Architectural Acoustics
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Lecture – 21
Introduction to Auditorium Design

Welcome everyone. We are exactly at the middle of the course. So, today we will start with lecture 21 that is module 5 and this module is entirely dedicated to Auditorium Design. And it will be a kind of 5 lectures, we will try to give you a comprehensive overview of how to design and account for the acoustics while we are taking up auditorium as our design.

So, till the last module, you had been exposed to the Acoustical criteria for different space designs up to large size lecture halls where the capacity was up to 300. Now beyond that, it is a big facility which has to be reinforced with proper acoustics, otherwise the purpose of the space might get lost.

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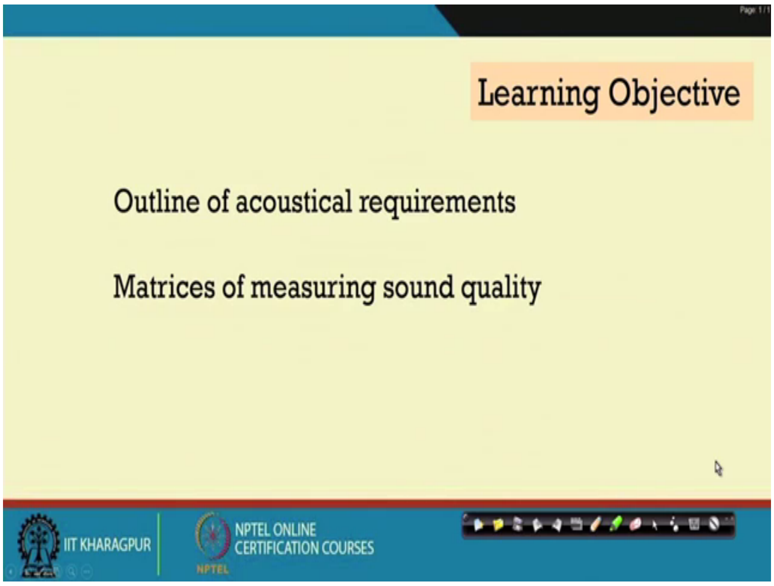

So, we will first try to look into the outline of the acoustical requirements of a particular auditorium, when we are talking off. And the matrices of measuring the sound quality because here, the purpose of the people or the audience is not just exchange of dialogues or whatever we had; not only speech, but maybe musical performances, theatrical performances and many other such performances which demand proper sound quality.

People up must be coming here or the audience must be coming here paying much of money to get an entry ticket to the facility. So, we have to be very much careful to give them the maximum or the best quality that is possible in that particular environment. We as architects need to look into each aspect like starting from the shape size form as well as the acoustical treatments inside, the seating design because all these separately has been touched upon in the previous lectures. And you will see, it is rather the similar application of the principles, but in a different form.

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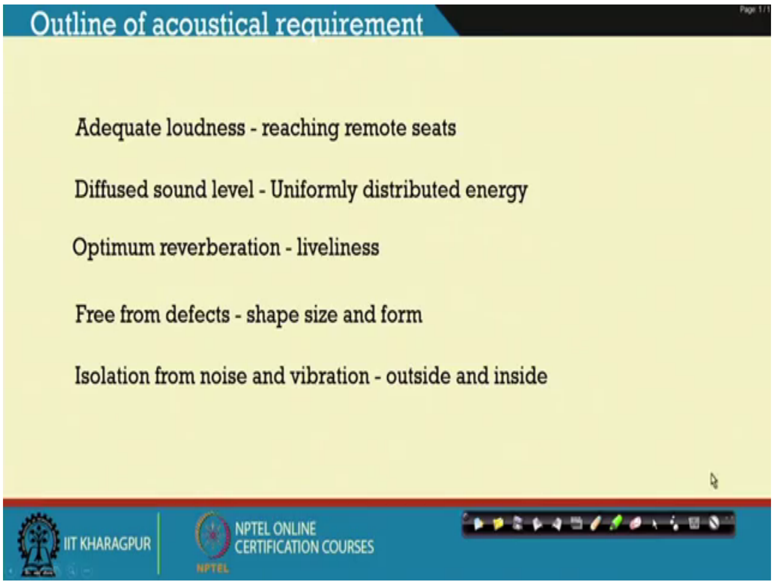

Now, coming to the acoustical requirements, we first need adequate loudness. Now, it is no more a small space and only a source sound, without any reinforcement or without any electoral acoustics cannot be reached till the end of the hall if you think of with; think that the sound source is not enough loud. So, reaching the remote seats is the first requirement so that the auditorium is a success at any seat or any point within the setting area.

We need diffused sound level; that means, sound should not be specular, that is directly reflected sound should not reach individuals so that it does not disturb individuals neither create sound shadow zones or dead spots within the space. So, we have to be very careful and it is best to target for diffuse sound or which will give an uniformly distributed energy level within the entire space.

Coming to the optimum reverberation time: we have already categorized that such auditoriums are life spaces. When it is music it is obviously, its liveliness should be higher that is RT should be higher. Now, we have a big volume over here and we have the absorptive surfaces, the reflective surfaces, the way you will design or you will plan your of your reflective surfaces, your diffusive surfaces and your absorptive surfaces; you will get the different types of reverberation time and different type of sound quality within the space. So, liveliness or achieving the optimum reverberation time which is desired which has been earlier given in the lists in the graphs, you can refer to and start from that point.

It should be free from defects. As has been told earlier flatter echoes, echoes because this is a large space, the dimensions will be of that order which might got might cause reflections multiple times and lead to echoes which was not a problem when we were considering spaces such as rooms or classrooms where echo was not really a concern. Rather room modes were concern over there; and obviously, never to repeat again to repeat like isolation from the noise and vibration from outside as well as within the system. So, when you are within the system, different noises or vibrations can happen which should be eliminated and obviously, external sound should be cut it.

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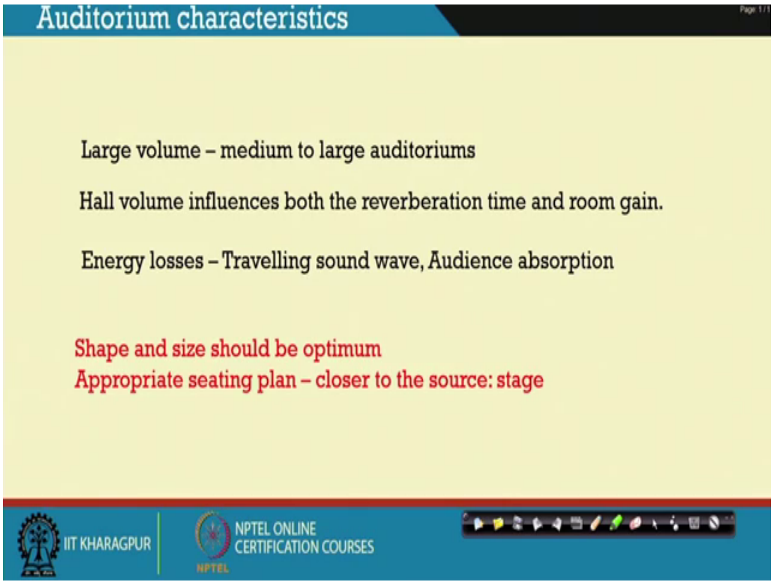

Now, when we talk of auditorium, we can always think of a large volume. For the medium to large auditoriums, it is really a large volume; whenever we think of an auditorium architects as architects would be architects, you all can scale or think that it is of a big order.

So, hall volume inflow influences both the reverberation time and the room gain. Now, what is room gain? If the sound source would have been outside that is in a open space, the sound would have moved around and the sound pressure level would have changed with time and say it is measured at a certain distance. The same sound when it is within that envelope that is within that auditorium, if it is measured at any point within that space, the sound pressure level because of that envelopment, that is because of that covering, it will gain in its level and that is called room gain.

So, we will also look into that later, but so, hall volume influences both the reverberation time as well as the room gain and energy losses due to the traveling of the sound wave within the system is also to be accounted for. So, auditorium is characterized by its large volume, its reverberation time, its room gain and the losses of energy because of the traveling of the sound wave multiple times on the multiple surfaces which are not very near which are quite apart are characteristics of an auditorium.

Further, is the audience size say- 500, 700, 1200, 2200, 2700; we have auditoriums of such scale. So, audience as a absorptive member should always be accounted for. So, shape and size should be such or should be so optimum that it fits in the audience closest to the source so that minimum energy loss happens and this room gain factor is also maximized. So, the objective is to bring the people closer to the source of sound which is the stage and that again reminds us of the Romans, Greeks who had stripes ratted of concentric circles and which was developed through human need.

People started sitting like that to get the maximum of the sound when it was open air designs. We had covered this in the initial or the first lecture.

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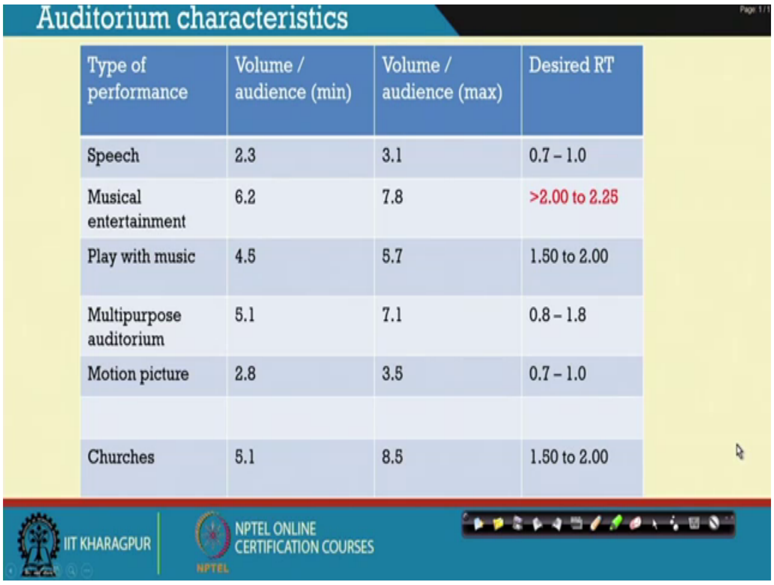

So, coming to the other characteristic which is the desired reverberation time and the volume per audience, we have a list here. For Speech you see the volume per audience is quite low as well as the desired reverberation time which is denoted by RT here is also quite low compared to other performances say Musical entertainment, Play with music, Multipurpose auditorium, Motion pictures.

I have also put churches as a reference so that you can think of the first introductory lecture which had so many religious chants, and the reverberation time was also quite long and as well as the volume per audience was also very big. So, we can see volume up to 8.5 cubic meter per person here; sorry, the volume unit is in cubic meters and time that is RT is in seconds. So, this chart will help you in getting the starting point that is per person volume for calculations per say.

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Now, coming to the Measuring of the sound quality; the matrix R, Loudness, Spatial Impression, Intimacy, Early Decay Time, Clarity, Warmth and Brilliance. Now, we talk of loudness in case of auditoriums as I told initially that loudness within the space, because it is a huge space. So, the energy that is the strength of the sound energy is very much important. So, we have to look into them one by one.

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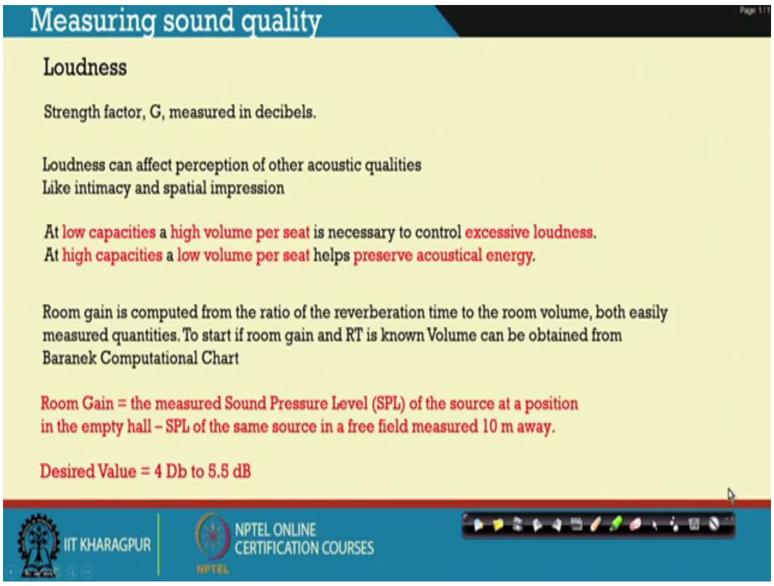

Strength factor which is also called the room gain or G is measured in decibels and loudness can affect the perception of other acoustical qualities.

So, if you do not have proper loudness, your feeling of intimacy or having a special impression will not be felt. So, that is the very first point that is having enough of strength in the source sound is very much important. So, a low capacity auditorium will demand high volume per seat and that will be necessary to control the excessive loudness. Say the sources sound is very high and the volume is small, then the sound that will create excessive loudness.

So, you need high volume per person in small capacities; whereas, in high capacities, you need low volume per seat to preserve the acoustical energy. So, when it is high capacity, it is a challenging design. Within low volume you have to accommodate your people. Room gain is computed from the ratio of the reverberation time and the room volume both easily measured quantities. And the Baranek computational chart has been provided in the next slide which is adapted from Baranek's graph, and it has been given you as a helpful measure to start with the initial volume if you can have a targeted gain that is the room gain.

So, room gain is the measured sound pressure level as I have told of the source at a position in an empty hall minus the sound pressure level of the same source in a free field condition measured 10 meters away. So, room gain is the difference in the sound pressure levels. And hence, it is in decibels and the desired value is between 4 to 5.5 decibels. So, if we see the graph in the next slide.

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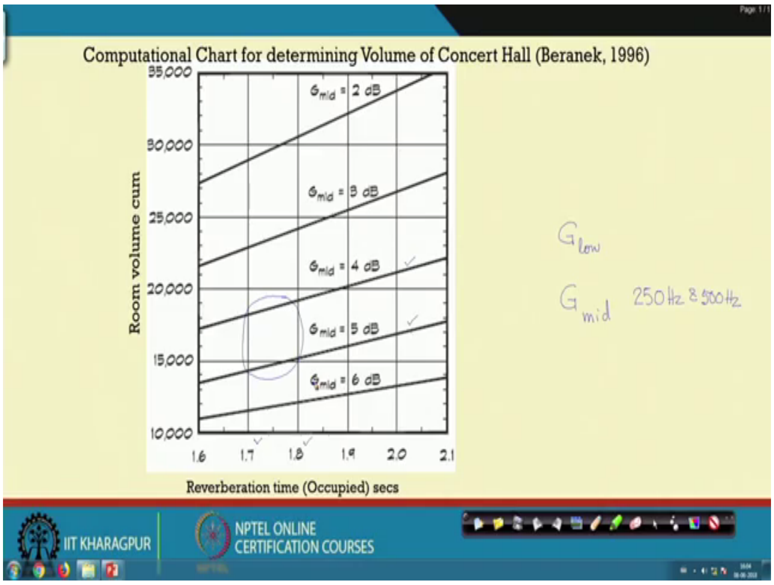

You see that here on the x axis you have the reverberation time which you are targeting for the occupied seats and on the y direction you have the room volume in cubic meters.

And there are certain lines which you can see here are for different gains that is room gains and in see in the G in the G, you see it is written mid; we have G low also, but we go by the G mid that is room gain at 250 hertz and 500 hertz. So, if you know the targeted g mid value say 4, 4.5, 5 you have to follow this line or this line or any point in between and if you have a targeted RT of any of these. So, your volume should be around here.

So, you can choose your volume starting volume, initial volume so that you can end up to a better design by better auditorium design following all other principles that have been told earlier.

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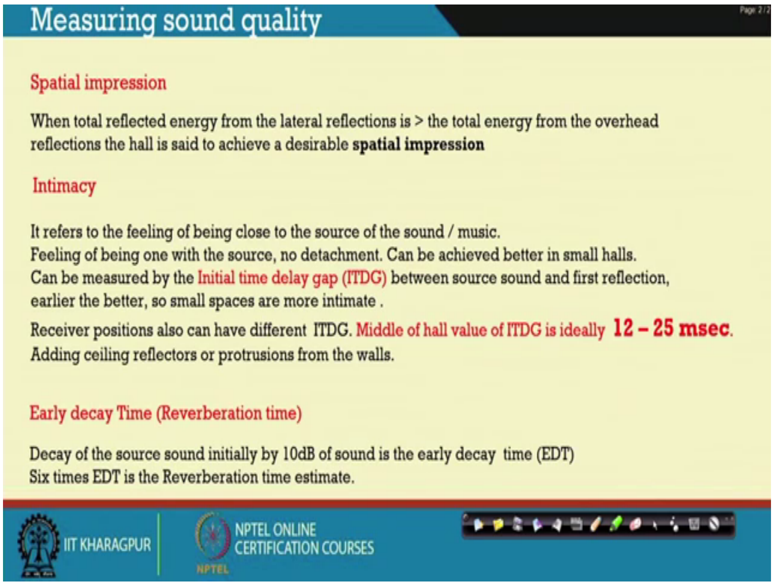

Now, coming to the next phenomena that is spatial impression if you look into the previous lectures, I think lecture 11 has Spatial impression, we had the term impression. Here, it is spatial impression: impression as q that was measured. Here, also we see spatial impression. When the total reflected sound from the lateral reflection that is from the walls, the energy which is coming from the sidewalls from the early reflections. If the energy is more than that what is coming from the ceiling, then we say the hall is having a special impression.

So, to achieve a desirable spatial impression, you have to have more lateral reflections rather than more ceiling reflections. Coming to intimacy; we know intimacy word means closeness. So, it refers to the feeling of being close to the source of the sound which here we are accounting music. So, feeling of being one with the source that is not being detached is the concept of intimacy and how to measure it? That means the initial time delay gap that is the first source sound and the first reflected sound the minimum gap is the better is the intimacy.

So, in the front position, it is believed that you will always get direct sound and reflected sound close to it; at the back seat the direct sound will reach you reach at the back along with it the reflected sound will reach. So, the if the time gap between the direct sound and the reflected sound first reflection is very close, then it says the hall is intimate where wherever you are sitting in the hall.

So, even if you are sitting at a far off point if the initial time delay gap is within 12 to 25 milliseconds, this can be calculated through geometrical acoustics. You can create ray diagrams and find out at what time the sound is reaching delayed at the last point the first reflected sound reaching at the last point. And the distance from the source and its time that will give you help you in calculating the intimacy.

So, these boundary conditions are first to be determined to achieve a good sound quality within an auditorium. So, the receiver position can also have different initial time delay gap, but the middle of the hall value is suggested to be 15 to 25 milliseconds. You can add ceiling reflectors to minimize the distance or reduce the distance to achieve a better intimacy because the walls or the side walls are fixed.

But some overhanging items from the ceiling which will act as reflector can help in reducing this ITDG that is Initial Time Delay Gap. So, mind that you will see various things hang from the top within an auditorium which you will be capable of doing after the few lectures. You will be confident why those are there. And hopefully by calculating with the speed of sound and calculating with this millisecond difference, you can also achieve similar quality similar mathematical values so that you can get you can achieve a better hall.

Early decay time, this also indicates a portion of the reverberation time. Early decay time is the first 10 decibels sound decay is called the Early decay time, and the Later decay takes around 5 times that is total it is 6 times the early decay time which is called the Reverberation time which forms actually the reverberation time. So, this also should be measured that the decay of the source sound initially by 10 dB is called the Early decay time and it is it should be less or optimum. So, that the Reverberation time which is 6 times of that is actually achieved.

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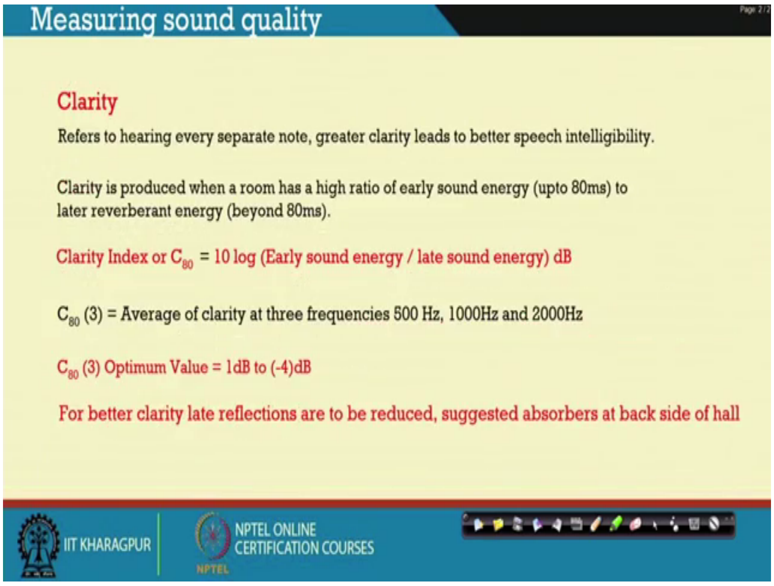

Next is Clarity; we had covered this while we discussed speech intelligibility. So here, how it is different? In speech intelligibility the time was less, in speech we wanted sound to decay or get cut the early sound energy to be bigger or the early sound energy, and the late sound energy division that is time line was different; in case of clarity it is different. In case of clarity, we have that time as 80 milliseconds; whereas, in case of speech intelligibility we had that time within 50 milliseconds even 116th of a second was also told by some researcher some scientists.

So, clarity refers to the hearing every separate note and greater. Clarity leads to better speech intelligibility clarity is produced when a room has high ratio of early sound reflection to later sound reflection that is later reverberant energy which is beyond 80 millisecond. So, clarity index or C 80 is 10 log early sound energy by late sound energy in decibel. And again, here you can calculate; you see here C 80 3 that is the frequency average at 500 Hertz, 1000 Hertz and 2000 Hertz.

So, average clarity of these three frequencies give you the C 80 3 and the optimum value is 1 decibel to minus 4 decibel. The minus sign is because it is a reference scale is a compare it you are referring from 0. For better clarity late reflections are to be reduced; suggested absorbers suggested absorbers at the backside of the hall. So, you are trying to cut down the late sound reflections or the late sound energy; that means, you have to cut short or you have to absorb those energy.

So, you have to see within 80 milliseconds you are trying to reflect the sound within the system; reflect or diffuse within the system. But beyond 80 milliseconds, you are targeting to decay the sound. So, that so that you can get a higher value of clarity. So, to get a higher value of clarity, you are encouraging the early sound energy and not encouraging the late sound energy. So, you need to put absorbers beyond sounds reach after eighty milliseconds.

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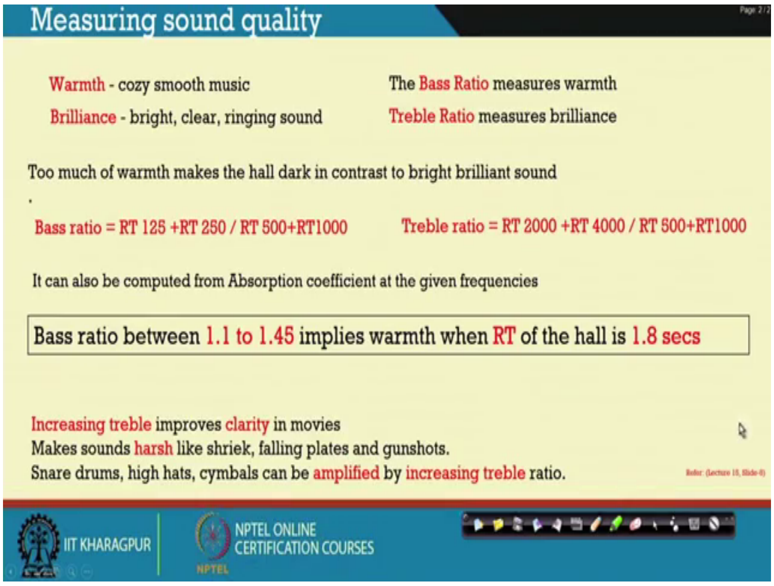

Next is Warmth; how cozy is your hall; how smooth is your music? The opposite to it is Brilliance. Now, Brilliance is how bright; how clear; how ringing sound it is making within the system or within the environment? Warmth is measured by the Bass ratio. Brilliance happens when we have a high Treble ratio. So, we have the feeling of warmth, when the Bass ratio is higher. Now let us see what is Bass ratio? Too much of warmth may actually fill the hall dark; in contrast too much of brilliance can bring brightness to the hall. But both are not desired to a very great extent, because you do not want a dark and dull hall neither a bright and brilliant hall.

So, we actually need a balance between the Bass ratio and the Treble ratio. If you see Bass ratio is defined as we all know RT is reverberation time. So, reverberation time at the bass frequency that is the low frequency that is RT at 125, RT at 250 summing it up and when divided by reverberation time at 500 hertz and 1000 hertz gives you the Bass ratio.

Similarly, if you calculate the Treble ratio you will see reverberation time at 2000 hertz and reverberation time at 4000 hertz divided by the mid band that is the 500 RT reverberation time at 500 hertz and reverberation time at 1000 hertz is the Treble ratio. And it can be computed from the absorption coefficients also at the given frequencies. So, it is it may not be always RT may not be available to you; you can get the absorbers absorption coefficients at the given frequencies and you can you can actually calculate the Bass ratio or the Treble ratio.

So, bass ratio between 1.1 to 1.45 implies the warmth when the original RT that is RT for 500 and RT for 1000 is 1.6 seconds. So, your desired bass ratio will be the RT of 125 and RT 250 will be 1.1 times 1.8 seconds. So, if you have these things in mind, then it will be easier for you to select the absorbing materials. We will see that. Now, increasing the treble improves clarity in case of movies, pictures. It makes the sound harsh like shriek, falling plates, gunshots; those becomes very harsh. Share Snare drums, high hats, cymbals can be amplified by increasing the treble ratio.

So, whatever is the purpose to bring in warmth in a system you have to increase the bass ratio and that does not mean to any extent, but between 1.1 1.45 times the RT at 500 plus RT at 1000. So, you can achieve a warmth within your space. You can refer to lecture 15 slide 8 to get some information on the reverberation time and the values.

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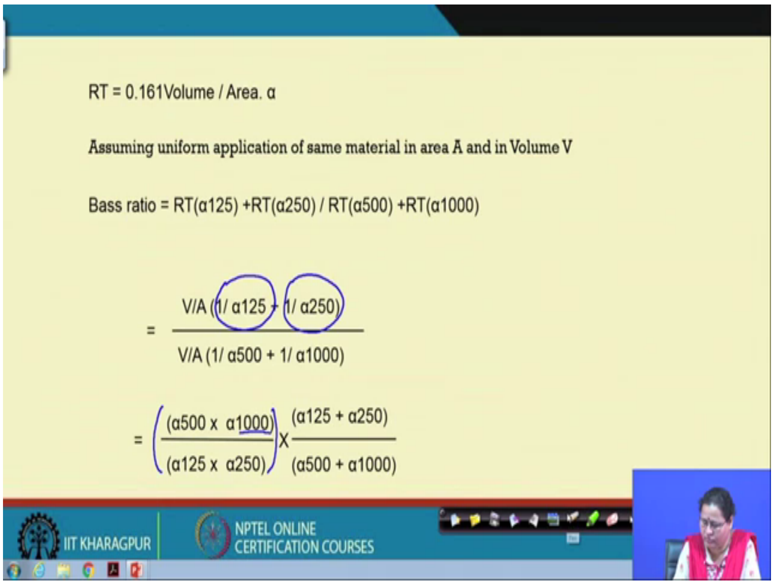

As we all know that reverberation time the formula is 0.161 V by the entire absorption. We can actually represent bass ratio which is in terms of reverberation time of alpha 125 RT of alpha 250 divided by alpha 500 and RT against alpha 1000, we can convert that as we all get the charts of the alpha values at different frequencies. We can actually make an estimate of the bass ratio while selecting materials or absorbing materials which will help in achieving warmth in the hall.

So, here you can see that V by A into 1 by the alpha values are here in all the cases which when simplified, you can get the bass ratio in terms of alpha 125 plus the absorption coefficient in frequency 125 plus the absorption coefficient in frequency 250 divided by alpha 500 and plus alpha at 1000 hertz. And it is multiplied with this factor which is the reciprocal of the product of the 2 alpha values.

So, you see it is multiplied by alpha 500 or the absorption coefficient at frequency 500 into alpha 1000 that is absorption coefficient at of frequency 1000 divided by alpha 125 and alpha 250.

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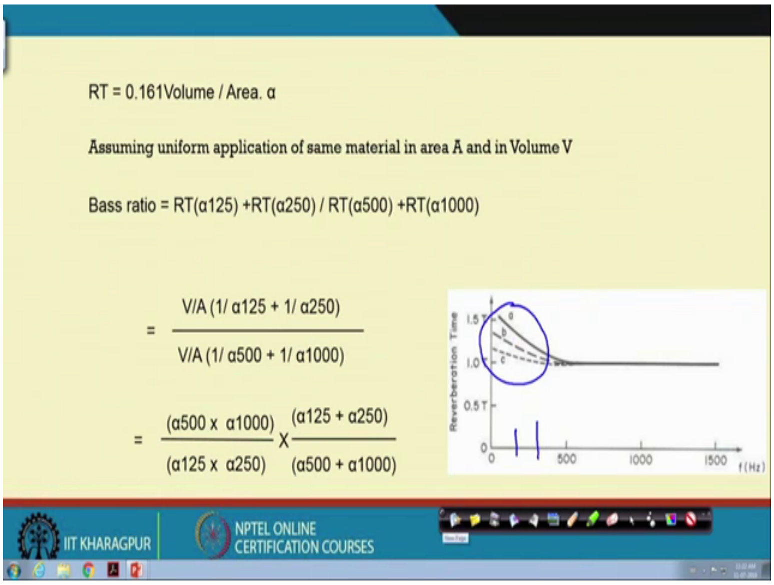

So, if we now go to the graph, where RT which is here what you see is the reverberation time which has been calculated as per the NRC and we are desiring 1.1 or one point up to 1.45 as warmth. So, that the bass ratio is such that we can get a feeling of warmth or during musical performances.

So, we are desiring a higher T value that is 1.5 up to 1.5T when the frequency is at 125 or at 250. So, here you see we desire a higher alpha value over here. So, a low a higher alpha value over here so that we can actually get higher reverberation time in this particular zone, but it should be within the range.

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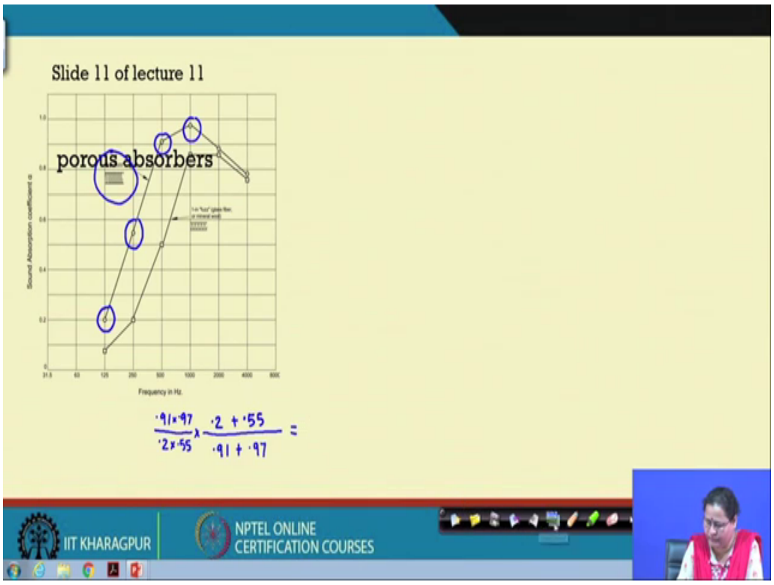

So, let us try to see what was happening in this particular porous absorber which has been taken from slide 11 of lecture 11.

Here, if you see the alpha value corresponding to 125 hertz is 0.2. If you see the alpha value for 250 hertz, it is around 0.55. This is for the 2 inch fuzz that is the porous absorber of glass fiber. If you see at 500 the alpha value that is the absorption coefficient is around 0.91, and then here you get at 1000, it is around 0.97. So, if you add this, and then multiply with the product of their reciprocal, you can get an estimated bass ratio and you will find that this value will be something around 3.2.

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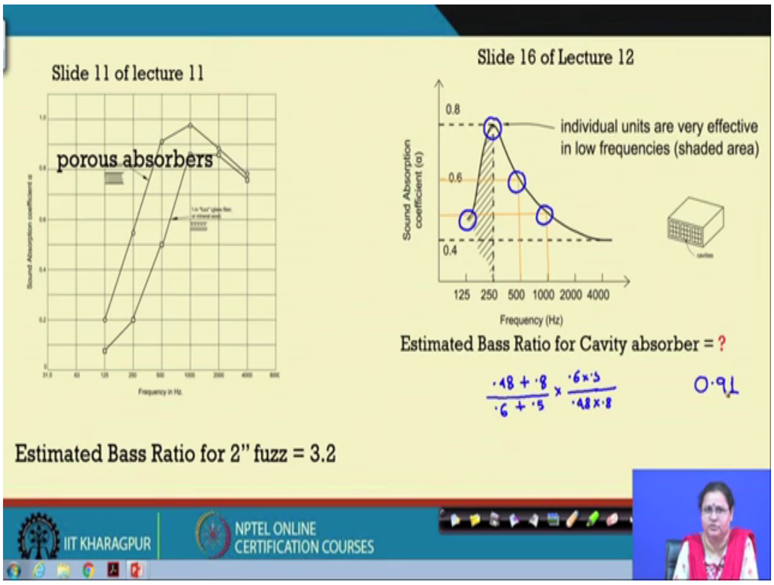

So, as we saw in the previous graph, this is also not desirable. So, we have to keep our value within 1.5, 1.45 when the RT against the NRC was 1.8 that was recommended.

We see another item that is slide 16 of lecture 12. It was an example of cavity absorber; how the absorption is taking place. Here, again if you see you will see that at 125 hertz frequency the value is around 0.48; at 250 hertz which was the purpose of this particular cavity absorber to trapping sound of 250 hertz frequency, you see you get around 0.8. Then, at 500 you come to some value of 0.6 and then, down at 1000 hertz, you will get another value say around 0.5.

These are estimated values you can get correct values from the chart and then, you again multiply it with 0.6 into 0.5 and then, divided by 0.48 into 0.8 that is that will give you an estimated bass ratio of this particular absorber. So, this will come around lesser than 1 and you will find if you calculate it out, you will find it will be something around 0.91. So, even from these graphs, you could have estimated whether it will be a better bass absorb whether it will whether the item will have better bass ratio higher bass ratio or a lower bass ratio, just by seeing the graph you can find it out.

So, with these words I say if you cover your entire auditorium with porous absorbers, you will end up in having higher bass or the lower frequency sound will create a disturbance or annoyance and you will not achieve that quality. Similarly, if you leave the hall with entirely covered with cavity absorbers, you will also end up in problem. So, only the maximum will be maximum 250 hertz frequency will be getting absorbed. So, you can think of mixing two or more absorbers and try to that is it is kind of iteration how you can reach that: yes, there are softwares to work for you, you can select your items, you have to think of the visual aspects and then, you can make a choice.

But, above all you have to remember that your objective is one to achieve warmth and keep your bass ratio within that particular value.

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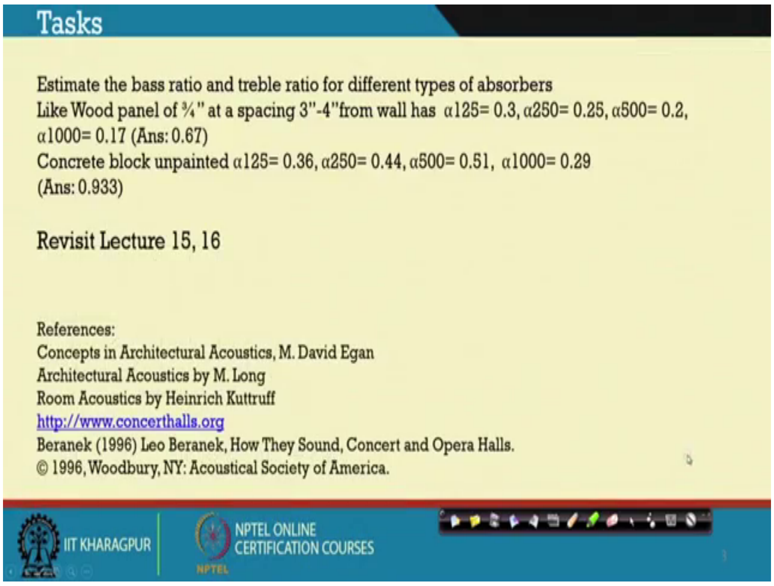

So, I leave you with small tasks of calculating out the bass ratio and as well as the treble ratio for the different types of absorbers. The bass ratios the answers are already given. You can revisit the previous lectures that is even lecture 11, 12 along with it lecture 15 and 16. And we will move on to the next lecture.