Principles and Applications of Building Science
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Lecture – 14
Sound Propagation

In this module we will be looking at the Propagation of Sound. We looked at the basics; we talked about decibel scale and frequency spectrum in the earlier classes. We will here look at how sound propagates. So we will talk about the basics of it.

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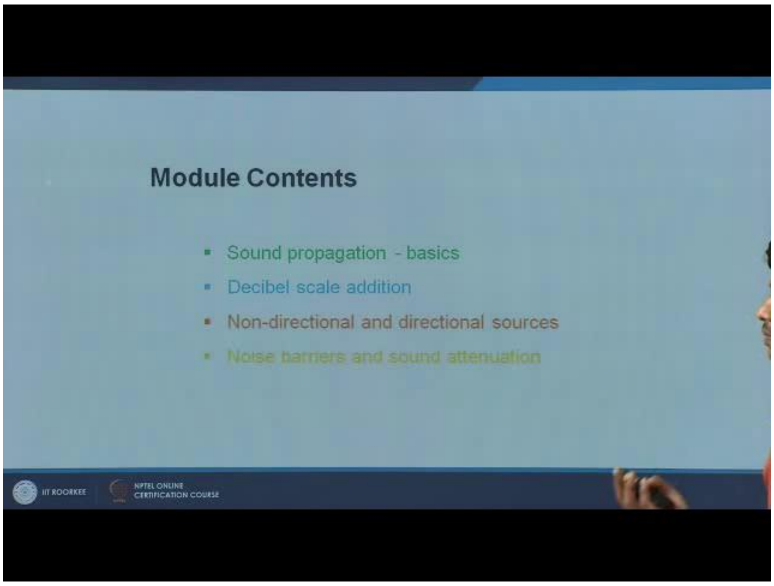

Another crucial thing is about the addition of sound level. When you have two sources 3 sources how do you add decibels. Then we will talk about the directional and non-directional sources. Then we will finally end up with the small calculation associated to noise barriers and sound attenuation.

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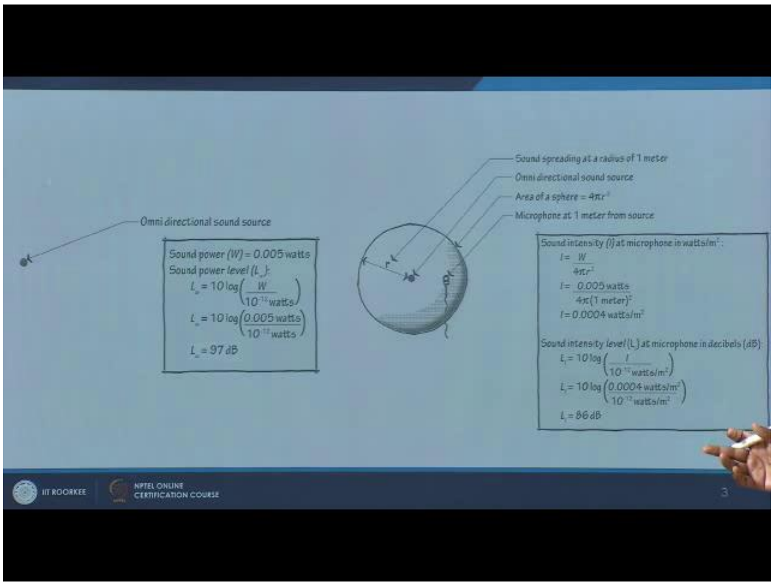

We have been assuming sound as a point emitting sound in this space equally in all directions. Imagine there is a sphere you have the sound source emitting sound equally across all the directions it can be take any particular direction we call it Omni directional source, take any particular direction let us assume the sound power of 0.005 watts, the sound power level then if you substitute 10 power minus 12 watts that is W reference watts you know the reference watts you will get around 97 dB this is a sound power level. So, you have from sound power you have the sound power level.

If I have to calculate intensity we looked at it I is W by 4 pi r square. So, now you take a sphere, so this W I W is a source characteristic. So, this will be L W. If I want to further investigate what is the intensity an intensity level. First I need to find out what is the intensity from power I can find out the intensity the same, you know source I am taking 0.005 watts, if I substitute and take say r as 1 meter at the distance of 1 meter so the sphere this whole thing becomes 1 meter. If I want to find the intensity; intensity is 4 in to 10 power minus 5 from that if you further want to find out the intensity level. As such you know the levels are more important for us then the intensity itself you have the intensity reference again 10 power minus 12 watt per meter square. You will get a sound intensity of 86 decibels.

Now, you go ahead further we talked about 1 meter; if I go further way 1 meter so the total thing is 2 meters now. At 2 meters if you calculate the same sound source 0.005

watts substitute 2 instead of 1 the sound intensity comes down. So, here you had 0.0004 watt per meter square.

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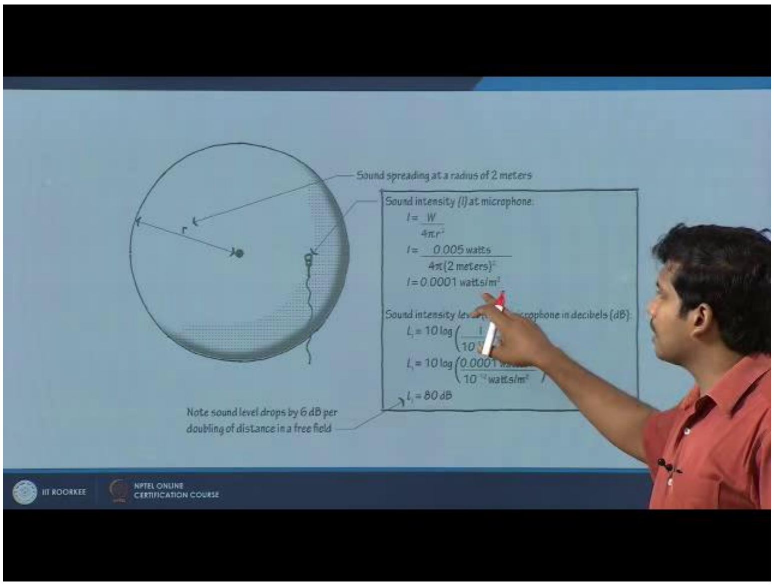

Here this is 1 1 in to 10 power minus 4 watts per meter square. Further, you find the intensity level. See this is typically difficult to remember say instead of saying 4 in to 10 power minus 4 and 1 in to 10 power minus 4 we can simply take a level. If you substitute and take the sound intensity level it becomes 80 decibels.

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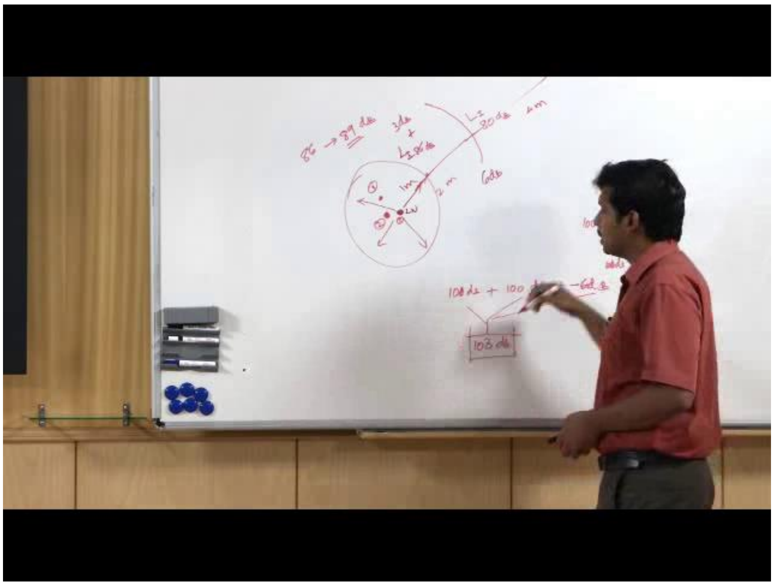

So, instead of 86 decibel at 1 meter here it was the LI was 86 dB, if you go 2 meters this becomes 80 dB this is again intensity level. So, 6 decibels have reduced if you go further 1 meter. Instead of 2 meter if you take 4 meters not 3 meters if you take 4 meter you will notice that this is further coming down to 74 dB. As you double the distance from 1 to 2 2 to 4 4 to 8, if you double the distance every doubling of distance you will find a reduction of 6 decibels that is in the free field without any obstructions. Imagining the sources of point source and it is Omni directional source.

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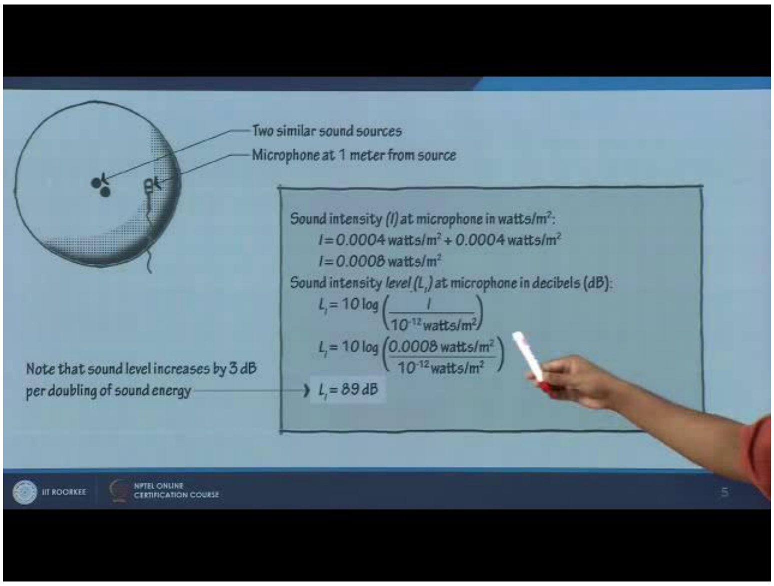

Now imagine there are two sources. Apart from this you are introducing another source, this is also equal we said about 0.005 watts per meter square. Now, there are two sources take the intensity 4 in to 10 power minus 4. So, there are two sources; I one and I two, if I am adding it so first how will I find the total intensity levels. First I will add these two then I will take the intensity level it is going up by another 3 dB instead of 86 dB it is coming to plus 3 dB. So 1 plus 1, this is source 1 this is source 2 if you add that you get an addition of 3 decibels which means increase of sound from 86 to 89 dB means one more source have got added up.

Similarly, if you are able to reduce the sound level from 89 to 86 dB it means that you have totally turned off one of the sources. There are 2 pumps, 2 motors in a room each one is emitting 86, 86 dB you add them you will end up with 89. If you turn off one of the pumps or one of the motors you will reduce 3 decibels which means one of the sources is turned off.

Now, imagine there are 3 sources first two sources have the same intensity, but the third source is almost like one quarter. It is like pretty quitter than what these two things are; it is like adding another decimal here. If you sum it up you are getting 86 as a number here, if you take the intensity you do not see a difference in the sound intensity level it still remains as 89. What does this mean? I have put additional source this is source number 3.

So, imagine now there are 3 sources; one source is 100 dB the second source is also 100 dB. Now if I add this I am going to get 103 dB in the logarithmic addition we will look more examples of it. If I am adding another source which is about say 60 dB and turning on another source which is 60 dB if I further add this to this I will still be getting only 103 dB I will not be finding further increase to it. If there are equal sources or if one source is more than slightly more than slightly less than the other we will look at the specific numbers, but this is what it amounts to. If the threshold the difference between this and this or any of the sources is pretty much lesser you will not find a reduction or increase in overall sound pressure level. Imagine you are adding 100 dB plus 60 dB there are two sources, the overall number will be still be 100 decibel the lower sound pressure or sound intensity level source will not be heard.

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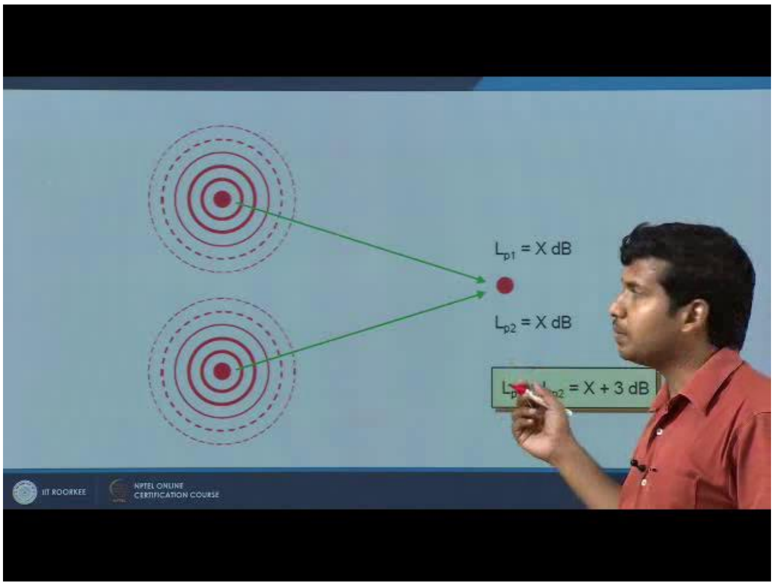

How does it get added up? L p1, now we are looking at sound pressure L p1 plus L p2 x it will become 3 decibel.

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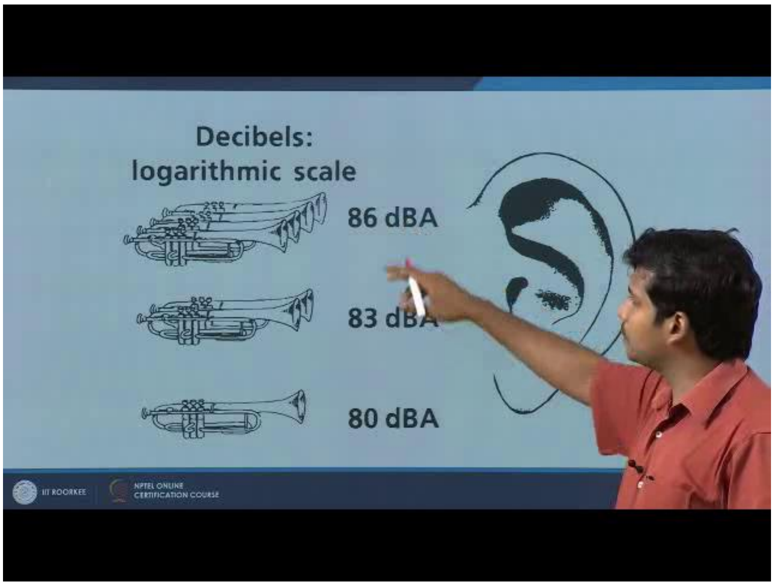

Simple logarithmic addition, one source two source plus 4 sources each doubling of the source is 3 decibel increase will be perceived.

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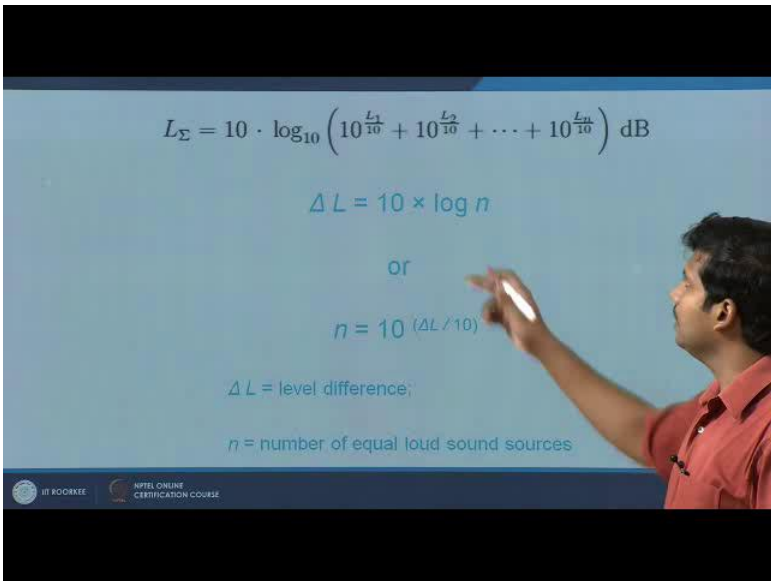

Simple logarithmic addition as I said you have to take 10 power L 1 by 10 antilogs taking simple thing. This is the second sound pressure L 2 by 10 etcetera by L n by 10 overall if you sum it up you will get the total cumulative value. Simple way if you have equal sources, like we said here there are 200 decibel sources or 10 number of 100 decibel sources you have motors 10 motors operating each one is producing 100 dB it is much more simpler you can just say 10 in to log n, n is a number of equal loud sources you will find what is the level difference.

So, when the level changes by 1 decibels say you know 80 to 81 dB 90 to 91 dB it is noticeable; 3 decibel is very noticeable and as per as high it is almost doubling or halving the sound level. If you recollect in the pollution control board table we refer to a term called equivalent sound pressure level.

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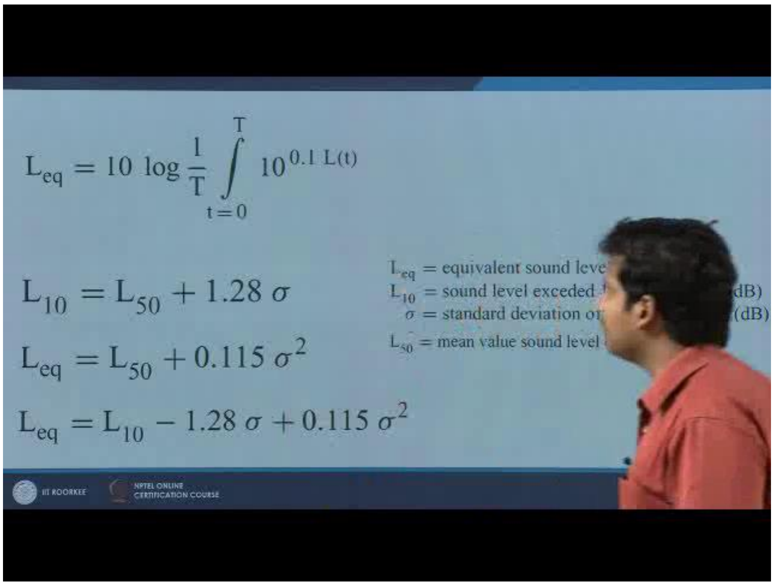

This is exactly what we will be looking here, we have L equivalent which means equivalent sound pressure level. Two terms will be commonly occurring that is L equivalent that is linear equivalent sound pressure level another is L a or a weighted sound pressure level equivalent.

The moment you see the term equivalent which means that it is a time integrated sound pressure level. As we know reported some of the measurement I showed you two three measurements that were taken during the occasion of Diwali. The measurements were taken at specific every second in the sound pressure level was significantly varying. So, this was measured for 20 minutes duration that I showed you. For the 20 minutes there is a lot of data, so if I have to tabulate every second how is the sound pressure level variation. So, every second there will be a time stamp and there will be sound pressure level at different frequency.

Right now let us keep the frequency aside; you have a linear sound pressure level. So, there is a time stamp 1 you have L 1, you have the time stamp 2 you have L 2, so it goes on up to L n. What do we do if I have to report the whole thing as table, what pollution control board wants if I have to report a value or if I have to submit a report to pollution control board? I have to prove that the activity which I am doing does not create more sound and it does not pollute the ambient. Say if I am like I said if you are conducting some show in the residential area in the night time, the night time sound pressure level should not exceed 45 dB as per the pollution control board terms.

In that instance what you will do, you will take a series of sound pressure level measurements across different times so you will be measuring at continuously at specific intervals; continuous measurements are needed. Then you tabulate it take a time integration sum it up you will get the equivalent sound pressure level. So, it is like a average value, but it is not typical average value it is a time integrated value which you will get one single number which is called equivalent sound pressure.

So, if you are working on a weighted scale you will get a weighted equivalent sound pressure level.

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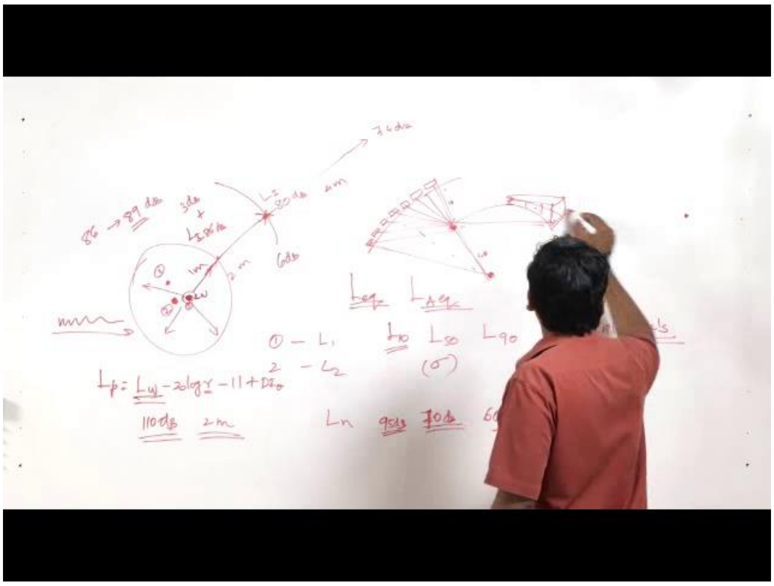

Other than these three parameters are important that is L 10 L 50 and L 90. These are called percentile sound pressure level, percentile levels. These are commonly used in environmental noise measurements. Apart from L eq and L Aeq you also will be coming across terms like L 10 L 50 and L 90. These are like 10 percent of the time there is a exceedance. These are exceedance sound pressure level and this is nothing but the sigma or the mean value. If I say L 50 during this 1 hour duration or 8 hour duration the sigma or L 50, 50 percentile values say 70 dB it means the average sound pressure level is 70 dB during that 1 hour or 8 hour duration in which I have taken the measurement.

On the other hand when I say 90 percentile it means that for 90 percent of the duration during which the sound pressure levels are measured, for 90 percent of the time the particular value existed. In this case it could be like say 60 dB, for 90 percent of the time the sound pressure level was around 60 decibels. 10 percentile means what is exceeding for 10 percent of the time? If I measured for 8 hours for 10 percent of the total duration the sound pressure level was say 95 decibel. This is a slightly more detailed way of representing the sound pressure level. Apart from simply saying e equivalent or A equivalent value.

So, if I say L 10 is 95, L 50 is 70, L 90 is 60 dB typically for pollution control board number what I will be giving I will be giving the number 70 dB. Say if it is a industrial area I will say that sound pressure level recorded was 70 decibel which says that average it is 70 dB. But how high it went for 10 percent of the time it went above 95 dB, it was above 95 dB. And for 90 percent of the time it was around 60 decibel which is still agreeable. The average gives you a more or lesser rough estimate of what the sound pressure is, but actual number the sensitivity of it the impact of it you will get with L 10 or L 90 these two things are also important. Some relation between each of them if you know one you can calculate the other simple statistical relationships I have put here.

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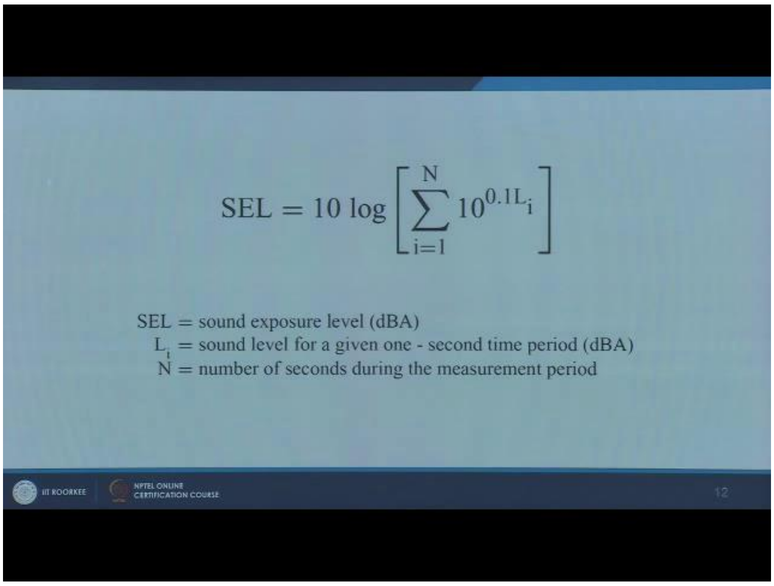

The other term which is important is a sound exposure level. This depends on how much impact it causes you, for how much time you are a person as a person are exposed to it. Say you are operating particular machinery, the machinery is producing 90 dB sounds if you are just going to operate it for example, 5 minutes the impact which it causes to you or your ear hearing ability is different, when you are going to operate it for 8 hours a day. The same machinery when you operate for 5 minutes versus the same machinery you operating it for 8 hours. So, the impact that causes you the exposure you have for the sound varies. So that exactly is given by the sound exposure level.

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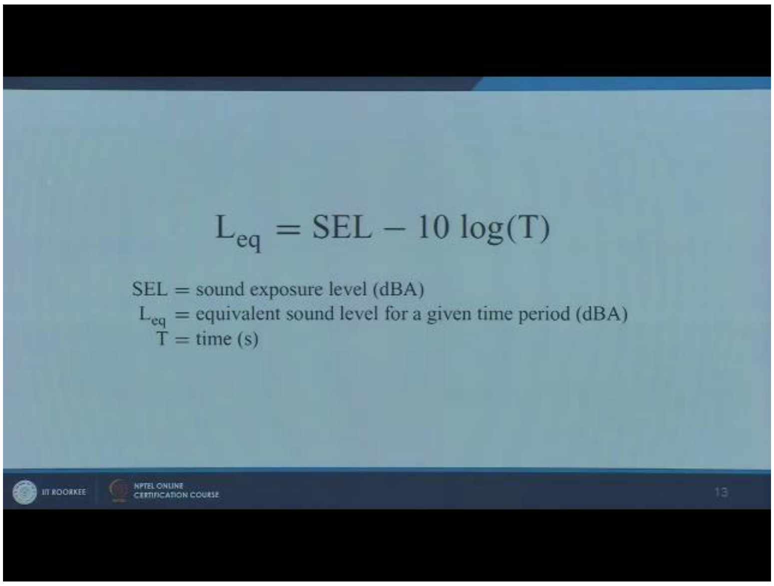

If you know equivalent sound pressure level you can determine SEL along with the time you have to know how much time it is or if you know one the other equivalent sound pressure level can be determined.

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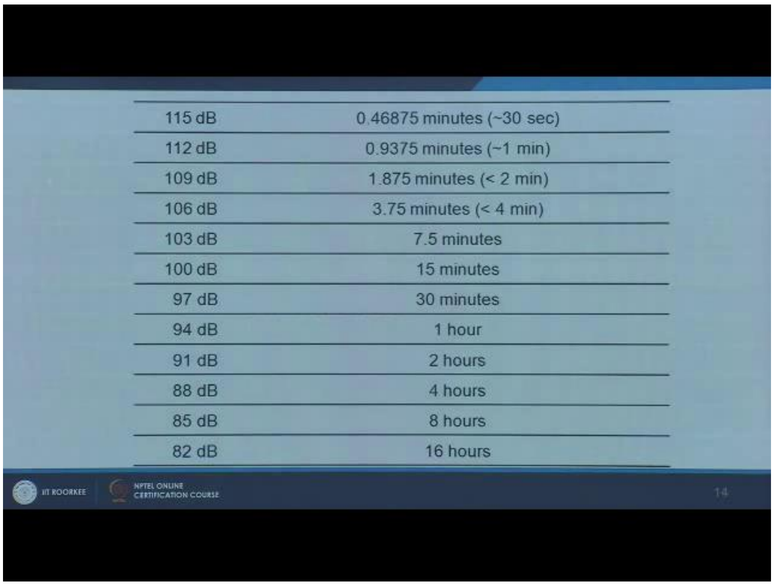

115 dB	0.46875 minutes (~30 sec)
112 dB	0.9375 minutes (~1 min)
109 dB	1.875 minutes (< 2 min)
106 dB	3.75 minutes (< 4 min)
103 dB	7.5 minutes
100 dB	15 minutes
97 dB	30 minutes
94 dB	1 hour
91 dB	2 hours
88 dB	4 hours
85 dB	8 hours
82 dB	16 hours

So, what actually happens? Let us start from this 82 decibel sound, these are studies done with industry workers. If it is 82 decibel sound if a person is experiencing or exposed for 16 hours after 16 hours he will start getting impacted in terms of temporary and permanent hearing ability related problems. As sound pressure level increases, say as it goes to hundred decibel if he is exposed to more than 15 minutes he is going to have hearing related problems. If he is exposed to 150 dB sound like jet propulsion, less than 30 seconds he will be having hearing related problems.

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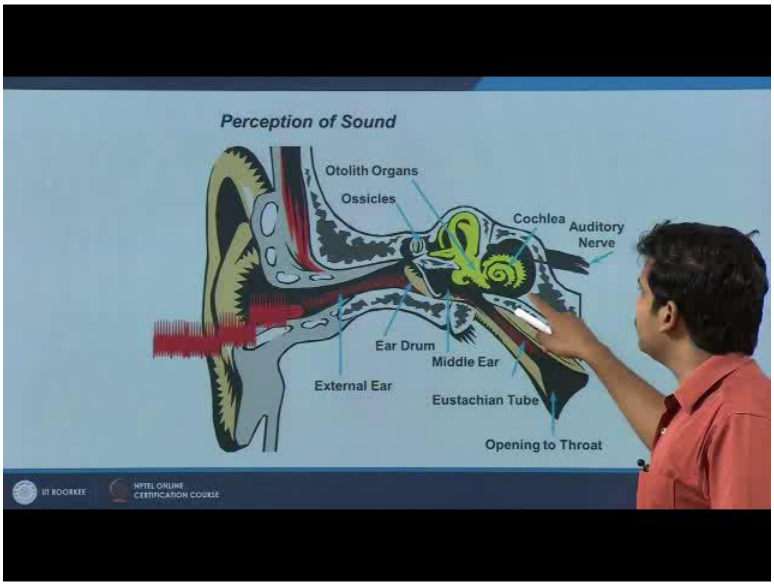

So, when I say hearing related problem typical cross section two things are important; one is a cochlea, then you have you know the ear drums.

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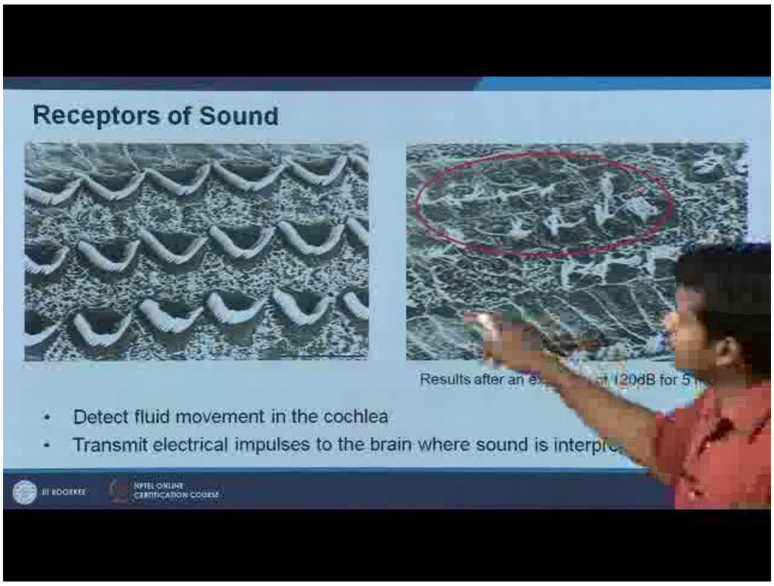

These are two closer looks of the images of this particular portion the cochlea. This is a healthy ear this is after an exposure of 120 dB for 5 hours. More or less these hairs are the receptors have been lost which means there is a permanent hearing loss which is going to happen for this particular person.

How does sound propagates outdoor? We looked at this equation the relation between L p and L W that is sound pressure will be equal to sound power minus 20 log r minus 11, r is the distance here. So, we also talked about last time how sound varies as it travels through distance.

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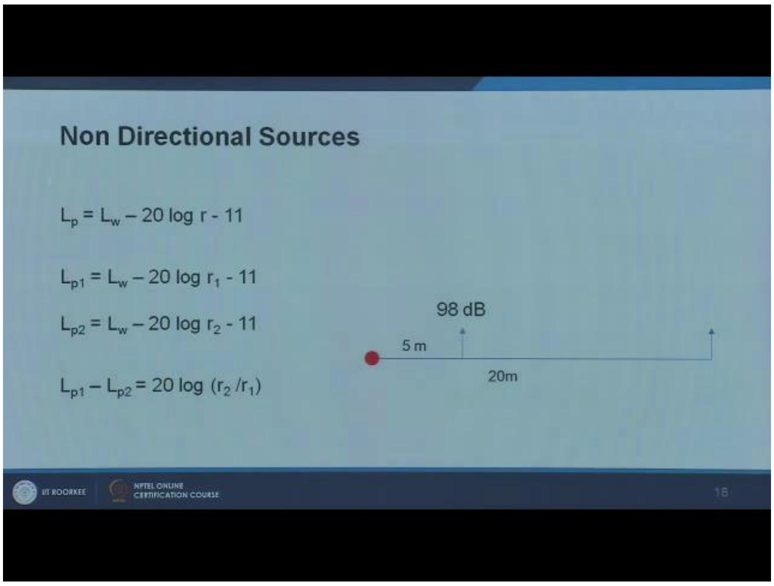

We are talking about first non-directional sources. Again similar you know the spherical point here it propagates across, there is no barrigation around it can propagate in all the 360 degrees. So, if you take the first distance as r 1, if you have second distance as r 2 what will be the pressure difference between the sound pressure 1 and sound pressure 2 the difference will be r 2 by r 1.

If you substitute say for example, you have a sound pressure of level of 98 dB at 5 meters after 20 meters that is you are actually first it is 1 doubling and 2 doubling after 5 meter it is 10 you are doubling it then you have another one you will have about 6 decibel reduction in sound pressure level.

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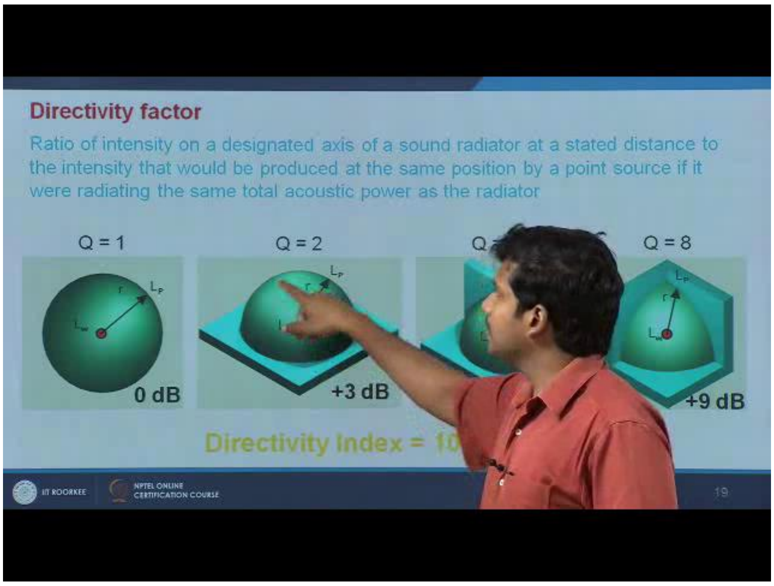

We talked about the non-directional sources, but most of the sources we experience are non-directional. There is no single point in the space from which you are going to hear sound. Most of the building and building related or transport related sounds are directional. Simple example of directional source you put a motor in the center of the room like this you are suspending the motor it is emitting the sound again it will be directional because motor has lot of components each component has directional factor, but imagine you are fixing the motor on the floor plate. Now there is one dimension in which the total sound propagation is blocked. So, it only hemispherical in which there is a directional quantity introduced.

The same kind of equipment it can be a motor or a pump fixed at 90 degree wall angle here you are fixing it, then it is only a segment of this hemisphere in which the sound is getting propagated. Instead you are putting it in a room corner the same source then the directionality of the sound it is blocked in three sides, so this same thing will be reflected and re reflected it will be coming back to the same direction. Ideally the perceived sound pressure level should be increasing from this to this to this and then to this.

This is expressed in terms of two quantities; one is directivity factor and directivity index. Q we refer to typically as directivity factor, it is nothing but the ratio of the intensity of Omni directional source. You know a directional source with respect to Omni directional source. Directivity index is 10 log of Q theta that is directivity factor.

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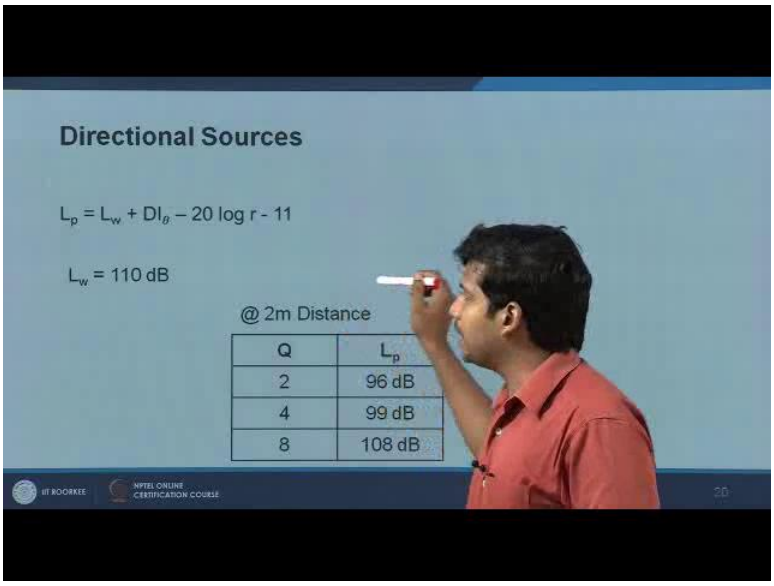

We will substitute it and see it in the equation. This fits in to the equation there is a series of derivation which I am not presenting right now. This fits in to this whole equation the same equation, it adds as another factor plus DI theta that is directivity index adds up as another factor. Now let us substitute some numbers and see this. Let us take a constant sound power level of 110 dB and let us also fix the distance let us take 2 meter distance we are not propagating further we are holding a 2 meter distance.

At this particular point a 110 dB sound power source if you have to find this on pressure level first for a Omni directional source the sound pressure level this will be nullified the effect of DI theta will be nullified because Q is 0, now Q is 1 DI theta will be 0, so the effect is nullified. Then for a particular floor plate the pump fixed on a floor plate one direction it is totally cut off. The directivity factor becomes 2, log of this you will get 3 there is a 3 dB addition. Then the next case Q is 4 here two sides are blocked you get 6 dB addition here, instead of 90 3 it becomes 96 then it is 99. Then when you have 3 side enclosures only one side sound is going to propagate you have a Q of 8 which means it is nine dB addition.

The same distance, the same sound power source as the directivity varies if you are curtailing more and more direction if it is focused on one side the sound pressure level is going to increase. The same pump put in the center of the room versus fixed on the floor plate versus fixed on a wall corner and fixed on a room corner the sound pressure level at 2 meter is considerably going to vary. This is what we need to first understand.

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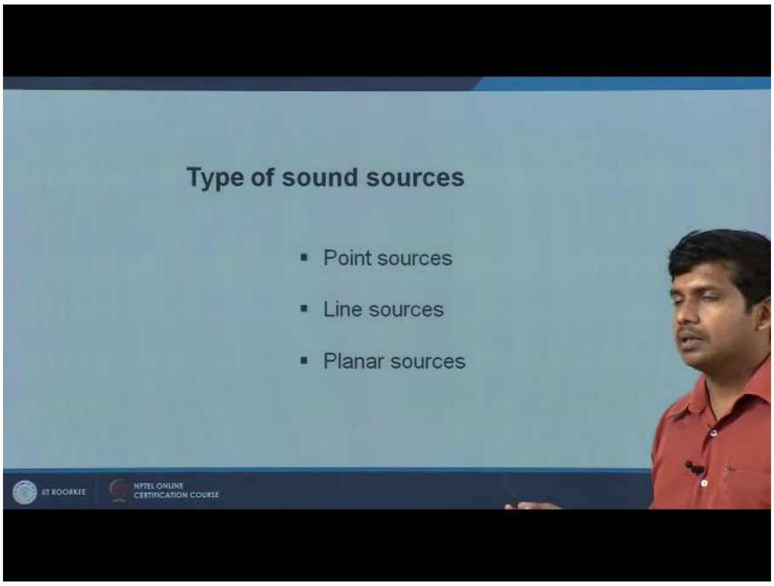

Apart from this there are 3 types of sound sources. So far we have been talking about sound as a point in the center of the space or point with a direction fix to some point. We you know sound is getting emitted from a particular point. There are two types of other sources which are of importance apart from point source. Next is a line source, third is a planar source.

I can give you specific examples for each of these sources the propagation pattern differs. As a part of this course I am not introducing you equations or derivation related to line or planar sources, we will start by point source alone we have to precede further with building acoustical related, design related things. So, first is point source which we have been looking at. To differentiate it I will give you some example.

Imagine you are located at the point you have a train which is passing by, you have a train which is getting along when you stand here. This particular thing is not a point it is a linear source or you are at certain distance, you have a traffic corridor, and you have a series of vehicles. So, when you have a traffic corridor on one side you have vehicles each one is a vehicle for example, each of this vehicle is going to emit some sound you are located at this point. So, now at this point you will be hearing distinctly each of these vehicles. Now this train again you will be able to hear this is one single source.

In this case now if I am moving further from a particular distance say I am at 10 meter instead I am going to say 40 meter distance what is this feel like, they merge with each other and you will be able to get one single sound pressure. You will not be able to distinguish between which vehicle is emitting which sound, but as you get closer and closer the source characteristics are revealed so you will start feeling each of them as specific point sources, each one is a point emitting sound. As you go further and further they merge together and you start hearing them as line sources. Really far off this will further merge in to one single source. Like the same train example instead of this point if you are really far off say around 50 60 meter or even more you will get this as one single point you will be listening to this as a point source.

For specific example say if you are working with the chiller unit or you are working with the air handling unit the whole machinery is emitting some sound, if you have to measure it some cases the planar sources the total sounds get emitted from a particular plane or a particular surface you can treat it as a planar source. It depends on certain industrial calculation or even environmental calculation they use planar sources, some cases depending on the distance we will use line sources or point sources. For simple calculation I have used point sources and I have been demonstrating you.

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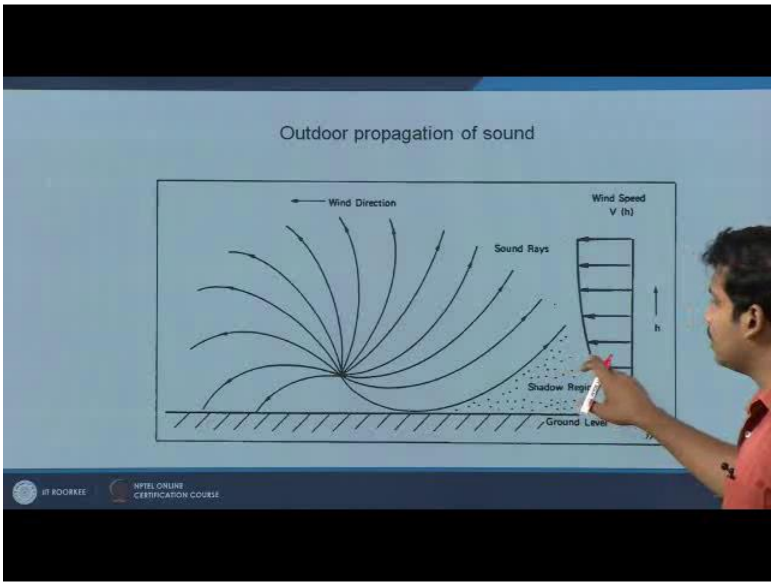

When we talk about environmental noise propagation simple thing we can understand it varies with respect to the wind speed and the wind direction say if there is a point source here it is emitting, this is a windward side as it propagates against the wind it tends to bend up, as it propagates away from the wind it tends to bend down.

If you look at the old roman amphitheaters these principles where nicely applied the source versus the audience, the source versus the receivers, the windward and leeward sides were carefully considered when they were because there were no amplification systems they considered carefully above the bending of sound across the wind.

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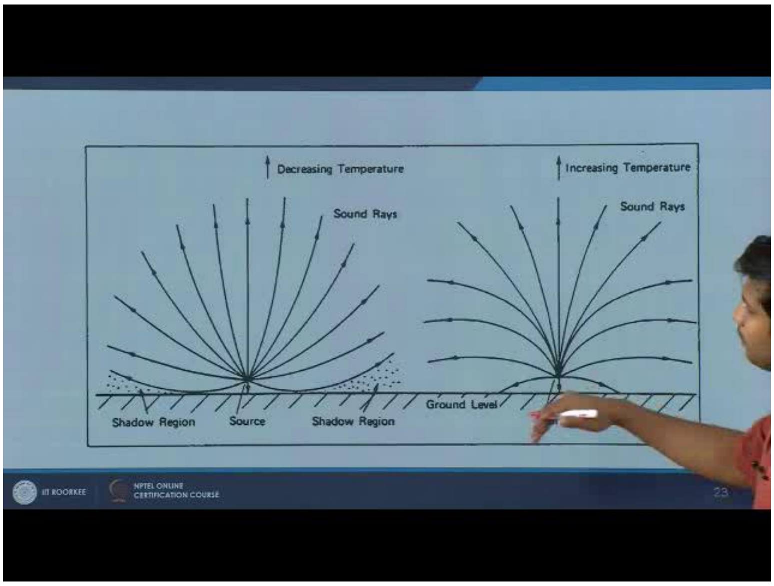

Again it varies with the temperature differential between the ground and the atmosphere. So, as the temperature decreases for instance then the sound tends to go up as a temperature increases it tends to bend down.

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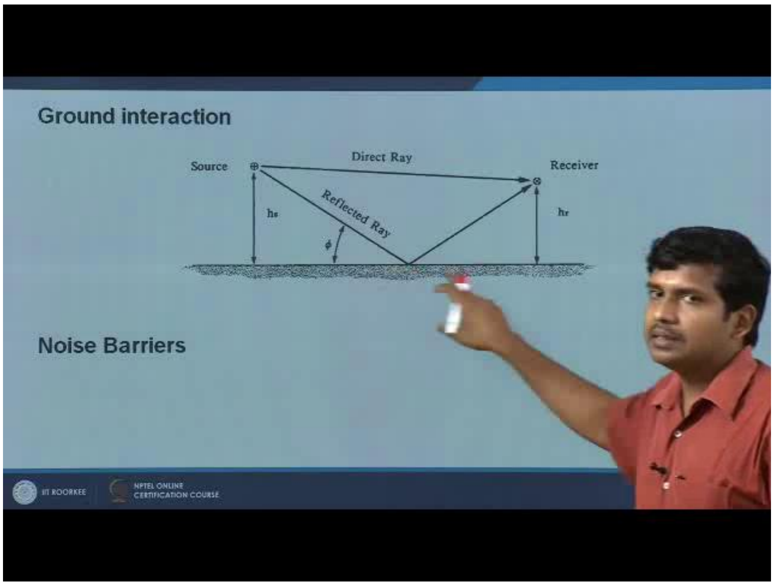

Then you have ground interaction; say for example sound propagating from source to receiver through a glassy surface or a say concrete surface or metal surface. Then there is a lot of reflected sound whereas if it is passing through grass or vegetation, then there will be a lot of diffraction and absorption happening in this surface, this is another crucial phenomenon.

Apart from this one quick thing that we need to understand by completing this we will have to look at noise barriers. Noise barriers are increasingly coming up in urban areas cities like Delhi we have lot of noise barriers being put up, it has increasingly becoming as people start realizing that increase noise levels are injurious to harmful to health and hearing, it disturbs their sleep. And more environmental noise activities for example, busy traffic corridors were intervening with residential areas with quieter areas then you will have to provide certain insulation measures of which noise barrier is one of the most effective techniques.

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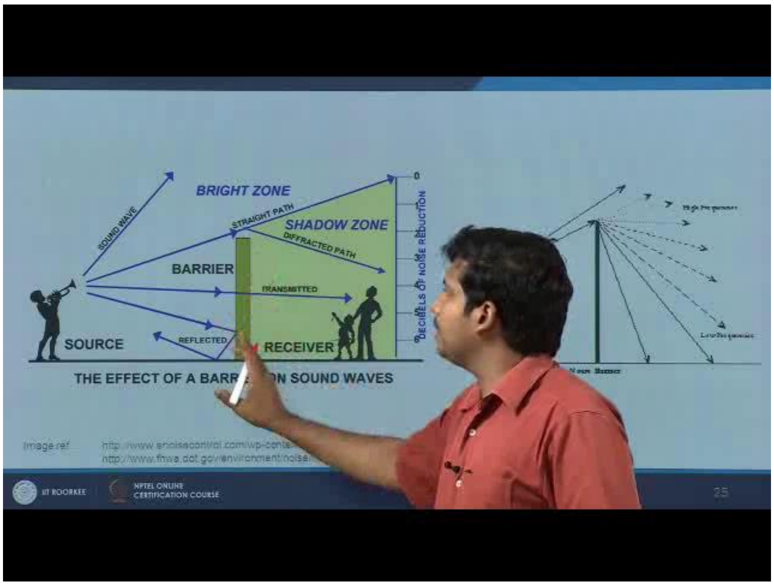

Before we look at the calculation part of noise barriers what is a noise barrier, it can be some objection object which is protecting the propagation or preventing the propagation of sound from the source to the receiver. It does direct reflections, it also scatters the sound, it depends on the surface treatment and the edge finish there are something called edge diffraction's which will happen. Instead of the straight path part of it is get reflected, part of it gets of the barrier because of diffraction and some of it gets diffracted back. So, typically you develop a something called shadow zone within which the barrier is effective. Imagine this is a source and this is a receiver the shorter the barrier the shadow zone will be much lesser as the barrier height increases the shadow zone will be more, this is the first thing.

Number 2; as the distance of the source increases or the distance of the receiver increases the effectiveness of barrier of the barrier considerably varies. So, how do we determine what is the effectiveness of barrier. Before that one more thing it depends strongly on the frequency. If you have a high frequency sound emitted from this point it gets reflected or scattered away, whereas low frequency sound which has high wave length; low frequency typically has high wave length and high frequency sounds have a low wave length inversely proportion. Low frequency sounds get diffracted and then they get back to this. So, typically environmental noise barriers are much effective and made on high frequency range, but if you have to make it effective for low frequency you need a special treatment or special design of barriers in order to curtail low frequency sounds.

So, how do we calculate for this? One important number is there which is called Fresnel number; basically it revolves around calculating the path length differential. You have the source you have the receiver here this is located like this, you are making a noise barrier here, this is a source this is a receiver for instance then you have a straight distance here and then you have a sound traveling distance. This is a straight distance in the absence of this barrier this will be the direction and this will be the path in which the sound would have propagated.

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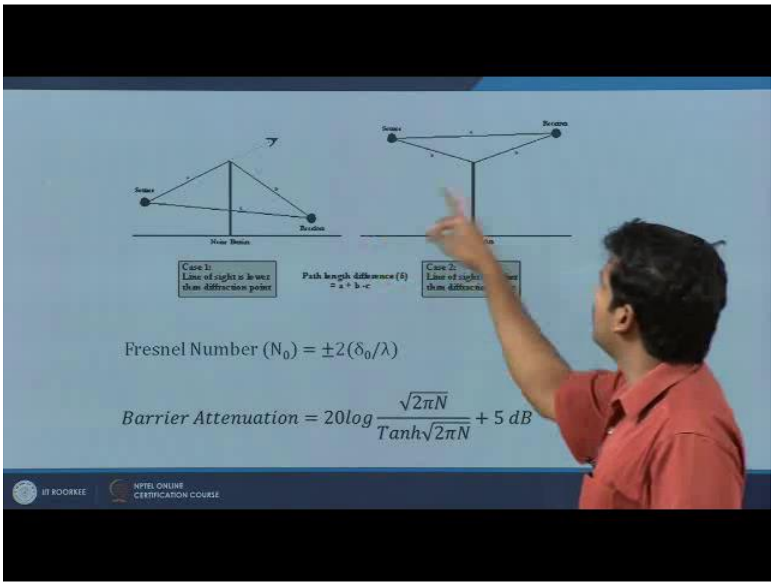

Whereas, now with the presence of barrier this is taking a different route this is here we are talking about it as A B and C; this is A, this is B and this is a actual distance C. Now we have to calculate the path difference that is A plus B minus C you will get a number if you substitute this with the wave length of the sound lambda is wave length of the sound. So, this number by wave length plus or minus 2 you will get a number called Fresnel number. This Fresnel number is very significant to determine the effectiveness of noise barrier.

Positive indicates the barrier is effective that is the receiver is not in the line of site that is if you are the source you cannot see the receiver or if you are the receiver you will not be able to see the source; that is the barrier that is you know causing a block between the line of site it is not allowing direct line of site. Whereas, the line of site that is the source and receiver are directly seen, the line of site is there then is becomes negative the effectiveness is not there. You will not have proper effectiveness of the barrier. Barrier is not causing say you have a source here you are in an apartment in the 20th floor that is a noise barrier you are in the direct line of site you will not have impact of the barrier.

Then once you know the Fresnel number you have this simple formula this is tan h hyperbolic tan square root of 2 pi Fresnel number by tan hyperbolic square root of 2 pi n plus 5 dB, so this will actually give you the effectiveness or the attenuation caused by attenuation is a simple term which we use to find out how much the sound pressure levels are cut. So, the barrier attenuation is given by 20 log square root of 2 pi n tan hyperbola square root of 2 pi n plus 5 dB. If you substitute some number I will be giving you some working examples for your exercises.

Once you do this you will be able to find how effective and how much sound pressure level is been cut by the noise barriers. So, barrier attenuation can be formed. First you have to determine the path link difference A plus B minus C, using this number you will be able to find the Fresnel number you further substitute this here you will be able to determine what is a barrier attenuation. There are different types of barriers and the calculations also significantly vary, but simple you know the basic fundamental thing is here.

This actually another important thing to note here, you have the wave length in the denominator so once the wave length is increasing that is low frequency sound wave length is higher the Fresnel number comes down. Whereas, if you have a frequency sound the wave length is smaller you have the Fresnel number which is in the effective zone. So, even a shorter barrier you will have much effective sound protection if the sound source is of higher frequency, whereas for low frequency sound sometimes taller barriers even may not be effective. It is not just in the vertical plane alone imagine a barrier you have a source, you have a receiver, it also depends on the path on this way also; it is also on the horizontal side.

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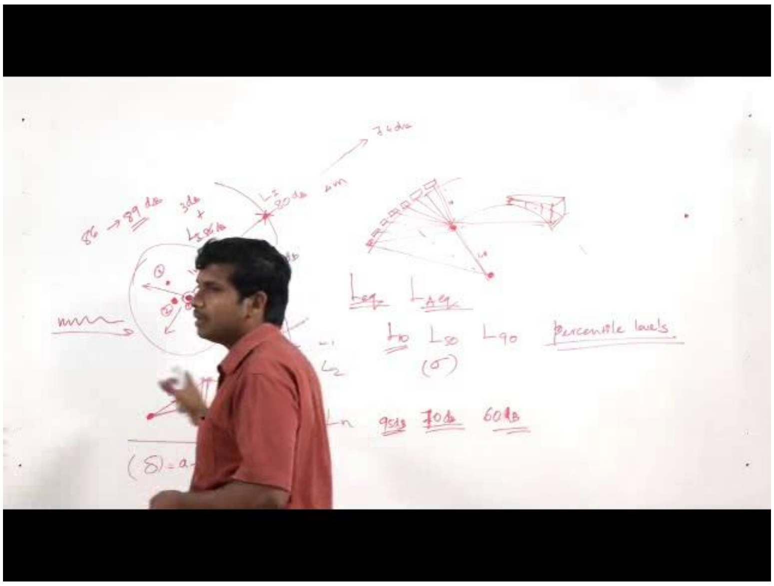

So, with this also you can calculate the path differential and you can with this determine how long you will need a barrier. So you have a pump or machinery here, you want to protect yourself then height matters and number two the width of the barrier also has a significant role. Using these simple equations you can find out what height and what width of the barrier is essential to give you sound protection.

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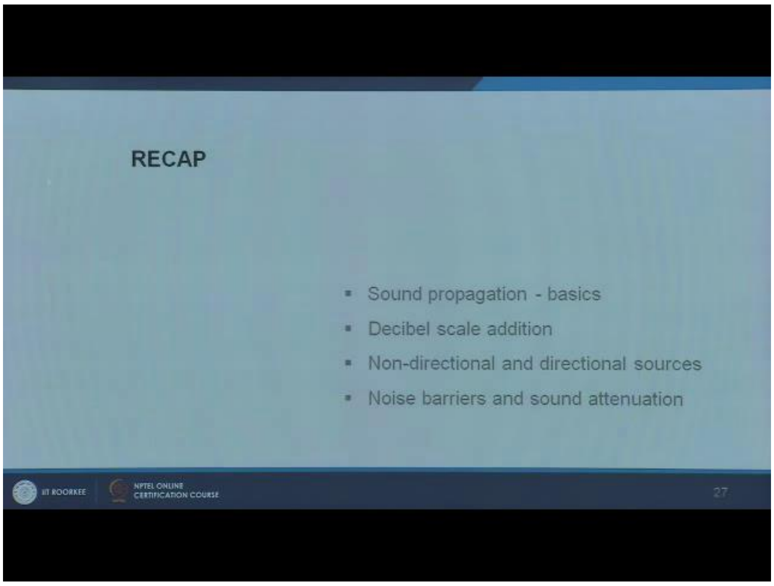

As a part of this module we looked at sound propagation, basics of sound propagation, how it varies with respect to distance. Then we looked at decibel scale addition. Then we talked about directional and non-directional sources. And at last we saw few calculations relating to the effectiveness or attenuation of noise barriers.

Thank you.