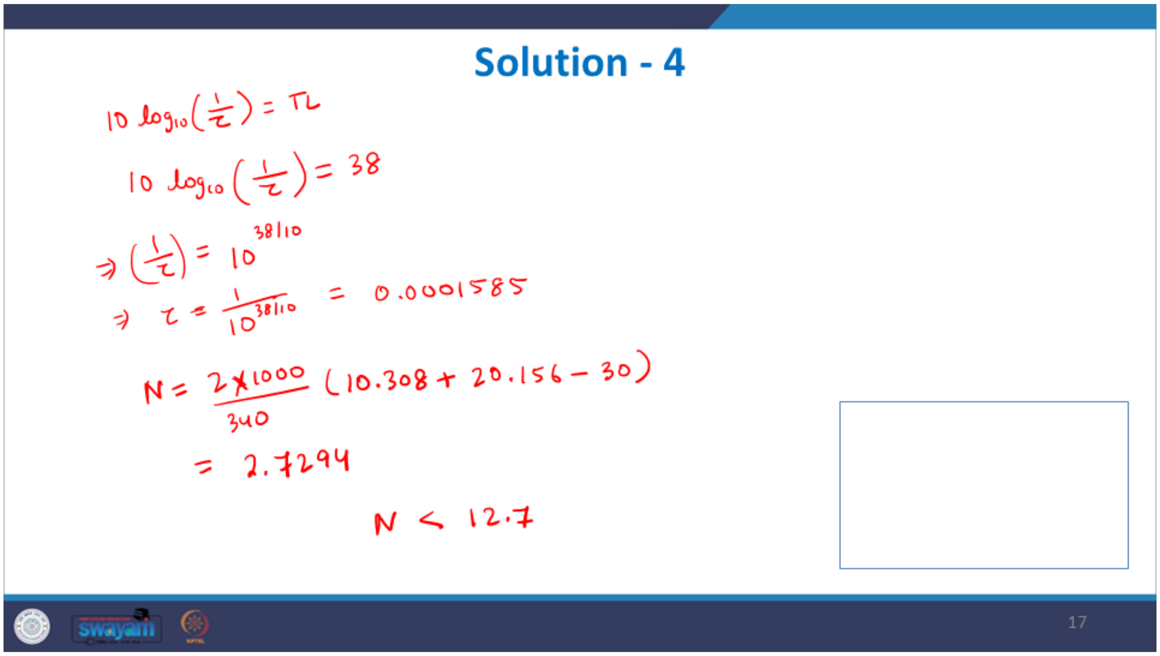
So let us do the sample calculation for one frequency. Okay so, here at thousand hearts so what I was saying is that you know your calculations will change from frequency and I will just like to rectify that the transmission loss is also a function of frequency so the TL values they are changing with frequency okay so when you do you and find out the insertion loss which is you know the insertion loss is given to be for an outdoor barrier so



here with the change in frequency this quantity will remain constant with the frequency and here because these values are changing so they change with frequency because the TL is changing with frequency so if TL is changing with the frequency the t tau will also change and Cd will also change with the frequency So, let us see for 1000 Hertz. Okay, let us first find out the various quantities which is A, B and d. So, here we have the distance d is given to be 30 meters between the two.

Let us find out you know the value A. This is our A and this is our B. okay so A is what it is the hypotenuse and this side is 10 and this side is 2.5 and here in this triangle this side is 2.5 both are right angle triangles and this is 20 meters okay 30 minus 10. so by by Pythagoras theorem if you apply it here A would simply be under root of this, this distance which is 10 square plus this height which is 2.5 so 10 square plus 2.5 whole square under root okay if you do this let's see what the value comes out to be this is what you get and similarly B again we use Pythagoras theorem and find out the hypotenuse of this right angle triangle 20 square plus 2.5 whole square and then the root

And we already know these three quantities. We have found them. Now, let us find out Cd and tau. So, let us begin with tau.



We know that. 10 log10 of 1 by tau is your transmission loss at 1000 hertz. We are doing these computations, okay? 1000 hertz. What is the transmission loss given to us? 38 decibels. So, use it again. Just like in the previous problem we solved, it was 38 decibels. In the same way, if you solve this equation. Okay, let me write it in a better way. So, if you solve it again like the previous question, this is the answer you are getting for tau and Cd. For Cd, first we calculate the Fresnel number at 1000 hertz. Let us see what it is.

A plus B, 10 point, this value is here. We use the values of A and B that we are finding, this, this, and this. Okay, when you solve this, the N that you are getting is now here. This N is smaller than 12.7, so. If you go back and look at this formulation for the diffraction coefficient, a quick recap. So, here when N is smaller than 12.7, we have this particular formulation: tanh square root of 2 pi N by 2 pi square N. So, let us use that.

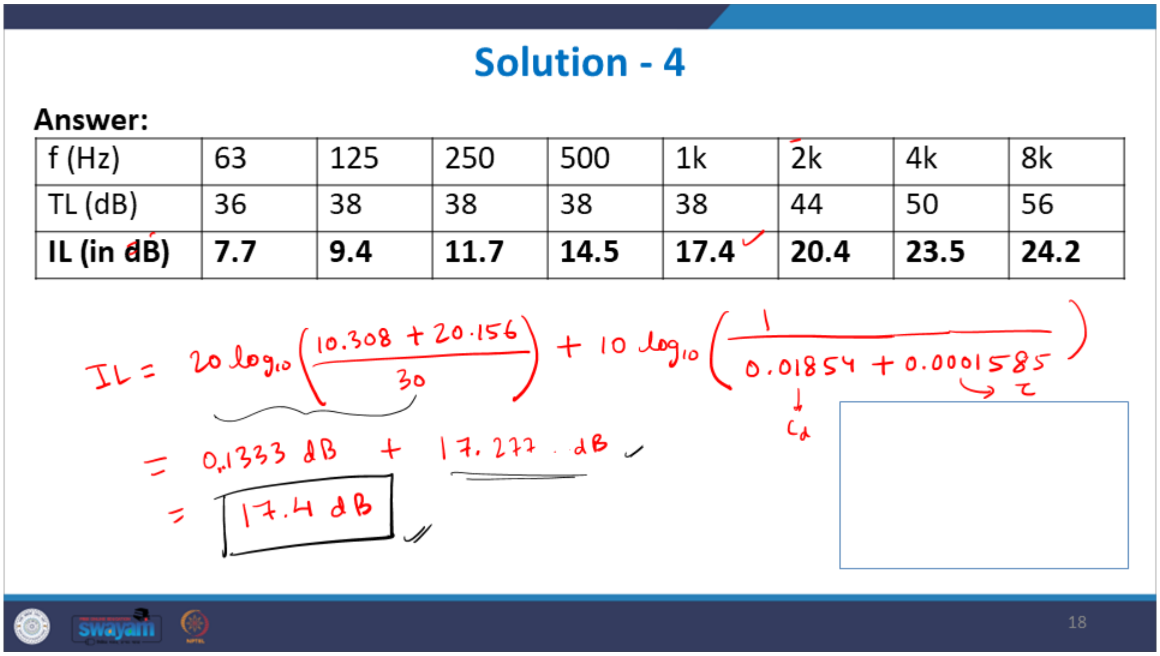
If you put the value of N, which is 2.7294, in this particular equation, what you get should be tanh square of this quantity here, okay? So, the root of 2 pi N with N being 2.7294, this is what you get. Divided by. Into N, which is this thing, okay? You can use various kinds of scientific calculators to find out the hyperbolic tan function. For this particular value, what it comes out as, if you solve this entire thing, it comes out as the upper part comes out as this. Which means that Cd comes out as this value here, okay? So now we have solved for all the unknowns in this equation, this and this as well. We have found them, so we can simply punch it to get our insertion loss. Which is our Cd and the tau, which is right here. This is our Cd, this is our tau, okay.

So, when you solve this equation, this is what you will get close to this value. Summing them up together, this is your insertion loss for the first case, and like this, you can solve for the rest of the frequencies now with both these equations. Now, for both the solutions, what we observe is that the very first term of insertion loss comes out to be very small because typically we don't have barriers which are very high, you know, like 15, 20, or 500 meters. So, the value of the first term is typically very low compared to the value of decibels of the second term. You can observe it here as well as in the previous question. You can observe that, again, the contribution to insertion loss because of this first term is very small compared to the contribution due to the second term. So, that is one note you can take over here.

So, let us make that note here. That you know this has a much higher contribution to insertion loss in both these cases. For most of the practical barriers, obviously, if you had a very high barrier, the results would change, but in general, we do not have barriers more than 3 to 10 meters high. So, in these practical cases, So, in these practical cases, the contribution due to the second term is coming out to be much higher than the first term.

Okay. So, sometimes, you know, what engineers do is that sometimes for a short-height barrier, they typically evaluate just the second term and get a very close estimate of the overall insertion loss. So, that is some practice that some noise control engineers do—just using the second term, they can give us a very close estimate of the insertion loss. So, basically, Here, only this term can be closer to. So, anyways, we have obtained for the thousand Hertz. In the same way, you can obtain it for the rest of the cases. So, I think this is how we have solved it. So, when you solve it like this, you can get the value for the rest of the cases. I think it is better to erase this so that it is visible.

So in the same formulation you can use and for every frequency you can get the answer. So for 1000 Hz 17.4 and then for the rest of them it is like that. So it is varying with the frequency. So one thing you have observed is that the second term has higher contribution. The other thing you observe is that in general with the increase in frequency the insertion loss is increasing.

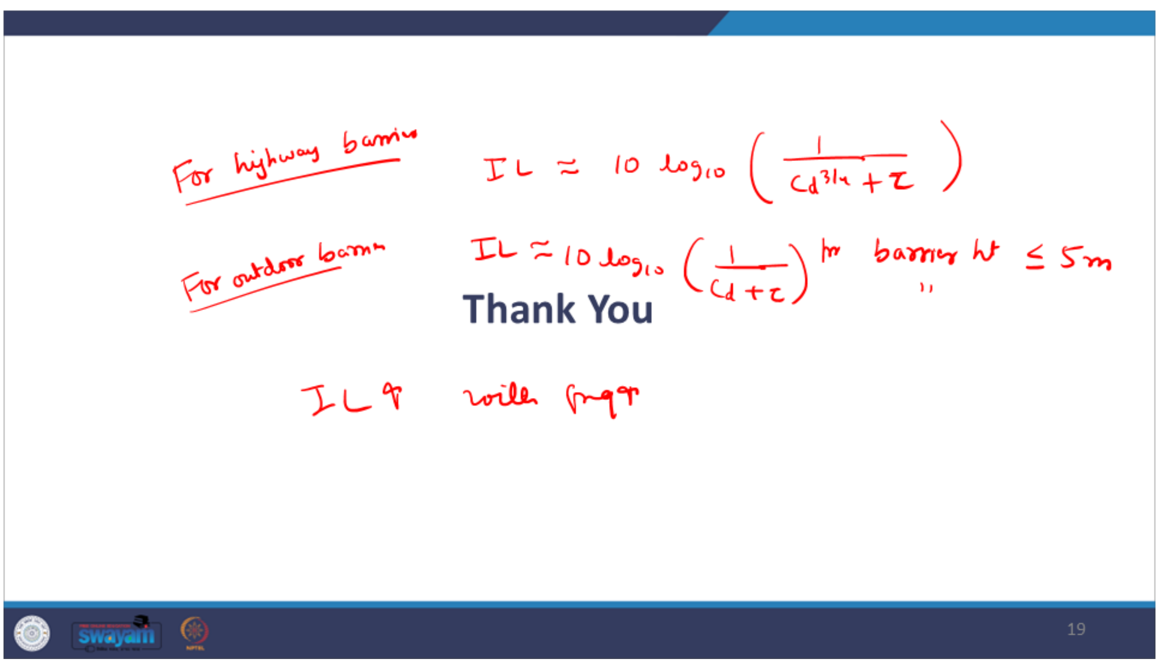


Solution - 4

Answer:

f (Hz)	63	125	250	500	1k	2k	4k	8k
TL (dB)	36	38	38	38	38	44	50	56
IL (in dB)	**7.7**	**9.4**	**11.7**	**14.5**	**17.4**	**20.4**	**23.5**	**24.2**

Okay So some notes. You know IL typically increases with frequency increase okay and IL can be very closely approximated to the second term of the equation, okay for outdoor barriers. This is just an engineering approximation okay. but it's always advisable to calculate the entire thing but just for a quick estimate this can be done because the second term is usually much higher given that barrier height is you know typically smaller than 5 meters or up to 5 meters you can take that approximation for outdoor barriers in the same way for highway barriers again you can take that approximation for highway barriers



you can again take the approximation given that and for outdoor barriers let me just okay, for the same condition, okay, and IL increases with increase in the frequency. Okay, so with this, I would like to end this lecture. Thank you for listening.