Architectural Acoustics
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Lecture – 16
Acoustical Criteria and Space Design

So, today we will start with the next module which is mostly dealing with Acoustical Criteria and Space Design. And we have in the previous modules we have learnt reverberation time, we have learnt what is live room, what is dead room and with volume how these values of the reverberation time changes.

We also learnt intelligibility that is the portion of the sound which we hear, and from that it was which was actually calculated out from the articulation index. We also found how the impulse 1 impulse overlaps with the other and how this phenomena takes place, and we will carry on further how to use these knowledge in actual space design. So, we will look into the acoustical criteria and move into the individual space designs gradually.

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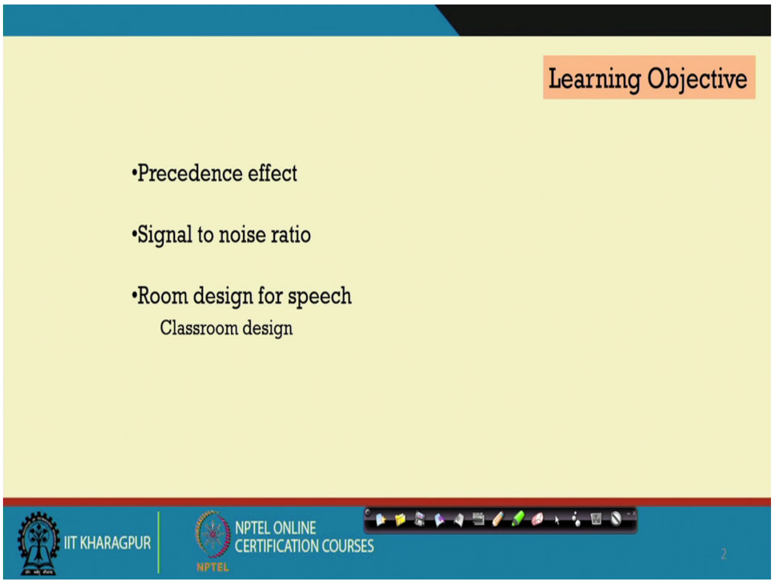

And this is the particular objective what you see in front of you it is precedence effect, signal to noise ratio, room design for speech. Why particularly speech because we had earlier discussed that reverberation time for speech is of a particular type that is we try to keep it low. Because we want clear sound to be reaching individuals or the listeners or the receivers.

And under that we will try to see the broad aspects what are to be covered in particularly classroom design. Because we as architects may not come across designing and of auditorium individually, but every time school design classroom where classroom is a major component we need to know these. So, we will get into some parts of it and further lectures we will be continued starting with classroom and then moving to other spaces.

So, in this module actually we will flow from one lecture to the next and hence there will be some overlaps. So, we had already learnt that reflected sound helps in hearing up to a certain period of time that was 35 milliseconds, 50 milliseconds depending on what performance it is what the performance is happening.

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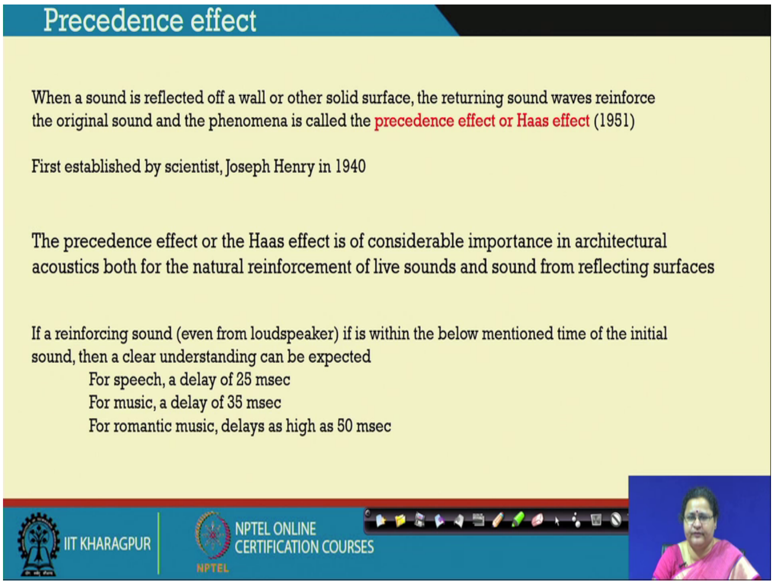

And this particular effect is called the precedence effect or the Haas effect which was initially established by Sir Joseph Henry in 1940. And later on it was known as the Haas effect by the Haas effect or the precedence effect since 1951, and it is when the sound is reflected of a wall or other solid surfaces, the returning sound waves reinforce the original sound and that phenomenon is called the precedence effect.

This we have discussed many a times while discussing reflection and this particular precedence effect is actually taking care of the helpful sound, helpful reflective sound which will help the sound wave or the original sound source wave to get reinforce to reach the people. And hence it is it is understood that it is of considerable importance of architectural acoustics.

Because sound what is produced at this point source is to be travelling to the every corner of the space where the audience is sitting. So, it is not only my voice which is reaching, but it is also the reflected sound which is helping it to reach helping it, and it is reaching to the ears of the audience. So, it is of very much importance and we have to keep this in mind that is the precedence effect in mind.

And as already I mentioned for speech we are only going to take the reflected sound which comes within 25 milliseconds, and that will actually carry that that will actually reinforce the source sound and you can get a higher intelligibility. But for music a little higher than that time can be accounted that is 35 milliseconds, and for very romantic music's you can further go up to 50 milliseconds. And these are all experimentally established found out through geometrical ray diagrams.

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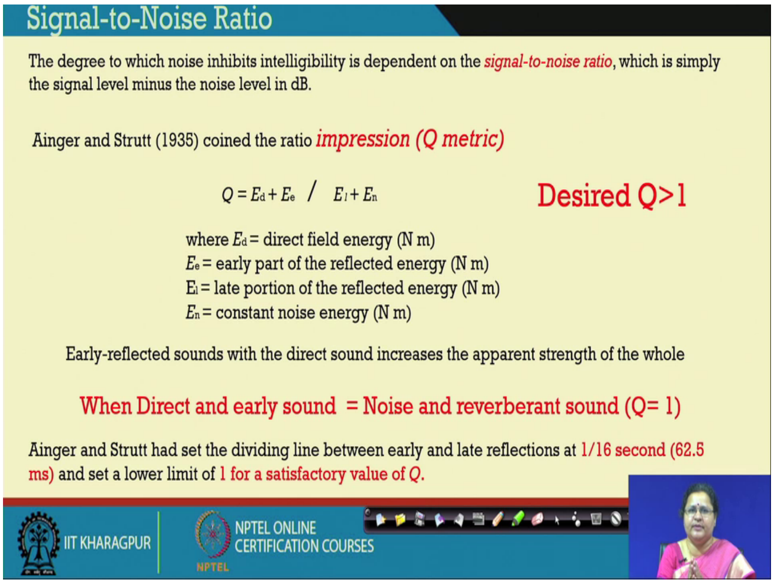

So, we also introduce to in the earlier thing we also take thing in to consider in to the noise inside the environment. We had discussed in the earlier lecture also that it is the say the fans are moving inside a space, say the air conditioning mechanical sound is coming in to the space. These are all account these are all negative to what sound we are producing. So, we do not want that sound to reach the persons ears, but it is reaching. So, in that case we cannot stop that because we cannot have a full proof room where there will be no sound of fans, no sound of mechanical ducts, and other sound which is coming from the road side.

So, we have to account for and we have to look in to what phenomena happens over there; and that is what is the purpose of signal to noise ratio. I have also introduced in my prevail in the previous module this phenomena and the degree to which the noise inhibits the intelligibility that is it is an negative to the intelligibility is dependent on this ratio and which is simply the signal level minus the noise level in decibels.

And initially in 1935 Ainger and Strutt two scientists coined this term as impression it is called the Q metric. And it is desired that if you have if you have the signal that is source sound level and if it is as equal as the sound noise level then the Q metric is 1. So, how do we define that?

So, Q is the Q is the metric which is the talk which we are accounting considering which is the direct field energy and the helpful reflection that is which is coming in 25 milliseconds in case of speech, or which is coming in 35 milliseconds in case of music. And which is divided by which is not required that is which is not unwanted which is noise that is the late portion of the reflected energy and the constant noise energy which is already persisting like the fans are moving, or the AC duct the air conditioner is making some noise, or there is a continuous noise coming from the road.

So, those are all accounting towards the towards the denominator part. So, that is why Q if it is more than 1, it is we are having more energy positive energy in the signal side and more it is the denominator is high that is Q is getting lesser than 1 which is highly undesirable. So, the early reflected sound with the direct sound increases the apparent strength of the whole, and we consider that as a positive component towards the numerator that is an addition to the direct sound field.

So, when the direct sound and the early sound reflected is equal to the noise and the reverberating sound we get Q is equal to 1. And again Ainger and Strutt in their experiments fact said the dividing line be because you have to find out which is late portion of the reflected energy? To get the late portion of the reflected energy you need that time which in precedence effect is stored for speech it is 25, so there it was descriptive it is a defined.

But Ainger and Strutt when they worked on they told 116 second that is 62.5 milliseconds is the lower limit of is the maximum which can be accounted in the early part of the reflected energy. And I have sown shown you in my previous module that how this the remaining part of the that is late reflection creates the reverberation time and that actually is the noise to the next syllable which is spoken in case of a speech.

So, for a satisfactory at the minimum value of Q desired is 1, when the signal is equal to the noise other than that you we always expect that Q will be of the order of 2, 3, 4, even so that we get very good strength of the signal and very less part of the noise. So, with this understanding we will go to the next slide here.

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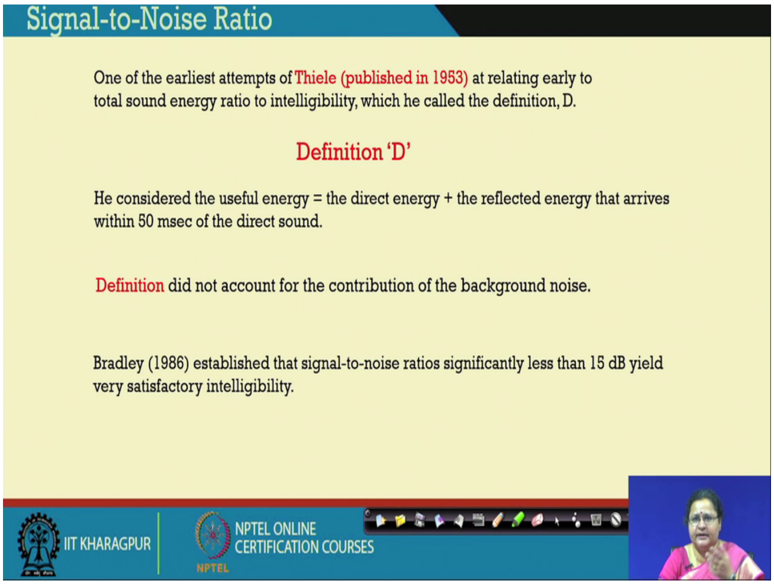

We see that Thiele another scientist worked and defined another term that is called Definition 'D'. Though these are not much in use it is to for as a background am just giving you essence of it he only considered that the useful energy is the direct energy that is the whatever the source is source is generating. And the reflected an energy that arrives within 50 milliseconds.

In this particular concept that is the DC definition he never accounted the background noise in the whole thing. But yes this also gave some insight, or some understanding that yes it is not only the original sound, but it is also the reflected sound which actually what the precedence effect talks about is all that is contributing towards the signal.

And the earlier concept which was the signal to noise ratio which I already explained where which is the impression Q, which is considered that where it is also taking care it is as a a ratio where the upper part is the important which is required and other part the denominator part which is undesired. So, upper part is the desired sound, lower part is the undesired sound.

So, further see the years 1986 Bradley worked till even up to 2000 and he established that single signal to noise ratio which will be significantly less than 15 will yield a very, very satisfactory intelligibility. And later he told if it is between 10 to 15, if the signal to noise ratio is between 10 to 15 it is satisfactorily intelligible that is up to 80 to 100 percent intelligibility can be achieved.

So, these are some background studies what the scientist started doing and you can see the dates it is just before said 15, 30 years back all these things were happening.

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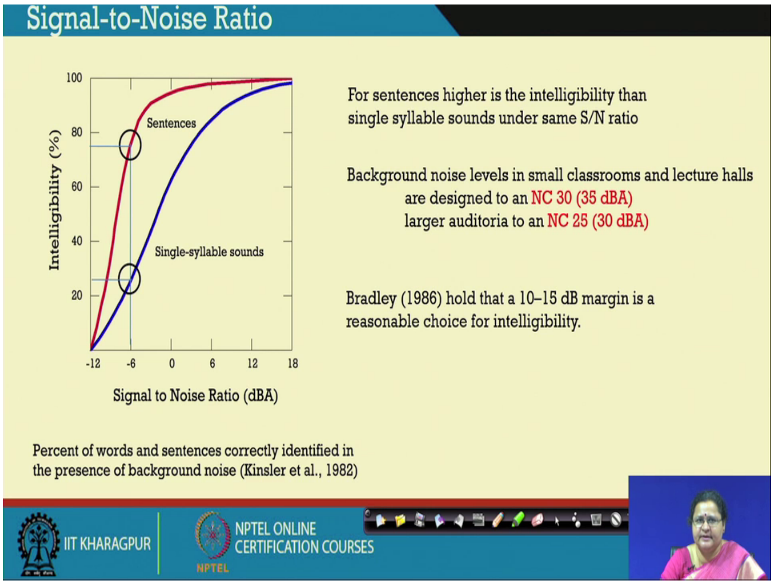

Now, we will see how we can take care or take help of these. Because with all these calculations we cannot go deep in to the calculations, but we have to take the lesion from it how it is to be dimensionally considered or how these effects to be taken in to account while we are designing the spaces.

So, here you see there are two curves where one is in blue, which is showing that the single syllable sounds are being spoken and how is the intelligibility which is in y direction varying from almost 0 to 100 percent on the y axis. While the signal to noise ratio is plotted in the x axis where you have a signal to noise ratio of 0, 6, 12, and 18;

what was told by Bradley? If you are in this particular zone if you are in this particular zone that is in this portion you are getting very high intelligibility.

So, if you come down here if you will see that if you are in this signal to noise ratio of this particular zone between something between 9, 10, 11, 12 to 15 you will get a good intelligibility that is whatever is told, whatever be the background noise if the source have if the signal is order signal to noise ratio of if of is of this order you will get a good sound.

So, for sentences higher is the intelligibility than single syllable sound under the same signal to noise ratio. What is find here again I repeat if you see the blue line it is at a lower level they are considering the intelligibility. Whereas, the sentences are having a higher intelligibility even if the signal to noise ratio is low.

But almost at the upper part we are having similar kind. So, the curves are almost moving together what you see at minus 6 when the signal to noise ratio is you see a word, or a syllable is very less heard whereas, a sentence is quite well intelligible. So, you find that sentences are having higher intelligibility even if the signal to noise ratio is negative.

So, we will come to that ratio and for background noise levels in small classrooms and lecture rooms the designs are to be carried out following NC curve number 30, NC 25 which Professor Bhattacharya has already explained I believe. And this is again I state that Bradley holds a that 10 to 15 dB margin is the reasonable choice for intelligibility which I had already shown that is on the upper part, where you see the red line and the blue line are almost close.

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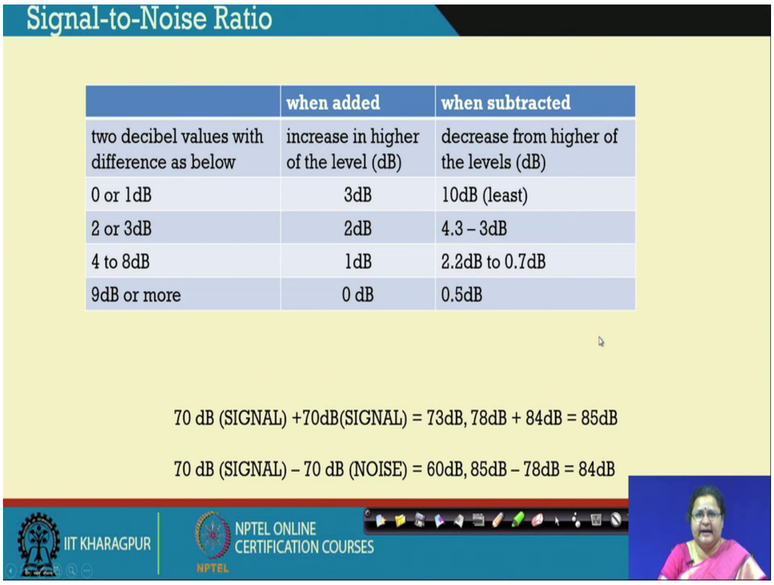

So now, I was talking of signal to noise ratio and so much of dB, so much of dB, but how to calculate it out that has also been thought by Professor Bhattacharya. But I give you a chart here which will help you in a quicker understanding. So, every time you are doing a logarithmic subtraction, or a logarithmic addition.

So, if you follow keep this table in mind like if two decibel values with differ with differences which are mentioned in the rows below are added the logarithmic addition the second column, the second column is the where you see the increase in the higher of the levels is by 3 dB.

So, if you have two decibels, two sound sources with almost producing same sound say of 70 decibel then the overall sound level in the spaces increased by only 3 dB. So, it will be 70 will be increased by 3 dB, that will be 73 dB. If two sound sources of 70 dB are working. But we are not concerned with this part because we are going to calculate the difference this has been already explained and discussed.

So, I have given this chart comprehensively so that you can have even add and as well as subtract. But when you are subtracting what is happening? The decrease from the higher of the levels in dB, so what are you doing? The signal is the plus noise has to be subtracted from it.

So, whatever is the desired is the signal so if that is of say 70 and you have to subtract something which is very close to it say it is also 70. Then what will happen the over overall signal will reduce by 70 dB. So, you will get 60 dB of signal sound receiving the audience, in spite of the noise which is produced at the 70 dB.

So, let us see what happens? So, the first row shows that divisions that 70 dB signals plus again 70 dB another signal. So, the strength of the total signal is 73 dB, similarly you can work out 78 dB plus 84 dB that is see the difference in these two is 78 to 84 is 6 dB. So, you go here between 4 to 8 dB where the increase is by 1 dB, so of the higher value.

So, it is the 84 dB that is the maximum sound is increased by overall sound level in the room will be 85 dB. Now, coming to the subtraction if you have a 70 dB signal, with a 70 dB noise, so you are subtracting you are ears are only taking the signal. But what is the strength of that signal? It is 60 dB, because if you go to the first there is 0 or 1 dB is the difference that is 70 minus 70 is 0.

So, you will get a reduction of the signal by 10 dB. So, the signal here is 70 dB the reduction is 60 dB, reduction is by 10 dB, and the effective sound is 60 dB, say the signal is at 85 dB, and the noise is at 78 dB. So, the difference between these two is 7 dB. So, we go to the third that is the fourth row here. So, 4 to 8 dB if you have, and the difference is between 2.2 to 0.7, if you go to go to detail calculations it will get 1 dB.

So, what will have happened? So, 85 dB sound will be sounding as 84 dB. So, what you see that gradually when the gap is increasing that is when you come to 9 dB or more you see when the difference between signal and the noise which is our concerned is 9 dB, or more. See what is happening? The subtracted value from the signal is only by 0.5 dB merely very low almost 0.

So, if you have a signal higher than that the noise by around 10, 9, 10, 15 dB you come out with that that there will be really not much loss in the source. So, the source sound signal which is not only source I am making the mistake it is the reflected sound plus the source sound together which is 85 dB around.

And if the this is 75 dB then practically it will remain as 70 85 degree itself. So, that is why the Bradley's thing which has been discussed in this particular graph stands holds good at this particular area at where the signal to noise ratio is increasing the intelligibility. So, now with this understanding we find that when we are going in to design for a room for speech?

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The fundamental requirement in designing such room for speech which has been told by Doelle, in 1972 is there must be adequate loudness that is if we are talking of un reinforce sound. If we are talking of the source sound if the direct level should be high, so there must be adequate loudness.

So, you have to speak such that the sound can move and the sound level must be uniform within the room. So, that it does not create any jerk in the receiver part receiving part. The reverberation characteristics of the room must be appropriate. So, depending on the use of the room I had given you the charts where you could see that if it is a dead room, medium dead room, or a medium live room up to a live room how the reverberation time changes.

So, with respect to the volume which you can calculate from the length into breadth in to height of that particular space, you can actually find out the reverberation you can select a reverberation time it may be approximate. But to start your design you need a reverberation time which is of your desire. So, you start because you have a range and you can keep on varying.

So, then there must be high signal to noise ratio which you have learnt in the previous slides that if you have a high signal to noise ratio; that means, the difference value is not making effect towards the sound, towards the signal. And the background noise let us see this could be received by background noise levels must be low, and it should not interfere with the listening environment.

Some sound which we are acquainted with like a fan moving in a classroom or in a regular room where people stay people live we know these are the noise levels and which people are acquainted with and the brain does not consider those sound, they can make out what the signal is coming.

Then the room must be free from acoustical defects which I have already told we mostly come across the regular rectangular shapes. And if we come across such shapes you have to remember the standing waves the phenomena of room modes which we have discussed in the previous to previous module. So, we have to take care of small rooms standing waves is very much important.

If we have very big spaces then we have to think of very long delayed reflections that might cause flutter echoes, that might cause echoes and focusing etcetera. And we have to keep take keep in mind the component of resonance that is the standing wave formation how to trap it those were discussed and learnt while we were doing acoustical absorbers.

We have to also keep in mind two phenomena like beyond 30 to 40 feet it is difficult to understand unreinforced sound, and the optimum volume per seat is expected to be 120, 110 cubic feet which is 3.1 cubic meter whereas, the range is mentioned that it should be between 8 to 150 cubic feet. So, something in between which is 110 cubic feet is appropriate or the optimum volume per seat that is the thumb rule for calculation.

So, when you are starting your design if you can keep all these points in to mind and also the concept that v is involved in the RT. So, for particularly rooms for speech where RT is very important that is on a lower side we have to remember that lesser is the volume better is the sound intelligible.

So, better is the intelligibility when the volume is low because you can achieve a lower RT, with lesser amount of absorbing surfaces and if you have enough of loudness inside the space the signal is going higher. Because you will have some small components of noise always in the space or always while designing you cannot get dead rooms.

So, you have to account for that apart from the delayed reflection that is the reverberation time reverberation time. So, you have to account for all these things while starting the design also have helped you with the graph where you can find out that length is to breadth is to height ratios from which you can initially start your design.

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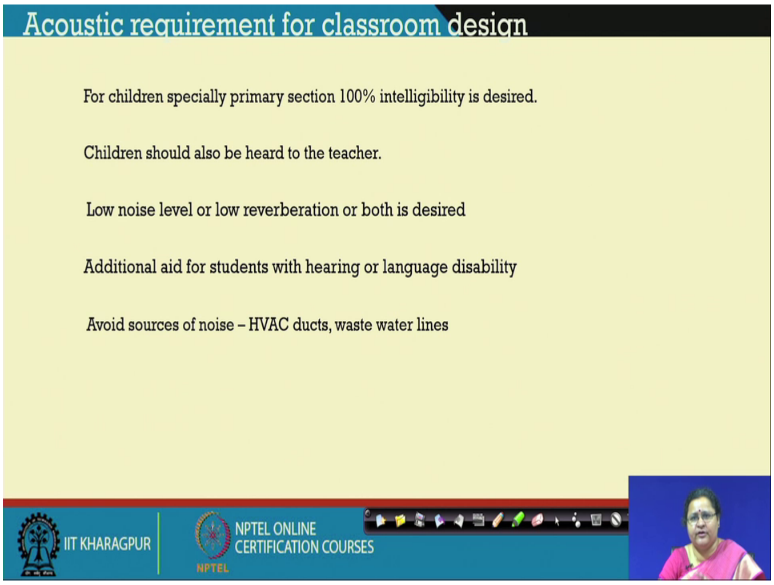

Now, let us come particularly to classrooms now as I have told you our brain can actually segregate, or find out even if it is a big noise coming in. We consider that this part is to be absorbed which we will consider and rest we do not ignore. So, that is how we human beings are taking into the sound. So, we have our brain can discriminate which is signal which is noise, so we are not concentrating on the noise part.

But think of children if a small portion is told to you in the context an adult can understand whether it is what the word is supposed to be. But in the context of children they do not have any perception. So, they are they should be given the entire word entire syllable. So, each and every syllable forms the word.

So, when a child is learning his brain does not know what could be the rest part which we as adults can make out what is the context this would be the word, but a child does not he is developing that skill. So, in case of classrooms we have to be very particular on the point of intelligibility. So, every syllable has to be sent to the child.

So, in that case we have to be very careful that the sound is to be almost 100 percent intelligible if is that is our desire, but even 80 percent does holds good. And the children who are talked who are at the receiving end should also be heard to the teacher. So, that there should be a good communication between the teacher and the and the child, or the or each and every individual children were sitting scattered in the classroom.

So, that that is the primary part and low noise level or; obviously, low reverberation time if not both are desired in case of classroom designs particularly for the primary children. Additional aids for students who have hearing problems or language disabilities they should be aided with otherwise the purpose of the classroom gets lost.

And source noises like even the fans the HVAC ducts, the waste water lines that is the rain water ducts which we which are integral part of the design we have to keep in mind the services those kind of sounds should be avoided. So, you are not supposed to keep such architectural elements which are which are integral part of design.

But one should plan for that that waste was that is the rain water down comers from the roof or some outlet pipes from the toilets which is just next to the next to the which is having a adjacent wall to the classroom such kind of things should be avoided.

So, while designing you must start your design keeping in mind that it should be in a noise free classroom should be in a noise free zone. And all these service related noise which can come should be planned in such a way that they are farthest from the classrooms or the set of classrooms.

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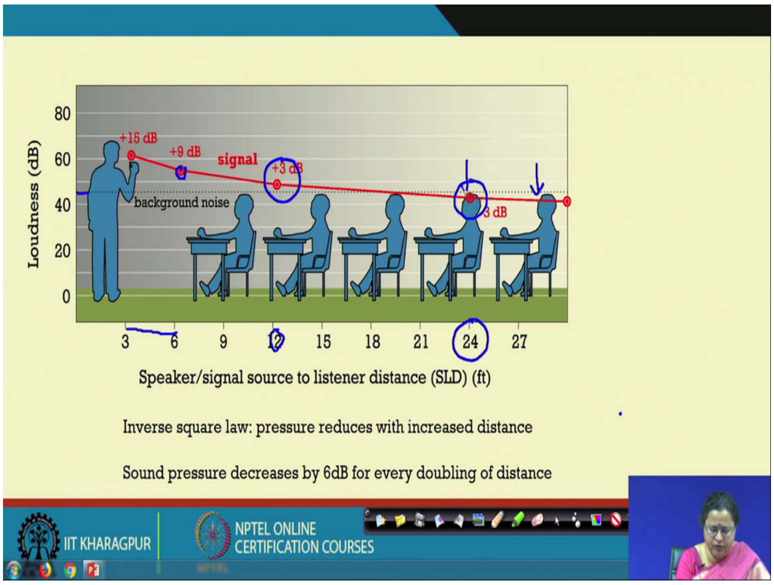

So, let us now see in this picture which through our understanding which we had earlier it was told by Professor Bhattacharya, the inverse square law you know that the sound pressure will reduce with increased distance. And also for every doubling of the distance the sound pressure decreases by 6 dB.

So, see here the background noise has been set at some 40, 45 where you see the background noise level. So, that is a continuous noise which is the reverberant sound, and the backgrounds noise which is there and see at the instructor who has given started something from around 60 dB.

So, there is a big gap, so expected that the signal to noise ratio is satisfied. What happens from one there is a movement from 3 feet to 6 feet, what you find 15 dB drops to 9 dB. So, you get 9 dB sound reduction here that is only for the source sound, then when I when you have moved to say 12 feet distance the source sound has gone down from 9 dB, to 3 dB. And when you are at most at 24 distance; you see the source sound has gone down by another 6 dB that is it has gone down to minus 3 dB.

So, again after from here another 48 which is not within our zone because you would cannot hear it at all that was what which was told. But then how come is this person this child ear is listening, how for how come is this child listening. They are all getting the reflected sound.

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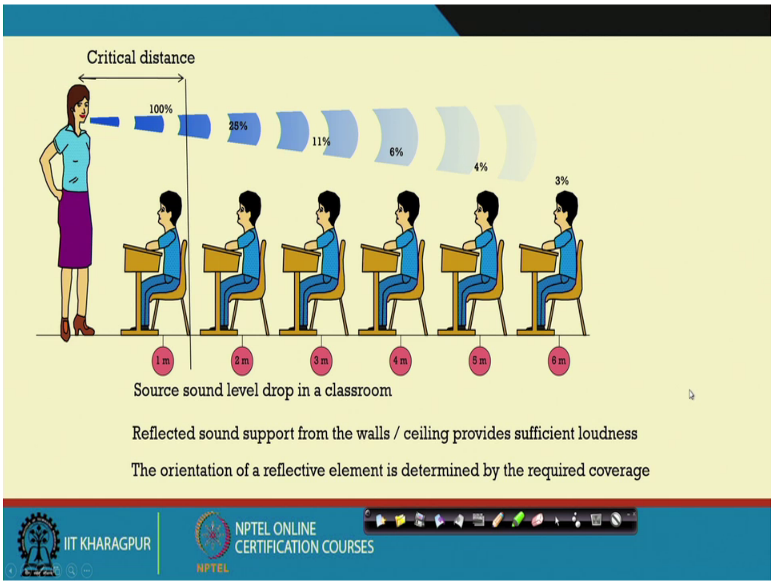

So if we go to the next slide what we see that the sound pressure is gradually going down is decaying, and after almost at the end not much sound of the original sound of the list of the speaker, who is the teacher in this case is not reaching. It is only the mostly the reflected sound which is reaching.

And you see after a there is a marking of a critical distance which is mentioned over here, which is a function of many things which will which am coming in the next slide which actually after which actually the source sound and the reflected sound are matching. So, they are equal when this critical distance beyond this critical distance it is only the reflected sound and the source sound pressure gradually decays drastically.

So, the reflected sounds support from the walls or from the ceilings should be sufficiently loud, so that the last person here can actually get the sound. So, if you keep absorbers here and there and every sound is getting absorbed then you cannot your sound cannot reach this person.

So, we have to be very careful while we are designing a classrooms. So, apart from this I missed out the orientation of the reflecting element is also determined how much of coverage you actually desire. So, let we will see this.

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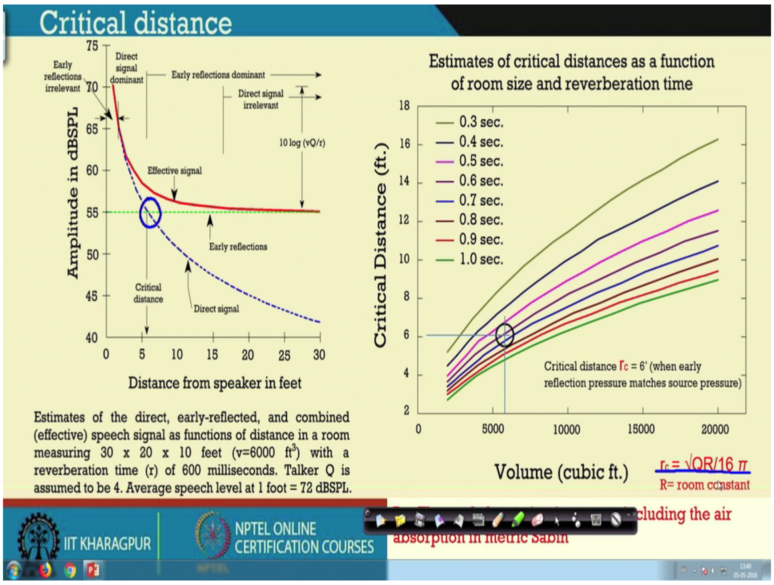

So, now here we see how to find out this critical distance? Here also I will equip as architects with this tool you see this graph. Here you see that with different reverberation time with the set of reverberation times a number of curves have been drawn for different volumes which is in cubic feet. So, you see 5000, 10000, 15000, 20000 and say if we consider classrooms our desired RT will be 0.4 to 0.6, 0.8 which we had already discussed earlier. So, here you see it is 0.6.

So, what happens? Here this is the curve which you are going to follow and you see here the critical distance is 6 feet. If you had targeted for 0.4 then your critical distance would be little higher. So, with increase in reverberation time your critical distance is moving taking a back seat; with increase in reverberation time the critical distance is falling.

So, the reverberation time actually determines the critical distance. So, if you see this curve here you see that the critical distance where it matches the early reflective sound is the point which is the critical distance. And the effective signal that is the summation of this two is the red line, and after a certain distance we see that it is gradually moving to the towards 30, it is only the early reflection which is reaching.

So, with a volume 6000 feet cubic feet that is room measuring 30 cross, 20 cross 10 feet height. And with a reverberation time of 600 milliseconds we find that it is coming to and Q as Q as 4 we get this. So, we have the equation over here that is the critical distance which is the function of the Q that was the impression which we have started with. Then the r which is the total amount of absorption within the room big R under root which is divided by 16 pi which is called the r c or the calculation for the critical distance. So, R here is the room constant, which is actually which is actually the reverberation time of the room including the air absorption in metric Sabine that is called the room constant. And here we find what the critical distance concept is?

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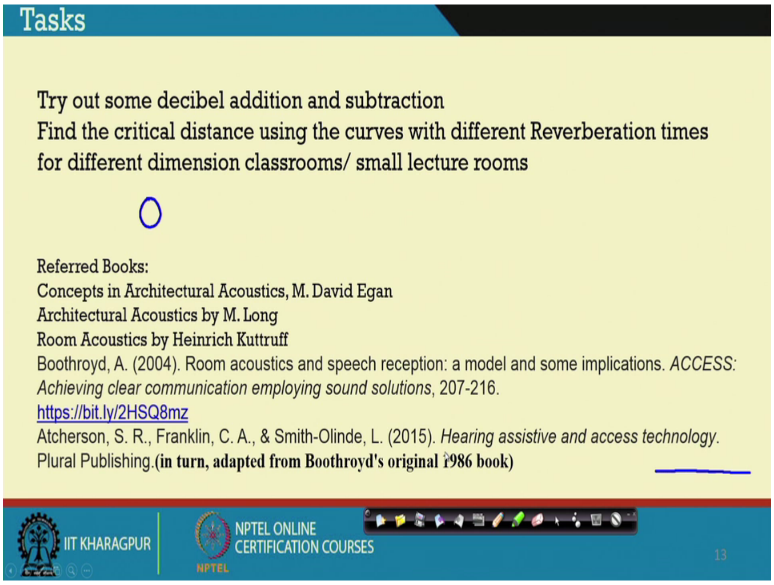

Now, with this we will carry on with the next lecture and I give you some tasks like try out some decibel addition and subtraction. Because what you found in the previous slide that you can actually add the reflect, the reflected sound or the early reflection with the source sound in that case you will need some decibel additions to cut off the find out the signal to noise ratio that is what is the signal to noise ratio.

You can do some subs you will need the subtraction of the decibels, find the critical distance using the curves with different RT that is reverberation times; for different dimensions of classrooms that is different dimensions of classrooms that this classroom for say 30 students. You I have given you the basic values what should be the volume consideration.

So, in that case you have the volume with you, the range of volume with you, the classroom capacity, if you know what will be the volume? What is the desired size? If you totally consider all the graphs you will get a good understanding what should be the proportions of the classrooms.

We will continue with the classrooms details in the next lecture and by for this time I close this lecture.