Architectural Acoustics
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Lecture – 09
Concept of Reverberation

So, good morning students welcome to the NPTEL lecture course on Architectural Acoustics. This lecture 9 is on the Concept of Reverberation. So, in the lecture 8 we have seen the how the refraction and absorption can take place in a in closed area and how can we measure the absorption, for a particular surface for a particular panel, which can be rendered in a surface.

So, today we will going to discuss about the reverberation, which is one of the major and most important phenomena in room acoustics.

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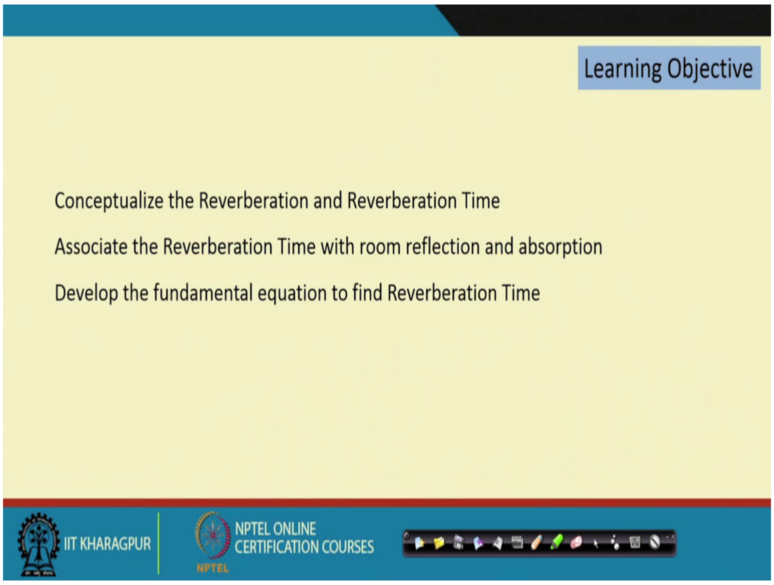

So, the lecture objective will actually outline like, the we will conceptualize the reverberation and the reverberation time. And we will associate this reverberation time to the room reflection and the absorption because, this two are the one of the very striking phenomena in the indoor acoustics. And how to relate that with the reverberation, the and we will try to develop, or we will definitely going to develop a the fundamental equation to find reverberation time in a enclosed space.

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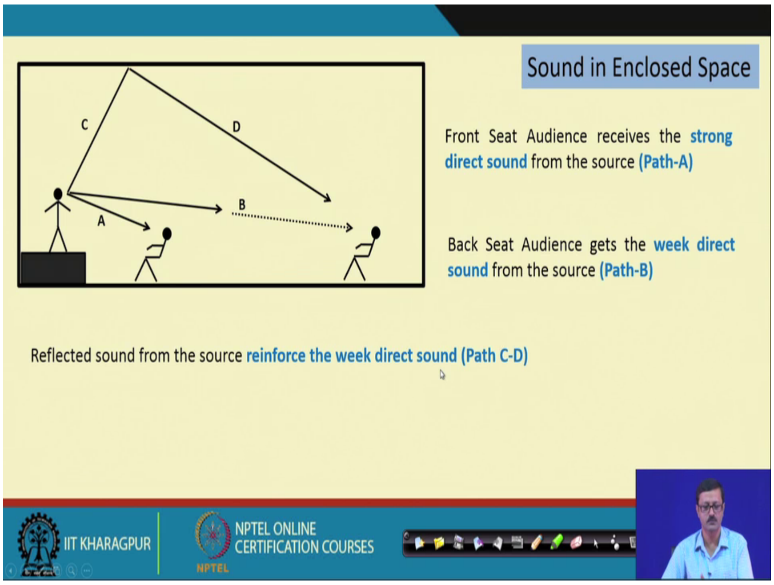

So, in a enclosed space suppose there is a stage and, there is a speaker and there are two three audience one audience in the very front row and one audience in suppose sitting in the very back seat. So, here will be some phenomena will going to happen. So, suppose the path A, the sound path A will take the direct sound from to the front listen other the front audience.

Whereas the front the back listener, or the back audience which is in the backseat with the audience in sitting in the back, he or she will get a very very weak direct sound because, when the sound is passed from this particular source to the back seat in between he has to of that particular sound has to actually encounter lot of loss.

The frictional loss with the air, there may be air moisture, there may be some other things like the some other surfaces sometimes, maybe there are some other the audience also in between the front and the backseat. So, by virtue of that there is a weak the sound will sound intensity will be fall down. And there will be another way the person, who is actually in the last seat, or a rare seat will get a sound by virtue of path C-D, which is a pure reflection from the ceiling.

So, this C D this reflection will also encounter some loss, but it will not going to encounter the loss by virtue of the people who are sitting in between these two rows. So, this C D path will going to reinforce the week direct sound, which is actually coming from the path B.

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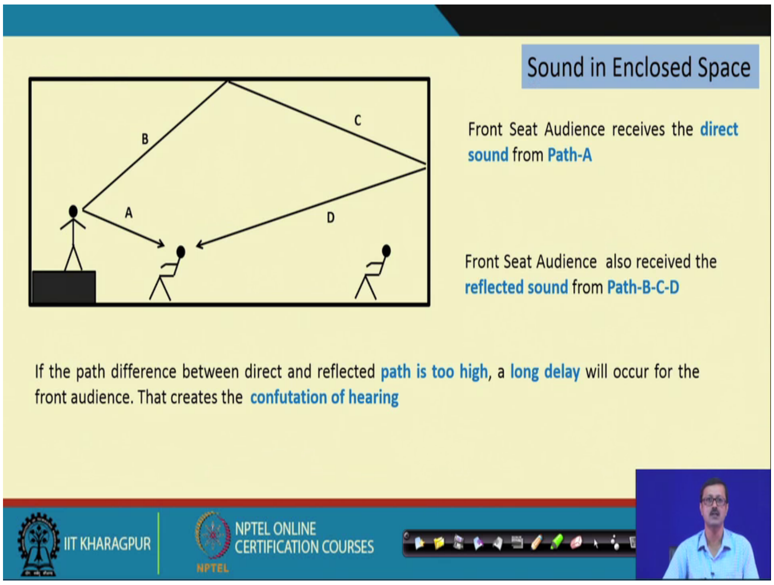

So, which is going to be beneficial for us, that is the number one criteria and number two criteria, what we can say that this path A is the direct sound from the source to the listener in the front row.

But this listen A which is in the front row, is also going to get a another sound by virtue of reflection by the path B C and D, from the ceiling and the back wall. Now, there is a problem the problem is the person, who is sitting in the first row will get two sound one A. direct sound from A and another indirect multi reflected sound from BCD. And there will be definitely lag the time lag the same sound will appear to him or reaches to him or her in a time lag. And if the time like is too much, I if I am sitting there I will definitely distinguish between the initial arrival and the final arrival of the sound and that will create the confusion of the hearing.

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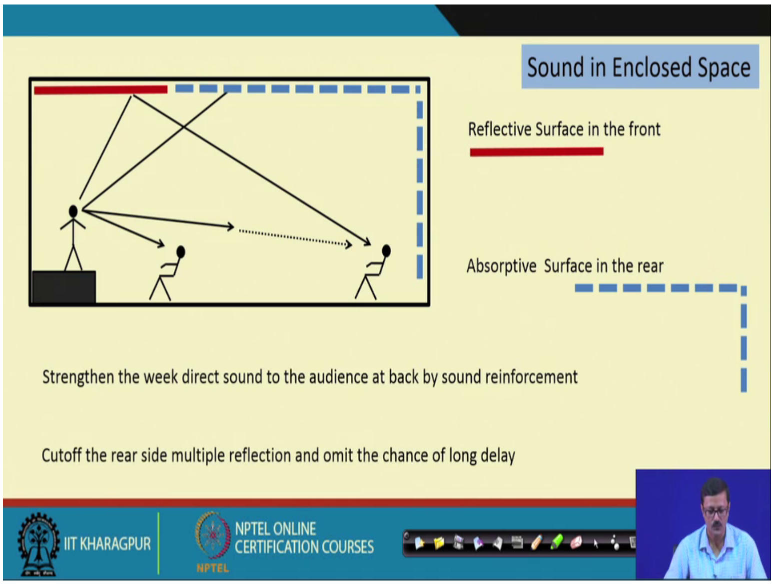

So, this two the fundamental problem, we can handle by virtue of some absorptive surface and the reflective surfaces. So, let us do some kind of a reflective surface like this, which is in the rear part of the auditorium or the hall. So, what will going to happen if I put this blue colour reflective surface absorptive surface in the rear? So, there is no chance of inflection and there is no chance of any reflection and, the person in the sitting in the first row will not get the second multiple reflection sound.

So, there will be no chance of any kind of the any kind of the sound delay or so, but in the front portion I have if I put the reflective surface, which is red in colour, then this sound will reflect and then that will go to the last bench, or the last listener which is in the rear seat and, that will going to reinforced the sound which is the actually weak sound and that will be reinforced by this reflection.

So, by virtue of last three slide what you understand is that, both reflector and absorber is very important in a hall, but we should actually place it in proper position. If you just reverse back the position the front portion is the absorber and, the rear portion is a reflector things and behaviour will be going to change the and automatically there will be lot of confusion and lot of hearing problem will be occur in this room.

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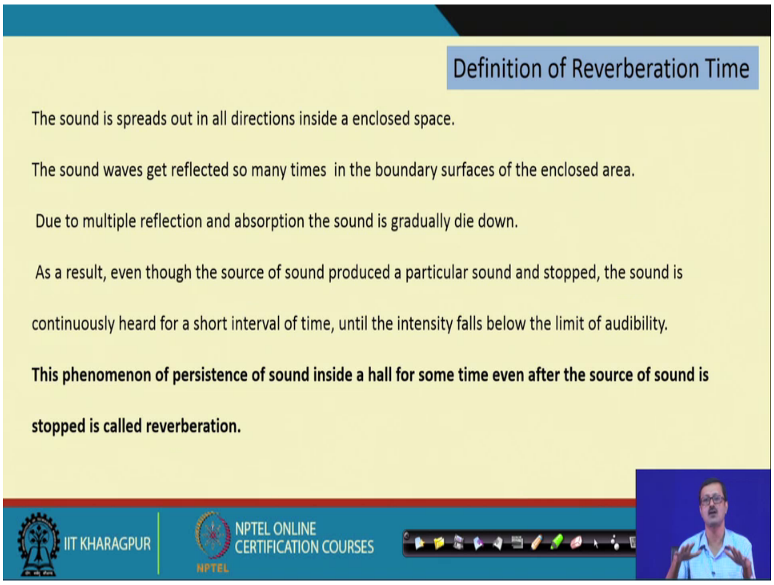

Then the next is we will define the reverberation and the reverberation time, this is very important for our understanding of the room acoustics. The sound is spread out and you know it is spread out in a particular enclosed space, it is a kind of a the near field and, then there is a far field kind of a propagation and, when it is going to propagate and then it will going to reflect, or going to strike in the different surfaces, different boundary surfaces and it will going to reflected back or may be absorbed, because of the surface is character of the surfaces..

And due to if suppose it is a reflective surface all together, it is a reflective surface and, there is a gradual and multiple reflection will occur in the various part of the hall. And due to this multiple reflection the sound will not going to decay and, sound energy will say as it is almost as it is for a longer duration and, sound will then there will be kind of a problem will occur because, I am getting a new sound which from the source and the old sound is reflected back and stay back for a certain amount of time.

So, there will be a mismatch between my new hearing new sound and the old perceive sound and, that is called the reverberation it is not the echo, but it is the reverberation as sense of the old sounds which was in a steady state, is stay back for a longer duration and, it will create a confusion of hearing by virtue of new sound arrival.

So, the phenomena of persistence of the sound inside a hall, for sometime even after the source is stopped or whatever is called reverberation. So, the sound is something like a stay back for a longer period after or the time. Suppose you entered to a empty hall which hall, or may be empty room, a quite a large room which is no furniture nothing only the surfaces of the blank surfaces are there.

And if you shout if you talk the you will feel like reverberating it is the sound is stay back for a quite a long time, or if you can go to some kind of a charged, or maybe some kind of the big auditorium, maybe at the time of construction and all because after you give some absorber the reverberation time will not going to perceive. So, those time you can see the when there are hard surfaces, the sound will stay back for longer duration.

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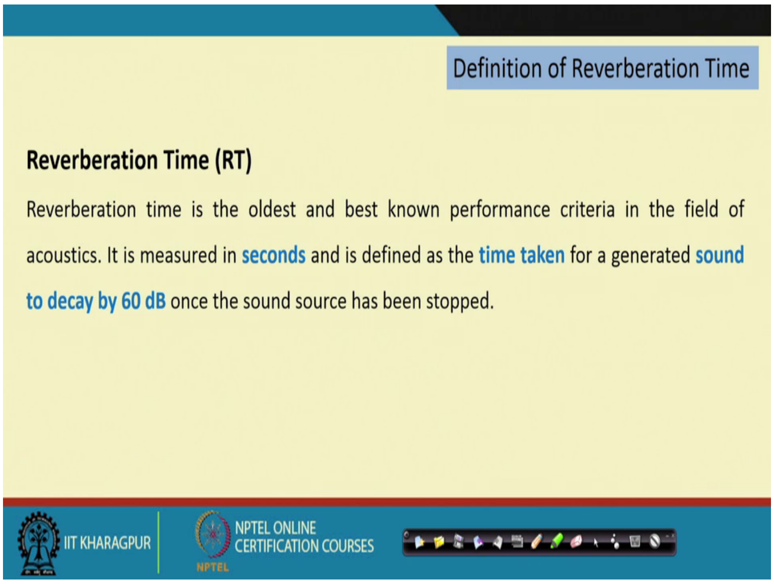

Now, the definition of the reverberation time now, as I understand that the reverberation is a staying back, or the sustaining amount of sound. So, I need to find out how much time it will going to stay back in a particular room and, how it can be modeled and, how it can be actually formulated. So, by virtue of a support some definitions, I can actually start thinking of modeling the revolution time. So, it is known as the revolution time is defined as, the amount of time measure of course, in second to drop the sound level from some level to a 60 dB degree (Refer Time: 09:31).

So, suppose a sound level is 100 in a steady state, how much time it will take to fall 40 decibel. So, there is a decay by40 decay by 60 decibels.

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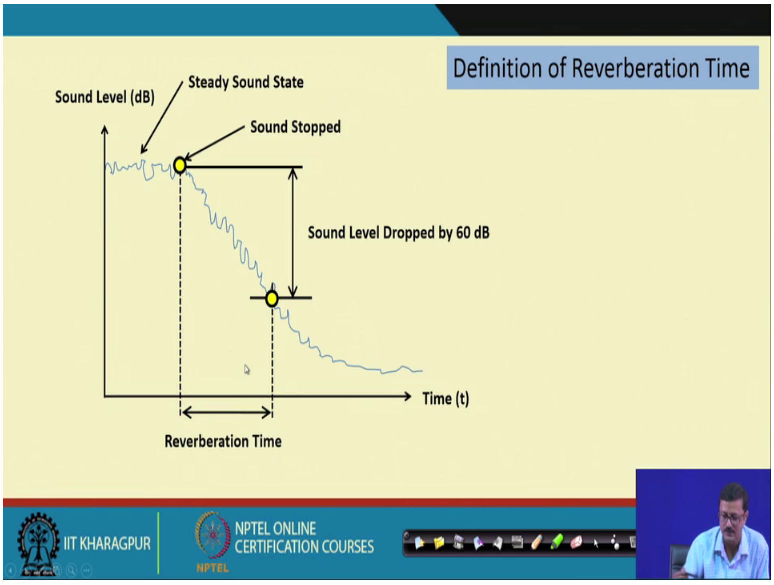

So, let us go to a graph, suppose in x axis I am plotting the time and, y axis I am plotting the decibel level, or the sound level and I start some sound in a particular room and after sometime. I will stop the sound and when I stop the sound, sound is still there because of the multiple reflection and I will get a graph like this.

The initial portion of the graph is flat because, it is a steady state this part, this part is a steady state and, then this particular point I have stop the sound. So, there is no input. So, gradually it will decay down, why it will decay down because there is multiple reflection, if there is a multiple reflection some amount of definitely sound will be definitely absorb. So, by virtue of some typical time lag, there will be some decay and that the sound energy will decay down like this, by virtue of definition of the reverberation time I have to find out the how much time it required to drop the particular sound energy level by 60 dB.

So, as I told suppose it was 100 dB. So, I have to find out at 40 dB to get I mean to decay from 100 to 40, how much time is required in second and that is nothing, but the reverberation time.

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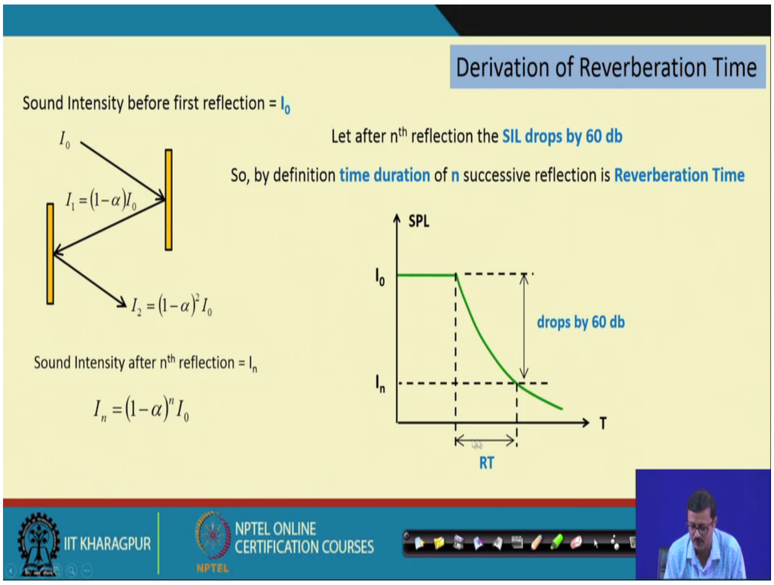

So, let us define this reverberation time by virtue of some physical some virtue of some physics so, or physical understanding.

So, suppose a sound is initiated by a intensity of I 0 and, there is a multiple reflection is occurring suppose it is the initial, sound in a particular in a room and, when it is strike in a particular surface. The amount of energy is reflected back is 1 minus alpha into I naught, which I have explained in the last lecture, because alpha times I naught is absorbed. So, this is remaining for the room.

So, it is goes for the second reflection to other surface which is may be opposite surface, or maybe the orthogonal surface. So, after second reflection the sum absorption will be happened over here, the absorption is this I sorry I minus alpha into I naught times alpha. So, this much amount is again reflected back after the second reflection.

So, that is 1 minus alpha to the power 2 into I naught. So, I can say after such n reflection are the after some n reflection so, sound energy intensity is suppose I n and, this I n will be one minus alpha to the power n into I naught, and by definition let us suppose this I naught to I n this drop is 60 dB. So, let us find how much time is required to get this particular drop.

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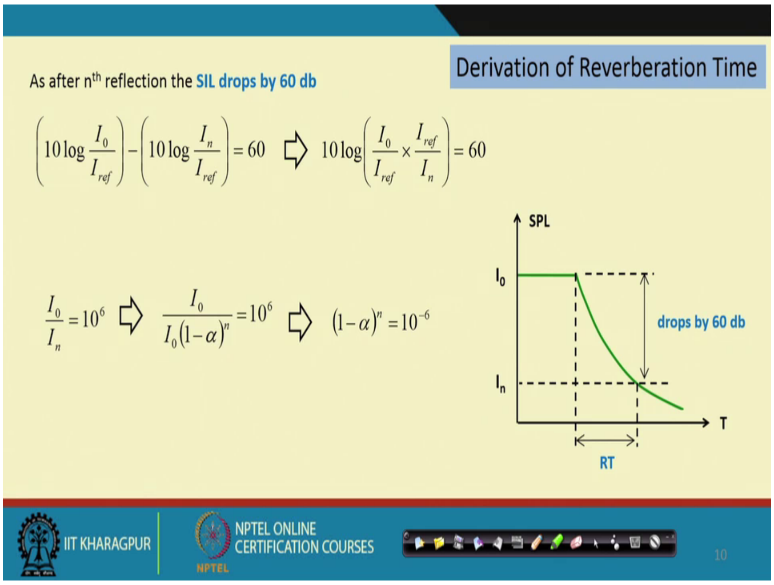

So, what we have do is that our initial energy was I naught which is this and, for I naught this particular sound level, I have measured the what is the sound intensity level and, next after drop of 60 dB it is after n reflection I n. So, this will be the sound intensity level at after sometime after some n reflection and, the difference between this two is nothing, but 60.

So, now if I modify this equation so, I will get this equation and, then further I this I reference and I reference will going to cancel out and finally, I will get I naught by I n is equal to 10 to the power 6 and, I n from the last slide I know this is I naught into 1 minus alpha to the power n. So, this I naught will also gets cancelled and finally, I can say 1 minus alpha to the power n equal to 10 to the power minus 6.

So, somehow I have relate the initial and the final level of the sound intensity, initial and final level of the sound intensity levels that is 60 dB and finally, got this particular final equation.

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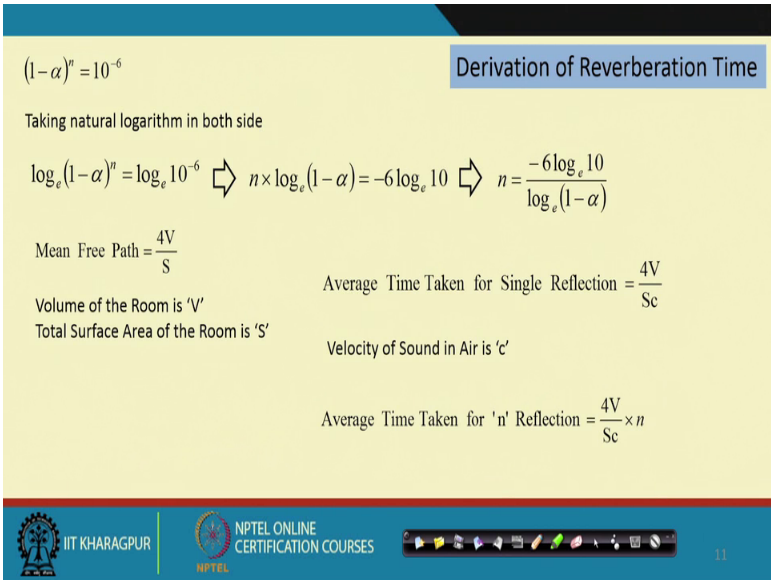

Now, let us go to the next slide and, see the how this further it can be handled. So, I will now take a natural logarithm with base e for this and, if I take the natural logarithm it will look like this. And this n will come in front and finally, I can find out how much is the n, this is minus 6 log natural log of 10 and the log natural log of 1 minus alpha by or natural log of 1 minus alpha.

Next we will have to conceptualize another thing that is mean free path, the mean free path is the mean path covered by any kind of in a particular three dimensional space for a particular ray. So, suppose from a particular point here ray is initiated and it is strike to be a particular surface and, it is follow the law of reflection it is go to the another surface.

So, virtually it will follow the law of reflection and, strike different surfaces and by virtue of this the striking of different surfaces. It will travel some path and, as you know the path length of the path will not be always equal. Now, if you take a sum up some this particular all the path and, then take the average and that is called the mean free path. And this mean free path will be all equal to for a rectangular room is 4 V by S, where V is the volume of the room and, the total surface area is the S.

The derivation of the mean free path is not in our scope and, it is required A the volumetric integration and, A particular colonial kind of the study. So, as we suppose let us suppose this mean free path is 4 V by S. So, this mean free path the unity centimeter or meter and this is a path length. So, I can say that the average time taking to cross a this mean free path for a 1 single reflection is 4 V by S into c, where c is the velocity of the sound because, path by velocity or the distance by velocity is the time.

So, for single reflection you required 4 V by S c time. So, for n reflection you required 4 V into n by S c that particular time. And this time is nothing, but your reverberation time because, I have by definition after n reflection the dB drop by 60 and n reflection, you take you are taking this much amount of time, the sound is taking this much amount of time.

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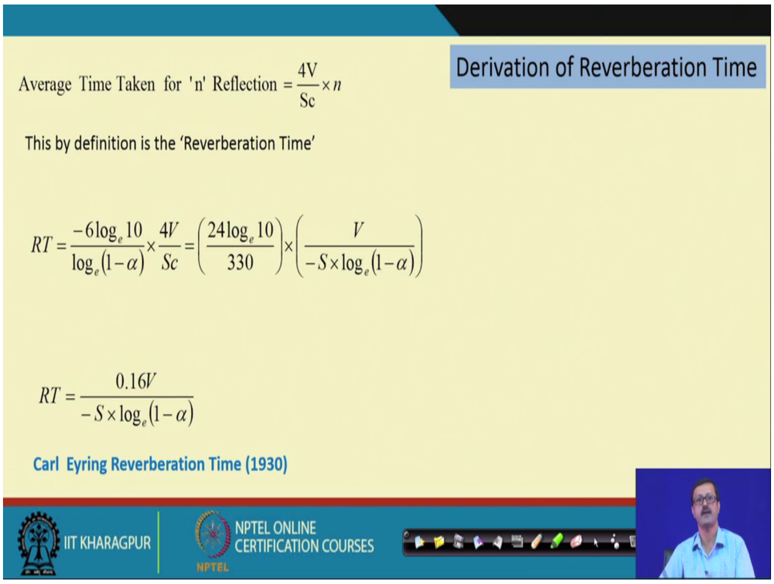

So, by definition this 4 V by S into c into whole into n is your reverberation time.

Now, let me multiply everything. So, reverberation time and this comes from the earliest slide as n, then S c and this 4 V is from the mean free path the single reflection path. So, now, take everything out this 24 is 4 into 6 log e e to the power 10 and, this 330 is nothing, but this value of c the velocity of the sound in normal air, then we left with this V by and this A and log of that.

So, finally, we can get equation like 0.16 V by minus S log 1 minus e, this 0.16 is nothing, but this particular value this particular value is the 0.16. And this equation is called Carl Eyring equation, which was given is in 1930 and by that physicist for to calculate the reverberation time, Sabine's actually modified this equation to a further extent and the extent is this.

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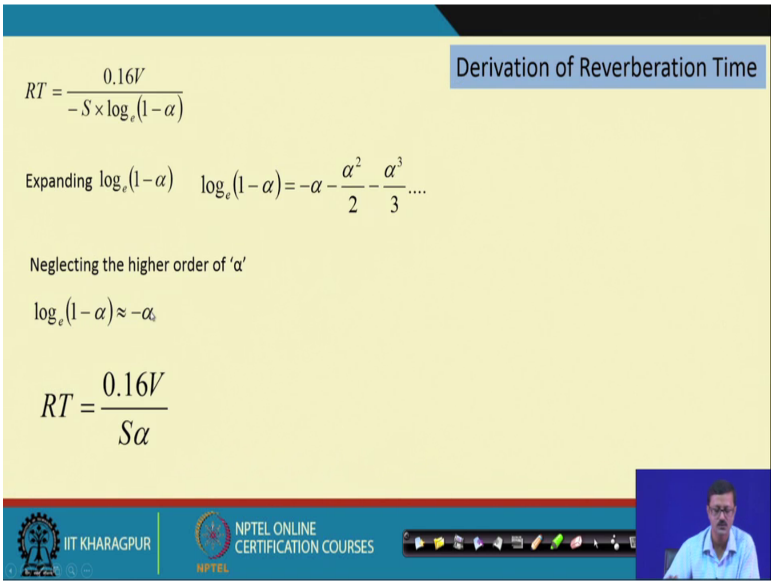

So, he took this equation further and what he do is that, if I expand now this log e base 1 upon alpha 1 minus alpha, this will actually lead to a series like, this minus alpha minus alpha square by 2 minus alpha square by cube by 3 like that. So, as the alpha is less than 1 quantity of alpha the amount of alpha, the absorption coefficient is always less than 1 and, this is a small quantity. So, we can neglect the higher order of alpha. So, we can neglect this particular part.

So, we can say this log e that e base, that natural log of 1 minus alpha is very close to minus alpha. So, I replace this log terms by minus alpha, this minus and this minus will get cancelled so, it is S alpha. So, I get the equation has 0.16 V by S alpha.

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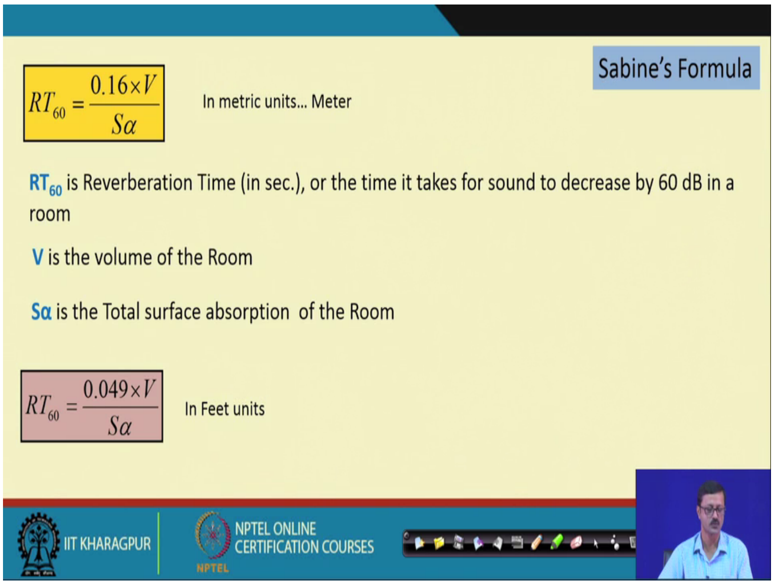

And this is the standard reverberation time equation given by Sabine known as Sabine's formula, where V is a volume of the room, S alpha is the total absorption of the room and S is the particular surface area, area of the surface and alpha is the corresponding sound absorption coefficient of the surface.

So, if you use this equation, which is given in the yellow box, you can use the metric unit the meter and those unit, but if you want to use in feet and inch feet unit, then you can use the same equation in the given in the this red box, where only the instead of the 0.16, you have to use 0.049.

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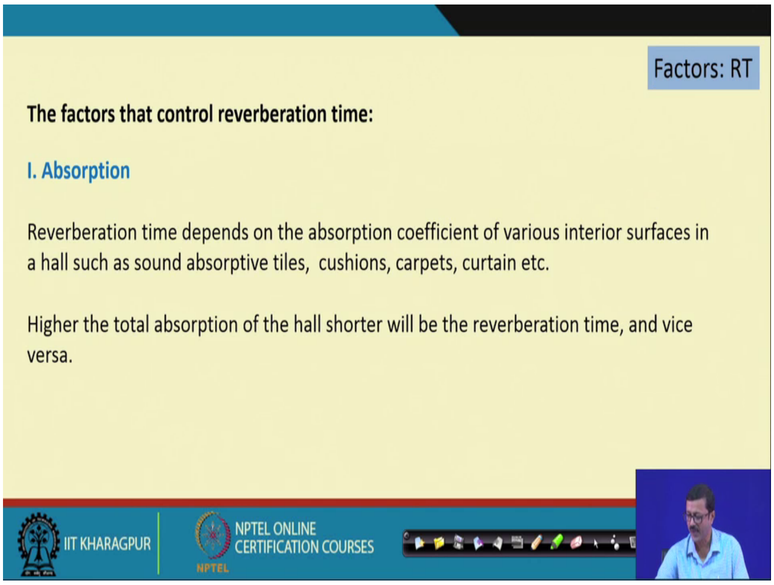

Now, what are the factors that going to affect this particular reverberation time, the first one is absorption, why because as the absorption is increased, or decreased your alpha value will going to increase, or decrease and for that total absorption the S product alpha is going to also going to change and, there will be variation in the in the reverberation time.

So, if you go for a higher absorptive surface like cushions in the chair, carpets in the floor absorptive tiles in the walls, or ceiling we are going to render different higher values of sound absorptive material and, definitely to the total absorption will be higher and, we are we will be expecting in lower amount of the lower reverberation time. What is the second factor?

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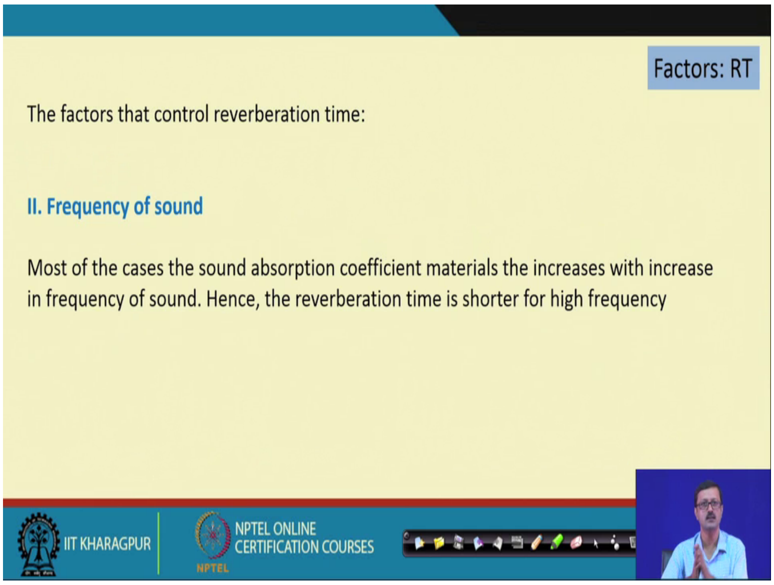

Second factor is definitely the frequency of sound, why frequency of sound is not reflected in the RT equation, but still it is a factor because as we know and if you remember in the last discussion we have shown, by the change of the frequency of the sound, the alpha value is also going to change. And it is incremental suppose the alpha value for 200 and 50 hertz will be lower with respect to the 2000 hertz.

So, if the alpha value is changed for a particular frequency, I also I must say that frequency of the sound is also going to change the reverberation time of course, it is not reflected directly in the equation, but of course, it is reflected by the NRC value, the average what we have taken and the third and the final one is the volume of the room.

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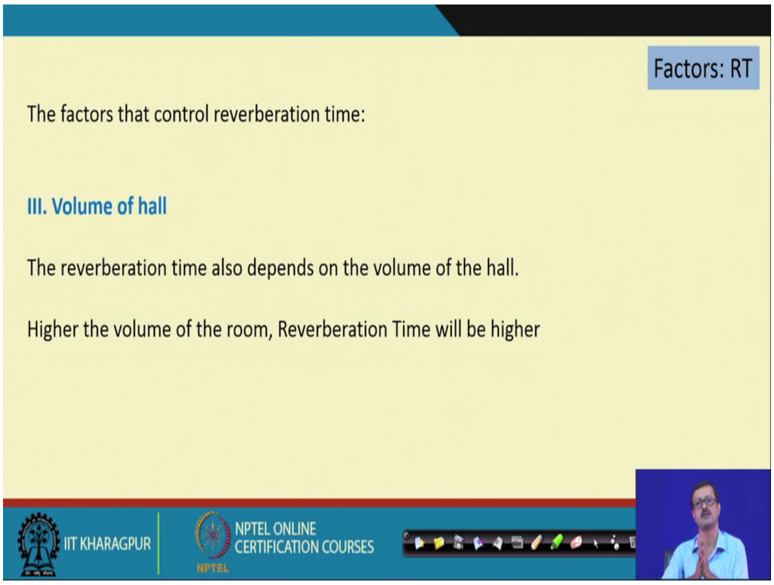

Because as the volume of the room is increased, your reverberation time is going to get going to be increased and, because your length of the mean free path is going to increase there will number of more reflections, number of more travel for a single reflection and, total number of travel is also going to be high and the that require larger amount of time.

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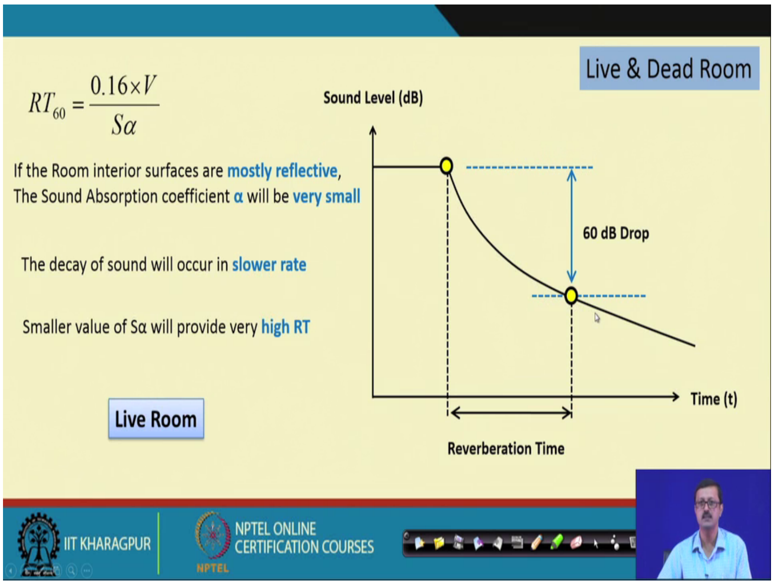

So, those three volume of the hall the frequency of the sound and the absorptive surfaces amount of the absorption coefficient is the three basic parameter to define, or to understand the reverberation time, here I have always written RT 60, if you remember in the last slides also it is sometimes written in the some way the RT is this, but it is better to write RT 60 because by definition RT is 60 dB draw.

So, that RT 60 is written in this formula in this way, sometimes we also calculate the RT value RT 30 what is the drop for 30 decibels sometimes, we also can think of some RT 10 what will be the drop initial drop of 10 decibel. So, for further minute correction of any interior of auditorium or so, particularly in the electro acoustics part. So, that is why it is better to write RT 60, but as in general if you RT; that means, it is RT 60 the 60 decibel the basic definition point of you the sound reverberation times of any enclosed area.

So, let us is now discuss some other way around how to find out the sound reverberation time to relate to some other definitions live, and dead room. Suppose a particular room is fully reflective. So, what will going to happen, your steady state this is the steady state in this yellow dot is the stoppage time of your sound. So, sound will decay and this decay will depend upon the amount of surface and, amount of reflectivity or the absorptivity of the surface.

If surface is reflective that is most reflective means the alpha value of the surface is very low. So, almost it will give you lot of reflection and, the decay will occur in a very very slow rate very slow rate. And due to this decay is very slow rate you see this particular line is extended like this and, you will get a very high reverberation time very reverberation time. And due to this is very high this particular room, this type of room is called live room and there is a dead room also.

This is a dead room in that case, what I have here is that is a steady sound this stoppage of the sound and after the stoppage of the sound it is reflecting in the various surfaces and, the surfaces are totally absorptive surface, or mostly absorptive surface having very high value of alpha. So, after striking it may not come back, or may be it come back or the very the weak intensity will come back may be after 2 3 5 6 50 reflections, it will going to decay. And it will be decay the rate of the decay of the sound will be very faster and, that is why this line this is the decay line will be very stiff in order and will get the drop in a very quick time.

So, if the this line is very stiff this reverberation time is also going to be a very small and, we will get a very low reverberation time and, those rooms where there are the reflective surface is less and it is full of absorptive surface are called dead room. So, this dead room and the live room will be explained further by professor Shivana Gupta and, her lecture when will be dealing with the auditorium and other acoustical spaces.

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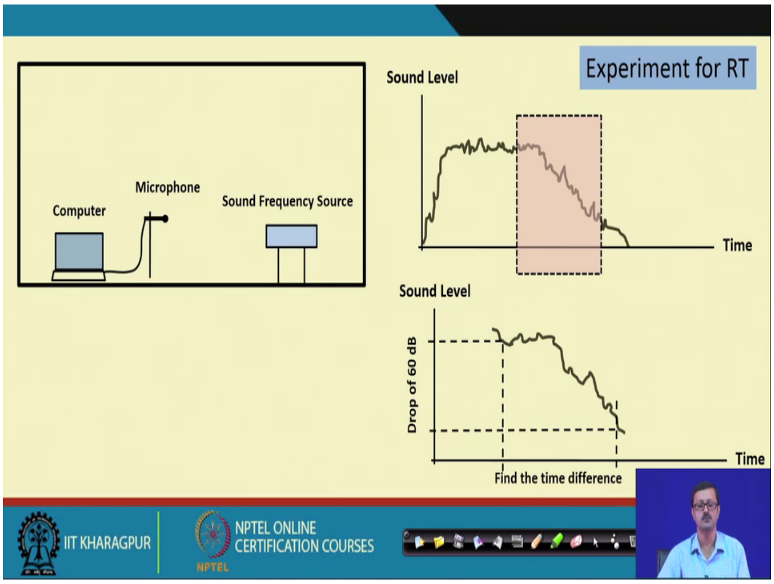

Now, let us know (Refer Time: 26:13) let us understand the how this particular experimental way, the how the reverberation time can be calculate, how can be it calculated in a particular room. So, suppose this is a I have what I have drawn here is a section of a room and, in that you just put a some sound source sound frequency source. So, this is a particular sound source, which will give up you can control that different frequency, if you one 1000 frequency, you push a button and it will give you a 1000 frequency, you can regulate the volume of the this particular source also.

So, high volume or low volume something like that and, in another corner you put a micro phone and it attached that micro phone with the computer, whatever it is received in the microphone the sound is received in the microphone, in this particular point in this particular point that will be actually recorded in the laptop, or maybe a computer. So, after this particular thing you start with some frequency and, after a steady state is arrived you stop that particular frequency.

So, you will get a kind of a graph in the in your laptop, or in your computer where in the x axis is the sound level so, it is initially built up carries a steady state and, then there is a drop after you stop. Now, you zoom this portion after this stoppage portion to the decay portion, you zoom this portion, you recorded you save it in your computer and, then you zoom it portion. And after zooming you find out what is the time and, what is this time the difference of time this too point and as you see in the x axis the drop of 60 dB. So, you see how much is the drop from this particular point to a 60 dB and record what is the or just note down note down what is the time difference.

So, if suppose it is 3 seconds and this is 3.15 second. So, the time difference is 0.15 second and you can say that the reverberation time is 0.15 second or so, so like that in various part of the room you can go you cannot do only one, you can do you can take a reading in the corner for placing the microphone in the corner, you can in the middle in some the sides.

So, may be 6 7 area, you can actually find out you can actually has to take this microphone in the human ear level this level, otherwise it would not be that much practical, you cannot take it in the floor level or maybe in the ceiling level, better if you take in the human ear level and, in various point in the in the room and, then get the average out of this particular the time. And you can say that this is the tentative duration time of the room.

So, this is a very brief in a very brief I have explain the experimental procedure for the reverberation time. So, we are almost in the end of this chapter of reverberation concept of reverberation, I hope you understand what is reverberation and, I also hope that you have the derivation may not be way that much important, but how that particular definition is translated by derivation to a reverberation formula is very interesting.

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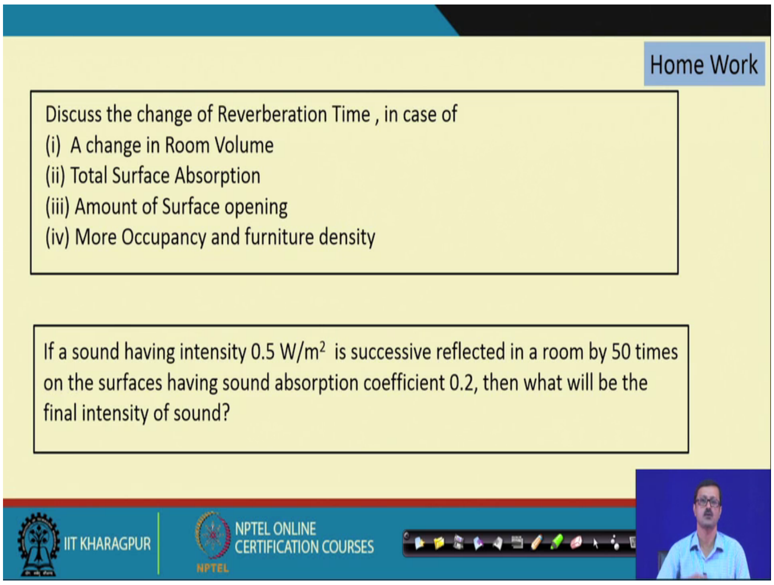

So, let us take some the homework for today and, the first homework is again some kind of descriptive, discuss this 4 phenomena in case of a change of volume total surface absorption amount of surface opening and more occupancy and the furniture density, how it will reflect the reverberation time of a room, what do you feel, write two three lines on this particular 4 cases, that is one descriptive type and a subjective type, or a mathematical type is that.

If suppose there is a sound intensity of 0.5 watt per meter square was there in a particular the room and, there is a successive reflection successive reflection of 50 times and, after this 50 times of reflection, you got the final absorption, you have to find out the final absorption intensity of the sound after this 50 reflection.

If you imagine this 50 reflection is occur in a surface, having the sound absorption coefficient of 0.2. So, the absorption surface is having 0.2 alpha value. So, there are 50 such reflection. So, it starts with 0.5 what will be the n product, what will be the n the intensity of the reflection. So, that you calculate and these are the same books.

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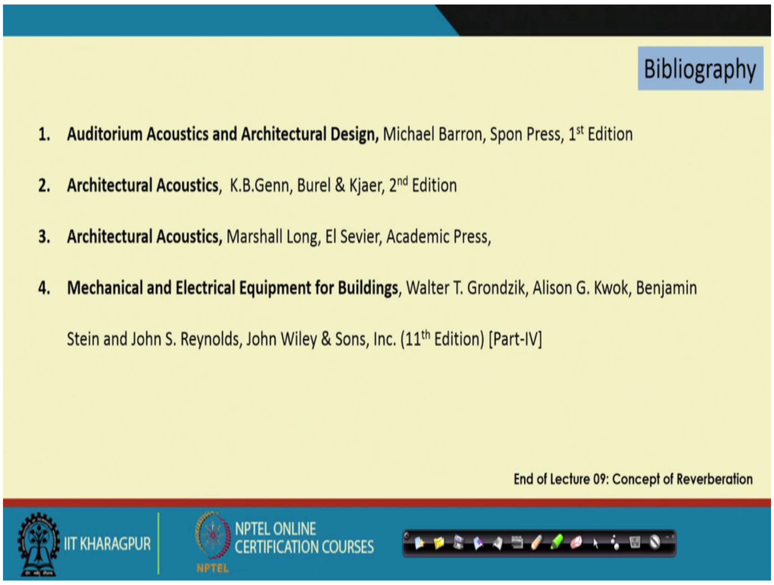

Which I have followed for the last lecture also and this reverberation lecture, you can also go through these books and, for your further studies. So, that is the end of the lecture number 9 concept of reverberation and will go further for the reverberation time applications and all in the next lecture.

Thank you.