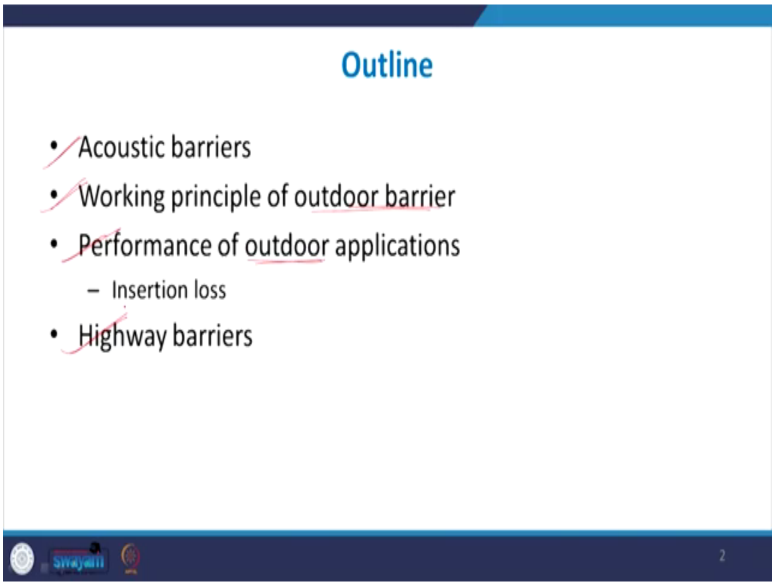
Acoustic Materials and Metamaterials

Prof. Sneha Singh
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture – 13
Barriers

Welcome to lecture 13 of the series and Acoustic Materials and Metamaterials. So, today's class we will be discussing about barriers. I am Dr. Sneha Singh. I am a professor at the Department of Mechanical and Industrial Engineering department at IIT, Roorkee.

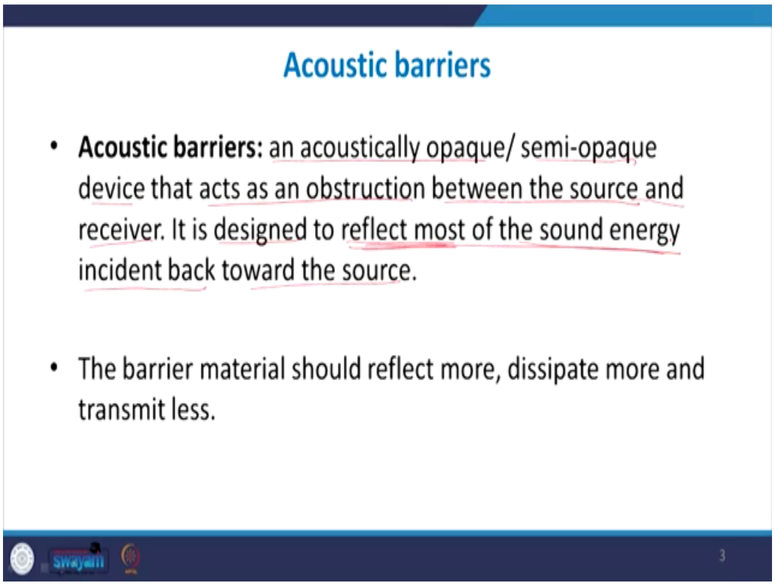
(Refer Slide Time: 00:45)



And in this particular lecture I will discuss about the acoustic barriers. What is the working principle behind this acoustic barrier?

So, we will discuss about acoustic barriers can be of 2 types indoor and outdoor, but outdoor barriers are the most commonly used ones. And so, we will discuss about the principles of this outdoor barrier and we will derive some expression for the performance of outdoor barriers. And then we will discuss about a special case of barriers which is called as a highway barrier.

(Refer Slide Time: 01:17)

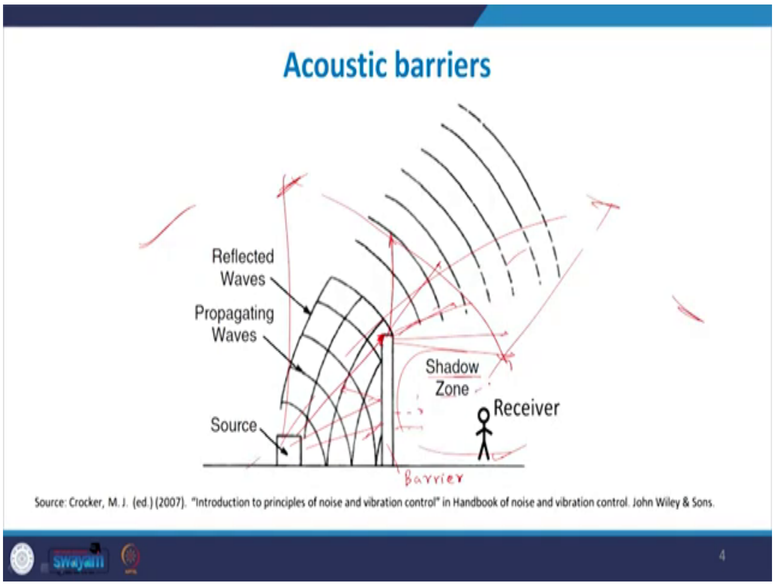


So, acoustic barriers they are defined as an acoustically opaque or semi opaque device that acts as an obstruction between the source and the receiver. So, it is designed to reflect most of the sound energy that is incident on it back towards the source. So, reflection is the most. So, this is one type of; this is one type of blocking material.

So, by this what I mean is that let us say we have a source and a receiver and we place some acoustically opaque device or semi opaque device and by opaque if you think in the terms of optics, then a material that is opaque to light means that the material is not allowing the light to pass through it.

So, that becomes a opaque object and if it is transparent which means the light can easily pass through it for example, a glass which is a transparent object. So, in case of acoustic barriers also we are using acoustically opaque materials which means that these are those materials which do not allow the sound waves to pass through it. So, they are designed to deflect most of the sound waves that is incident and minimize the transmission.

(Refer Slide Time: 02:32)



So, this particular figure shows you how a typical barrier works. So, let us say we have a source here and a receiver here and a barrier is being placed in between them. So, this is the barrier.

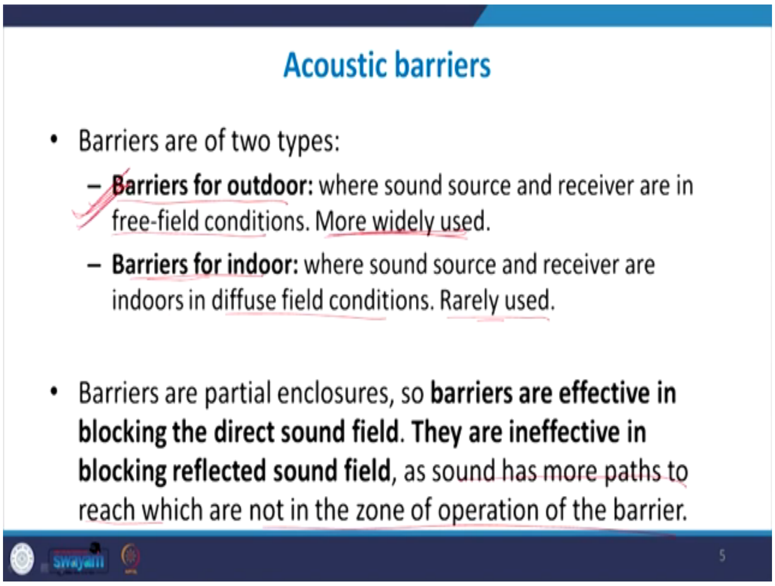
So as the name suggests this is like an obstruction between the source and the receiver. So, the way it operates is that some sound waves are getting and hitting this material then it is going to block these sounds waves. So, the direct sound will be blocked. Only a very very feeble transmitted wave can pass through. Most of it most of the incident wave will actually get reflected. So, this is one way of blocking that is it is reflecting everything transmitting only negligible amount.

At the same time, some sound waves will hit or at the edge of the barrier and when they hit on the edge of the barrier they will get diffracted some sound will. So, when the sound is hitting the edge of the barrier some portion of it will be diffracted away some promotion of it will be diffracted towards within some zone.

So, there will be some small zone within which no light waves will be diffracted and that zone is called as the shadow zone. So, whenever we have a barrier in place and we place a particular receiver within the shadow of the barrier then that is the place where the minimum sound is received. So, that is based where the receiver gets the minimum amount of sound.

So, as you can see here that the barrier is not a full enclosure, it is always partial. So, even though it can block the sounds it always has a zone of operation. It cannot block the entire sound waves because they will be other paths to which sound can reach.

(Refer Slide Time: 04:20)



So, that is why when we are using such various outdoor. So, suppose we are using it outdoors and there are some other objects present in the environment. So, the sound wave will also have other paths to these the receiver right. So, that is why a barrier is good enough only for outdoor applications because in the outdoors we are assuming that it is almost obstacle free they are not many obstacles around.

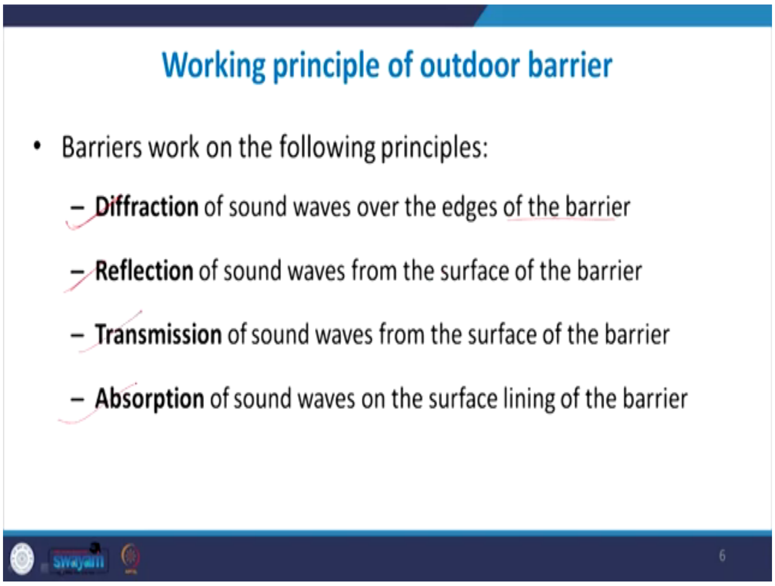
But when we use the same barrier within an indoor, then in the indoor we will first of all have the walls and the ceilings they will act as reflectors. So, within the this walls and ceilings what will happen is that even though the barrier is blocking all the sound that may reach the receiver directly or from diffraction, but it is unable to control the other sound paths.

The sound may also get reflected from the back of the receiver and reach the receivers here. So, that is why the 2 types of barriers are barriers for outdoor and indoor, but the most widely used one is the barrier for outdoor because it is here in the free-field conditions.

Whereas, in the diffuse field conditions where the sound has more paths to reach which are not in the zone of operation of the barrier, it is almost ineffective and it is very rarely used. So, this is the type of barrier which you will be studying which is the outdoor barrier.

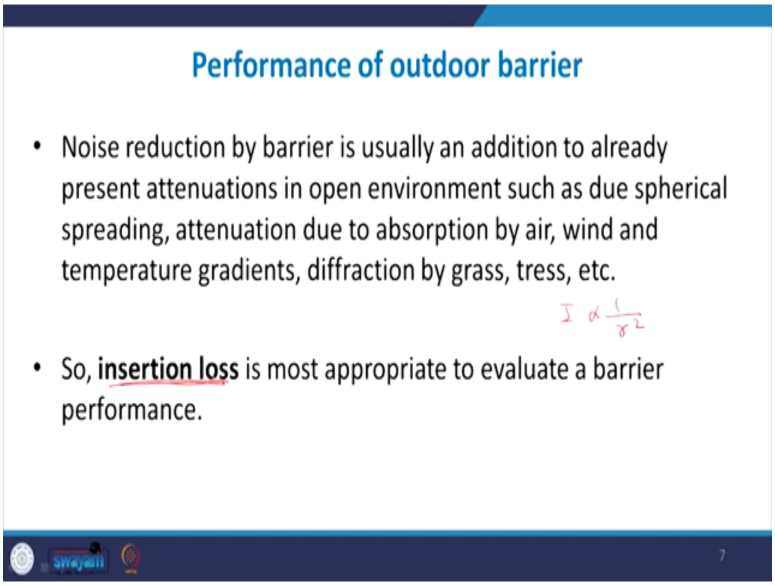
So, as discussed again I would like to state this fact is that barrier is effective only in blocking the direct field. If the sound also has other paths to reach the receiver through reflections then the barrier is ineffective because it is not fully enclosing the receiver. It is only a partial obstruction. So, it can only block up a certain zone of the direct sound field it cannot block or it is ineffective in reverberant or reflected field environment. So, for diffuse field such barriers are not used.

(Refer Slide Time: 06:14)



So, the way they obstruct the sound or the way they work is they use the 4 principles which is diffraction of the sound waves which takes place over the edges of the barrier, the reflection of sound waves from the surface of the barrier and transmission and the absorption of the sound waves through the surface.

(Refer Slide Time: 06:36)

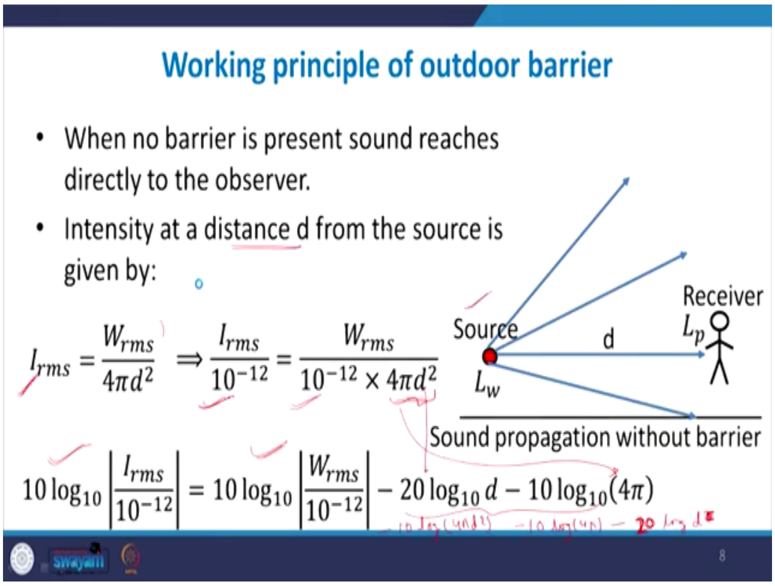


Now, usually the barriers they are placed outdoors and in the outdoors we already have a lot of mechanism like we have trees, we have other natural surroundings then we have buildings etcetera. So, trees etcetera they act as absorber of sound.

Similarly, even humans that are present can act as absorbers of sound and then buildings can act as reflectors. And moreover in the open field environment the sound itself will start attenuating because as because in the open field we assume a source to be to be spherical. So, we assume the wave front is in the open field in general the wave front is spherical in nature and the spherical way front it decreases the intensity for the spherical wave front, it decreases with the intensity, it decreases it is inversely proportional to the distance square. So, as the density as the distance of observation increases the intensity will drastically reduce.

And similarly some attenuation can take place due to air friction. So, because there are many other mechanisms in operation. So, the best criteria to evaluate a barriers performance could be insertion loss because we already have some attenuation taking place. We just want to know what is the contribution of barrier to this loss. So, we use insertion loss as the metric for evaluating it is performance. So, let us derive an expression for the insertion loss of a barrier.

(Refer Slide Time: 08:08)



Now, when this is a source and this is a receiver and no barrier is present. So, when no barrier is present then the sound let us say this is the source which is emitting some power level W and this is reaching the receiver here and this is the where we take the measurement.

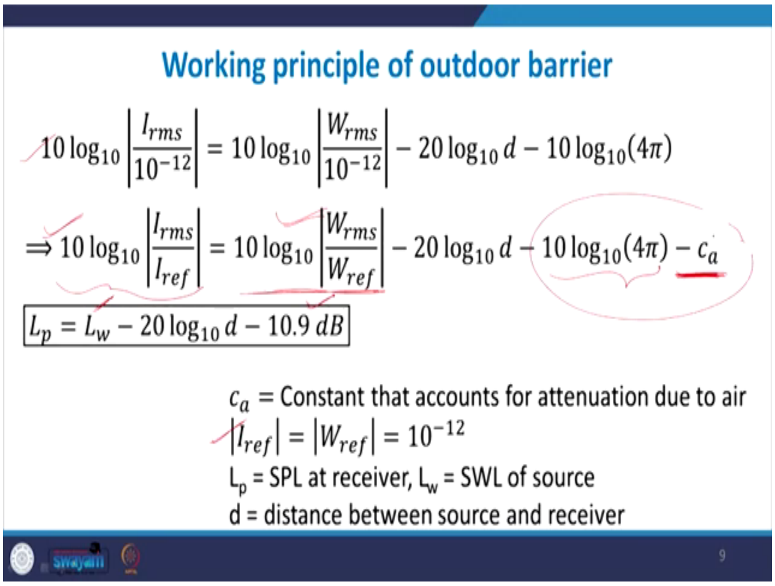
Then the intensity at and the distance between the source and the receivers here is d then the intensity at a distance d for a spherical wave front is given by the constant the sound power level that was being emitted divided by the surface area over which it is getting distributed.

And because we are assuming a spherical wave front here your open field conditions we always take the sources as spherical. So, the whatever sound power level it is a emitting it will be distributed evenly in a sphere with diameter as with the radius as d.

So, W rms by 4 pi d square will give you I rms. So, this is the expression for intensity at a distance d. Now let us define that the both the sides with this particular value 10 to the minus 12 and take the 10 log of that. So, if we take the 10 log of this is the expression in the left hand side and this is the expression in the right hand side.

So 10 log 10 of W rms by 10 to the power minus 12 we have separated and this quantity gets separated here. So, it becomes 10 log of 4 pi d square and so this is what 10 log of. So, minus 10 log of 4 pi d square, this becomes minus 10 log of 4 pi minus 10 log of d square and 10 log of d square can be written as this can be removed it will add as 20 by the property of log. So, this entire expression can be replaced with this particular expression 20 log of d which is due to this one and this is due to this one ok.

(Refer Slide Time: 10:19)



So, that is the expression we have got. Now, we know that the reference intensity the value for the reference intensity is 10 to the power minus 12 and the value for the power reference power is also 10 to the power minus 12. So, when we were when I was discussing with you about the decibel scales. So, in that particular lecture we had defined. So, I had defined what is sound pressure level what is sound intensity level and what is sound power level and what are the various reference values for the pressure intensity and the power.

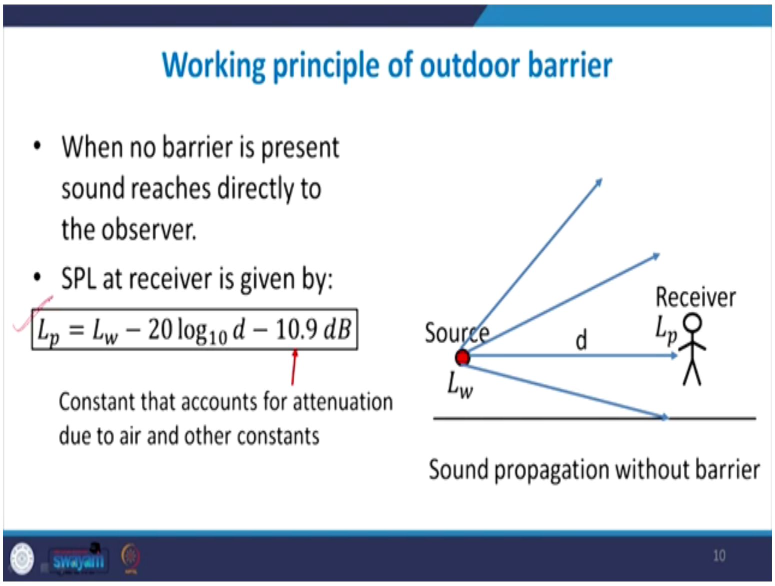
So this both are 10 to the power minus 12. So, we can replace them by this and this expression and this is carried forward. Another expression is now added because some sound will some sound will attenuate because of the increasing distance from the source. As a distance increasing obviously, the pressure the intensity will go down, but sound power can also decreased. As it is passing through the air the particles they are propagating.

So, how does the sound propagate in the air? It is through the longitudinally oscillations of this air particles. So, as they are doing this oscillation the air itself will have some friction and due to this friction some attenuation of these particles can take place.

So, this is the attenuation due to air. So, now, we can replace this entire expression as this 10 log 10 I rms by I reference becomes the total sound pressure level at the receiver. So, this is the sound pressure level here. This is the expression of a sound pressure level. This is the expression for the sound power level of the source.

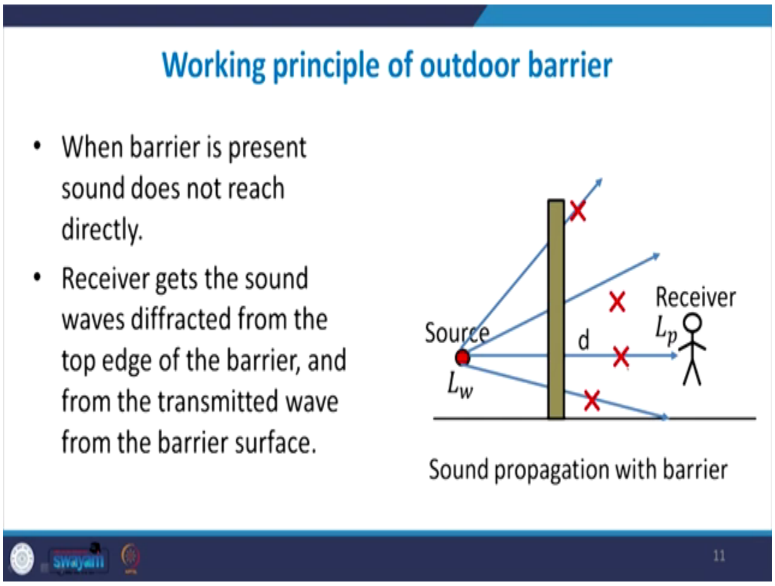
So, the sound pressure level at the receiver is the sound power level at the source minus 20 log 10 of the distance between the source and receiver minus a constant value which experimentally has been found as 10.9 db. So, this is the constant which takes into account. This expression as well as the attenuation due to air, these together become 10.9.

(Refer Slide Time: 12:30)



So, we have obtained the expression. This is the expression for the SPL at the receiver when no barrier is present. Now, let us derive what is the expression for the spl when barrier is present.

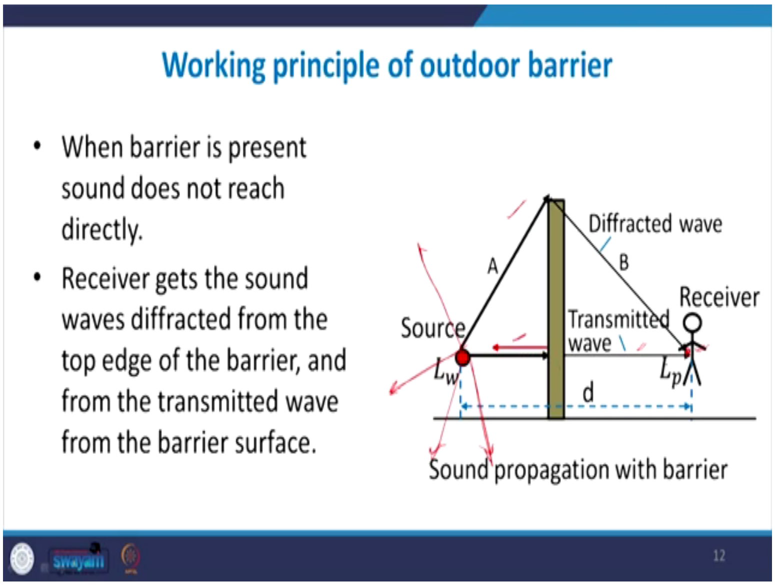
(Refer Slide Time: 12:38)



So, when the barrier is presented it is obviously going to block these sounds not completely there will be some transmitted wave also. So, in the case of a barrier suppose with this, this is the position of the listener's ear or the position where we are measuring.

.

(Refer Slide Time: 13:52)

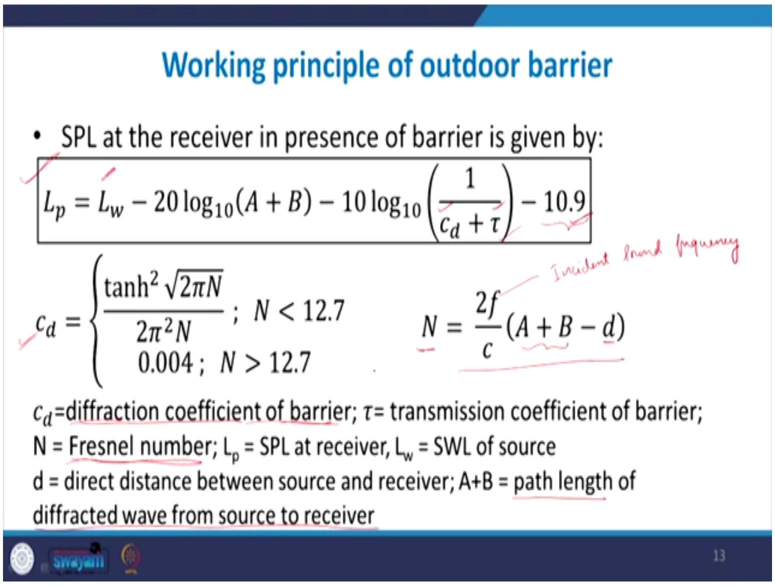


So, in that case there are 2 now that become they become 2 different pathways to reach this particular point of observation. The sound can either reach directly. Now I have assumed here that this is outdoor barrier wave only now discussing outdoor barrier. So, we are assuming there is no reflections. It is a free field condition there are no significant reflections then in that particular assumption the there are 2 only 2 possible pathways one is that the sound directly reaches from the source, but this direct sound wave it gets blocked by the barrier. So, some part of it gets reflected and only some transmitted wave comes.

So, this is the first pathway that it is getting it through the transmitted wave and the other pathway is that when this same sound because it is radiating sound uniformly in all the directions this particular source. So, all the directions the sound is being emitted.

So in this particular direction as it hits the edge or the top of the barrier the diffraction can take place and one of the diffracted waves can then reach the receiver. So, this becomes the second pathway. So, these are the 2 different pathways to which the sound can come to the receiver. So, the total SPL will be the summation of the SPL due to this transmitted wave and the SPL due to this diffracted wave.

(Refer Slide Time: 14:25)



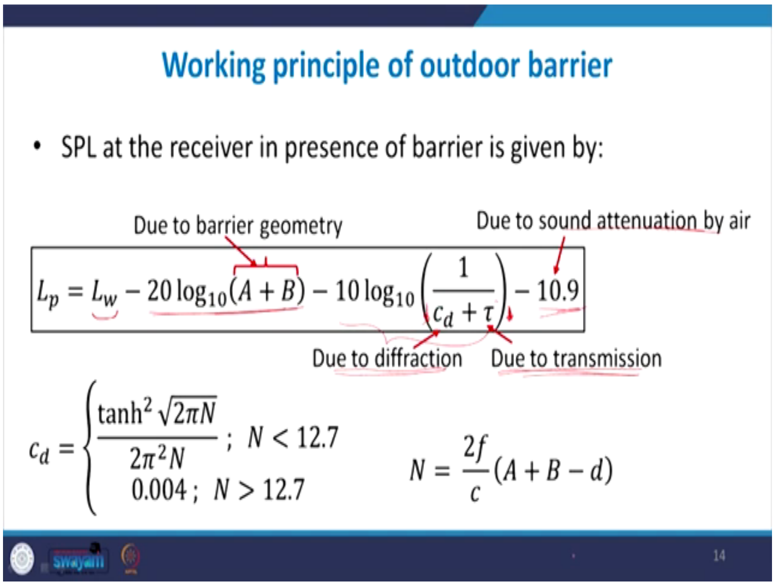
Now, the derivation for this involves a lot of theory on diffraction as well. So, let us directly take the equation. The equation that has been derived is when such a case presents itself that is we have a barrier and then we are finding out what is the SPL due to this transmitted and diffracted waves then Lp comes out to be or the SPL at the receiver comes out to be the sound power level of the source minus 20 log 10 of A plus B.

And what is this A plus B? This is the path length of the diffracted wave from source to receiver. So, you simply calculate what is this path length from here to here and then from here to here. So, the total path length covered by the diffracted wave minus 10 log 10 of one upon c d plus tau minus 10.9. So, 10.9 is obviously that constant which you already know is due to the air attenuation and due to the other expression and this particular thing is because of what is the attenuation due to diffraction and due to the and what is the loss due to the transmission. So, whatever thing is getting lost in transmission.

So, here c d we call it as diffraction coefficient of the barrier; c d which is given by this complicated expression which is tan h square under root of 2 pi N by 2 pi square N and here n is the Fresnel number. So, this Fresnel number is defined as 2 f by c A plus B by c. Here f is whatever is the incident sound frequency.

So, whatever sound frequency is incident into the path length A plus B becomes the paths length of the diffracted wave and d becomes the path length of the direct wave. So, this is the definition for N and this complicated expression here is given to you. So, you can input these values and you can get what is the SPL in the presence of barrier.

(Refer Slide Time: 16:34)



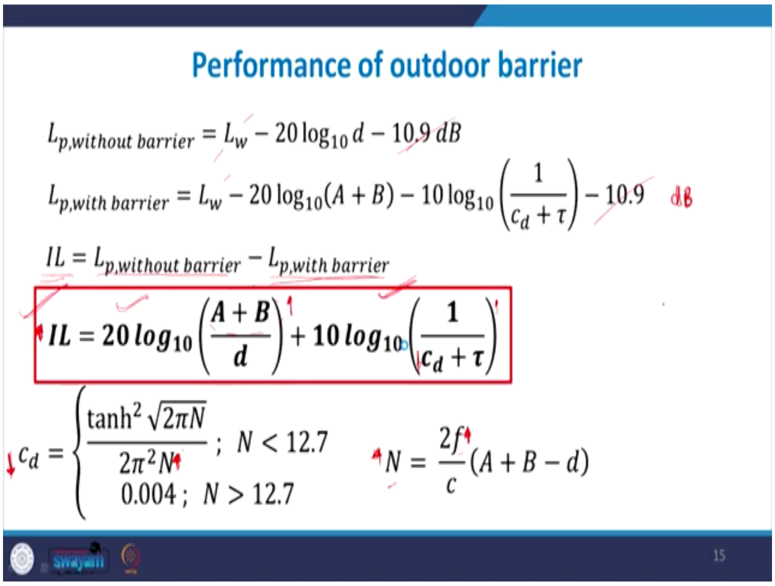
So, let us decode what the various thing stand for. Here we have a constant sound power level then some attenuation is happening because of the barrier geometry. So, if you see here if the height of the barrier increases as you increase the height of the barrier then the diffracted wave has to cover a longer pathway.

So both A and B are going to increase. So, A plus B will increase as the height increases. So, the same diffracted wave will have to now cover a longer pathway and as the distance or the pathway increases there will be attenuation because it is a spherical wave front and it and the intensity is inversely proportional to the distance square. So, this that is why we are getting this particular expression here.

So, this is due to the barrier geometry. If higher the barrier higher will be this attenuation and then this is due to a this is the due to sound attenuation by the air is constant and this is due to transmission. So, if the material is made up of a party if the material of the barrier has got very low transmission coefficient which means that it can only transmit very less sound then this particular quantity will go down right for a material that allows very less transmission.

So, if this goes down this overall expression is going to increase. So, this particular expression will increase. So, which means that there will be more loss there will be more attenuation. In the same way this is the loss due to diffraction. If this also goes down then overall SPL at the receiver goes down.

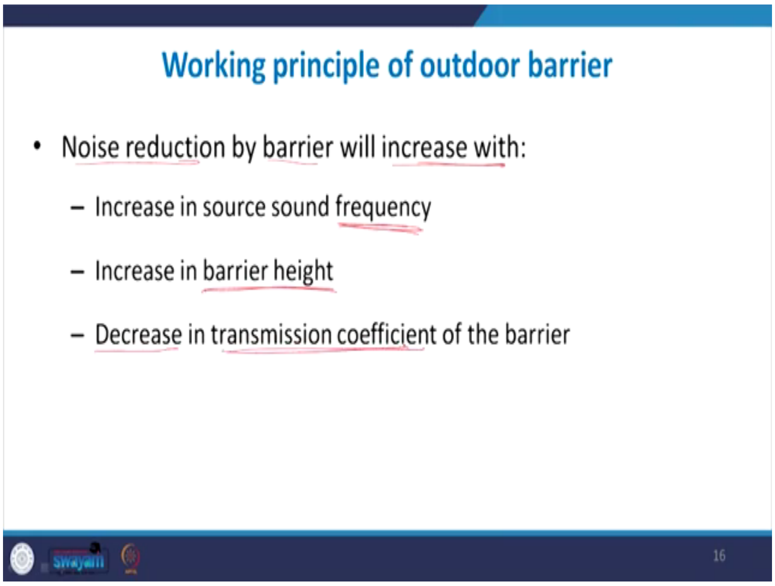
(Refer Slide Time: 18:17)



So, if you define what is the if we define the insertion loss then the insertion loss by definition is whatever is the. So, it is a difference between the sound pressure level without the material minus the sound pressure level with the material at the same location. So, we have already derived expression for what is the SPL without barrier and with barrier. So, the total insertion loss is then you subtract the 2 expression this obviously gets canceled out. So, here the unit is decibels.

So, this obviously gets canceled out when you subtract this gets canceled out and this is 20 log 10 of A plus B minus 20 log 10 of d which becomes this expression and this expression. So, you left with only these 2 expressions. So, this is the expression for the intensity loss due to an outdoor barrier.

(Refer Slide Time: 19:16)



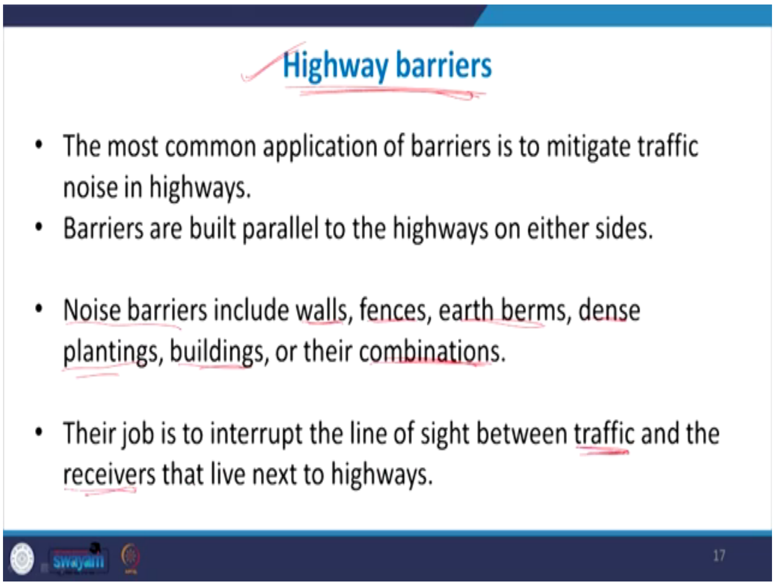
So, from this expression what do you get. You get that the total noise reduction or the insertion loss. So, a good performance of the barrier. So, [vocalized- barrier performance is going to increase or the noise reduction is going to increase. When you increase the sound source frequency, why? Let us go here this N is dependent on the frequency right. So, if you increase the frequency here, the value of N is going to increase and when the value of N is going to increase then up to the certain limit. So, only up to the certain limit beyond a certain limit there is no effective frequency.

So up till a certain limit this particular value is going to. So, this is increasing N is increasing which means this denominator is increasing and this is only this would not be increasing much because it is within the sinusoidal function and it is a square root. So, overall the denominator increases more. So, this particular expression goes down right. So, when N increases this particular expression goes down.

So, when this particular expression is going down then this overall quantity is going to increase which means the IL is going to increase. So, IL increases with the increase in frequency. Similarly it increases with increase in barrier height. If the barrier height increases as I have explained earlier then this particular value is going to increase the higher the barrier height the higher will be the path taken by the transmitted wave. So, when this value increases again IL is going to increase.

Similarly IL will increase when the transmission coefficient decreases. So obviously, logically also if there is a material which has got a very low transmission coefficient which means that it is a very good blocking material. It is blocking most of the sound. It is allowing very little sound to pass through. So, when tau is less this expression again will increase therefore, overall the IL is going to increase. So, that is the various factors on which the noise reduction of a barrier depends on.

(Refer Slide Time: 21:24)



Now, we will consider another special case which is called as a highway barrier. Now barriers the material that we discussed right now it has got many applications, but the most common application is as a highway barrier which means if you see the highways in general. So, traffic noise is a very big it is a pollutant it is a very big noise pollutant.

And if people are living close to highways then these residential areas they get a lot of noise due to the traffic. So, usually when such busy traffic busy highways are designed then some barrier is put along the road. So, you can have it in the form. It can be in many forms for example, you have a roadway and there could be trees planted along the roadway.

So, whenever you bring in the highway you will see a lot of trees and vegetation. So, we have trees and vegetations they are also acting as an obstruction between the traffic noise and the adjacent residential area. Similarly you can have some big cement walls or you can even have some earth berms etcetera. So, that all of this acts as a barrier. So, just by the layman term it acts as a obstruction between the traffic noise and the adjacent residence area. So the that is the most common application of a barrier which is as a highway barrier here.

(Refer Slide Time: 22:49)

So, let us have a look at some of the common type of barriers. As I explained anything can constitute a barrier noise barriers can include walls, fences, earth berms, dense plantings, buildings or even their combinations all of this can act as a barrier between the traffic and the receivers that are living next to the highways.

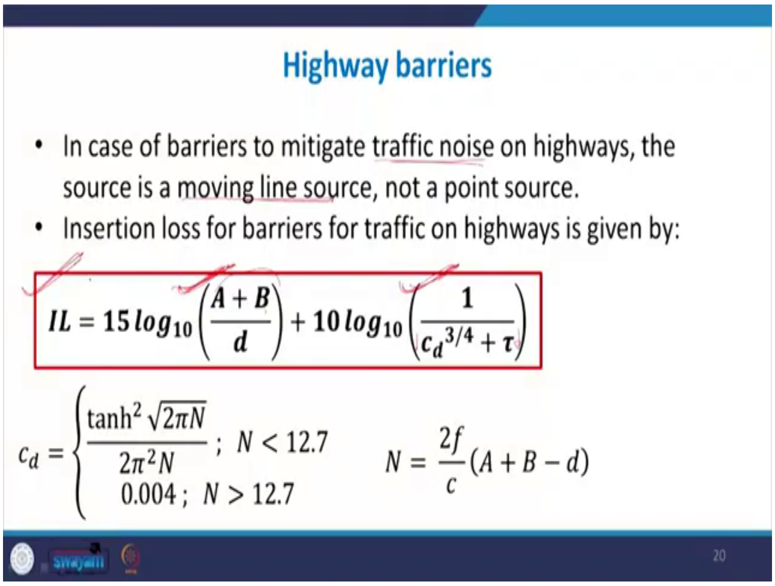
So, let us see here we have a highway here and there is lots of big trees planted all around. So, they are acting as barriers here this dense vegetation. So, here the wood of this is of a hard material. The wood is acting as a blocking material, it is reflecting the sound away and it is not allowing it to pass through where as the grasses and the leaves here they are more like absorbers they are absorbing the sound. So, the sound is getting dissipated passing through these leaves etcetera.

Similarly when we have a highway we can also have something called earth berms. So, we just have a small small very small earth hills placed on both ends. This again acts as an obstruction between the noise that is generated from the traffic and the adjacent area.

(Refer Slide Time: 24:04)

Similarly, one of the most common ones today are the cement walls. So, you have a roadway and you have some walls constructed on both ends of the roadway. So, these walls are constructed not only for the purpose of making the structure more concrete and providing a guide way to stop accidents, but there are also serve a secondary purpose and that is controlling the noise while the vehicle is passing through. So, they serve both the purpose and then we can have a combination of this wall vegetation and berms. This entire thing is acting as a barrier.

(Refer Slide Time: 24:42)



So, because the highway barriers they are one of the most common applications of barriers and we have derived an expression for the insertion loss of a barrier. However, the same expression cannot be used for highway barriers because first of all the traffic noise that is going through it cannot be assumed as a point source.

Instead when there is a road way and there is a line of traffic it is a busy road way and the line of cars are going through a line of vehicles then more than a point knows the point source which we consider them as a line source which is generating a cylindrical wave front and this is one of the rare kind of wave fronts which I did not discuss in this particular course work. You can go and read it for further reading if you want to.

So, the traffic noise is considered as a moving line source we generates a spherical wave front and hence whatever we derived for sorry it serves as a it gives you a cylindrical wave front and whatever we derived for the point source or a spherical wave front is not applicable here.

The expression for insertion loss of this highway barrier then becomes this is the expression. So, it is slightly lower than the IL for a typical barrier where we are assuming a point source. So, this is the expression. The same thing here 15 log 10 A plus B by d and the same thing. So, it depends on the same factors if you increase the height of the barrier this expression will increase IL will increase.

If you decrease this or decrease this expression with increase and IL increase. So, as you increase the frequency the performance will improve. As you increase the height and the performance will improve. As you make the material more resistant to transmission or as you decrease the tau then also the performance is going to improve.

So, now we that we have studied both types of barriers. We will do some tutorials on their tutorials based on their performance for a better understanding and that we will do in our next class.

So, thank you for listening.