**Acoustic Materials and Metamaterials**
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**Lecture - 14**
**Enclosures and Barriers – Tutorial**

Welcome to lecture 14th in this week and today's lecture is going to be a tutorial on Enclosures and Barriers. So, let us solve a few problems that help improve the understanding of barriers and enclosures.

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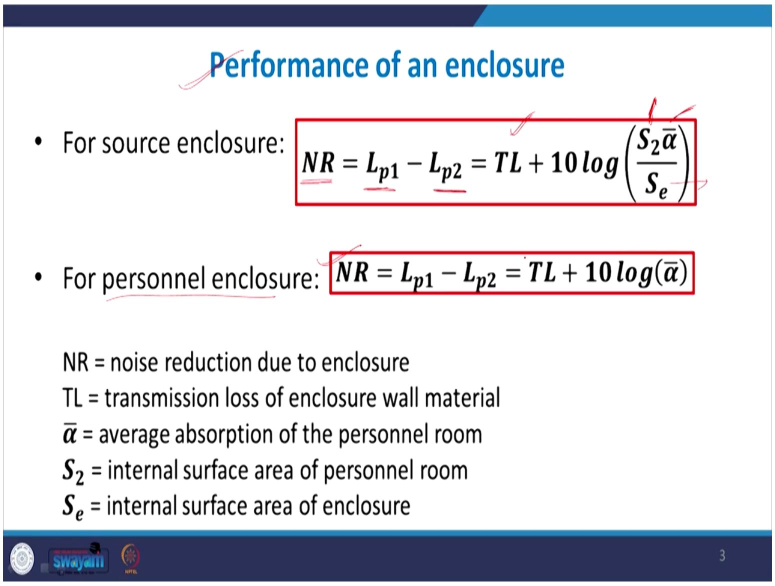


So, to before we start solving these numericals, let us just quickly review the formula that we had derived.

So, for an enclosure the performance of an enclosure is given by it is measured in terms of the noise reduction, which is the SPL before the enclosure minus the SPL after the enclosure and this is given as transmission loss plus 10 log of S 2 alpha bar by S e. Here this is the surface area of the receiving room. So, this is for a source enclosure.

So, whatever is the receiving room that is surface area is given by this; this is the average absorption. Do the average absorption of the surface area or the receiving room and this is the surface area of the enclosure. In case of personnel enclosure, both the receiving room and the incident room are the same. So, the noise reduction in that case is given by the transmission loss plus 10 log of alpha bar, where alpha bar is the average absorption of the receiving room.

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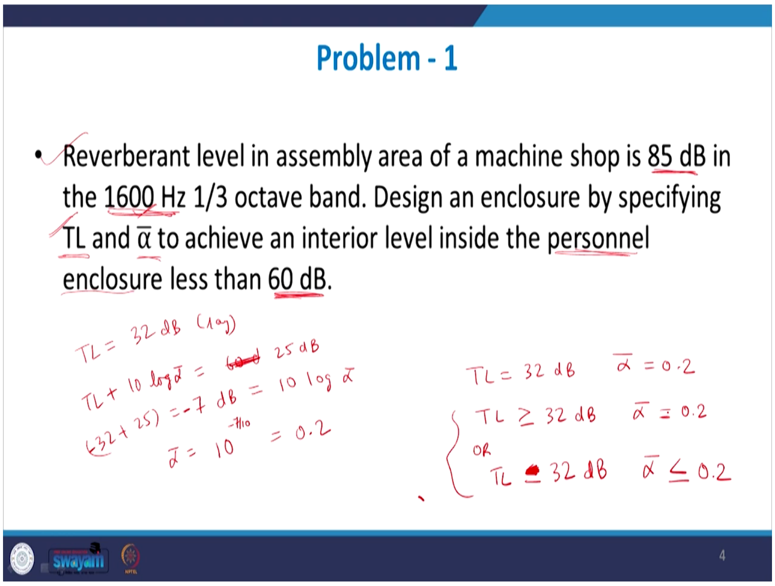


So, we have these two expressions. So, let us solve one problem. So, the problem given is that ok; the reverberant level in assembly area of a machine shop is 85 decibels in the 1600 hertz one third octave band. Design an enclosure by specifying the transmission loss and alpha bar to achieve an interior level inside the personnel enclosure which is less than 60 dB.

So, here we have to design a personnel enclosure and outside the personnel enclosure the steady state SPL is given by 85 decibels. And what we want to achieve is that after it passes through the enclosure, so within the personnel room it has a steady state SPL of less than equal to 60 dB.

So, let us derived first what is going to be for 60 dB and then we can increase and decrease those values.

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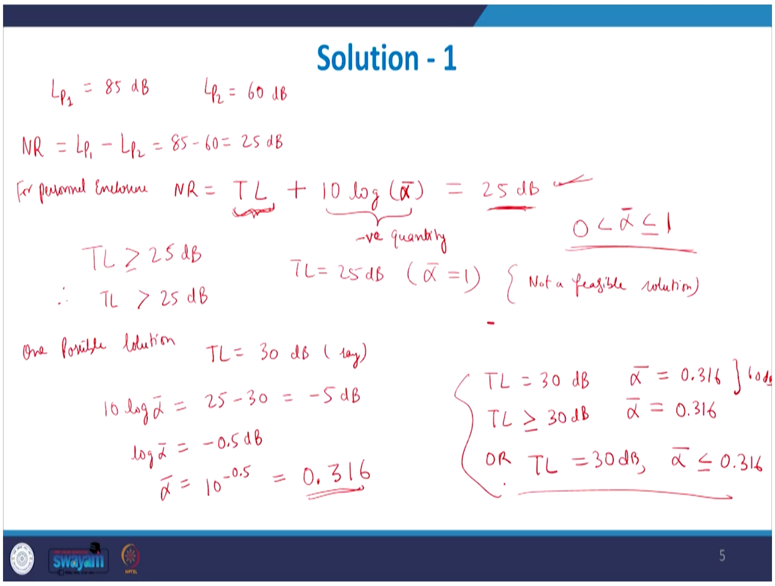


Now, the let us mention state what is mentioned to us. So, L p 1 is given as 85 decibels and L p 2 is given to be 60 decibels. So, we are taking the maximum case and then whatever we get, we can obviously, increase and decrease to get the overall solution. So, minimum this is the level that is desired even more.

So, what should be the minimum noise reduction due to this personnel enclosure; it should be L p 1 minus L p 2 which is coming out to be 85 minus 60 which is 25 dB. So, minimum 25 dB noise reduction is required.

And we know that this is a personnel enclosure, so for a personnel enclosure the noise reduction is given by this expression T L plus 10 log alpha bar, where this is the average absorption of the personnel room. And this is what we have to find, right; so find some appropriate values of T L and alpha bar. So, in this case there are many possible solutions, because as a designer you can choose any you can value you have got these two factors that you can vary.

So, you can vary this factor and this factor, so that overall sum comes out to be 25 decibels. So, as a designer they can be many possible solutions to this. And when you will be doing your assignments or the end of the course a question paper, then most of the questions will be objective or multiple choice questions. And in that case a few options will be given to you and as a designer you have to see which of them satisfies the criteria.

So, I am just going to note down a few solutions here. So, let us say that this transmission loss; now you see alpha bar, now alpha is always a value that is less than or equal to 1 by definition, it cannot be more than 1. So, overall this value would always be a negative quantity, because 10 log 10 is going to be 1 and this is a fraction, so it will always be a negative quantity.

10 log of 1, so when alpha bar is equal to 1, this will become 0; otherwise for any other fractional value this is going to be a negative quantity. So, in that case the first thing which we have to take is take T L slightly more than the overall that is desired. So, T L should be greater than 25 dB, greater than equal to 25 dB; T L will be equal to 25 dB when, when alpha

bar is equal to 1. But it is very hard to design a material that is alpha bar equals to 1 and that too at a low frequency. At low frequencies the absorption is quite less.

So, alpha bar equals to 1 is obviously, not a feasible solution. So, we are taking some alpha value which is a fraction. So, therefore, we take T L is greater than 25 dB. So, let say one possible solution I am giving you; let us say T L is equal to 30 dB. So, in that case if T L is 30 dB, then 10 log alpha bar should come out to be this is the expression, right. So, 10 long alpha bar will come out to be 25 minus 30 which is equal to minus 5 decibels.

So, if you do that, then log of alpha bar comes out to be minus 0.5 decibels ; alpha bar is going to be 10 to the power minus 0.5. So, the value for this is coming out to be. So, this is the value which is coming out to be 0.316. So, that is the value we are getting. So, here we have fixed one parameter and then we are accordingly manipulating and getting what should be the value of the second parameter to get this particular noise reduction.

So, the first solution is T L is 30 dB and alpha bar is 0.316 for a 60 dB sound. If we want to have more than 60 dB, then that means, and T L must be greater than or equal to 30 dB with some fixed alpha bar; or T L should be equal to 30 dB and this alpha bar, because alpha bar is going to be you have to reduce this value. So, it should be less than equal to 0.316 to get a more than 60 dB noise reduction.

So, this is one possible set of value; in the same way. So, that is the solution, in the same way you can have another possible set of value; for example, if you assume that the same T L, let us do it here. Let us assume that the second solution can be, we are assuming T L is equal to let us say 32 dB instead of 30 dB say.

Then in that case T L plus 10 log alpha bar again taking the limiting case comes out to be 25 dB. So, 32 minus 25 which is equal to 7 dB, so minus 7 dB becomes 10 log alpha bar. So, alpha bar again becomes 10 to the power minus 7 by 10, if you solve this expression. And this value comes out to be approximately 0.2. So, this is another case T L is coming out to be 32 decibels, alpha is coming out to be 0.2. So, you have these two cases or.

So these can be, so many possible solutions are there.

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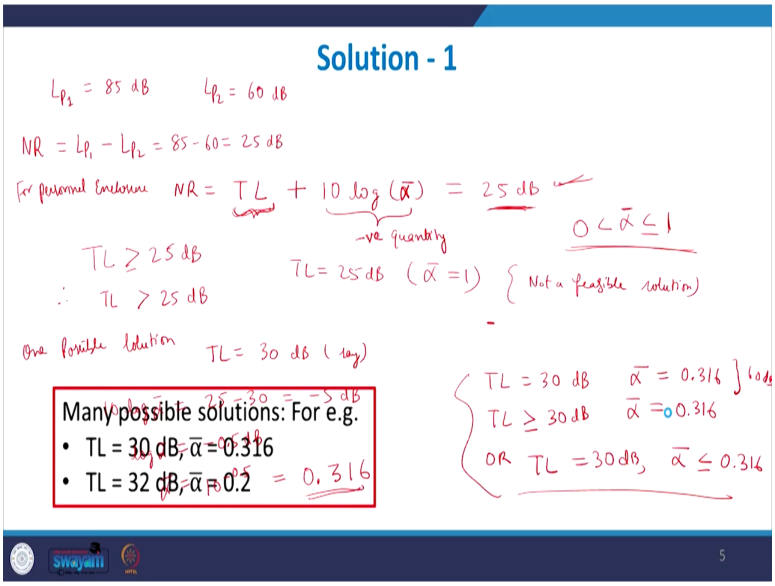


So, here I have just given you two possible solutions 30 dB and 0.316 and 32 dB and 0.2; but they can be many possible solutions to this question.

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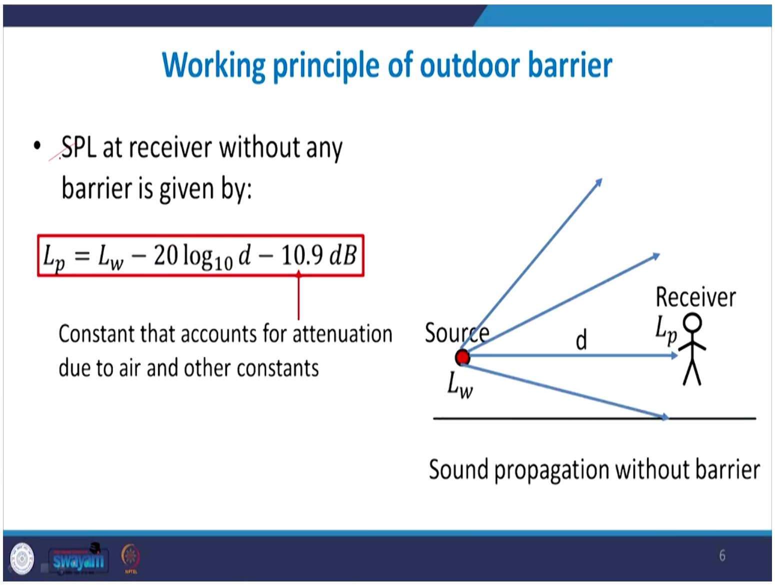


Now let us solve some question on barriers. So, to quick review of barrier is that, when the SPL is there.

When there is no barrier, then the SPL at the receiver is given by this expression L w minus 20 log d minus 10.9 decibels; here d is the distance between the source and the receiver.

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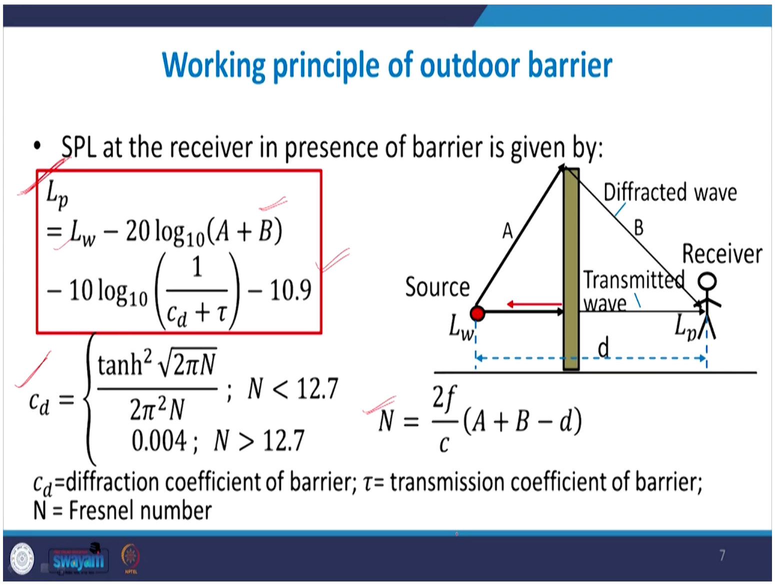


And when the barrier is present between the source and receiver in that case the SPL at the receiver is given by L w, which is the power level of this source minus 20 log A plus B; here this is the distance of A plus B, which is measured from source to the barrier edge and then from value edge to the receiver minus 10 log of 1 upon c d plus tau minus 10.9.

And this c d is also given in terms of Fresnel number. So, all this expression is given to you, which unfortunately you will have to memorize. So, let us solve a second problem.

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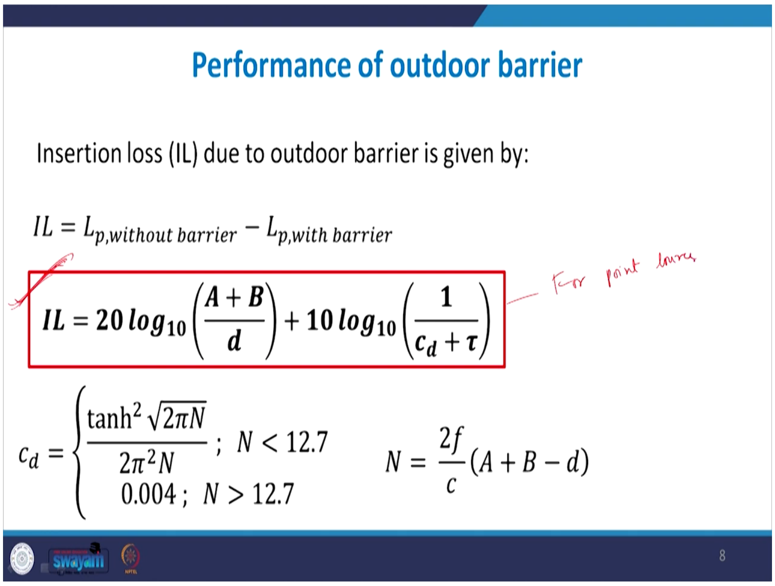


So, now, we have this L p without the barrier and L p with the barrier. So, the insertion loss you when you subtract the two expression, it comes out to be this ; this is for a point source assumption. So, the source is small.

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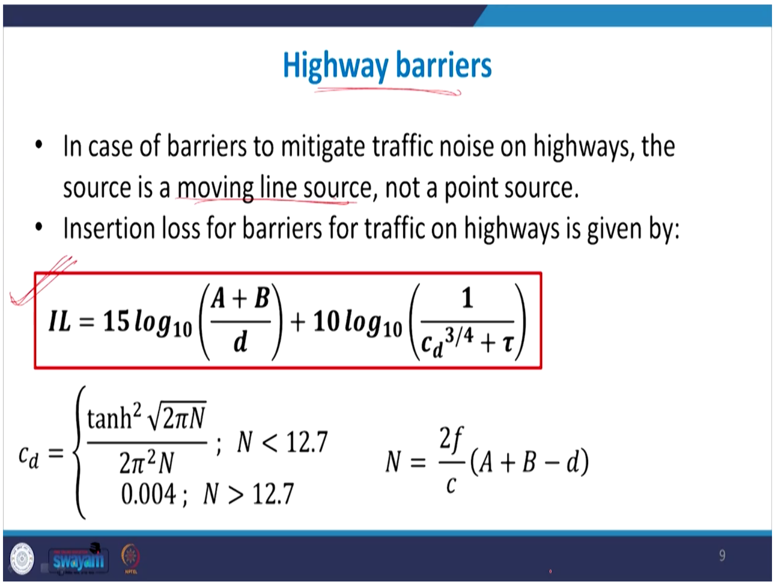


However when we have highway barriers, then we assume it to be a moving line source; in that case the same insertion loss expression becomes this. So, it is quite similar to this. So, this is the expression for the insertion loss of a highway barrier. So, based on this few formula let us now solve a numerical on barrier.

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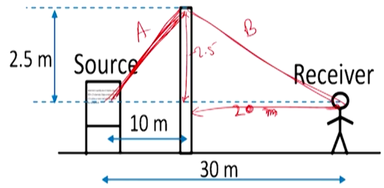
## Problem - 2

- A barrier is placed between a transformer (noise source) and the personnel (receiver). Table gives the sound power spectrum and TL of the transformer. Find the SPL with and without the barrier.




| 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 |

So, the problem 2 here is that, we are given a barrier is placed between a transformer which is noise source here and a personnel who is the receiver and the table gives you the sound power spectrum. So, here the L w is a function of the frequency and it is given a set of values; and the transmission loss is also function of frequency, it is given as a set of values.

So, quite in our previous lectures, so I had given you, I had told you that; all the performance matrix whether it is the transmission loss, insertion loss or sound absorption coefficient they are usually function of a frequency and as the frequency increases, then these value also increase. Performance in general increases at higher frequencies ; it is the low frequency region which is a difficult region for noise control

So, here T L is given to you, L w is given to you, everything is given to you for different frequencies and this is the schematic. The source is placed here and then at 10 meters you have a barrier wall and then between source to receiver you have 30 meters and this height is also given to you.

So, what you have to find is; you have to find the SPL with and without the barrier.

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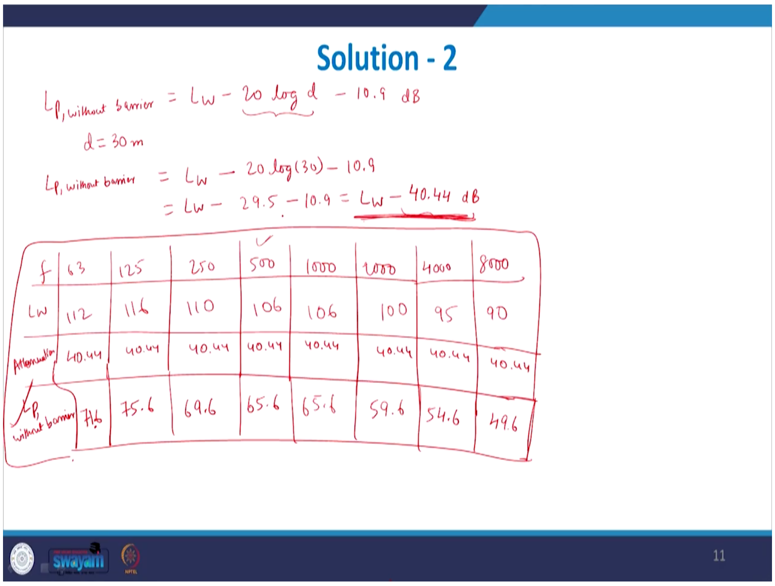


So, let us to solve this question. So, SPL let us solve first SPL without the barrier. So, SPL without barrier will be given by L w minus 20 log of d minus 10.9 decibels. So, this is the expression that we have got.

So, here L w is given to you for different frequencies, d is fixed and what is the value of d ; d is equals to 30 meters. So, this is something which is fixed and is not dependent on the frequency. So, if you take this expression here. So, L p without barrier will be L w minus 20 log of 30 minus 10.9; when you solve it, this is what you get. This overall becomes 29.5 minus 10.9, so this becomes L w minus 40 point approximately 40.44 decibels.

So, let us redraw that table. So we had the frequency at different, we had different frequencies it was still 8 k. So, we are drawing the table. So, frequency is given to you, L w is given to you ; as this is the value of L w which I am reproducing from the table. And we have found this value, this particular value. So, the attenuation, let us just say whatever attenuation is taking place total is given by 40.44, it is the same everywhere.

Then the net L p will become L p without the barrier; this is going to become subtracting these expressions respectively for the different frequencies, this will be also a set of value with respect to frequencies. So, the end value is this 71.6, 75.6; we are simply subtracting this L w with the attenuation, L w minus 40.44 that is the expression we have got.

So, this comes out to be the SPL without the barrier; 71.6, 75.6, 69.6 and then they are the same, so same value will be there 65.6, then 59.6, 54.6 and 49.6. So, as you see, with increasing frequency the dB is decreasing. So, this is the first part of the solution which is the L p without the barrier.

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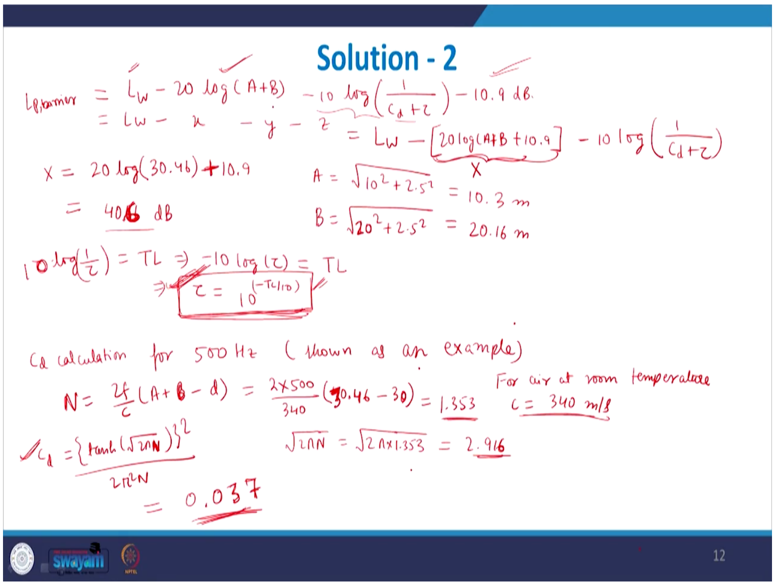


Now, let us find out what is the L p with barrier; then L p with barrier is given as L w minus 20 log of A plus B minus 10 log of 1 upon c d plus tau minus 10.9 dB. So, it is a long expression. So, let us first find out fixed expressions which we can write as L w minus x minus y minus z, so L w minus x. So, it is a subtraction of all these quantities, which can then be written as L w minus this quantity, 20 log of A plus B plus 10.9.

So, let us take the all the simple easy the constant quantities together and then the frequency dependent quantities separately. So, this is suppose let us say some capital X. So, let us find out the value for this capital X, this is coming out to be 20 log of A plus B.

Now what should be value of A plus B? So, you have this source here. So, you can see that this is going to A, right. So, this is going to be this is 10 and this is 2.5. So, A will be by the

Pythagoras theorem you will be 10 squared plus 2.5 whole square ; similarly B is going to be 2.4 under root of 2.5 whole square plus 20 square, because a total distance is 30 meters, ok.

So, from these two triangles you can find out what is the value for this A and what is the value for this B. So, A is found as root of 10 square plus 2.5 square which is 10.3 meters ; B is coming out to be under root of 10 square 20 square sorry plus 2.5 square, so this is coming out to be approximately 20.16 meters.

So, when you put this value together, so 20 log of A plus B is going to be 20 log of 30.46 minus 10.9. So, we have taken this constant expression together. So, this and this has been evaluated which comes out to be ; if you take them together what you get is 40.6 dB, this is the total value you are getting. So, one value has been found. Now to evaluate this particular expression, this is the other expression that is remaining; we need to know the value of c d and tau.

So, let us first calculate the value of tau. So, if you calculate the value of tau and c d; then what you get is, tau is going to be we know that 10 log of 1 by tau is equal to the transmission loss. So, in terms of this transmission loss, this is 10 minus 10 log of tau is going to be T L. So, if you take this in this direction, so tau ultimately comes out to be minus T L by 10 10 to the power, this is the value.

So, we know the value of tau and similarly we can find the value of c d. So, c d value finding that is bit more complicated; and due to lack of time I cannot show you for every frequency, but I will show you how to calculate c d for one particular frequency. Let us say, let us calculate c d for the 500 hertz frequency. So, this is the expression which we will use to calculate tau; and c d calculation for 500 hertz is shown as an example.

So, the value of c d depends upon N which is the Fresnel number. So, N is given by 2 f by c into A plus B minus d. So, for 500 hertz this comes out to be 2 into 500 divided by c which is we take as 340; for air at room temperature c can be taken as 340 meters per second. So, this is what we have taken. So, 2 f by c into A plus B which is going to be A plus B is 40 point.

So, A plus B was sorry here A plus B was 40.46, I forgot to put this 4 here; sorry this is the total value right, this is the same 30.46 was here. So, we put this as 30.46 A plus B minus d is 30. So, this is the value of the Fresnel number. So, for 500 hertz when you calculate this, then the value that you are getting is going to be somewhere around 1.353 sort of.

So, you get the value of Fresnel lumber, then c d can be calculated as it is the tan h of root 2 pi N whole square divided by 2 pi square N, and N value we already know is this, this is the N value. So, tables are available for calculating the value of this hyperbolic tan function. So, when you have root here root 2 pi N comes out to be roughly approximately root 2 pi N comes out to be under root of 2 pi into 1.353 which we get somewhere around 2.916 and this value can then be put inside tan h function.

So, the overall value of c d that you obtain is going to be for this particular case; the c d value comes out to be 0.037. So, this is the cd value for one particular frequency. So, so on and so forth for every frequency you can do the calculations. So, for every frequency you can first calculate capital N, which is 2 f by c into A plus B minus d and then put that N expression in the expression for c d and calculate the value of c d.

So, this can be done for every frequency. So, for every frequency you can calculate c d, for every frequency you can calculate tau using this particular expression and this is the way of calculation.

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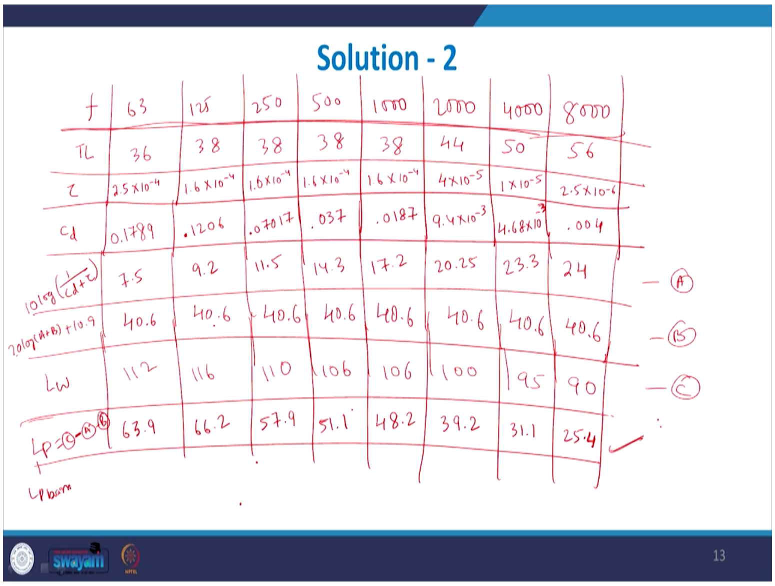


So, I will directly give you the results now. So, the results can be like this; let us divide this into frequency and various frequency is given to us 63 hertz, 125 hertz, 500 250 hertz, 500, 1000, 2000, 4000 and 8000.

So, these frequency table we have made and then the transmission loss for these was 36, 38. So, this was given in the question; the transmission loss for various frequencies, then tau can be calculated for every such this. So, this was the expression for tau, we are using this particular expression here. So, based on the T L value, tau can be 10 to the power minus 3.6, here 10 to the power minus 3.8 and so on.

So, the tau value is coming out to be 2.5 into 10 to the power minus 4, this is same value everywhere for here this is going to be. And similarly c d value as shown in the previous example can be calculated for every frequency; and the c d value simply comes out to be. In the last case when you calculate the Fresnel number, what you will get is at the Fresnel lumber which was given by this expression.

So, the value of the Fresnel number becomes greater than 12.7. So, we delicately take the c d value is 0.004. So, in the last case if you calculate that is what you will be getting. So, we have calculated this value. So, let us calculate the expression 10 log 1 upon c d minus plus tau. So, this was the full expression we have already have this value with us; we have this value, we have this value, together is 40.6. This is the last expression remaining 10 log 1 upon c d plus tau.

So, let us calculate this value. So, if you put these value approximate these values into this expression what you get is; 7.5, 9.2, 11.5 and so on. So, you get this value. And as you see a c d is dependent on the frequency, so the c d value is increasing with the frequency ; therefore, this expression value is also increasing with the frequency, it is going to be.

So, we have found this expression and this expression has been found; then the expression for 20 log of A plus B plus 10.9, this particular thing 20 log of A plus B plus 10 point plus 10.9 here ok. These two expressions together has been found as 40.6, it is same for every frequency. And L w is already given to us, which is for different frequencies it has different values.

So, total L p will be what, it will be; this is suppose column A B and C. So, L p would be simply C, which is L w minus A minus B, we see their C minus of this column minus of this explanation. So, it is going to be C minus A minus A. So, you subtract 112 minus 40.6 minus 7.5 and so and so forth you do for every frequency.

So, what you get, the final result is. So, that is the final value you are getting. So, this is the L p without L p with barrier. So, these are the two expressions you had to find.

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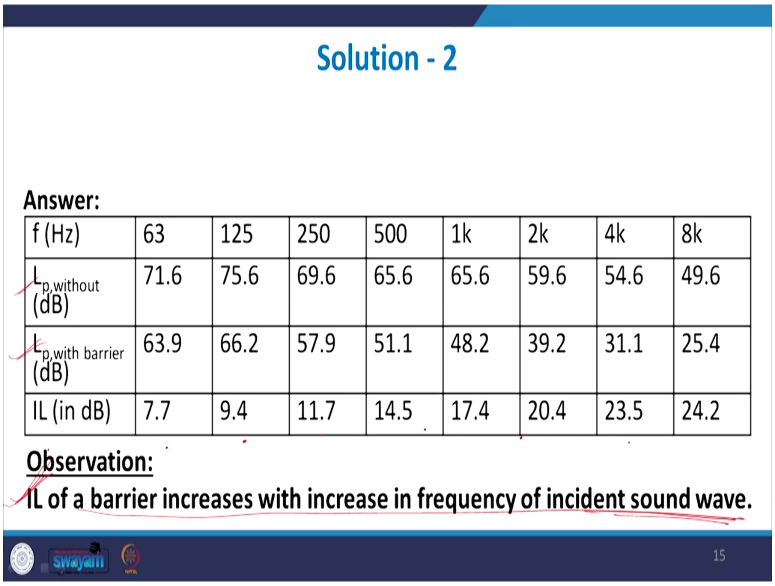

## Solution - 2

**Answer:**

| f (Hz) | 63 | 125 | 250 | 500 | 1k | 2k | 4k | 8k |
|---|---|---|---|---|---|---|---|---|
| $L_{p,without}$ (dB) | 71.6 | 75.6 | 69.6 | 65.6 | 65.6 | 59.6 | 54.6 | 49.6 |
| $L_{p,with\ barrier}$ (dB) | 63.9 | 66.2 | 57.9 | 51.1 | 48.2 | 39.2 | 31.1 | 25.4 |
| IL (in dB) | 7.7 | 9.4 | 11.7 | 14.5 | 17.4 | 20.4 | 23.5 | 24.2 |

**Observation:**

**IL of a barrier increases with increase in frequency of incident sound wave.**

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So, let us just go to the solution here. So, this is the solution, I am restating these solutions. So, L p was found without the barrier and with the barrier for every frequency. So, the insertion loss just as an additional inquiry; we had seen what is the insertion loss, so when we divide the two expressions, this is the insertion loss we get for every frequency.

So, the observation here we get is that, I L value is increasing with the increase in the frequency. So, performance increases with the improvement with the increase in the frequency, ok.

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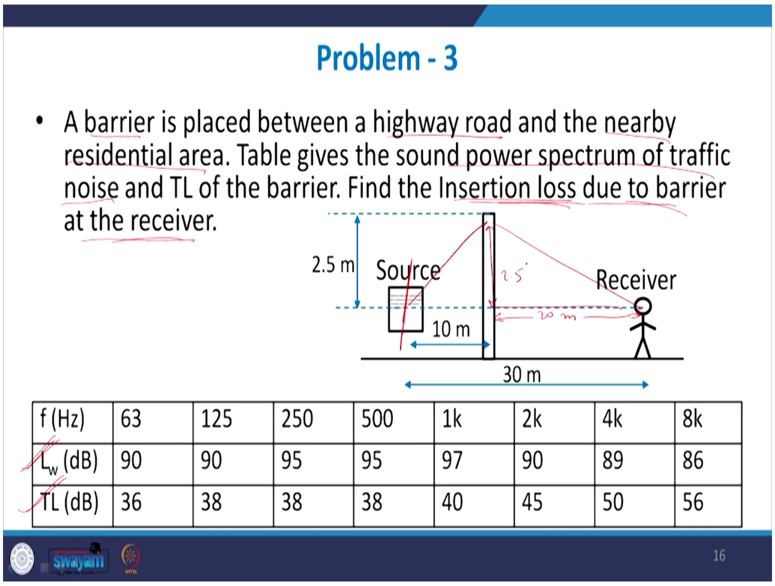


Last problem for this session, this is going to be a problem on highway barrier. So, we are going to find out, this is a question on the insertion loss of a highway barrier.

So, let us see. So, a barrier is placed between a highway road and the nearby residential area and the sound power spectrum for the traffic noise is given and T L is given to us, we have to find the insertion loss due to this barrier. So, just the way we did for the previous example, we will calculate for every frequency what is going to be the insertion loss.

So, here we do not need not need to find what is the SPL with or without ; directly we can put the expression for the insertion loss for a highway barrier.

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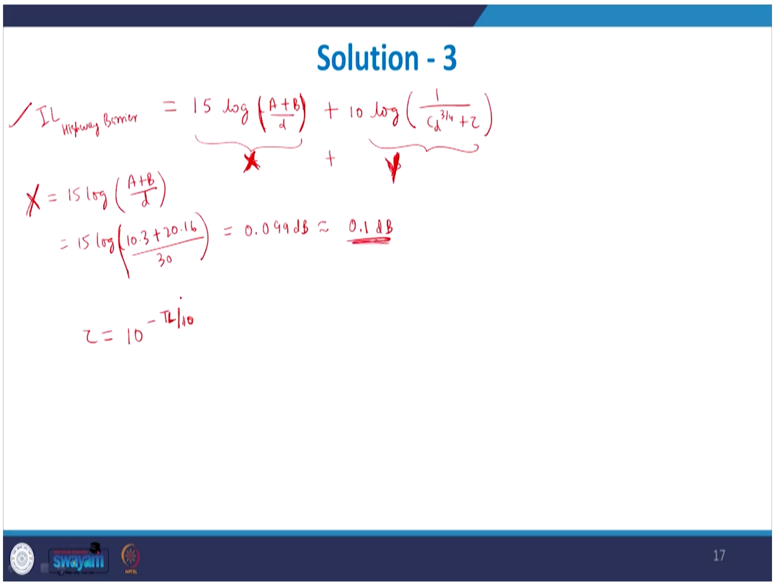


So, for the highway barrier, I L for a highway barrier comes out to be 15 log A plus B by d plus 10 log of 1 upon c d to the power 3 by 4 plus tau. So, this is the expression for the highway, insertion loss due to highway barrier. So, let us first calculate this value.

So, this is some expression A plus some expression B. So, we will calculate; now A is not dependent on the frequency, it is B which is dependent on frequency. So, let us first calculate the value of expression A, which is this thing. Now if you see here the same parameters are given to us. So, this is here this source is given as a box, but this is actually a line of traffic noise.

So, a can be calculated as under root of, this will be A which will be under root of 10 square plus 2.5 square, and the B will be under root of 20 square plus 2.5 square by Pythagoras theorem. So, using the same thing, what we will get is ok; let us call this expression as X and this is Y, just to not confuse it with the other A B.

So, the value of this expression X is coming out to be this which is 15 log of. So, the way we had calculated in the last case, A comes out to be 10.3 and B comes out to be 20.16 divided by the distance d is 30 meters. So, this value which we get is 0.099 dB or approximately 0.1 dB very small value, so very small attenuation.

Now let us calculate this particular value, so we make the frequency table here. So, tau is given by this expression as we derived previously. So, for every transmission loss value, tau can be calculated for every frequency and then c d can be calculated in the same way that we calculated for the last example. So, I will directly give you the results. Let us write it here.

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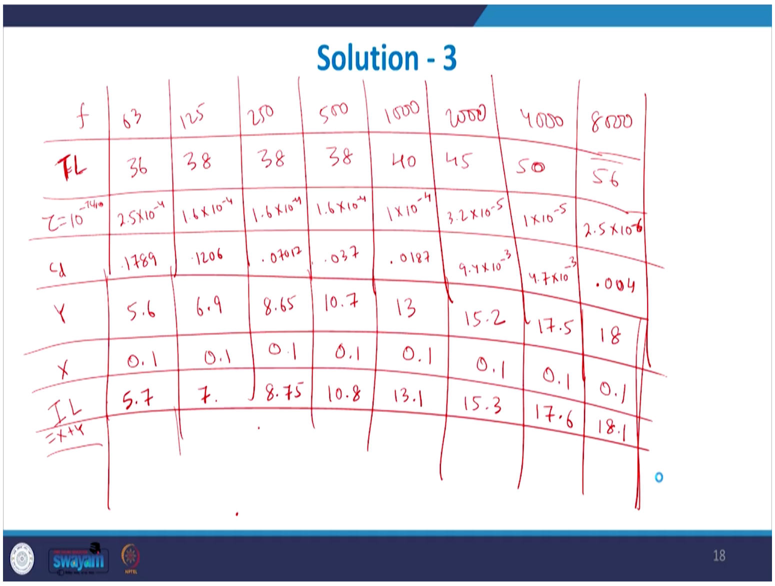

So, for that frequency tau value can be calculated, so T L is given to you. Let us see what is the T L value; so this is the T L value given to us. So, based on that tau value can be calculated as 10 to the power minus T L by 10.

So, this comes out to be, c d value is the same as what we calculated for the last case, because it is purely dependent on the frequency; and A B and A B are same, A B and d are same. So, based on that we can calculate the expression X and expression Y ; expression X is already been calculated which gives us this value.

Let us calculate the Y value, so the Y value comes out to be using the two values of tau, and c d this comes out to be 5.6 and X value is the same throughout it is 0.1. So, we have X and Y and we have the value of L w; sorry we do not need the value of L w, we directly need to calculate the insertion loss.

So, insertion loss is X plus Y. So, it is simply X plus Y, which we get as. So, this is the value of insertion loss we are getting by calculating separately expression X and Y.

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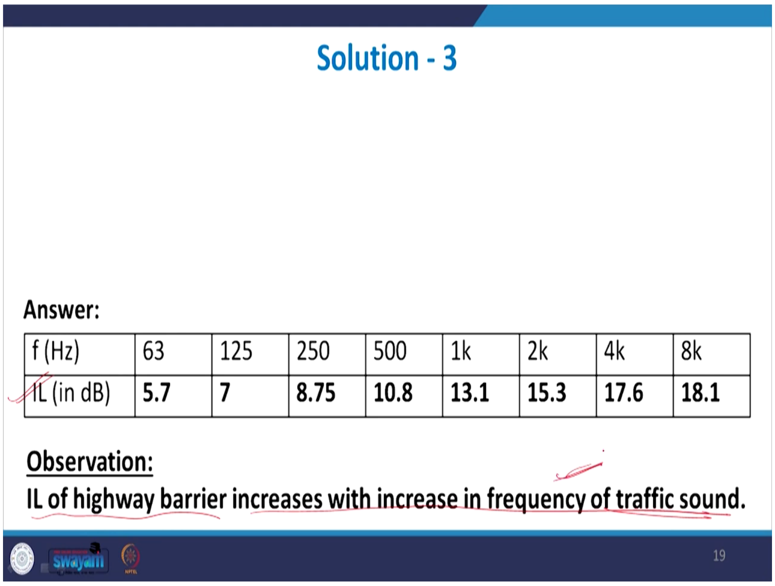


So, this is the answer; as you can see I have reproduced it.

So, again the same observation is there that, the insertion loss for a highway barrier also increases with the increase in the frequency of the traffic sound. So, with this I would like to close this tutorial and see you in the next lecture.

Thank you.