Acoustic Materials and Metamaterials
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Lecture – 12
Enclosures

Welcome to the lecture 12, in the series of Acoustic Materials and Metamaterials. So, this week we have began our discussion on the different types of acoustic materials or to say noise control materials that are available with us. So, we began with the discussion on the traditional acoustic materials and we studied in the last class that usually the materials for noise control they can be classified as barriers, enclosures, and sound absorbers. So, today's class will be the discussion on the first type that is the Enclosures.

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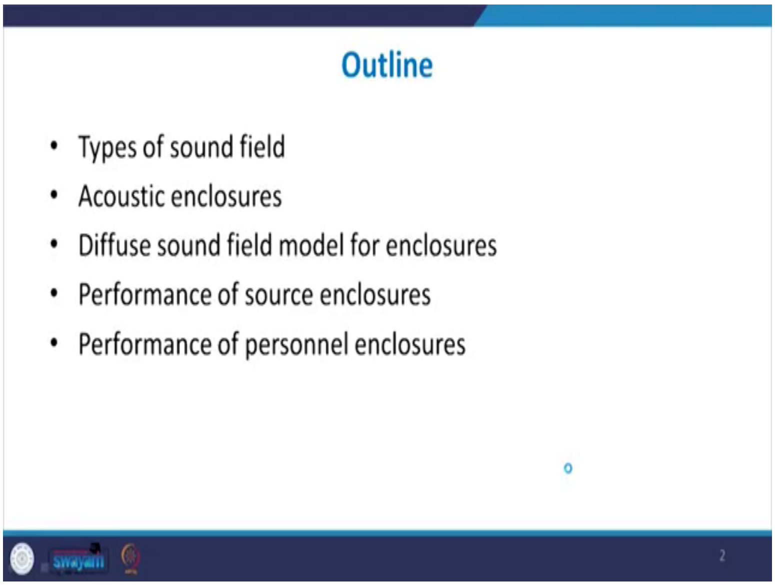

And, so, outline of the course is before we begin the discussion on the enclosures, I will give you a brief description on the different types of sound field that are available, because this knowledge is essential, for deriving the performance of enclosures, then what is acoustic enclosures? And, then we will use a particular sound field model, which is called as a diffuse sound field model for the enclosures. And, then we will derive the equation for the performance of source enclosures and for the performance of personnel enclosures.

So, different types of sound field exist. So, we have studied that the sound wave it propagates and we have derived the equation for the a linear acoustic wave equation for sound wave propagation in fluids, but this sound wave, which is generating from a source. And, then there is a receiver at some other end. Then, the sound wave can either directly reach the receiver through the fluid medium, without any obstruction or it can also reach the receiver through reflections from the other pathways.

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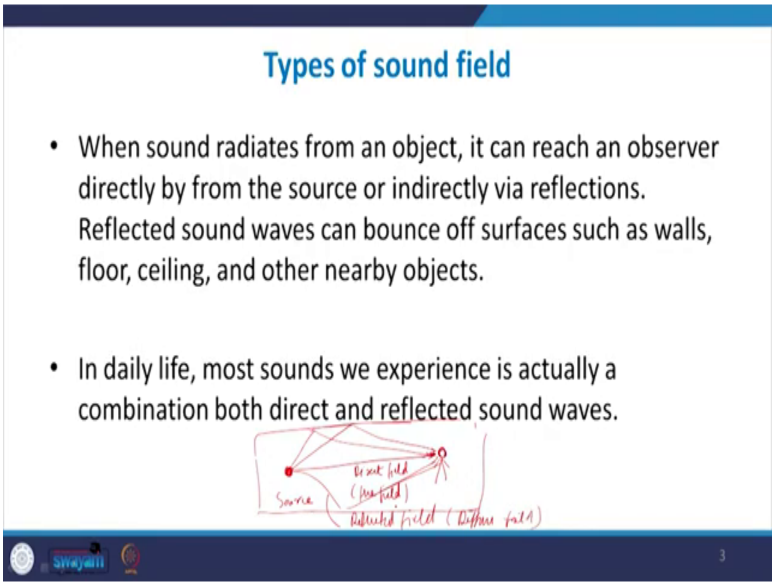

So, let us say if we have a source here. So, this is some source that is generating noise and we have some receiver, then it can directly reach the ear of the receiver this becomes the direct, the direct field or we call it as free field.

So this is reaching the receiver directly. Then, we have is then suppose it is contained within some room or within some environment and we have some reflecting surfaces all around it, or we have trees animals or the stones any other object that may be present in the environment; obviously, when we are living in the earth we will have so many objects around us it would not be completely empty. So, the same sound can then bounce off these different objects and then reach the observer. So, this becomes the reflected field or we call it as diffuse field.

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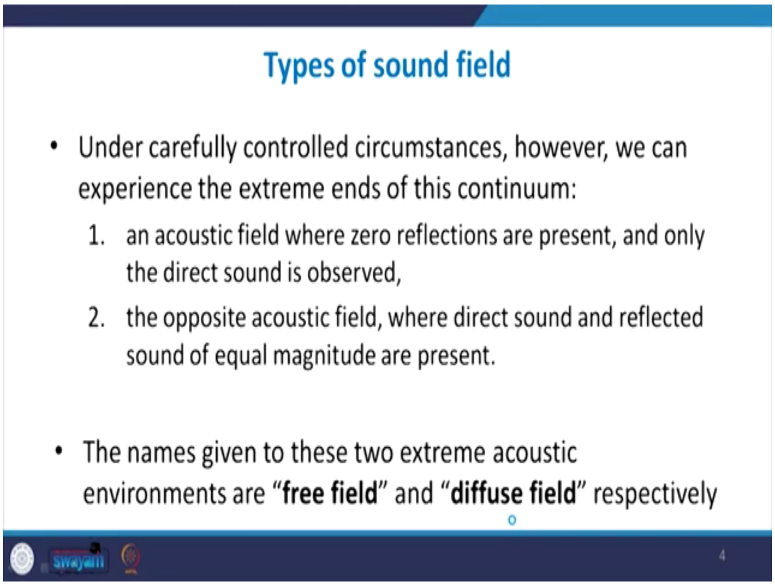

So, these are the different ways through which sound can reach the receiver and, based on that we defined two different types of fields so, first acoustic field we define is that. So, experimentally we can create an environment, which is like a complete open field.

So, all the obstacles and objects are removed. So, that this so, that the maximum or the majority of the sound that reach that reaches the receiver is actually the direct sound, which has not reflected from any other surface, or experimentally another field can also be created. So, let us say if some measurement needs to be done. So, we can have a room specifically designed which is called as a reverberant room.

So, in that all the floors, the ceilings, the walls etcetera everything is a hard reflecting surface. So, that there is no absorber, there is all hard reflecting surfaces around and there are many such oblique surfaces as well not only parallel. So, in that case what happened, what will happen is that any sound that is generated within that particular environment, it will reach the receiver directly, as well as it will have some countless other parts to reach the receiver by bouncing off other reflecting surfaces.

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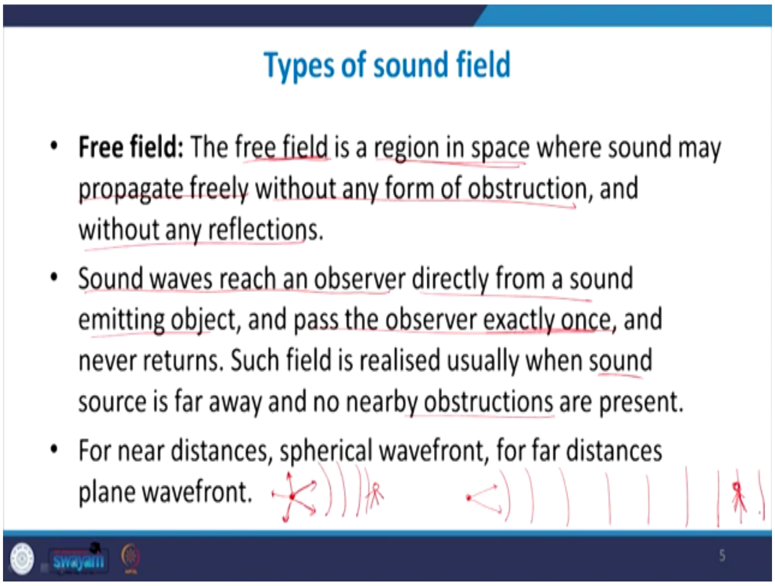

So, these two type of fields are free field and diffuse field, the definition is as I have already given you. In the free field it is that region of space where sound propagates freely without any form of obstruction and without any reflection. And, it reaches the; so, in this case any sound wave it will reach the observer just once directly and it will pass through the observer exactly once and it would not return back. So, there would not be echoes or reflections.

So, in so, most in most of the cases when the sound is placed in a very far away area or there are no nearby obstructions, then this can be achieved and in such fields what we assume is that. If, suppose the dimension of the source is small compared to the other dimensions like the distance of measurement etcetera. So, in that case in the free field we assume that small sources, they are; they are they have spherical wave front.

So, we assume them as point source and they are they are giving away spherical wave front. Whereas, if suppose the same source becomes too far away. For example, suppose a person is standing in a free environment and then there is a jet airplane that is passing at a at quite a significant height. So, in that case then the then the jet airways or the plane, it will emit a spherical wave front, but by the time it reaches the receiver that can be treated as a plane wave front so, if the object is here and the receiver is here.

So, it is this is a point object that is radiating radially outwards. So, the sound is being emitted radially outwards and the spherical wave front is reaching the receiver, but when the distance is too far away. If, suppose we have the receiver here and the source too far away, then that same spherical wave front that was being generated. After a certain distance it almost appears parallel like a parallel wave front as the radius of this pair increases.

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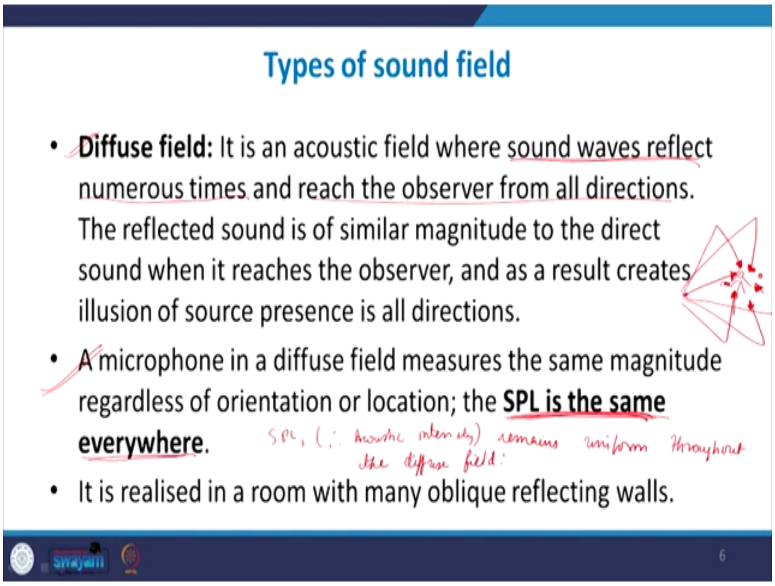

The second type of field that we discussed that I mentioned was diffused field. So, the definition here is that, the sound waves in this particular field they reflect numerous times and reach the observer from all the directions. So, if we have one observer here and the sound may be present here, but it can reach here, it can bounce from here, it can bounce from here.

So, there are many obstructions and it can reach the observer from various parts in all the directions. And, the magnitude of these deflected waves is almost similar to the magnitude of the direct wave. So, in that case if the listener has his eyes closed and the sound is reaching from all the directions. So, for him it is like an omnipresent sound, it is sounding is the same everywhere and they the listener cannot make out to where the noise source is. So, this is called as a diffuse field where we have that there are numerous such reflected waves that, overall these the waves are present throughout there is no directivity.

And, in such a field what is an important assumption is that, if you place a microphone within such diffuse field. Then, it will measure the same magnitude regardless of what it is orientation and location is because let us say if we place a microphone that is oriented here. It will measure the same a microphone here will measure the same, because the reflected waves are almost as strong as the direct wave and they are present everywhere at every location.

So, in that case for a perfect diffuse field the SPL is the same everywhere. So, both the SPL and the acoustic intensity SPL and therefore, the acoustic intensity remains uniform throughout the diffuse field ok. Then, there are there is another distinction that is called as a near field and the far field.

So, near field is the field of a sound which is very close to the source almost, almost of the order of one wave length. So, let us say there is a source emitting a sound which is having a frequency of 100 Hertz, at air at room temperature, then we can assume the speed of air is 340 meters per second, the corresponding wavelength of that particular sound will be 340 by 100 which is 3.4 meters. So, within that particular domain of 3.4 meters around the particular sound source, it will constitute near field and beyond that distance will be the far field.

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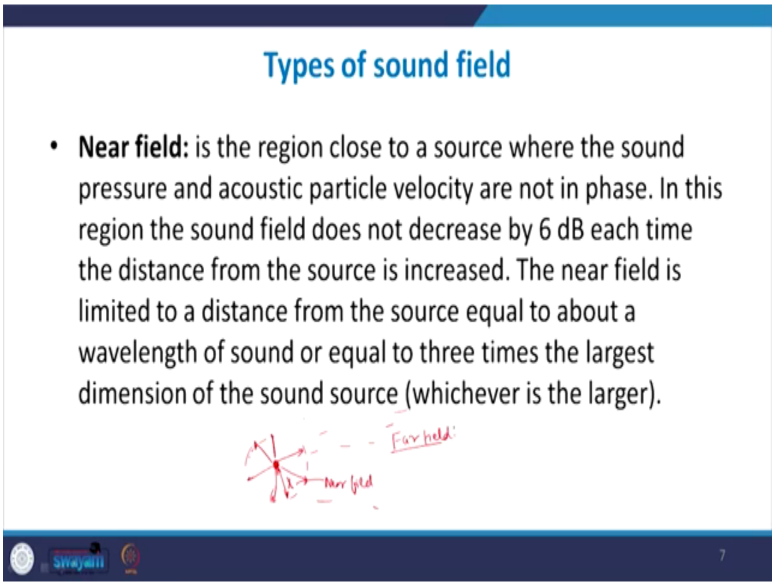

So, if we have a source which is emitting sound over here then up to lambda up to a distance of lambda, let us say we have near field and beyond that distance everything else becomes far field. So, the peculiar thing why do we study about this near field and far field is that so, we have this as far field.

So, why do we distinguish it as near field and far field is that, that the wave propagation equations that we have studied till now in this course or in acoustics in general, they all apply to far field measurement, because everything has its limitation. So, you cannot any instrument it cannot measure, proper waves in within the near field it can only measure in the far field because there, the sound waves takes the full propagating wave front.

So, whether it is a plane wave front which is a defined by a e to the power j omega t minus k x or whether it is a spherical wave front defined by a by r e to the power j omega t minus k r and so on. So, all these equations they are only valid for far field, but within the near field, or when the receiver or the point of measurement is extremely close to the source within a wavelength or so, in that case what happens is that as the surface is vibrating. So, there is a vibrating surface that is generating noise.

So, as a surface is vibrating some of the air molecules it will touch it, it will try to go and propagate away whereas, some air molecules they will just oxalate back and forth they will known not be any propagation. So, it will constitute the waves which do not propagate they just decay over time and it will also constitute of the waves which are strong enough and they propagate away.

So, within the near field we do not get exactly fully propagating wave front we it constitute propagating wave front as well as the decaying wave front, which is called as a evanescent waves or evanescent field. So, I am discussing this near field here why because any measurement that is being done is not done within the near field, but it is done in the far field. So, after just a brief discussion of what is meant by these various sound fields we will begin with a discussion on acoustic enclosures.

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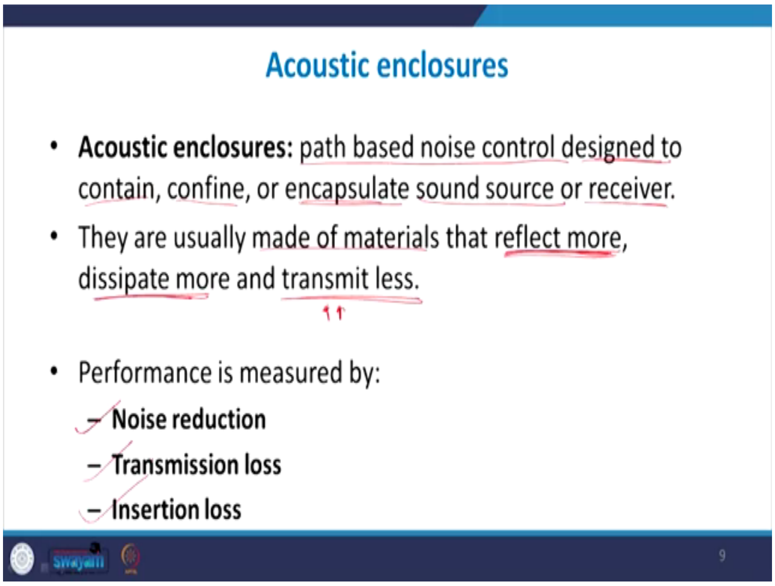

So, acoustic enclosure as we have defined previously these are path based noise control, it is designed to contain confine or simply encapsulate, the sound source or the receiver. And, they are usually made up of some hard materials which can reflect or block most of the sound, they can also be designed to dissipate more, but the main idea is that this is the main idea which is to transmit less.

So, this is the main idea that it is made up of materials that can block the sound or bounce the sound away and not pass this not allow the sound to pass through it. So, that is the main; that is the main metric that is the main purpose of using an enclosure to block the sound and not allow it to pass away. So, the performance of such materials is measured using the metrics like noise reduction transmission loss and insertion loss.

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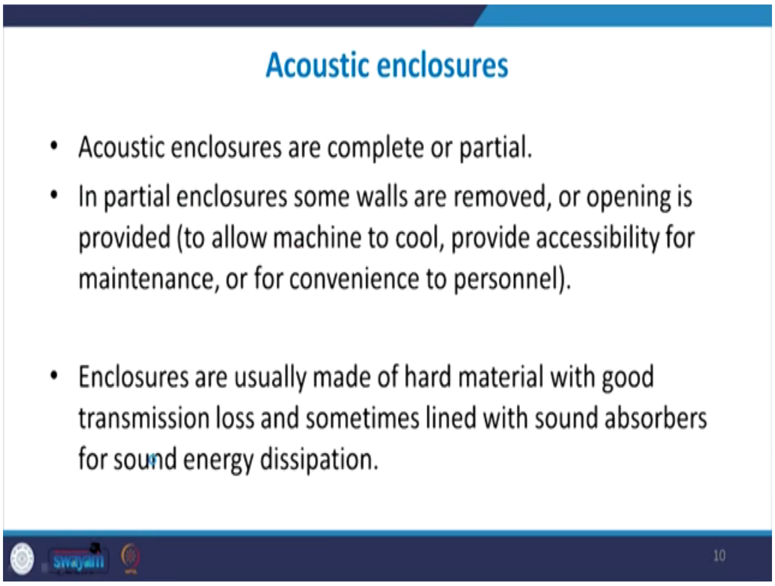

So, let us see; now an enclosure can be complete. So, usually by enclosure what we mean is that it is completely enclosing a particular sound source or a particular receiver, but it can be full or it can be partial. So, sometimes small openings are given within an enclosure, why? For example, for a source enclosure.

Suppose, some machinery needs to be enclosed from the surroundings, then some small opening or doors or windows can be provided, because the machine may need some timely maintenance. And, therefore, some opening needs to be given for timely maintenance or for cooling down the machine. Similarly, in a in the case of a personnel enclosure some openings or windows can be provided within the enclosure that is just, so, that the receiver or the personnel who’s working in a plant he does not suffocate.

And, he can there is there is sufficient ventilation and for and he feels comfortable and convenient within the enclosure. So, small openings can always be provided within the enclosure. So, when these small openings are provided. So, in that case; obviously, the performance of the enclosure will reduce quite a bit, because the openings will be like openings will allow all the sound to pass to they will be like completed.

So, they will reduce the overall transmission loss of the enclosure. So, if we begin the performance of the two types of enclosure that is the enclosure for the source and the enclosure for the receiver.

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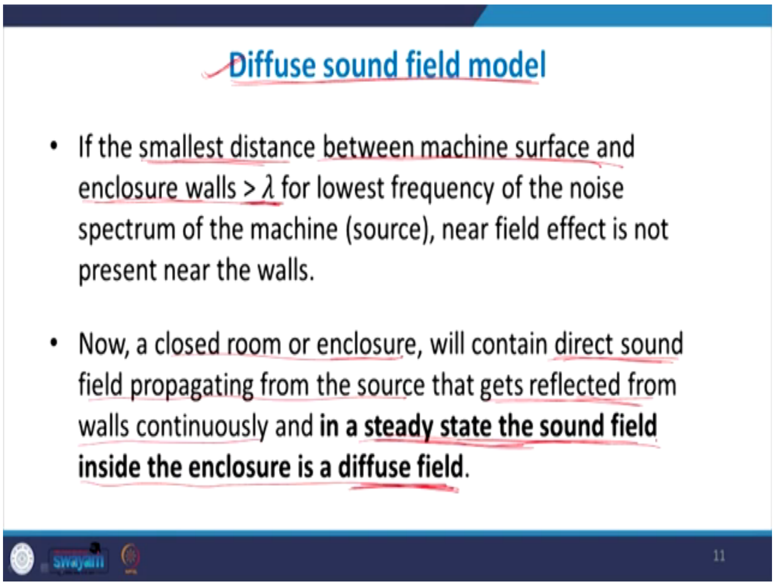

So, in that case the assumption that we make here is that it is a diffused sound field which exists within the enclosure this is the assumption. So, here first of all it is ensured that the enclosure should be big enough that it does not that the walls of the enclosure they do not lie within the near field of the machine source.

So, in that case a smallest distance between the machine surface and the enclosure walls must be greater than the wave length that is being targeted. So, that the walls they do not lie within the near field of the source. And, with this is one precaution that is always taken you cannot have too small an enclosure. So, that it the walls of the enclosure they lie within the near fields or at least one wavelength distance has to be maintained between the machine surface and the enclosure wall.

So, now we have a closed room or an enclosure and as we know that it is made up of material that deflects most of the sound, it does not allow any sound to pass through. So, the environment within the enclosure will contain the direct field that is propagating away from the sound, as well as the field that is being reflected from the walls continuously and because the enclosure is completely surrounding the source. So, there will be in numerable such there will be numerous such reflection.

So, the enclosure which is a good reflecting material will reflect a lot of sounds and the source will also pass on the sound and they will also be the reflections from the sound. So, overall in steady state condition the field within an enclosure becomes a diffused field. So, this is what happens in the steady state, the sound field inside an enclosure is a diffuse field.

So, now, that we have we have established the rationale for why the sound field within an enclosure is diffused field we can easily solve and find out what is the performance of an enclosure.

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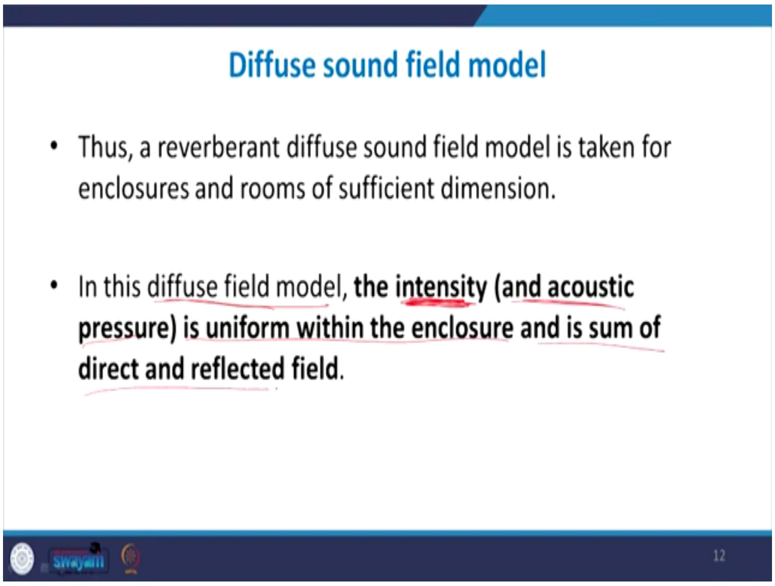

So, in this kind of diffuse field model, the intensity the acoustic intensity and the acoustic pressure will be uniform within the enclosure and it will be the sum of both the direct and the deflected fields.

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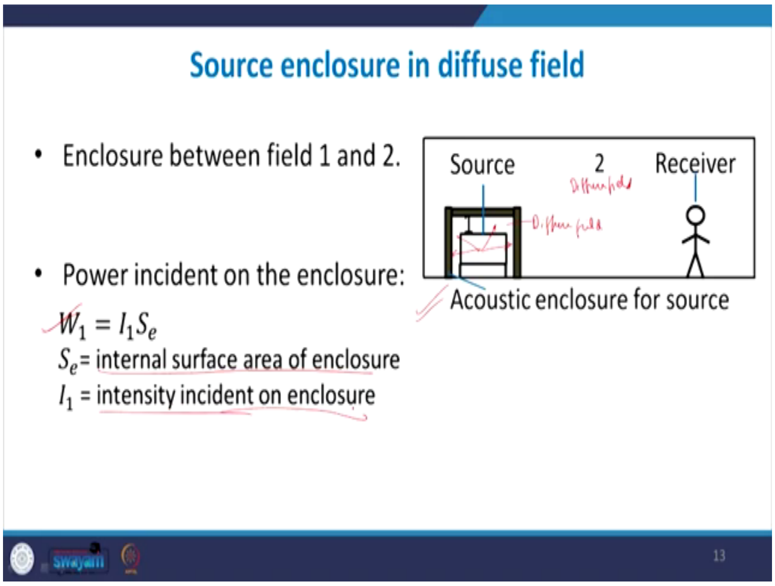

So, let us begin with source enclosure. So, we are here I have shown in this figure is that, there is a source it is being enclosed here and there is a receiver outside and the noise is being generated here.

So, here some power; so here this source is generating noise. So, some sound power will be incident on the enclosure walls. So, let the power incident on the enclosure wall be given by W 1. So, because the field inside this is diffused this is a diffuse field and this field itself is a diffuse field. So, that is diffuse field throughout. So, at under steady state, they will be a uniform intensity within the enclosure let us say that intensity is I 1 this is the intensity that is being incident, then the power incident on the enclosure becomes the intensity multiplied by the surface area.

So, whatever power is radiating that power is being incident on a particular surface area. So, it is the so, the incident intensity or the intensity of the wave that is incident on these walls multiplied by the surface area will give you the power. Here this is the internal surface area of the enclosure and this is the intensity that is incident on the enclosure.

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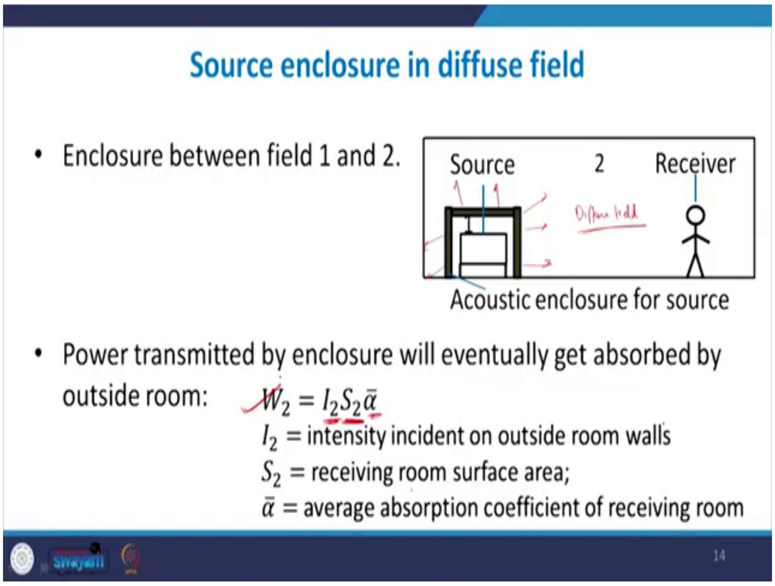

So, I 1 into S e similarly the power that is being transmitted by the enclosure. So, some power was incident on the enclosure that was W 1 and after reflection or some amount of energy may pass through the enclosure walls. So, what the so, whatever a sound power that is little or more whatever sound power that is being transmitted from the wall.

So, the power that is actually being transmitted from the wall will actually be absorbed under steady state or after a sufficient amount of time, this entire power that is being transmitted will now be absorbed by the outside room. So, it will eventually get absorbed by the outside room.

So, we can simply say that whatever power was transmitted is equal to the sound that was eventually absorbed. So, W 2 becomes I 2 which is the this is the here I 2 is because we have a diffuse sound field here also.

So, in this case whatever is the uniform intensity which is being incident on all these on the walls of the receiving room. So, this intensity multiplied by the surface area of the receiving room, multiplied by the average absorption coefficient of the receiving room, this together gives you what is the total power that is being absorbed by the receiving room. And, after sufficient amount of time whatever sound that was transmitted, whatever power that was transmitted from the enclosure will be get getting absorbed. So, this becomes the expression for W 2.

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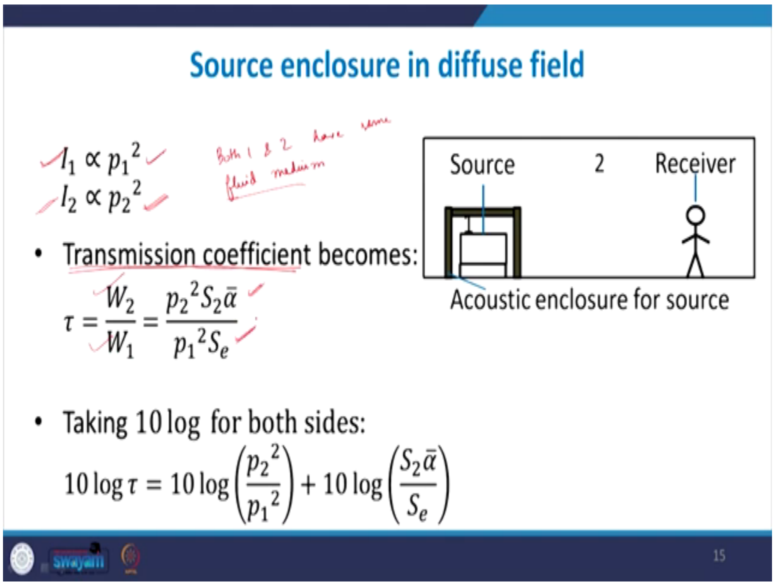

So, now that we have we have the expression for W 1 and W 2 and we know that the intensity 1 at any time is directly proportional to p 1 square I 2 is directly proportional to p 2 square and what we are assuming is that both 1 and 2 have same fluid medium.

So, rho c becomes constant and it is directly proportional to pressure square. So, if it is air inside then there will be air outside also this is the basic assumption we are making, then the transmission coefficient or the intensity transmission coefficient tau can be given by it is tau is defined as the intensity that is transmitted from a particular material divided by the intensity that is incident on the material. Now, we do not know the exact intensity that was incident and the intensity that got transmitted, but we know they are steady state values that is I 1 and I 2.

So, because now we do not know that exact intensity, which was incident and transmitted so, we take this ratio as the ratio of the power. So, tau now we can take as W 2 by W 1 which is p 2 square S 2 alpha this is the expression for W 2 we derived and this is the expression for W 1 that we have derived in the previous slides.

So, these are the two expressions we have derived. So, this is the expression ultimately which we get. Now, if we take 10 log 10 from both the sides, so we get 10 log of tau becomes 10 log of p 2 square by p 1 square plus 10 log of S 2 alpha bar by S e.

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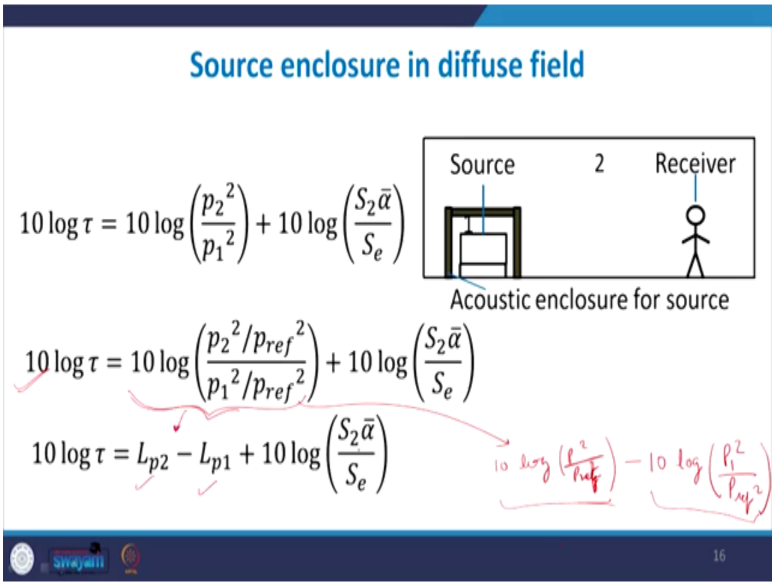

Again p 2 square by p 1 square if you divide the numerator and denominator by p reference square then this is the expression and as you see this numerator part just have a look at the numerator part the numerator is 10 log. So, you can separate this into 2 parts this can be separated as 10 log of p 2 square by p reference square minus 10 log of p 1 square by p reference square. So, by the property of log the numerator by denominator can be separated like this.

So we have separated the numerator and denominator. So, this entire quantity is what it is this is L p this is the SPL at field 2 this is the SPL at field 1. So, it becomes L p 2 minus L p 1. So, this expression becomes L p 2 minus L p 1 plus 10 log of this expression.

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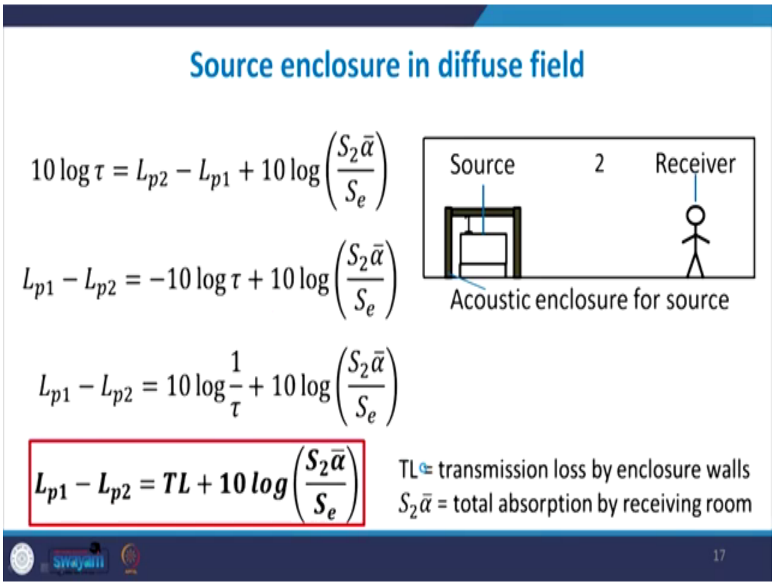

So, now taking the quantity on the other end what we get is L p 1 minus L p 2 is minus 10 log tau plus 10 log of this expression. And, minus 10 log tau is 10 log of 1 by tau and we know that transmission loss is defined as 10 log of 1 by the transmission coefficient. So, by the definition of transmission loss we have discussed about it is formula in our previous lectures this can be written as the transmission loss.

So, overall the difference in the sound pressure level from medium 1 to medium 2 is the transmission loss of the enclosure material plus 10 times the log of the surface area of the receiving room into the average absorption of the receiving room divided by the surface area of the enclosure. So, this is the particular case.

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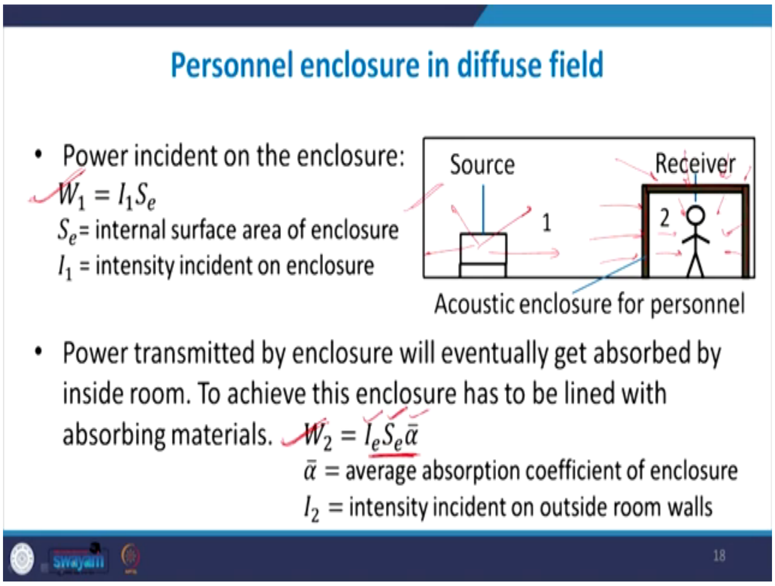

Similarly, we can find out what is the difference between the sound pressure level in case of a personnel enclosure. So, now, we have enclosure where, it is enclosing the personnel. So, here the sound is being radiated from here. And, this sound then gets incident on this enclosure walls and the sound that gets transmitted then gets transmitted here. So, then whatever sound is incident can be written as the intensity into the surface area over which that intensity is incident. So, we take the steady state or the uniform intensity I 1 into the surface area of the enclosure.

So, all of whatever sound is incident is an incident on these enclosures. So, W 1 becomes I 1 into S e. And, then so, whatever sound was incident on the enclosure some bit of it will get transmitted into the receiver's room or the personnel's room. So, when the sound is transmitted into the receiver's room again assuming that, after sufficient amounts of time has passed there is a steady state conditions or whatever sound is getting transmitted is eventually getting absorbed within the receiver room provided we have some sufficient absorbing materials present within the receiver room. So, ultimately whatever sound that was transmitted will gets absorbed within the room.

So, this can be written as the total sound absorbed which is the intensity that is present within the enclosure into the surface area of the enclosure multiplied by the average absorption of the enclosure walls. So, here the difference between the source and the personnel is that in this source case the energy was incident on the enclosure and then it was transmitted to the receiving room.

Here the energies again incident on the enclosure and then it is transmitted to the receiving room, but the receiving room and the enclosure they both have the same surface area. So, the surface area for receiving and incident both becomes the same. So, this was the W 2 and W 1 expression.

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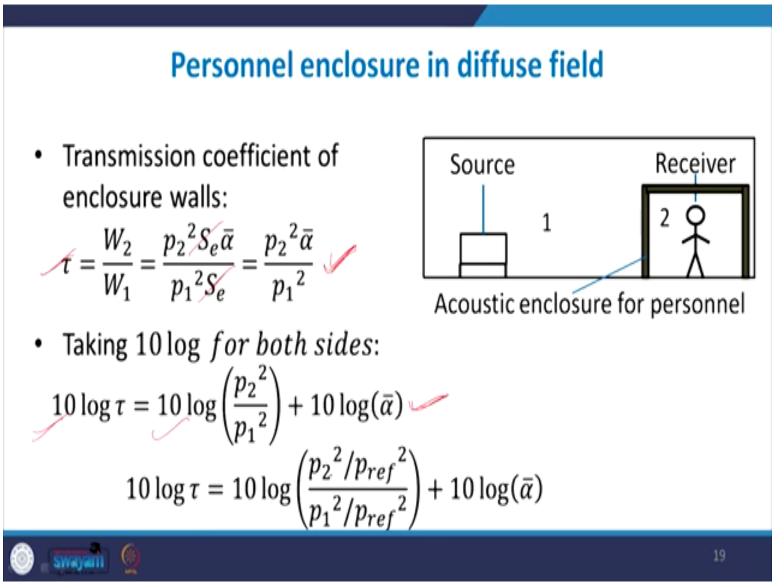

Now, taking that tau can be writ10 as W 2 by W 1 the same logic. So, here se cancels out and this is the expression we are left with. Now, if we take 10 log 10 then this is the expression we get p 2 square by p 1 square plus 10 log of alpha bar S e has already canceled out. So, again dividing the numerator and denominator by p reference square, then separating them with respect to the property of log just the way we did for source enclosure.

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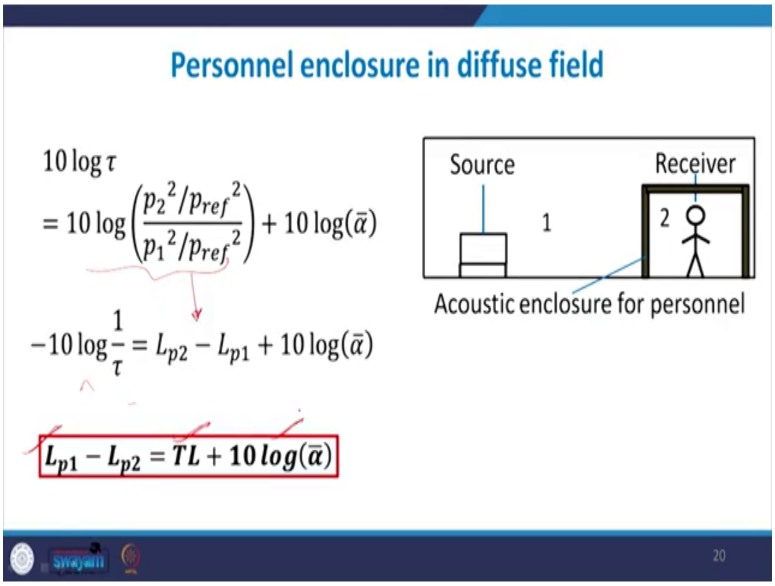

Overall what we get is this expression can be written as this particular expression 10 log p 2 reference by p r reference becomes the L p 2 and this becomes L p 1.

So, this entire thing becomes L p 2 minus L p 1 or the SPL at the field 2 minus the SPL at the field 1. And, then again taking it in the other end we get the net difference in the sound pressure level is given by the transmission loss of the enclosure material plus 10 log alpha bar, where alpha bar is the average absorption coefficient of the receiving room.

So, to sum the performance now we have derived what is the expression that we have derived is what is the difference between the sound pressure level, after it passes through the material. So, before the material the SPL before passing the material minus the SPL after passing the material and by definition this becomes noise reduction.

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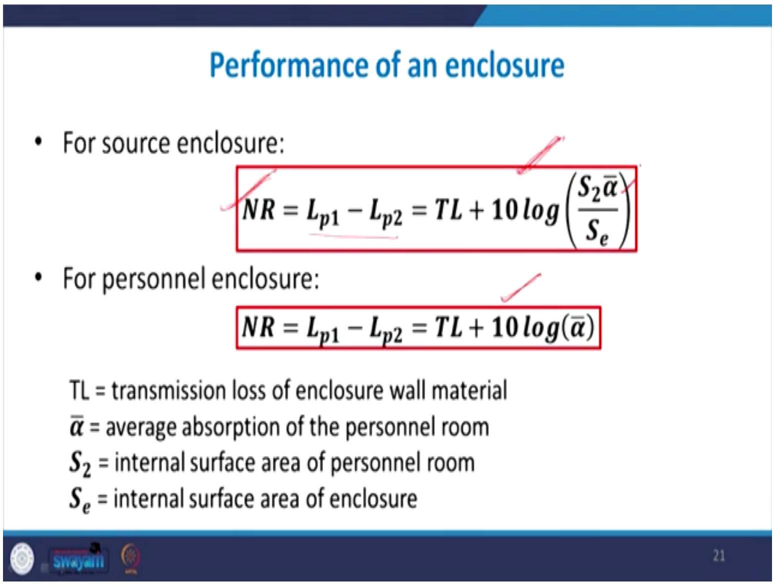

So, noise reduction or the performance it is one of the performance measured is L p 1 minus L p 2 and the expression for noise reduction of a source enclosure is this and the expression for this becomes this one TL plus 10 log alpha bar.

So, these are the two expressions that we have derived. So, from this what we see is that the performance is directly dependent upon TL. So, as the transmission loss increases or as the transmission coefficient tau decreases the noise reduction will improve. Similarly, as the absorption increases again reduction will take place.

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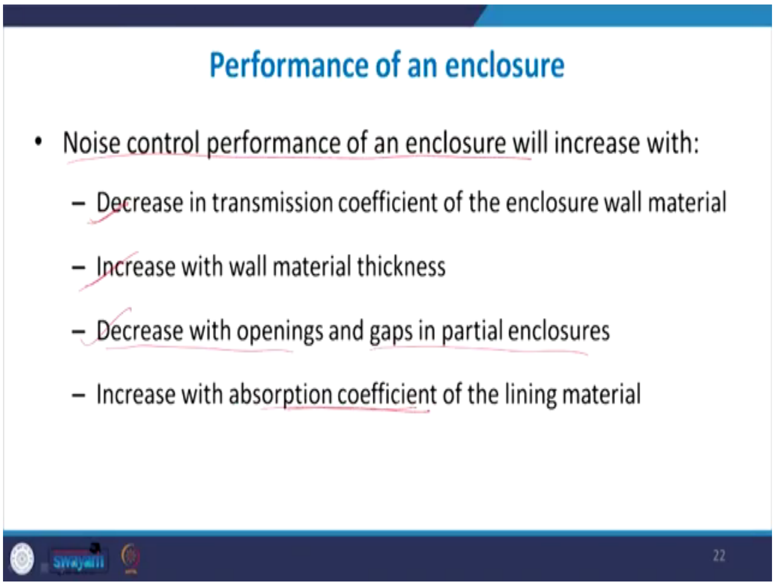

So, the overall noise control performance of an enclosure will increase with a decrease in transmission coefficient because when tau decreases TL is going to increase. It would also increase with increase in wall material thickness; it will decrease with openings and gaps in the partial enclosures, because if we have enclosures and some gap and opening is given.

Then the TL is going to reduce drastically because for that particular area the T will the TL is going to become 0, there is going to be no transmission loss. Similarly, as the absorption coefficient increases this will increase because this value is going to increase this value will increase, so NR is going to increase. So, these are the various factors on which the noise control performance depends.

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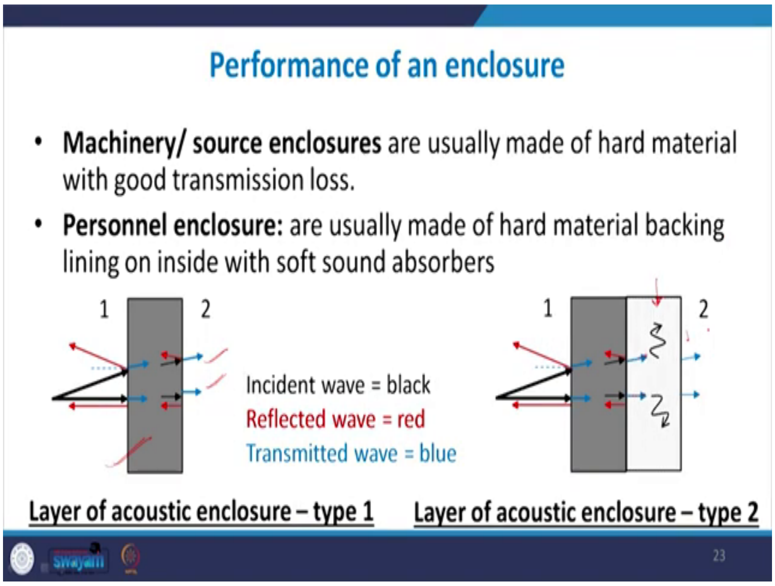

So, typically as I mentioned when we were discussing about personnel enclosures is that sometimes, the material the enclosure inside the enclosure at the receiving end is lined with absorbers. So, that whatever sound is being emitted can ultimately be absorbed within the personnel room.

So, usually in this case let us say we have a material this was a blocking material. So, reflections and transmission are happening and some sound wave is getting transmitted, but if we add a absorbing material, then the transmission is going to reduce further because after passing through the material let us say we have some transmitted wave. But, that will again get dissipated and even a lower magnitude of wave will then pass through. So, even the transmission can be reduced further if a hard material is lined with a absorber material. So, with that I would like to end the discussion on acoustic enclosures later in this week we will solve a few numericals based on it is performance and in the next class we will discuss about barriers.

So, thank you for watching.