Architectural Acoustics
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Lecture – 19
Acoustical Criteria and Space Design (Contd.)

So, we continue with Acoustical Criteria and Space Design. And, today we will be discussing lecture halls, this is lecture 19. And as I told while discussing in lecture 18 we will dedicate one more lecture that is lecture 20 on recording studios, and this is particularly for lecture halls. These are actually very much important which while we are planning for say schools, colleges and we do not consider these issues.

So, we leave a big space and say this is a lecture hall that is not actually true. But, we as architects need to know how the details how the structurally it can be considered because everything involves cost. So, if we can take care of these issues while designing the spaces, if we think of what will be the structure, what will be the form, what will be the room dimension, then we can what is the proportion we can rightly come out with lesser cost and lesser amount of additional arrangements for getting better acoustics in the entire environment.

So, we will move on to lecture halls and we will see.

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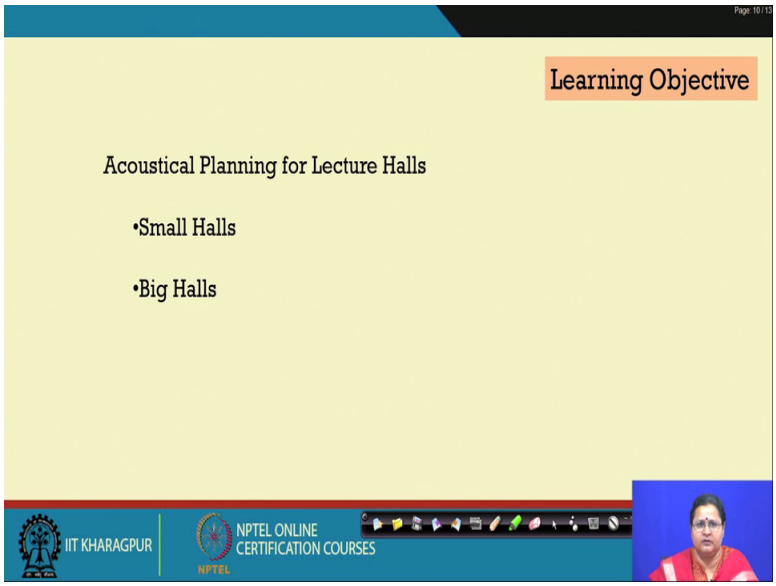

Small lecture halls and big lecture halls how to do the acoustical planning for such spaces.

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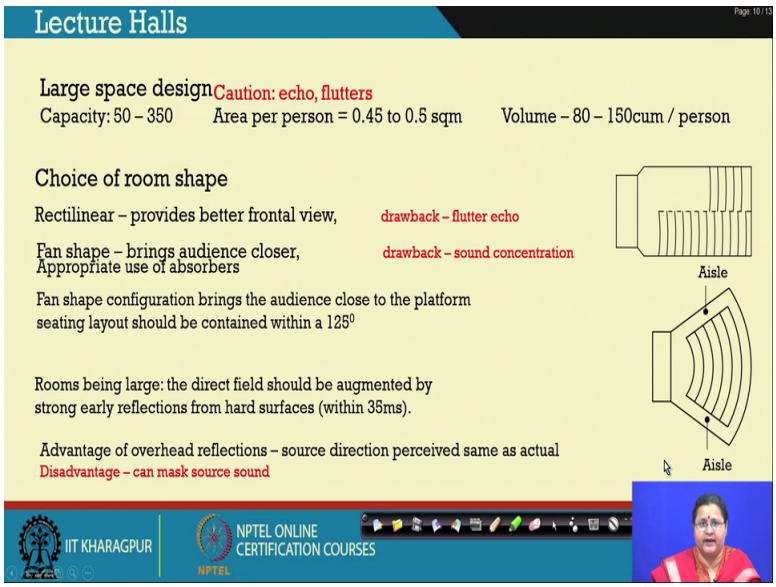

So, these are all under large space design. We started with classrooms where we were talking of room modes we were talking of speech intelligibility and we were talking of children who were very tender age who requires 100 percent intelligibility. Here also we need a very high speech intelligibility and the platform has changed from small spaces to large spaces. Here the caution of echo and flutters are very important. Capacity may vary if it is 50 its small it comes it is little smaller space; however when the capacity is up to 350 we have to do some area calculation beyond and look in to the recommendations has been done by Doelle in 1972.

So, area per person that is per person of the user of the audience is around 0.5 square meters, whereas the volume is between 80 to 150 cubic meter per person, and a more or less ideal is 110 cubic meter per person as I have already told. This also brings in a choice as because it is a large space, this also brings in the choice of room shape, because a long rectilinear room can be planned otherwise a fan shape room can be planned. See, the rectilinear rooms provides better frontal view. So, the purpose is to have a connection between the speaker or the person who is giving the lecture and the audience. So, we plan for a rectangular shape where you can actually attract the audience towards the

talker; that is the teacher in teacher or the presenter, but the drawback is of flutter echo, as we had already seen while discussing room acoustics.

Whereas, a fan shaped layout will bring the audience closer. But what happens? The drawback sound concentration if you have a circular back what you see over here, what you see over here a circular back there are chances of sound concentration in some areas here. So, this curvature has to be treated first of all either to be treated or to be very flat. If so, then you can actually have your audience much closer towards the speaker who is somewhere here. So, appropriately absorbers are to be used in two different cases it will be different: fan shaped configuration brings the audience close and but at the same time you have to see the people do not get a direct frontal view, they are all looking towards the speaker and the shape the presenter also has to look widely in to the audience.

Rooms being large the direct field sound, field should be augmented by strong early reflections from the hard surfaces and that too within 35 milliseconds. Because, you cannot take help of reflections which is at these points or which is at these points, but you have to reinforce your sound considering the source sitting over here, sitting or standing over here. At the same time you have your ceiling available to you. You can take help of the ceiling to reach the sound and as a reflector to reach the sound to the farthest audience.

This has been shown discussed in case of conference room. But see, in the small conference room also we had planned for absorbers at the edges, because those were unwanted sound, those were leading to delayed reflection which are not encouraged where speech is the purpose. So, if you want to communicate speech properly to the people you have to think of reflections within 35 milliseconds, and for that reflectors nearby the source is very very important.

Another important point is, when you are taking overhead reflections you see that the sound direction perceived by the audience is like the source is speaking. If you take help of lateral reflections coming from the side which I had already discussed that creates the spatial impression which is very much important for music but not here. Here if you take sound from the side, encourage sound from the sides that is the side walls you will have a perception that the speaker the sound is coming from the sides and you will be

confused that where is the source. So, to perceive the source direction reflected sound from the overhead ceiling is from the overhead is very important.

But, again reflected sound can mask source sound, which I had discussed in one of my previous lectures.

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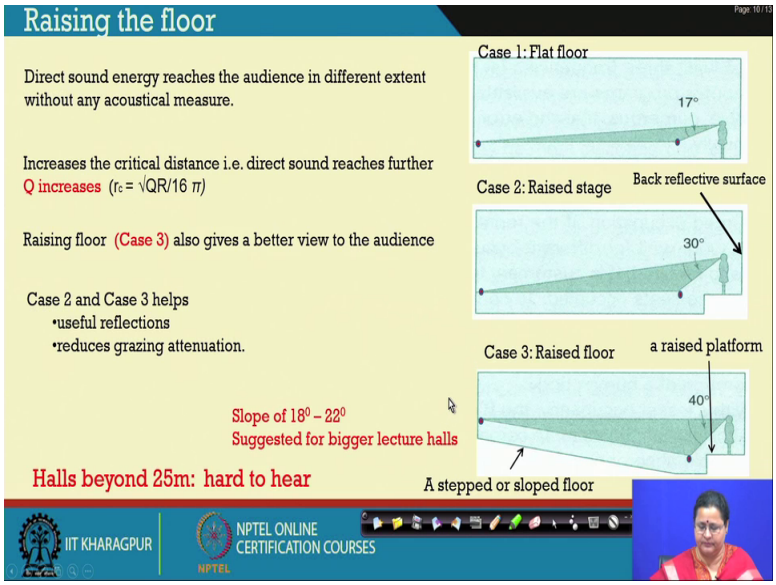

Now, I have also talked of grazing attenuation. In the first case you see it is a flat floor and the distance is quite high similar to that of a classroom, but the now the back wall has moved further. We had also raised in case of a classroom, we had seen that on raising we see here that the direct sound energy from a point source is reaching; the amount of energy reaching is now more in the case when the talker or the presenter is elevated in a stage.

So, this increases the critical distance that is the direct sound reaches farther because Q increases. In Q the upper part or the numerator had a component of energy from the sound source and other is the reflected energy which can always keep on adding from the ceiling which you can see on the top. So, in all the cases that reflected sound is coming from this ceiling, from this ceiling. And however, the sound source energy has been augmented from 17 degree to 30 degree to 40 degree when the in case 3 the floor is also raised.

So, the raising of the floor gives a better view to the audience also and that gives a contact communication between the talker and the audience. Case 2 and 3 helps useful reflections and it reduces grazing attenuation. The slope in case of case 3 is suggested to be 18 degrees to 22 degrees as usually followed for the lecture halls. For small lecture halls you can actually have step floor that can be actually built up on top of the main structural; main floor or the structural floor. Halls beyond 25 meters long it is little harder to hear.

So, what we understand from this particular slide? Raising the floor is important considering the number of audience inside the hall. If it is a large hall, large lecture hall accommodating around say 250-300 students in that case the stage should be elevated at the same time the floor should be stepped or sloped.

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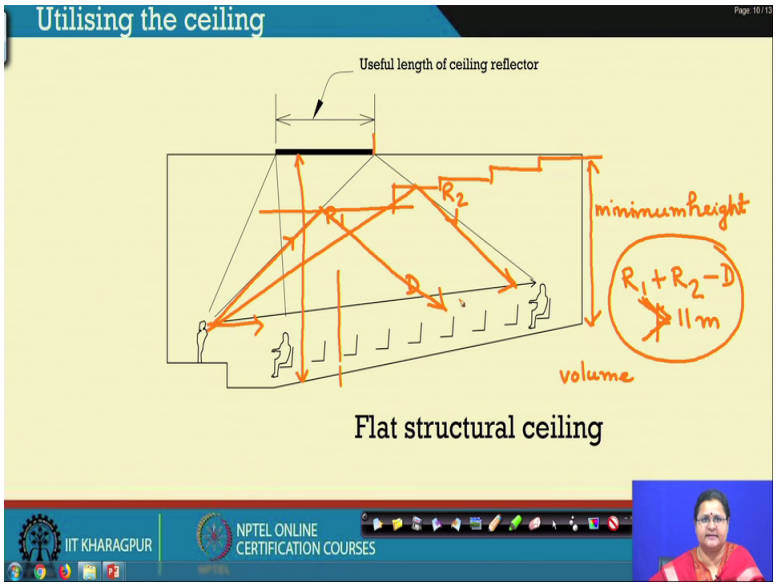

Now, coming to the utilization of the ceiling: how can we utilize the ceiling? We have the structural ceiling in this particular picture. To gain enough of height at this point, the overall height of the hall has increased which has increased the volume of the hall, which is not one of our objectives because volume increases the reverberation time. And we are to keep an eye on this reverberation time which should not go beyond 1 second: 0.9-0.8 is desired.

So, we cannot in increase the volume but we see yes the reflected sound is reaching to the last person, because the critical distance that is the direct sound source has energy

level has lost somewhere here. So, if we want to reach the reflected sound to the last person we have to take help of this direct reflection. And we see that the up to half of this structural ceiling we can take help of the reflection to reach the sound to this person, because every time you remember the reflected path length and the direct distance you have the relationship which was already calculated out earlier which should not be more than more than 11 meters.

So, we have to keep in mind that we should not cross this particular limit to keep the law; to avoid the long delayed reflection and to reduce the reflected early reflected; to increase the early reflection and stop the long delayed reflection. So, in that case if we can actually bring down the ceiling somewhere here then it would be useful. So, we have options of stepped ceiling so that the ceiling gradually increases to satisfy the criteria of minimum height here; minimum height here and we can actually step the ceiling gradually. So that the reflected distance is reduced, this R 1 plus R 2 gets reduced to reach this point. Again R 1 plus R 2 for such places also get reduced.

So, we can think of utilizing the ceiling in a different way. So, if the structural ceiling is at a lower height it is a smaller lecture room then we can have a flat ceiling with reflected surface. So, if it is a small lecture room, we can forget about stepping or having any kind of curvature and we can just go for a reflective ceiling. But if it is a large lecture room we will see in pictures also we need a stepped ceiling or a curved ceiling.

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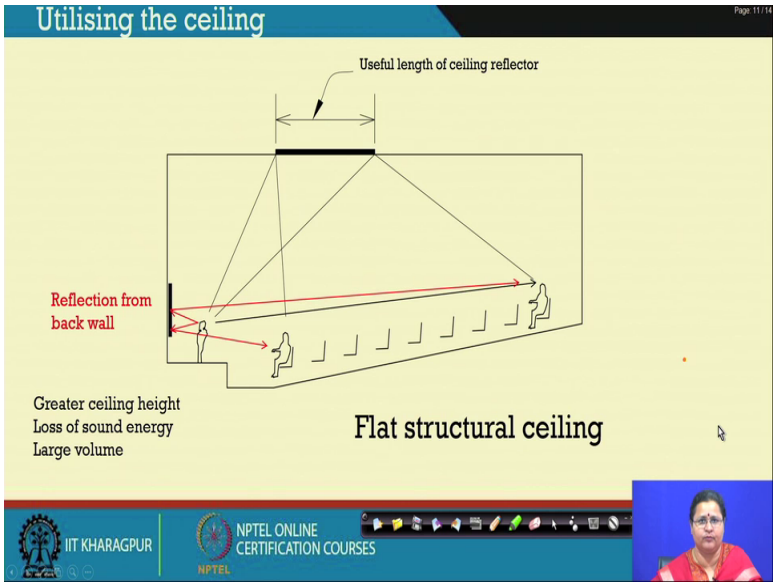

So, we move to the; so we see that greater ceiling height, loss of sound energy, and large is the volume. And we take care of this in the next slide. Here also we see another component which is the reflection from the back wall. So, reflection from the back wall of the speaker is also to be accounted for, and usually because I have taken; because this is a lecture hall for students we usually expect a black board over here.

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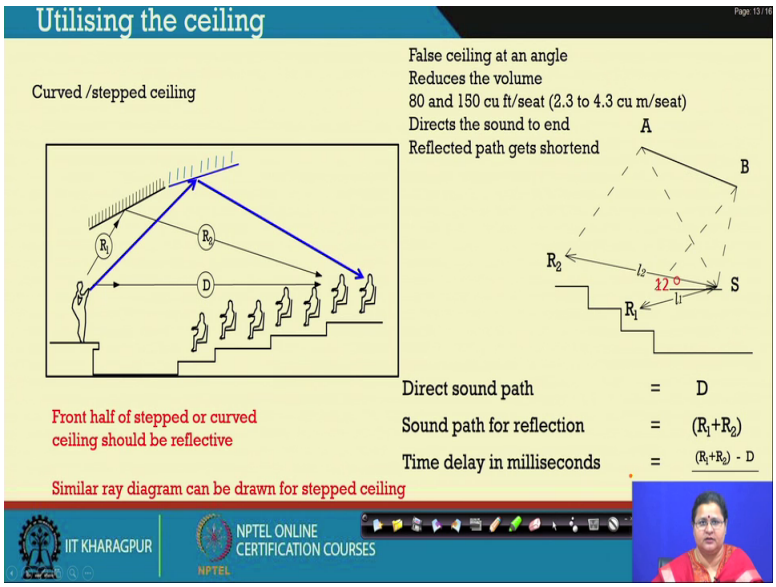

Now, curved or stepped ceiling in this case we can see that the R 1 plus R 2 has reduced, the false ceiling is kept at an angle of 12 degrees, and it also reduces the volume, the direct sound and the reflected path gets shortened, and we can actually plan for changing curvatures for reaching the sound to different parts of the audience.

So, this is how you can actually plan for it; it is this is supposed to be 12 degrees and that helps in carrying the sound reflected sound easily to the audience. So you see the delay, that is the between the direct sound and the reflected path which I was talking about in the previous slide. This was the formula: so R 1 plus R 2 minus d divided by 0.34; that is 0.34 meters is travelled by sound in 1 millisecond. So, this is the time delay. And this time delay should be is expected to be within 35 milliseconds in such kind of halls. So, front half of the ceiling can be stepped or curved and it should be reflective in nature to allow the sound to the last point.

Ray diagrams for stepped ceiling you can try out.

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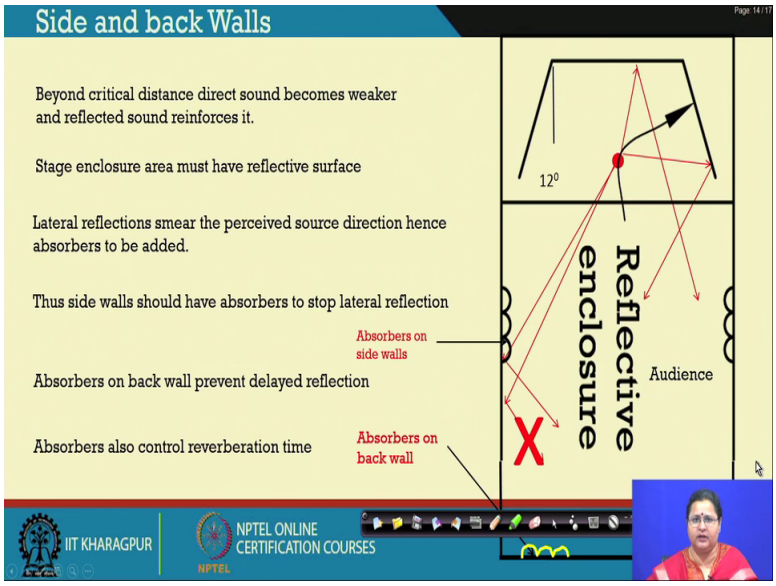

Now, coming to the side and back walls beyond the critical distance direct sound becomes weaker and reflected sound reinforces it; that is what I was discussing. And lateral reflection what I told they smear the perceived sound direction. Hence, absorbers are to be added on the side walls, because we do not want lateral reflections encouraged in such kind of rooms.

So, you see in this particular plan the reflective enclosure that is surrounding the, surrounding the source even the source is somewhere here we will see that this reflective enclosure is actually helping in sound reaching towards the audience. So, stage enclosure area must have reflected surface and now you see the ray diagram over here. So, the sound from the source is moving to the reflective surfaces: the lines in reds red and is moving towards the audience. Whereas, it is not encouraged the lateral reflections are not encouraged from the walls side walls, and hence we see a big cross over there which is trying to absorb the sound from the on the side walls. The side walls should have absorbers to stop lateral reflections. Absorbers on the back wall you see can prevent delayed reflection.

So, we have the side walls and the back walls to be treated with absorbers, we need a reflective enclosure for the stage area so that the sounds from the sound source immediately the sound gets reflected so that it reaches within 35 milliseconds to the audience. Absorbers also control the reverberation time.

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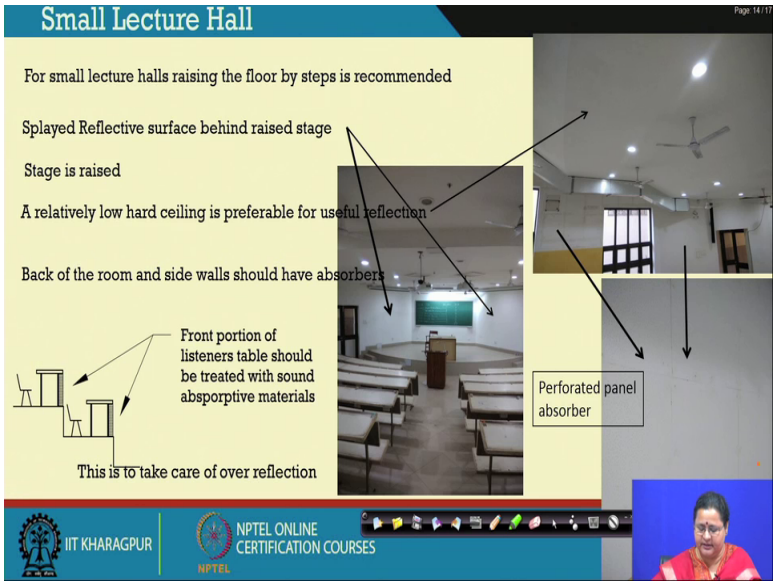

So, keeping all these points in mind we will see how the small lecture rooms are planned for.

So, here you see a picture where the side walls are visible, the lecture hall is raised by steps, you can see the steps are here. Splayed reflective surfaces behind the raised stage, so the stage is also reflected which you can see here. The reflected surfaces you can see those are coming out, you can see the board which is also forming a reflective surface. A relatively low hard ceiling is preferred for useful reflections inside this particular small lecture room.

You can also understand that it is a very circular kind of plan where the audience is arranged in a concentric manner. Back of the rooms and side walls should have absorbers. You can see in the picture these are the absorbers, this yellow is the absorber above it the white are absorbers, these are perforated sheets; you can have a closer picture. See the perforated sheets are here and here this is a absorber pushed, here and these are absorb perforated panel absorbers.

Sometimes in front of these you can also add some absorbers to take care of the over reflections. Here, in this case you also have similar kind of areas what you see here. Maybe, some absorbers could be added here to in to decrease the reverberation time. So, this is the picture from the Nalanda Tutorial Complex; Nalanda Complex where classes

are regularly happening and the capacities are around 120; this circular planning plan is having capacities around 120 students.

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Here is another example, where we see a direct flat reflective ceiling. This is also a lecture hall, this is also a lecture hall of a of a smaller scale it is having a capacity of 110, you can actually find out here, and find out the number of seats over here and you can see the walls the side walls are absorptive in nature, whereas the ceiling is reflective in nature. You see the absorptive all shown here a bigger blow up picture is shown here.

The stage here is also raised and the entire; from the slope you can understand that the audience area is also raised.

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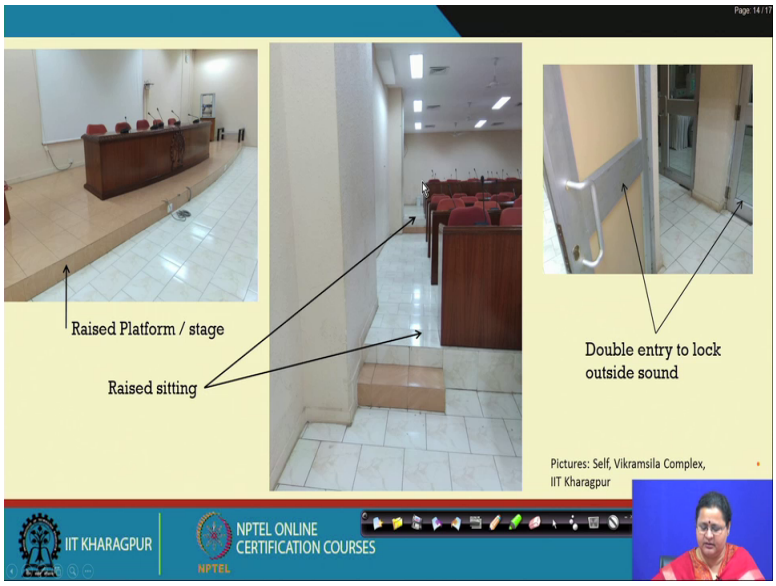

You can see the raise in the audience area, these are gentle steps two steps they are separated at after four rows another four rows are there with the level difference. Here, you also see that there is a sound locking area, so you have double entry to this particular room. And here you notice it is a completely flat ceiling.

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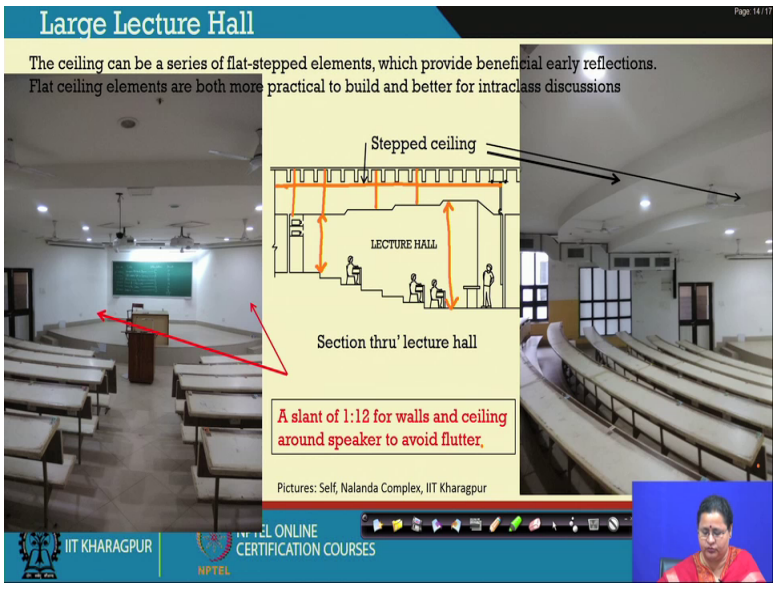

Now, coming to the large lecture hall, we again come back to the stepped ceiling. So, this stepped ceiling in this particular picture you can see that the stepping has been done such

that the minimum height is maintained here and this has been gradually done from the front to the back.

So, this is a kind of control how it has been done gradually. And this stepping kind of thing is visible stepping ceiling is visible in this particular picture. This ceiling can be beneficial for early reflections. If we had the ceiling somewhere here then it would be difficult to control the reverberation time. So, this kind of ceiling can be hanged from the top and it is easier to control, easier to build and you have to keep in mind that stepped ceiling are easier to be constructed.

We see here the same picture a slant of 1 is to 12 for walls and ceilings around the speaker is put to this avoid flutter echoes also.

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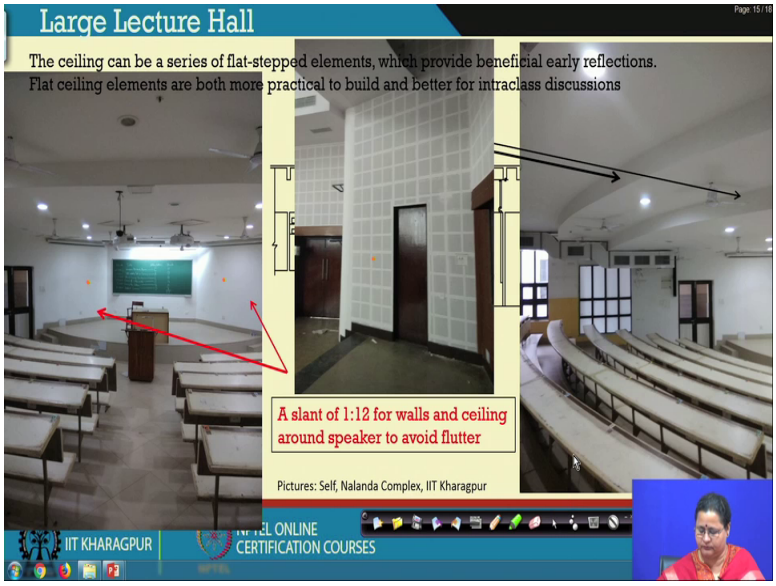

Here is another picture. Here is another picture where we see the slanted walls, this is another lecture hall in the main building complex of IIT Kharapur. So, these are the slanting walls here. So, you can see these are the slanting walls and here these are the slanting walls.

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Now, we come to the seating area, the floor. You see the room is rectangular in plan and there is a gradual slope from the edge you can see the entire floor is moving up. So, the seating area or the audience area which is having at least 250 seats because here you cannot count students can squeeze in to each of these benches and actually more than 250 can be accommodated over here.

And now look into the ceiling of this particular hall. So, you have a stepped reflective ceiling and you see the number of fans over here which can bring in low frequency sound. We have to be very careful of taking care of this humming sound from this fans and for that also we need to plan for slit slat resonators or resonators which particularly trap in individual frequencies. So, we will see some of those pictures also.

You see the absorbing side walls. Here also you can see that the stage is raised.

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Now, we come to some details picture. I was talking of the slat resonators, you see it is just below the black board all around the black board. Here on the ceiling there are fans, some sound from this area if some low frequency sound is generated this particular eh slit slat resonators can take care of it. The board here acts as a reflector. And what you see on the walls these are actually perforated tiles with 50 millimeter glass wool insulation inside it.

Coming to the back of the lecture room which is rectangle in nature, however the back is also full of absorbers. So, we do not encourage any lateral reflection in large halls, we do not encourage any long delayed reflection from the back walls.

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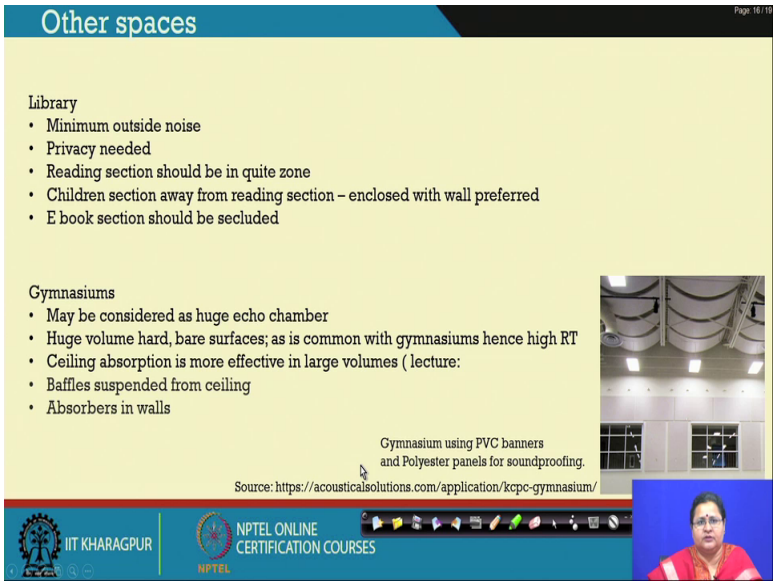

So with this understanding, hope you could take the lesson that what is the purpose, how to use it, and how to plan for its acoustics. We also encounter spaces like library, where we also we need to we have to be very cautious of designing it. Libraries can be planned differently there may be furniture's which can be taken help of, there may be their privacy is of at most important. Reading section should be in a very quiet zone. So, you have to plan for the reading section within the library how you can seclude that area from where the sources of sound can be possible. Children section should be always away from the reading section.

So, these kind of basic things while you are planning for a library you have to keep in mind all these aspects. You have to also keep in mind the lessons from open office design, because here it is an application of that privacy. So, the reading section has to be silence silent as much as possible, whereas, you have to keep children section, you have to keep e-book section you can put glass walls so that the openness is understood people can understand the way finding and that is what how architects can contribute.

Coming to gymnasium you just see the picture which have taken from the source is mentioned here; the where a huge volume has to be treated. It is considered as a echo chamber and this huge volume of hard surfaces which can lead to multiple long delayed reflection kind of echoes; I is to be treated. And you cannot put anything other than the ceiling as you have learnt earlier that for large volumes the lecture is not mentioned here;

for large volumes spaces the ceiling is the most appropriate area for putting for putting treatments to reduce the reverberation time. So, their lecture is in some room acc the room acoustics lecture. So, between 5 to 10 you will find in some lecture it is mentioned there here baffles can be suspended from the ceiling, because you cannot interrupt the floor. Absorbers in wall wherever possible can be applied. And here you see the PVC banners have been used and polyester panels are used for sound proofing.

So, what you will use you have a list of materials absorbing the alpha values for different frequency ranges which you can refer to and make a mix and match, but you have to understand where to apply, what is the purpose, where is the source, what is the need for that area, what is the purpose of that particular area.

So, hope by these lessons we could cover most of the spaces which are critical so far as speech is concerned. We are left with studio or recording studio which we will cover in the next lecture and hopefully after that we will move to auditorium design which is again another special area of design.

So, the books referred here.

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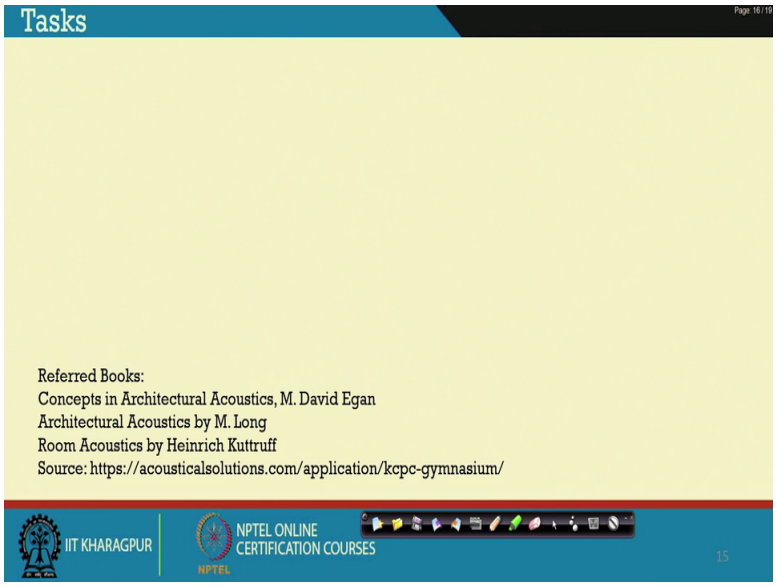

And for the task I would ask you or suggest you to work with different capacities of bigger halls say 200-250 capacity you have the tools with you; the volume say 110 cubic meter per person, you have the floor area- so from that you know the how to calculate

the proportion of that and from there you can actually create ray diagrams, create a steps ceiling plan, and make the ray diagrams and find out whether the reflective reflected distance and the direct distance how much milliseconds they are in gap and whether it is appropriate or not.

So, am not giving any task in particular, but you can keep on; as you can keep on doing this exercise in small class exercises which you are given for during your design studio.