Architectural Acoustics
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Lecture – 06
Room Acoustics

So, welcome you all back to lecture 6 which is on Room Acoustics, this has been split in two lectures lecture 6 and lecture 7. So, this as room acoustics 1 and after the basic understanding of sound physics, I hope you are all in a position to get through what I want to continue with.

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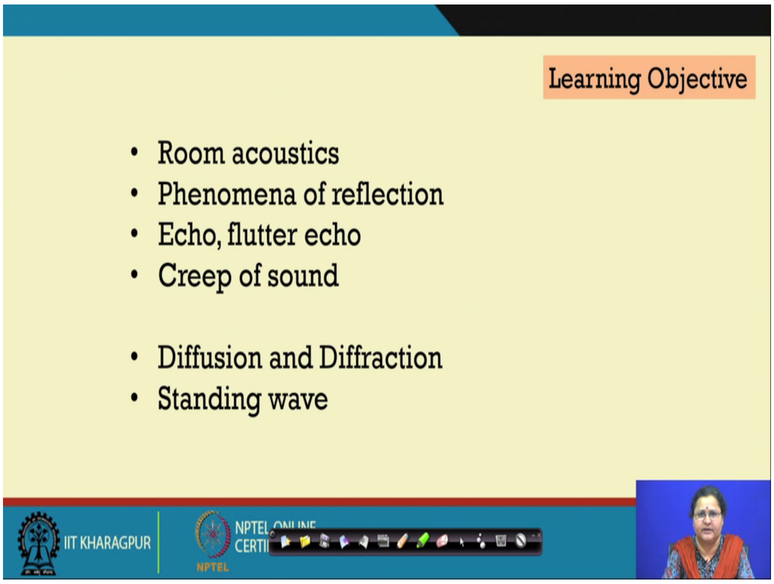

So, coming to the objectives of this we will first try to know what is room acoustics and, then the phenomena of reflection echo and flutter echo creep of sound and in the room acoustics part 2, we will deal with diffusion and diffraction and standing waves room modes etcetera.

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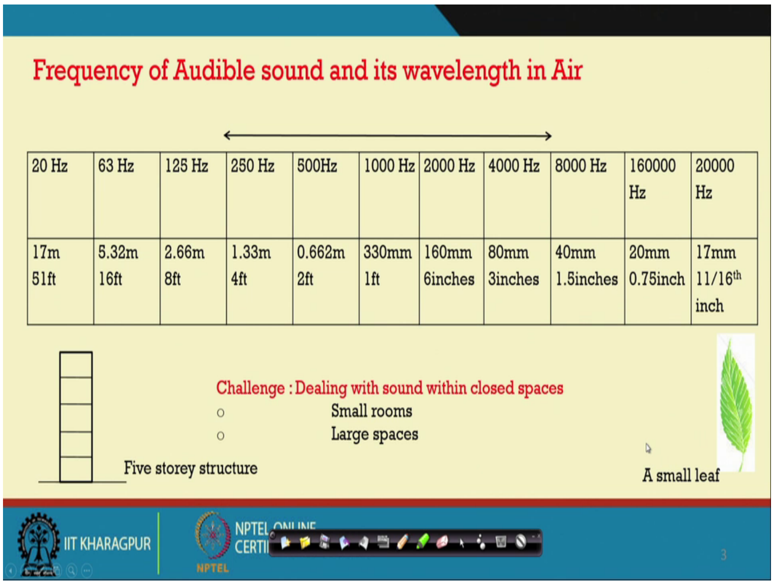

So, we have already learnt that we have an audible range, which is of the order of 20 hertz to 20000 hertz frequency. And if we look into the dimension of the wavelength, we will see that 20 hertz is the order of 17 meters or 51 feet, which is equivalent to a 5 storey structure. And on the other hand other end we have 20 thousand hertz which is of the order of 17 millimeter of wavelength, which is 11 16th of an edge, which is just a small as a leaf.

Now, particularly when we deal with our rooms spaces, where we need to communicate, it is mostly speech, or music, or orchestra, or a performance where we need to take our sound, whichever is emanated from the source to the receivers, whoever are spreaded inside. So, why wavelength knowing this wavelength is so, very important, we usually cover our species to music from 250 hertz to 4000 hertz, where which you can see by the arrow head over here. And we can move further to 8000 hertz and maybe down here to 63 hertz.

So, particularly this area 250 hertz to 4000 hertz, we can we need to take care and we if we see the wavelength. It is from 4 feet to say around 3 inches 1.5 inches. So, these are very much close towards our room dimensions multiples of these are actually our room dimensions, exactly this can fit our furniture's room items whichever is in the room.

So, all the items which we deal with the deal with within our architectural domain fall, within the wavelength of sound and we have to take care of that in certain cases, when the rooms are small. And, when the rooms are large this sound can behave in a totally different way when it is large.

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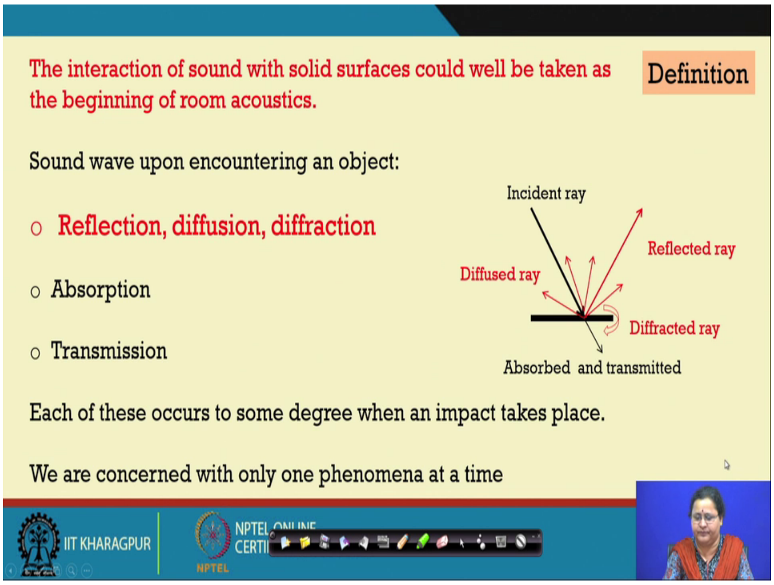

Now, coming to the basic definition the interaction of sound with solid surfaces could will be taken as the beginning of room acoustics. And sound waves upon encountering an object phases, reflection, some of it can get diffused, some of it can get diffracted, some of it can get absorbed in the material and, some of it can get transmitted.

If you see this small picture we can see that the incident ray is falling on an object and, it is getting reflected directly which is called specular reflection, some of it gets diffused as you can see the spreaded small arrows and, some of it can bend and go beyond that particular object, where it is falling on so, that is diffraction.

And a part of it can also get absorbed and transmitted, which we would not be covering in these this part of the lectures. So, each of these occurs simultaneously to some degree, when an impact takes place and, we will consider only one phenomena at a time for the time being.

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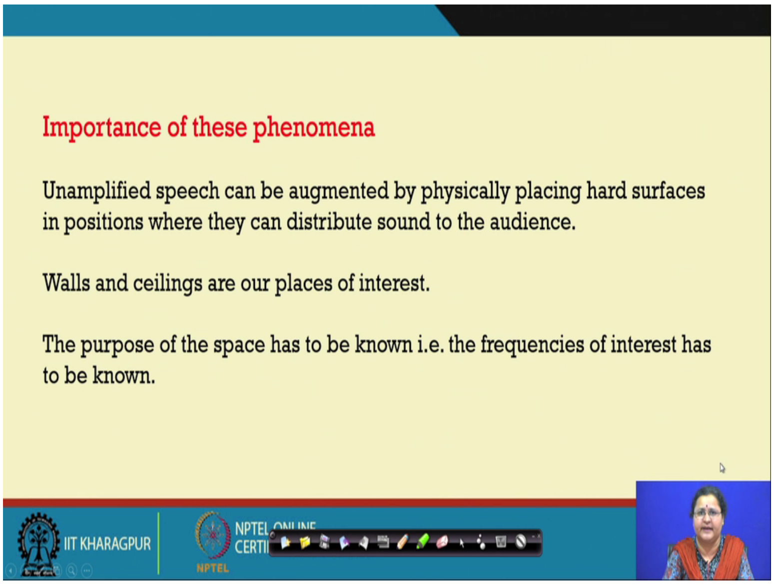

So, importance of these phenomena is that unamplified speech can be augmented by physically placing hard surfaces in position strategically so that the sound is distributed uniformly towards the receivers. Just take a case of a classroom, where one is sitting like me and the audience which are sitting in front of me. So, I should be audible to all the receivers all my students from the first row to the back row.

And this can be strategically done by placing sound reflectors, at particular location sound diffusers, at particular locations or sound diffractors, whatever is the purpose. So, we will try to unfold this phenomena one after one with reference to architecture. And walls and ceilings are basically our places of interest because, we need to take care of this unamplified sound to reach it to the receivers the best.

The purpose of the space has to be known that is why and the frequency of interest that is the frequency, which I am producing at this point of time must be known to me otherwise, I cannot deal that while I am taking while I am doing the design.

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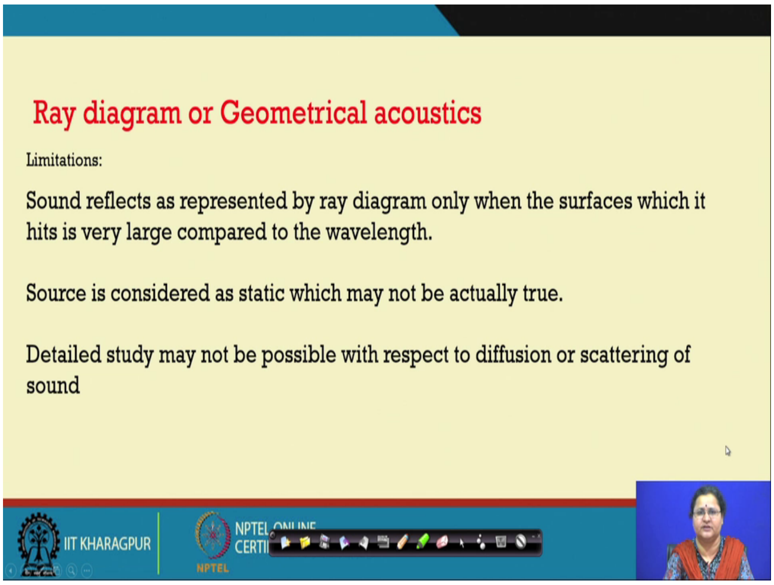

So, we will take help of ray diagrams, or geometrical acoustics with Dr. Bhattacharya has already talked about.

It is a simple way where we can actually demonstrate, ourselves within the spaces which we deal for the purpose of acoustics, though there are certain limitations because here, it is considered that sound reflectors as represented by ray diagrams. But actually it is to the process of ray refraction and compression, which you all know and you know by this time. And only when it the surfaces are sufficiently large, then only this reflection phenomena can take place.

So, we told you about the wavelength, which is of the order of 1 feet, 2 feet, 3 feet, half feet, 6 inches and half feet of that is 6 inches or even half of that. So, the wall surfaces are in comparison reflective surfaces because, we have our rooms of the order of 3 meters 4 meters that is 10 feet 12 feet and so on.

So, sources are considered as static, that is the way I am sitting here and talking to you I am a static source and, if it is not happening that way say I am moving around in the stage area, or the area where I am given to talk to you, then the ray diagram the ray diagram mechanism may fail.

But however, considering static sources, it gives us a very good estimate of where and how the sound will move and, how it will reach the receivers. And the other is we cannot do further detailed studies using ray diagrams in case of diffusion, or scattering of sound.

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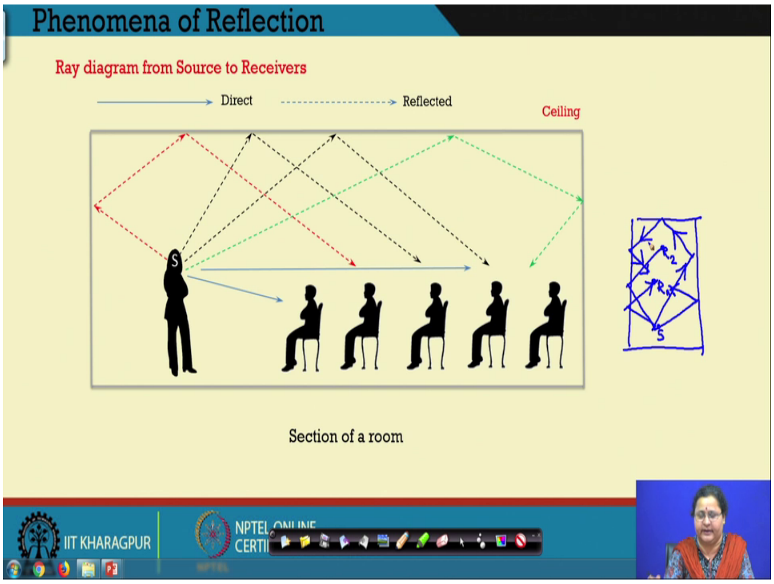

Now, let us come to the phenomena of reflection, what you see here a room is defined by its ceilings and side walls.

So, first let us think of the ceiling, which was not there when I spoke you all about the amphitheaters. Let the source be here who is generating the sound and, some direct paths to the receivers are shown in complete lines and, reflected paths are shown in dotted lines.

So, you see the sound which is generated by the source are reaching the receivers directly, at the same time some sound is moving towards the ceiling and reaching the receiver at a later time. And this is happening in multiple cases throughout the ceiling.

Now, if you take the help of the back wall just back behind the source, there also sound is moving and it is going and hitting back to the next surface and moving to the receiver. And this is happening on and on and also when it is going to the back wall, it is also experiencing the same. So, one particular receiver at a time is receiving sound from both the side walls and also the ceiling. The same is happening in case of the plan.

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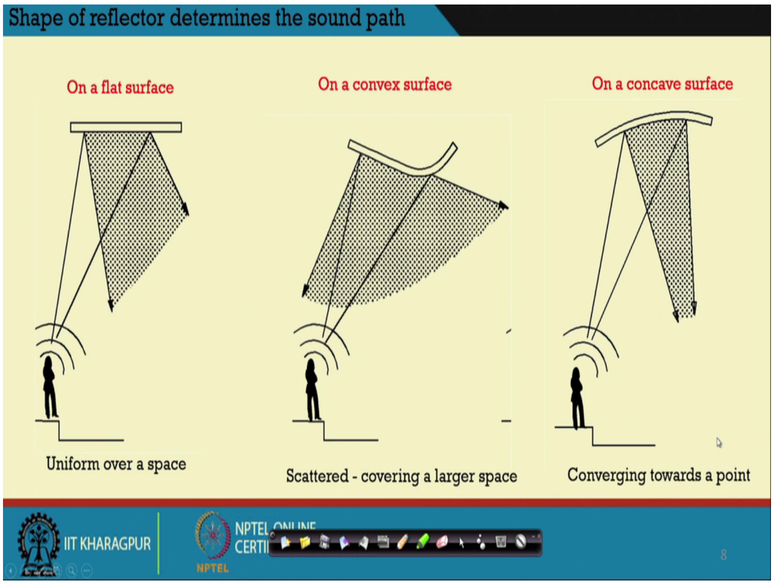

The same is happening in case of the plan. If we go to the plan, we will see multiple reflection are happening from the side walls to the receivers sitting at different locations, some may even come back to the receiver after multiple reflections from different wall surfaces. So, this phenomenon is happening on and on with the source sound, which is just generated and it is carried on.

But the source would not stop it will move to the next. So, we will try to see what happens after that. So, let us think now this flat is the surface where it is falling is a flat surface, then we will see that over the space the sound is uniformly distributed. If we see that the sound is falling on a convex surface, we will see the sound has scattered to a certain distance, which is more than that of a flat surface.

So, here we can see that a convex surface helps to distribute the sounds whereas; in case of a concave surface we can see the sound is moving towards a point. So, it means it is concentrating towards a point.

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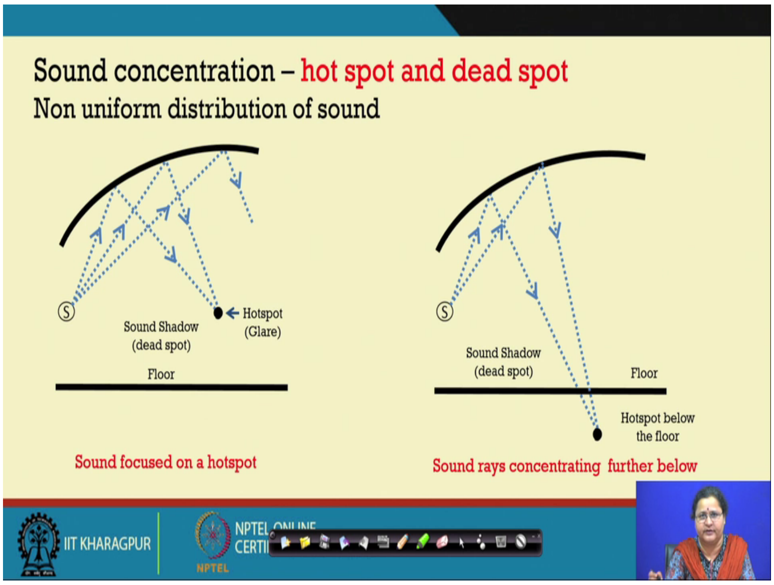

And if we go further into it, we can see that sound concentration can create some points within the floor where there will be a glare. So, all the sound from the source will go and concentrate in that particular area, which is called the hotspot. As you can see where the cursor is where the sound has actually concentrated. So, what happens the entire sound energy which was supposed to get distributed into the other areas, there no sound has reached particularly from this two reflected sound.

So, that creates a sound shadow area, or dead spots beside, or surrounding a hotspot. So, to take care of such situations, we can go into the next picture, where we see that on a flutter concave surface. This concentration of sound or the focus point can be taken below the floor level, which can at least take care of the glare to some extent.

So, this can be done by moving the source, this can be done by changing the curvature. So, we have to be very careful and, we can do this by the help of ray diagram to come to a solution, where actually the sound remains spreaded and does not concentrate at different points within the floor creating hotspots or dead spots.

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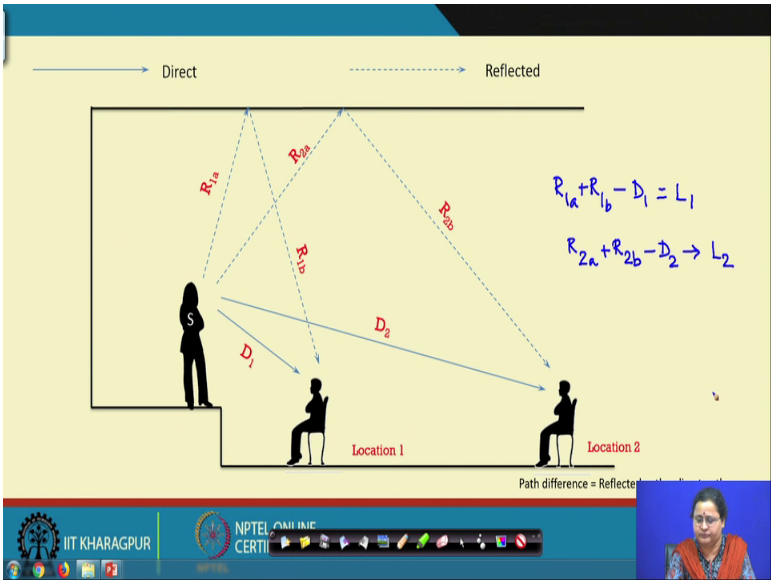

So, let us come to the phenomena, which I was already talking about while we were discussing the reflection in the previous slides. So, when the source is there the direct sound showing shown in continuous line and, the reflected sound in dotted line, we see at the two different locations the sound travelled from the source are different.

So, the direct path is D 1 and the reflected path to D 1 is are reflected path 1 A plus reflected path 1 B. Similarly, if you look at the location 2, it is R 2 a and R 2 b and that is what is reaching him after a short span of time, after he has heard D 2. So, the path difference is actually R 1 a plus R 1 b minus D 1 for the listener 1 and for the listener 2, it is R 2 a plus R 2 b minus D 2 in case of listener 2.

So, this path difference is continuously happening for all the reflected paths, which are happening for the for our case the simplest case, if we have 4 walls it is happening from all the 4 walls apart from the direct sound. The receivers are receiving reflected sound like R 1 a and R 2 R 1 b and then again R other set of reflected sounds, which is a summation and, which is more than the first or the direct sound.

So, this path difference should be heard within a certain time so, that these can help in strengthening or better hearing at location 1.

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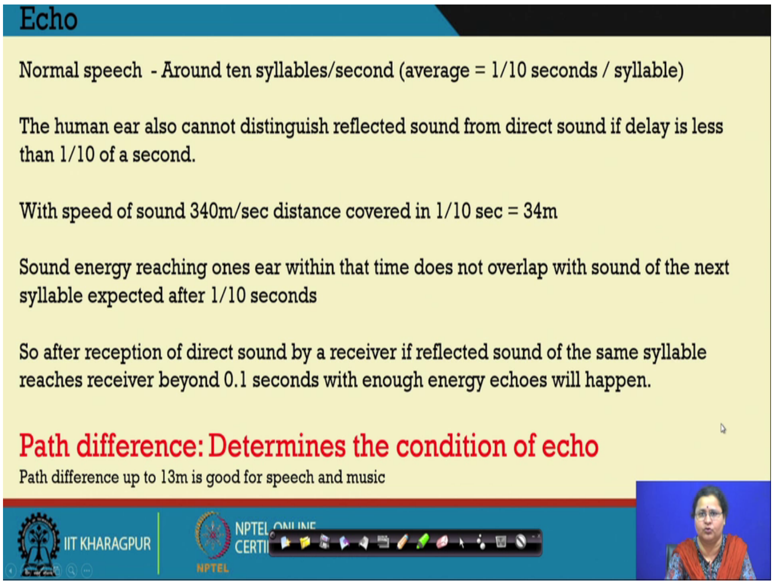

And for this we come to the phenomena of echo, what we have heard since childhood or we have studied, that if I am a source sitting here and, my voice is getting is of enough, enough energy. It is moving to a distance of say 17 18 feet, it 17 18 meters, or there is a hill, or a wall and it is an interrupted sound, I can get back the sound again back to me as a form of echo.

Now, the same thing can happen within the space, which is given to us for design. If these path differences are more than the condition of an echo automatically a person, or the listener at any position will get more get the sound, which is beyond the time which is expected, then it will end up with an echo. So, let us come to see or understand how much time it takes for our syllabus to be spoken. Normally around 10 syllabus are spoken; that means, 1 10th of a second is given for each syllable.

The human ear also cannot distinguish reflected sound from the direct sound, if the delay is less than 1 10 second. So, this 1 10th second is of primary importance and, with speed of sound as 340 meters per second, we say that the distance covered in 1 10th is around 34 meters. So, sound energy if it is having sufficient of energy and reaches ones ear beyond that time, will lead to an echo. And if it does not it does not happen, then it will actually strengthen the original sound.

So, we should have the objective in my, that no sound should reach beyond 1 10th of a second, or it should follow the criteria that the path distance should never be the difference in path, path difference should not be more than this criteria. So, after reception of direct sound by the receiver, if the reflected sound of the same syllable, reaches the receiver beyond 1 10th second, with enough of energy echo will happen.

The same can happen to the source the source can also get disturbed with his, or her own sound if it reflects back to him, in that case the direct distance becomes 0, and that is what happens when you stand in front of a barrier some few some few 100 few meters away say 17 18 20 meters away, you can see you can again hear back your own voice.

So, path difference determines the condition of an echo that is the learning from here. And we have to be very particular for this and path difference up to 13 meters is recommended to be good to very good, in case of speech and music. It can it is acceptable beyond this meters, this 13 meters, but we have to be very careful what is the purpose of the room, what is the clarity required in the room.

So, 13 meter if you go by the path difference of 13 meter, it will lead 100 percent to a good sound good sound, within then within that space; So, the acoustical condition of that room, you will be considerable considered as good.

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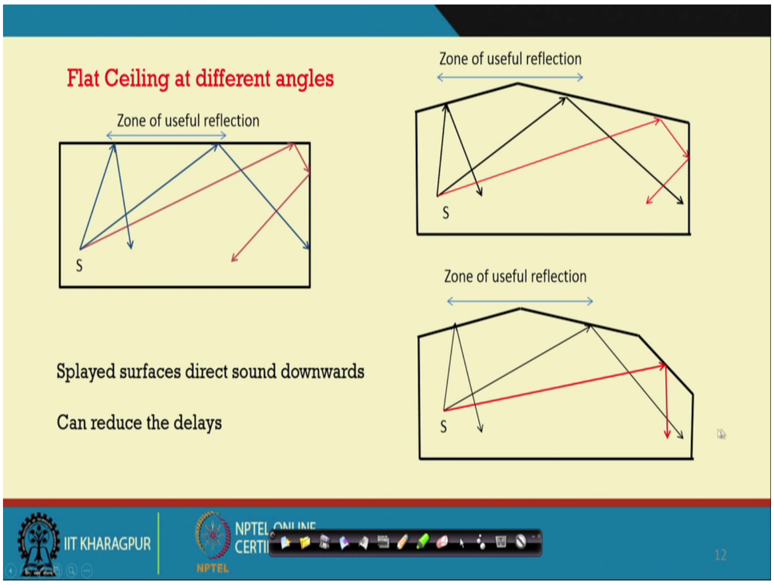

So, we can actually have such kind of problem with echo in bigger spaces. So, you see here in this first picture, when we have a very regular rectangular room, with a flat ceiling. You see that from the source we do not require more than 2 3rd of the ceiling to be reflective, because it can cover the whole of the length, or the audience within this particular distance.

So, someone sitting here and someone sitting here can hear very clearly. So, this is the zone of useful reflection. And beyond that actually it will lead to longer path differences. Let us see in the next picture. So, this is the longer path which we need to avoid. So, how to avoid let us see what happens here, if we actually play the room on the ceiling part, we can reduce the length which is shown in red colour.

So, this can actually lead to lesser path difference and that can actually help in not formation of echo's, we see another example, where it has been split twice, where we see that the sound is coming back to the receiver again.

So, actually playing of surfaces directs the sound download. And it can reduce delays so, when you will be tackling bigger spaces like say auditorium etcetera and, say multipurpose walls you can if you have the opportunity, you can actually playing your ceiling to take care of avoiding formation of echo's.

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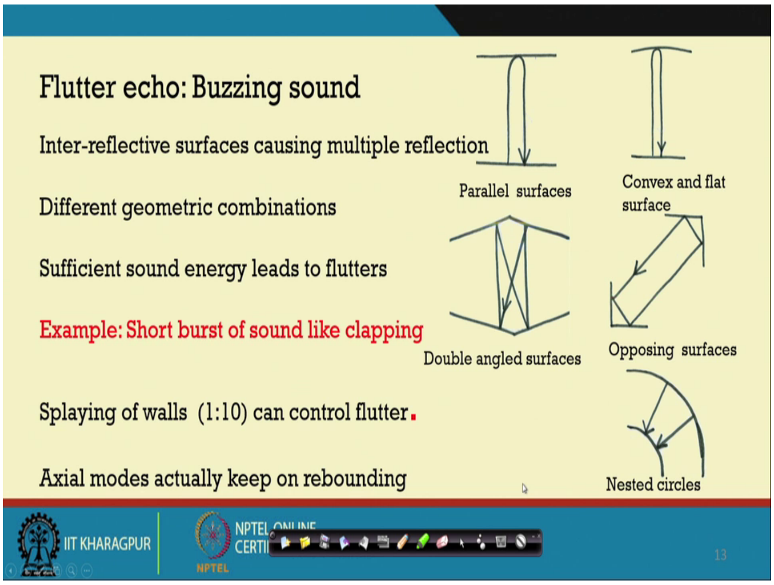

So, let us come to the next phenomena which is flutter echo, or the buzzing of sound. So, this is cause due to inter reflective surfaces causing multiple reflection and this can happen under different geometric combination. So, as architects we never need to know, what kind of shape we are going to finally, arrive at. So, we can see parallel surfaces always create a flutter echo when they are really very close to each other.

So, in particularly small spaces, if two parallel walls are there we should take care of these flutter echo's, next is a concave convex and a flat surface combination, it can happen when double angle surfaces are there, here you can see that this was is actually parallel to this wall. So, these two are parallel which is leading to again these two walls are parallel which is leading to flutter echo's. So, you never know through our design what conditions or geometric combinations you are going to arrive at.

So, you have to be very careful that whether these lead to any flutter or not. Fluttering is actually inter reflective reflection, if you have such reflective condition, then automatically we will end up with flutter echo, yes there are methods to correct it because, after construction you cannot demolish a wall.

So, this is another when it is opposing surfaces, you have corners you are speaking from one corner the sound is coming back from the other corner, you can see here very well when it is opposing surfaces. It can happen for nested circles also so, the sound can rebound from the other wall back to the back to the inner circle.

So, we have to be very careful to take care of flutter echo's and, sufficient sound energy should be there which can lead to flutter because, this is repeatedly happening from one wall to the other coming back. So, loss of sound takes place at every heat, but at the same time if it is having sufficient energy, it will keep on buzzing with in the room. So, short burst of sound like clapping that can lead to a flutter, if you have parallel walls, the sound will keep on buzzing after sometime it will actually disappear.

So, splaying of walls can lead to control of flutter. Just we see that that just we will see that in the next slide. And axial modes actually keep on rebounding, this part we will come in the next lecture that is lecture 7.

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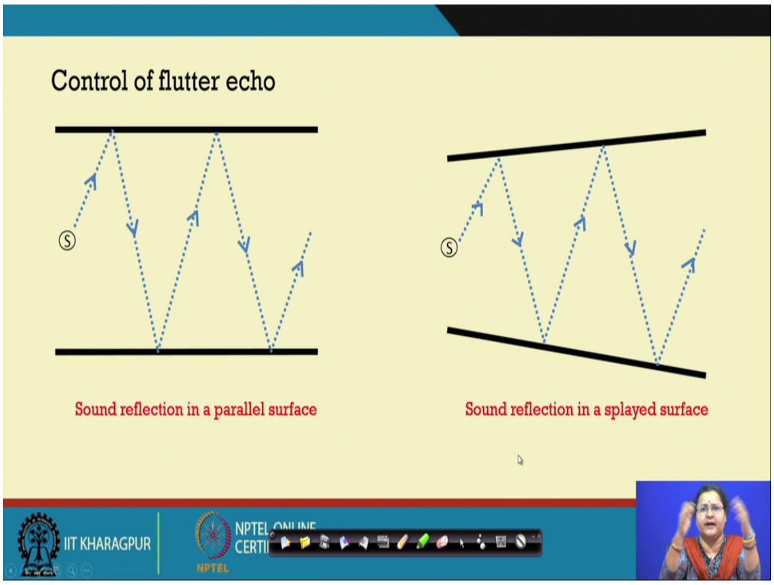

So, how to control flutter echo's as I told you if we have 2 parallel walls the sound keeps on rebounding from surface to surface. And, this helps in repetitive sound inside the room which creates the buzzing sound.

Alternatively if you splay the walls at say a certain degree the sound actually has to travel longer distances with losses and, automatically you can get your get relieved of your flutter echo's. So, that is why you will see for big phases like auditoriums, we go to flare up and go for finding out. We will come deep into this detail later on.

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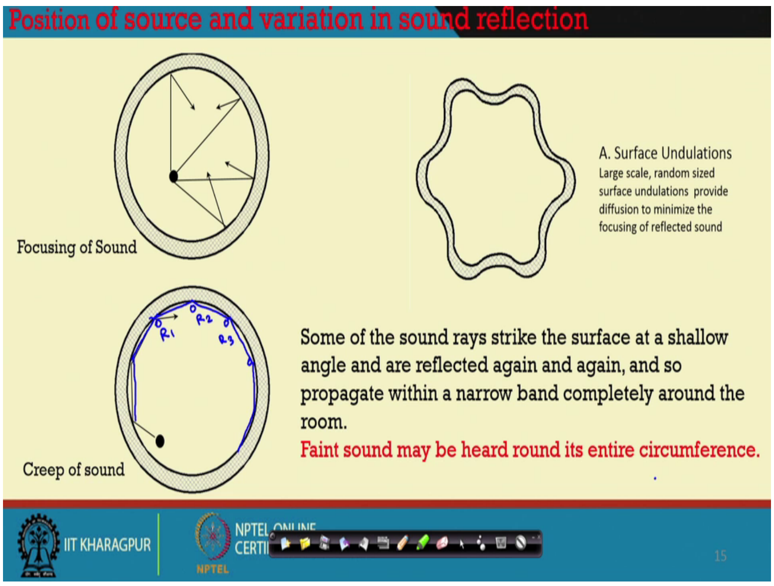

So, coming to the circular spaces, let us see how position of source can lead to variation in sound within a space. And this can be experienced very well in case of a circle, you see we have the source over here and from there the sound is actually moving reflecting one by one from the circular surface and are trying to converse towards a point. You can see the arrow heads all trying to converse towards the more or less nearby the centre. And we see another phenomena in this creep of which is called the creep of sound, where the source is more close to the wall.

The sound is actually taking a shallow angle and moving, moving along the and moving along the wall and, continues to move till it energy is lost. This is called creep of sound. And at any point wherever you can stand the receive is so, you will be capable of hearing even if it is a fable level of sound. And this is the phenomena what happens in case of a whispering gallery. Now, how can you take care of how can you take care of the sound reflections, you can create undulating surfaces.

This is a very schematic figure, you can create a combination of concave and convex surfaces which can nullify such effects. So, focusing of sound is important where actually nothing can be heard and the entire sound will be coming back to the more or less the central area of the circle and, another is creep of sound, where the sound will be moving around the periphery of the wall. So, this is the phenomena what happens in case of a whispering gallery.

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As you had seen the creep of creep of sound along a circular wall, the same can happen in when the two speakers are speaker and the listener vice versa. So, one can be the speaker the other can be the listener, the listener can be the speaker the speaker can be the listener, when they are standing at the focal point of an elliptical curved surface.

So, here you can see the sound originating from the speaker point is the focal point and, the listener is also standing at a focal point. This also leads to formation of formation of sound transfer from one point to another, which is also seen in whispering galleries.

So, as an example we have the Gol gumbaz at Bijapur, Victoria memorial hall or at Kolkata, Saint Pauls Cathedral at London, where this kind of whispering galleries are there and, people make fun over there going there and experience this phenomena. So, what did we what did we try to learn today.

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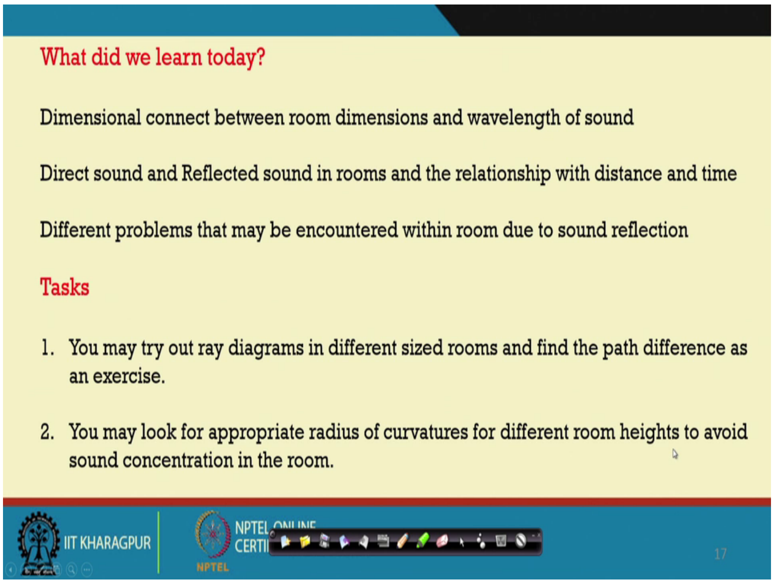

We understood the dimensional connect between room dimensions and, wavelength of sound. We understood the direct sound and reflected sound in room and, their relationship with the distance, as well as time which are very important, different problems that may be encountered within room due to sound reflection.

So, I expect that now you will look into the movement of sound in a different direction that is how the sound behaves in the spaces, where we are actually concentrating while we are designing. So, if we keep this component also in mind; obviously, we will come with good designs.

So, let me give you some task, you may try out ray diagrams in different sized rooms. And find the path differences as an exercise and, you see exactly at what kind of situations you will lead to echo's and, how you can take care of those.

You may look for appropriate radius of curvatures. So, that you do not end up in focus focusing of sound within your floor, that is you have to either make a very flat curve, or you have to think of some other way so, that the curve. So, that the focusing happens beyond the room area where your sound is generated; with this I complete this lecture room acoustics 1 and we will move to the next that is room acoustics 2.