Architectural Acoustics

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Lecture - 07
Room Acoustics (Contd.)

So, welcome you all back. So, we had a session of Room Acoustics 1, where we tried to understand only one phenomena that is reflection which happens within our spaces; with that is the architectural spaces and we understood the drawbacks of it, the problems with it, and we try to know how we can take care of this.

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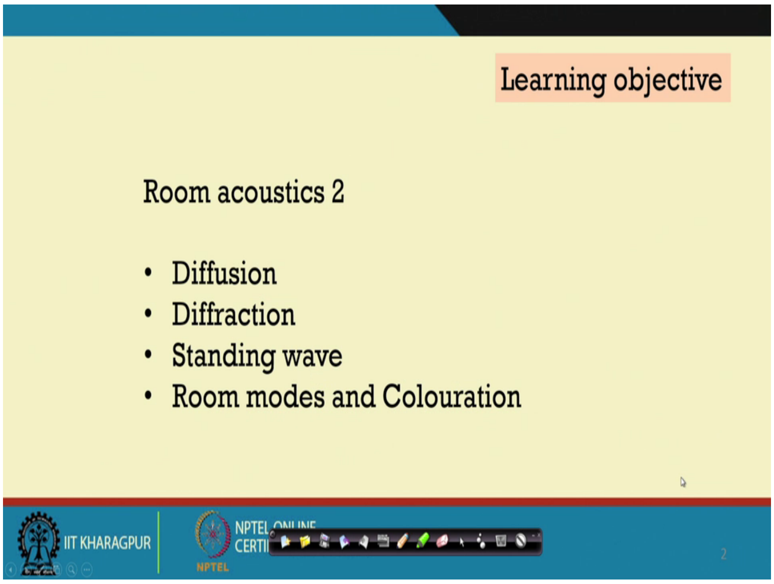

So, we will come to the Room Acoustics part 2 which will deal with the diffusion of sound, diffraction of sound, standing waves, room modes and coloration. So, I have given a basic understanding of what is diffusion- that is scattering of sound, diffraction- that is bending of sound but not on the other two.

So, first let us try to understand the phenomena through ray diagram or by the help of ray diagram the phenomena of diffusion and diffraction, and then we will move to the other two.

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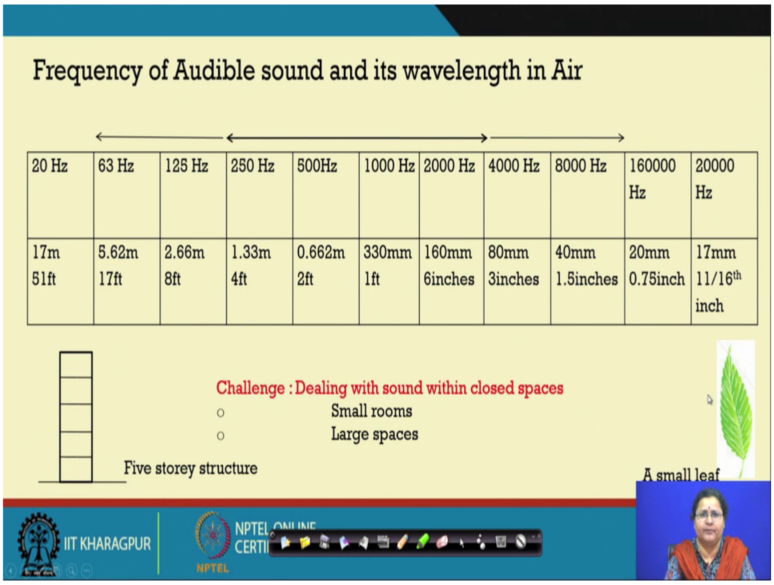

So, again I come back with the same slide where which is showing you the range of frequency which we hear that is the audible range from 20 hertz to 20000 hertz, and also the dimension that is from 17 meters to 17 millimeters. And here we see there are two more arrows where we need to concentrate on; that is the lower band and the comparatively upper band.

So, from 250 to 2000 everything was getting reflected, well with the dimensions of the wall etcetera. But when we are beyond 8 feet, 10 feet, 12 feet, 17 feet it may not be the same when it is a small room. Similarly, when we are on the other side that is having smaller dimensions there also the phenomena of diffusion may not happen, because the sizes or scattering may not happen because the sizes are growing smaller and smaller.

So, we will try to understand through the next slides which we will make you more clear.

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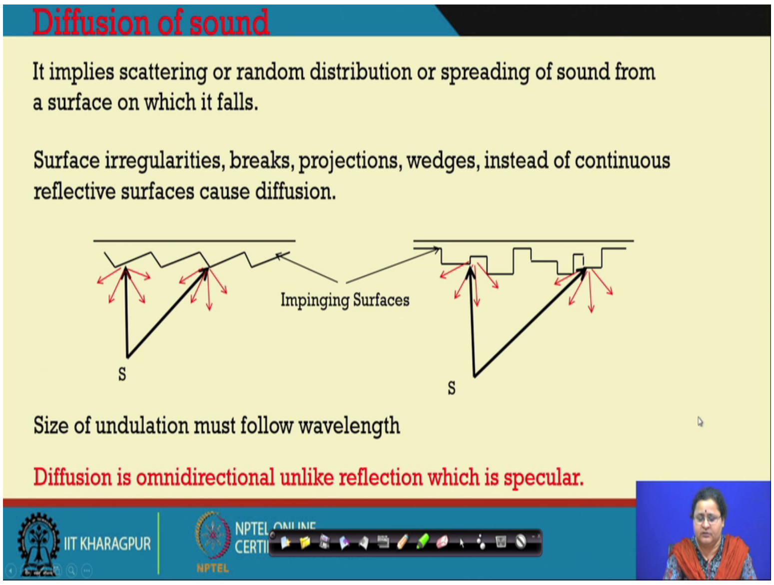

So, diffusion implies the scattering of sound or random distribution of spreading of sound from a surface on to which it is falling. So, it is taking place in all direction it is not only the specular reflection which was happening in case of reflection in one direction.

So, this diffusion is happening in all directions. So, surface irregularities breaks projections, wedges instead of continuous reflective, instead of continuous reflective surfaces can cause diffusion. Where do we have this inside our spaces? Say a curtain, say a blackboard edges say the chairs tables; say any material which is projected out, say a book rack within a classroom all can take part in the process of diffusion of sound.

So, you see here if the surfaces on to which the sound is impinging having irregularities may be at a regular interval, maybe very un-uniform like this. So, the sound hits there and actually does not come out similar to that the way it was incident in case of reflection it was coming out directly in one particular direction. Here it is spreading out all around and you have to be very careful that the sound which is entering into this gaps may get inside that and some may get really reflected if the dimension is of that order.

So, if we have these as small 2 inches 3 inches or say 100 millimeter 200 millimeter some of the sound frequencies which are having smaller wavelength that is the upper part may get directly reflected and some may get diffused. So, whichever are having lesser wavelength can actually get reflected and reach one's ear very sharply, whereas the other range may not reach the persons ear sharply it will be distributed.

So, some of the wavelength can really hits once ears and create an annoyance. So, we have to be very particular of the size of the undulations if we really know the wavelength with which we are going to play in this room. So, the room purpose is very important so that we can take care of the entire wavelength band and then decide on the diffused surfaced lengths and dimensions.

Hopefully you got this point.

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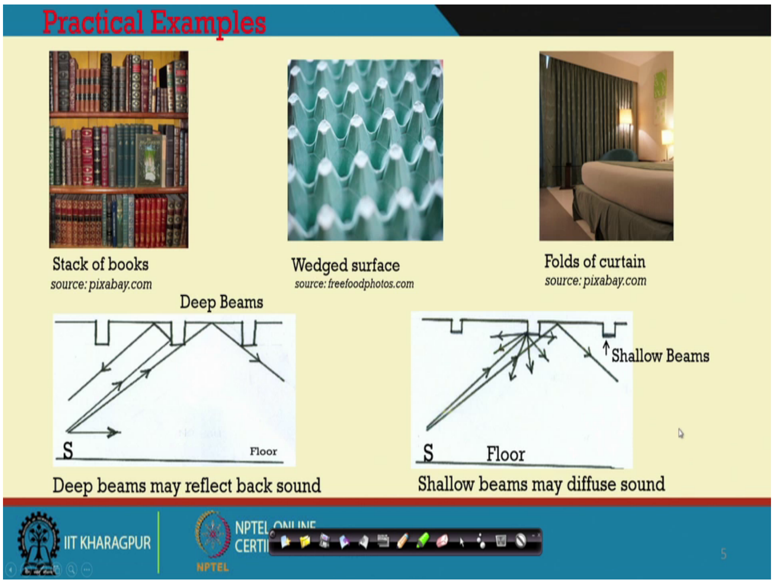

So, let us try to see practical examples. Within a classroom there can be a stack of books which are where you have actually got such kind of a surface: one book may be coming out, one may be inside, one may be at a different dimension, different thickness so actually you can get a profile like this.

On the other hand you can have very uniform shape which is wedge like, this is just a picture of an egg crate we usually use such kind of thing for diffusion. We will come to that later. And these can actually help in reflecting sound in a diffused fashion. You have folds of curtains, you can see in the window, you can see the curtains over there; though they also take a do a big part of sound absorption, but they also help in the diffusion process.

So, actually when you are inside a room the sound comes to you after rebounding very uniformly and that creates a life room. Otherwise if it is reflected on and on receivers can get glares, sound can reach them only by reflection then it becomes a annoyance to their ears. And what I told you: diffused surfaces if are not of particular dimensions not taking care of the wavelength which we are going to deal in that space then particular small wavelengths that is high frequency sound can actually reach your ear and create an annoyance.

We can see practical other practical examples; that is in structures you have deep beams within your big space. Say it is a multipurpose room you have very close beams which are quite deep. Here you can see formation of a flutter also and some sound gets reflected and some gets rebounded back towards the source. So, this is not a good place where sound will get reflected, whereas you can have shallow beams which can diffuse sound.

So, the corners of the beams the widths of the beams can help in diffusing the sound and spreading it to the floor directly so that people can hear or the listeners can hear better.

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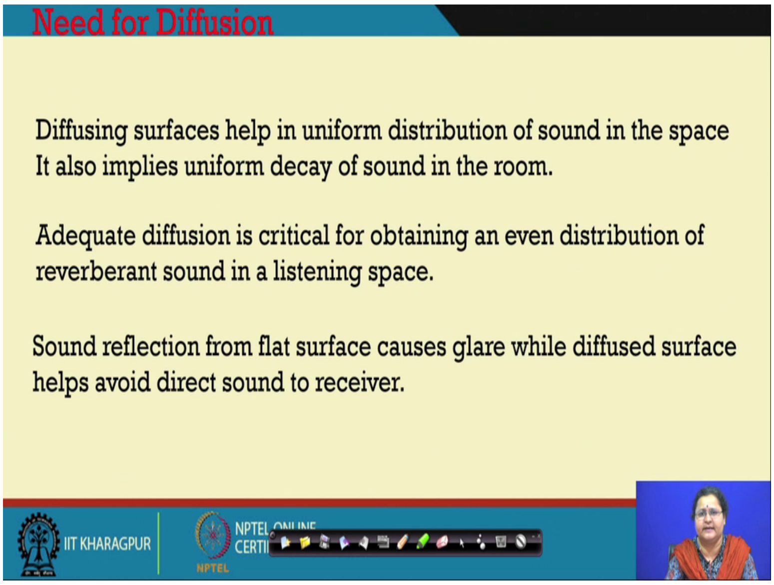

So, what is the need for diffusion? Diffusion helps in uniform distribution of sound in the space and it also implies uniform decay of the sound with in the room. So, it actually distributes the sound energy equally towards the receivers all from the front in the back. Adequate diffusion is critical for obtaining and even distribution of reverberant sound in a listening space. That means, you have to finish the sound which has been originated from a source within a given time that has been told during the phenomena of reflection.

So, you can actually achieve that very evenly if you have the diffusion very happening very evenly within that space. Sound reflection from flat surfaces causes glares, while diffused sound helps avoid direct sound to the receiver. So, that is one part. And other part is what I told you, you have to be very careful regarding the dimensions of the diffused surfaces so that larger frequencies do not get reflected directly, whereas other frequencies are diffused within the space. That will create an annoyance.

We will come to the thumb rules for that after we discuss diffraction. So, we move to diffraction.

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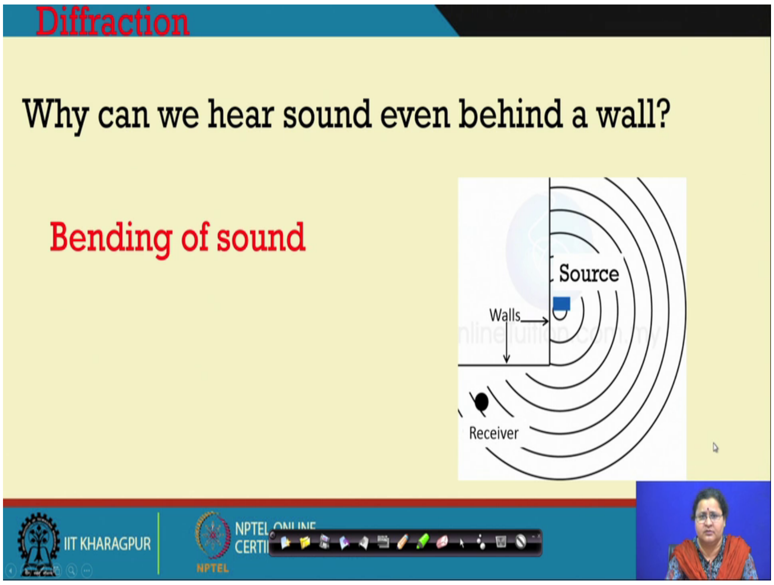

Diffraction is nothing but bending of sound. Why can we hear sound behind a wall, why can we hear sound of a car behind the building? That is because of bending of sound when the source is also not same we can hear some of the sound. That is because sound can bend and go into the receivers ears. This is a simple picture of it.

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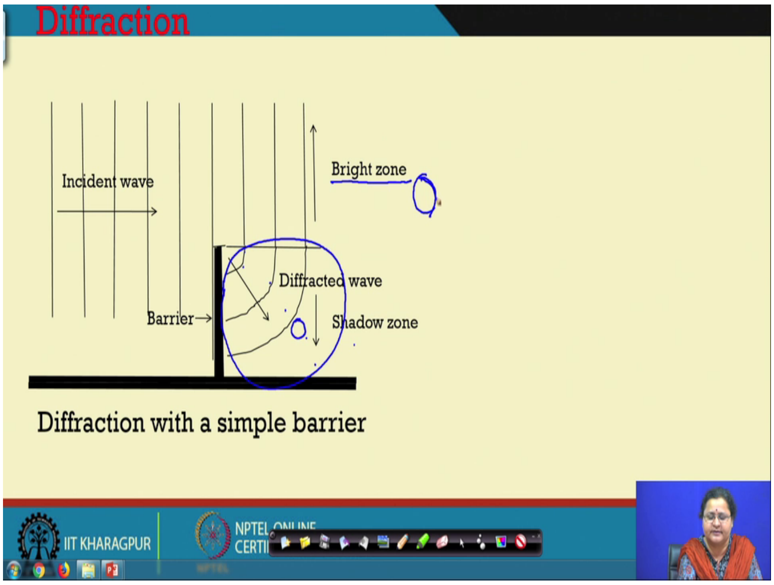

And we see that when incident wave is falling and is getting graded by a barrier, the upper part of the incident wave is travelling, whereas the lower part is hit and it may reflect back as you have known. But what happens? This upper part which is moving by compression and rarefaction is not in this particular zone, this particular zone is devoid of it. So, what will happen the energy will push these areas and will allow the sound to pass to this area; the energy to pass to this area which is nothing but diffraction.

Though one will listen very nicely in this particular zone one will get little sound but will get something, he will be in the shadow zone and one here will be in the brighter zone. So, if a person is standing here will receive direct sound, here if someone is sitting here will get the diffracted sound, here he will listen at a lower energy level here actually he will listen receive the sounds at a higher energy level.

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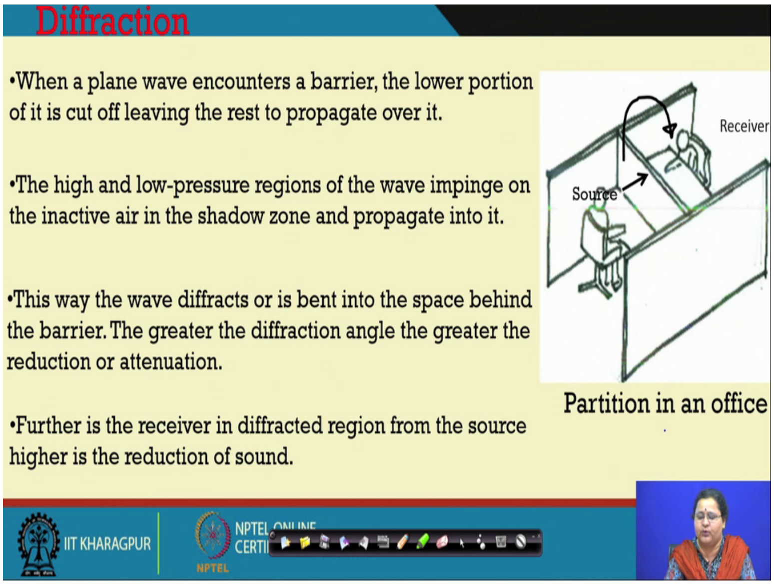

So, when a plane wave encounters a barrier the lower portion of it is cutoff leaving the rest of the propagation over it, and then the high and the low pressure regions of the wave impinges on the inactive air in the shadow zone and propagates into it; what you have seen just now. This way the wave diffracts or is bent into the space behind the barrier. The greater the diffraction angle the greater the reduction or attenuation of sound will happen. So, if you are far; obviously you will receive lesser and lesser amount of sound, but yes he will get something that is because of the phenomena of diffraction.

So, further the receiver in the diffracted regions from the source higher is the reduction of sound. Now, we see here practical example. This is an partitioned within an office; the person here is the source wants to talk to the receiver on the other end. Some sound is directly is working over a telephone may be he is working the sound is being generated and it is hitting the surface and it is coming back. But some of the sound is actually moving to the receiver on the other side.

So, this is the phenomena of diffraction. So, partially you can take care of the sound by putting this barrier, but you cannot completely take care if the partition wall is of not that height. So that is why to give privacy within open office area you have to take care of these particular heights of these partition walls.

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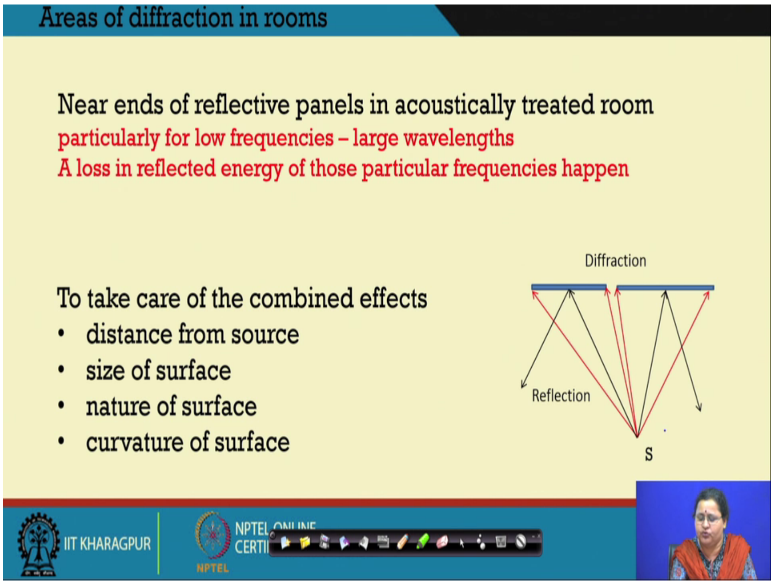

Now let us come to the areas of diffraction in a room. Near ends of reflective panels in acoustically treated rooms particularly the role low frequencies which have large wavelengths the wavelengths actually bend. There is a loss of reflected energy of those particular frequencies and you can actually not get those particular frequencies towards the listener.

So, you have to be very careful what is the gap between two reflective surfaces what you can see here; that the gap is very important. If you have longer wavelengths the sound will bend from the end and those will be lost, those will not get reflected towards the audience. So, you have to be careful what is the length of this reflecting surface so that it does not allow diffraction. If you required diffraction then what is the dimension or what is the gap that will allow diffraction.

So, you have to go by those dimensions which was shown in the first slide which is within our audible range and you have to choose the size of the reflectors either to allow diffraction or not to allow diffraction, whether what will be the dimension of the diffusing surfaces, whether to allow diffusion, so whether to trap in some of the sound inside it.

So, we will come to the process of trapping in that is absorption in certain cases, we will look into how we will take care of sound of certain; of certain wavelength, how we can actually use this phenomena with respect with linking it to the wavelengths. So, to take care of the combined effect of reflection, diffusion, and diffraction we have to know what is the distance from the source to the receivers. We have to know size of the surfaces- that is the reflecting surfaces or the diffusing surfaces we have to know the nature of the surface, what is the size of the undulations or the in case of the diffused surfaces. We have to know the curvature of the surfaces.

So, if we can actually take care of all these aspects then we can deal with sound properly within an acoustically well designed space.

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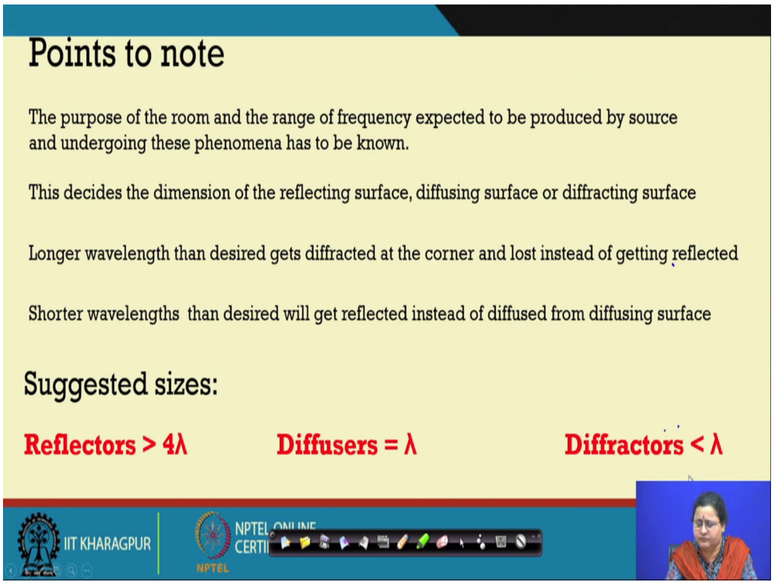

So, the points to note is the purpose of the room, and the range of frequency is expected to be produced by the sound, and undergoing these phenomena of reflection diffusion and diffraction are to be known at the first hand before you design.

And then, these will decide the dimension of the surfaces: different reflecting surfaces diffusing surfaces or the diffracting surfaces. The longer the wavelength then the desired they get diffracted at the corners and lost instead of getting reflected. As I already told you: shorter the wavelengths than desired will get reflected instead of diffused from diffused surfaces. That also I told, which one which can related to short wavelength long large frequency which will be directly reflected to the persons or the audience which will create a glare.

So, the suggested sizes are told that reflectors should be greater than the four times the wavelength of the sound range which you are going to deal with. Diffusers it is given as a thumb rule should be equal to the wavelength which you are dealing with, otherwise it will lead to glare of particular frequencies. And diffractions can happen when the wavelength is less than the; size of the reflectors is less than the wavelength which is our target.

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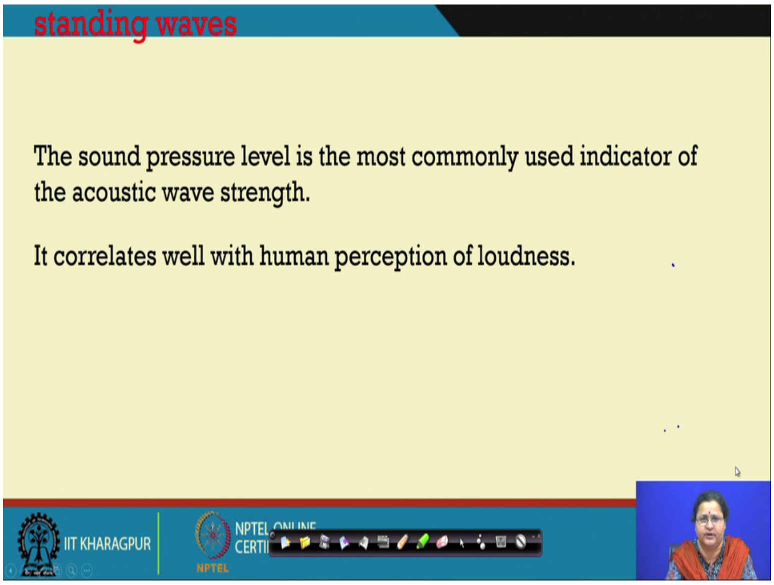

Now, we come to the phenomena of standing waves. You have learnt in the previous lectures that sound pressure level is the most commonly used indicators of acoustical waves strength and it is correlated with the human perception of loudness.

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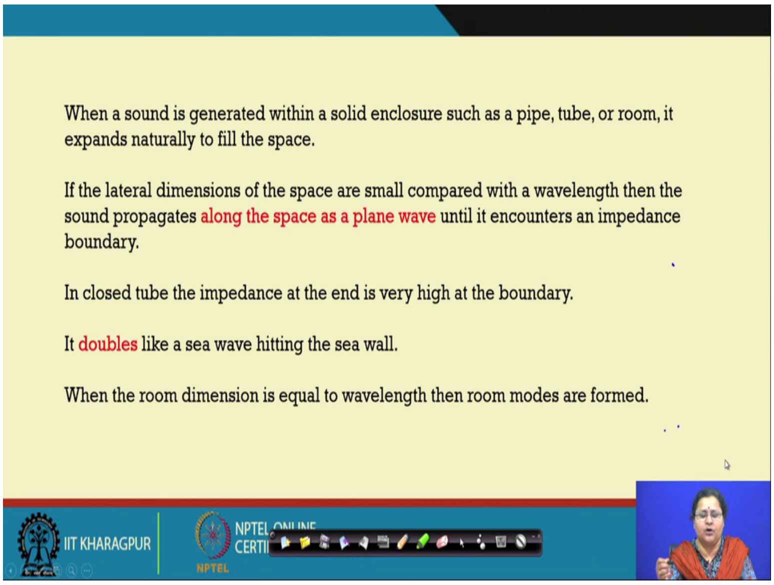

So, if we see that when sound is generated within a solid enclosure; say such as a pipe or a tube or in our case a room it expands naturally and fills up the space. So, the space in front of me is filled up by the sound energy which is thrown by me or by my voice.

If the lateral dimensions of the space are small compared to the wavelength then the sound propagates along the space as a plane wave until it encounters the back or the where it gets the boundary it again comes back and it keeps on going and coming back. In close tubes the impedance at the end is very high at the boundary. It actually doubles like when a sea wave it hits the wall if is it is having a embankment. The sea wave comes and hits very high it is similar or analogous to it.

So, the sound pressure level at the boundary is very high, when the room dimension is equal to the wavelength then it actually comes back and the room mode is formed.

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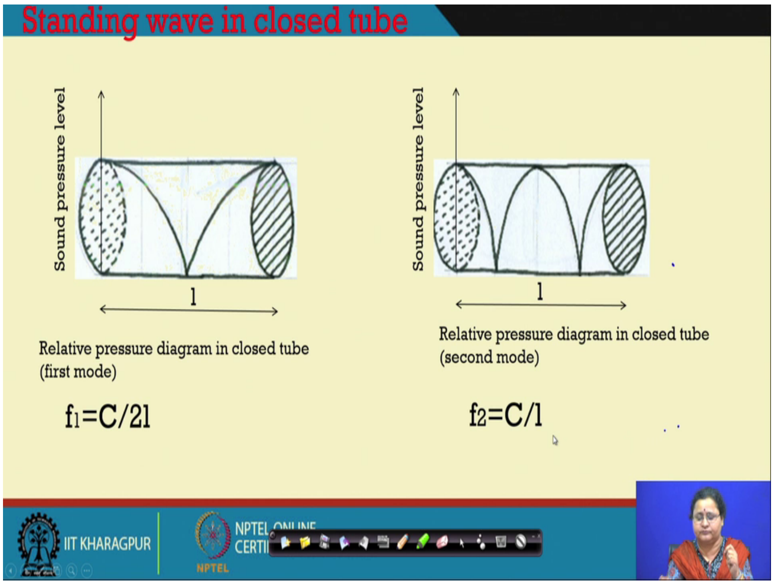

So, we can see this in the small example where it is a closed tube of length l, and you can see the sound pressure level which is marked in the y direction the curve is high at the sound pressure level is high at the ends. And the first mode, that is the first rebounding will happen at the frequency when it is C by twice the length of the tube; where C is the speed of sound and f1 is the particular frequency at which this phenomena will happen.

It will again happen at the multiple frequency of it that is when it is at a when f2 it is C by l. That is the second mode. The same phenomena which is happening in the close tube happens in a room of a small dimension.

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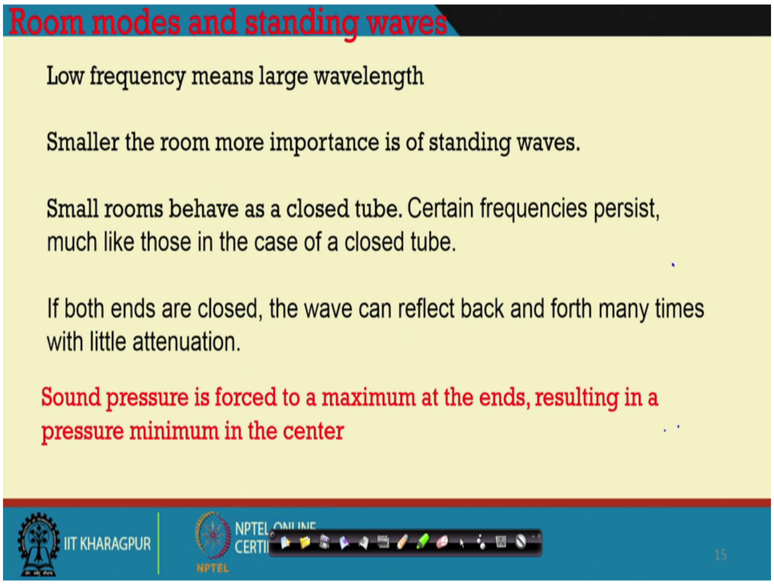

So, low frequency means large wavelength; I am talking about this many a time. So, smaller than more importance is that of standing wave; small rooms just behaves like a closed tube. Certain frequencies will remain similar to that of a closed tube and we will have very less attenuation, if both the all the sides of this room are closed room is closed my sound will go to the back and it will reflect back it will go to the; actually it will move to the wall in front of me and it will again come back, and it will keep on repeat repeating with very less loss of energy. And will happen in the wall side the sound pressure level will be maximum over there.

And as you have seen in my earlier slide you see these are the points that is that the centre those sounds will not be heard. The pressure level will be minimum. So, at the wall side the pressure level of these particular frequencies which by chance gets as a multiple of this room dimension will end up into the room mode, but we cannot allow this chance because we are going to design the phase for a particular purpose and we cannot say this as just happened, we have to take care of that.

So we cannot go to certain, you have to take care of that by putting some precaution for that. And we have know this phenomena and we have to also see if this is happening in this case I am just talking of the axial thing from m y place to the back wall; it can happen from this place to the slide wall, it can happen from this place to the ceiling. So, it can happen in all direction. So, we have to take care that the room dimension should be such that it does not end up in creation of multiple modes within modes within that room.

So, sound pressure is forced to the maximum at the end resulting in special pressure minimum at the centre.

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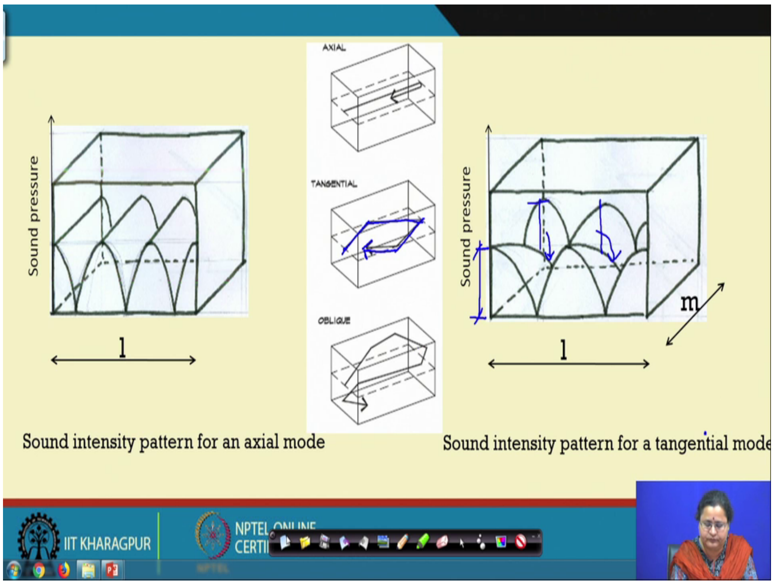

And we can see this happening inside this room. So, this picture shows you how the sound pressure is actually high at this wall area. So, this is just taking one dimension l that is in the axial direction you are thinking that sound has been originated and this is the space sound pressure profile. Seeing, what is happening in at least two directions that is a tangential which you can see in these boxes the sound is moving from the source which is here and it is moving through this way in this tangential plane then this is the sound pressure level profile.

So, you can see within the room there is no sound in these areas for that particular wavelength and it is having very high sound pressure level at these corners, these walls. So, this side walls are experiencing high sound pressure level that is called bass. So, we have to also know how to take care of these, and when it is oblique it is father difficult to draw.

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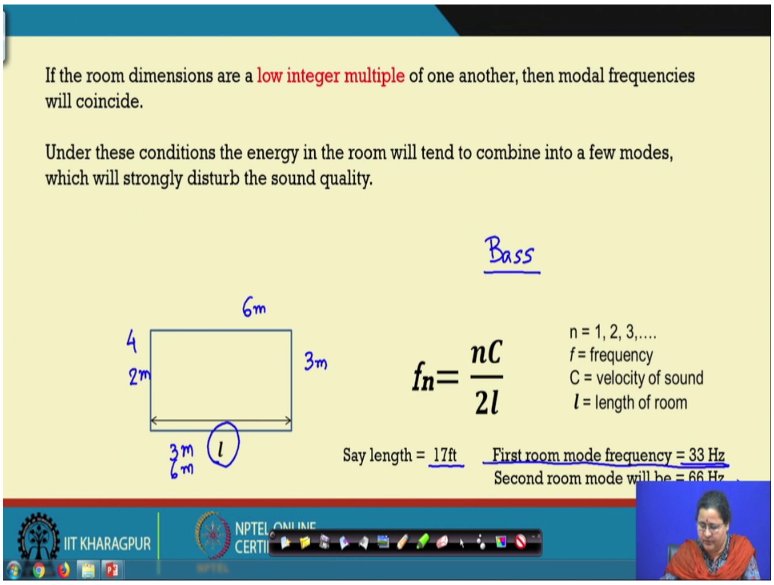

So, let us see if the room dimension are low integer multiples of one another, then model frequencies will coincide you can see if this is length l, if this was also l, and the height was also l what would have happened; all the sound pressure would have been confirmed for the particular frequencies which is actually coming out from this dimension l that would remain inside the room and that would have created an annoyance and that is bass. So, if we have this dimension known to us, and if we go for different different proportions of our rooms we can take care of certain part of it.

So, you can see for is equal to 17 feet, the first room would frequency is 33 hertz. So, the 33 hertz will be having maximum sound pressure level inside this room when we are only talking of this axial dimension. If this is having a breath which is a multiple or say the breadth is also l then the effect will be further high.

The second room mode that will happen will be at 66 hertz and this will go on. And that is if we go for a rectangular room which is say 2 is to 3 then, say this is 2 meter this is 2 meters, this is 3 meters or say this is 4 meters, this is 6 meters; these are 1.5 times the other. So, then you will end up with a different set of frequencies getting the effect of bass. But if they are pure multiple say this is 3 meters and this is 6 meters that is twice of it then the same will happen for this 66 hertz. The same will happen for 33 hertz and multiples of this, so this will create further annoyance.

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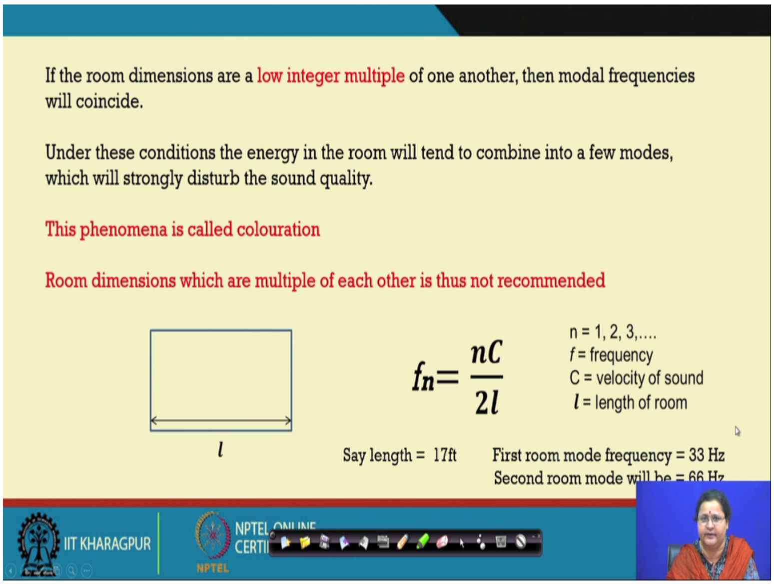

So, this phenomenon is called coloration. And room dimensions which are multiple of each others are not at all recommended.

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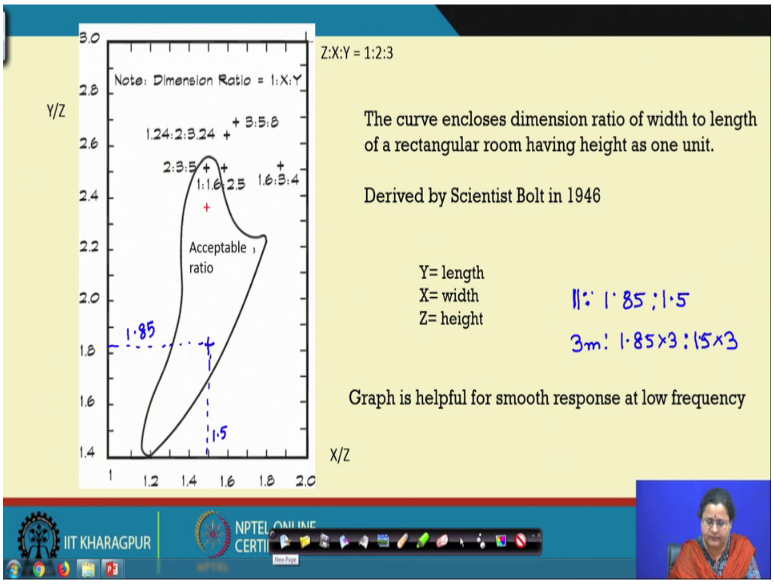

We see scientist Bolt in 1946 gave us this graph. When the Z that is the height is equal to 1 you can follow this graph. You are you should be within this acceptable range are which actually says that if you are in a point here that is the proportion is height is 1 that is Z is 1 and if you put it down it is 1.5 and if you go this way you can have something 1.85. So, where height is 1 you can have a length of 1.85 is to 1.5 ratio. So, if you have a height of say 3 meters then your length will be 1.85 into 3 meters and then your width or the breadth 1.5 times 3 meters.

So, if you follow your room dimensions within this particular zone then you can actually avoid these room modes. So, this graph will be helpful to you for smooth response at low frequency but, here I also give you another line important point. You should not have your points lying on this particular line, because here the proportion height is the height is to link is 2. If you actually go take point somewhere here as your proportion you will end up with bass frequency if that is generated in that room it will be a problem to deal with.

So, hope you understood this. So, this graph will help you in taking decision what should be the right proportion of the room to avoid bass or avoid standing waves or room modes. So, what did we learn?

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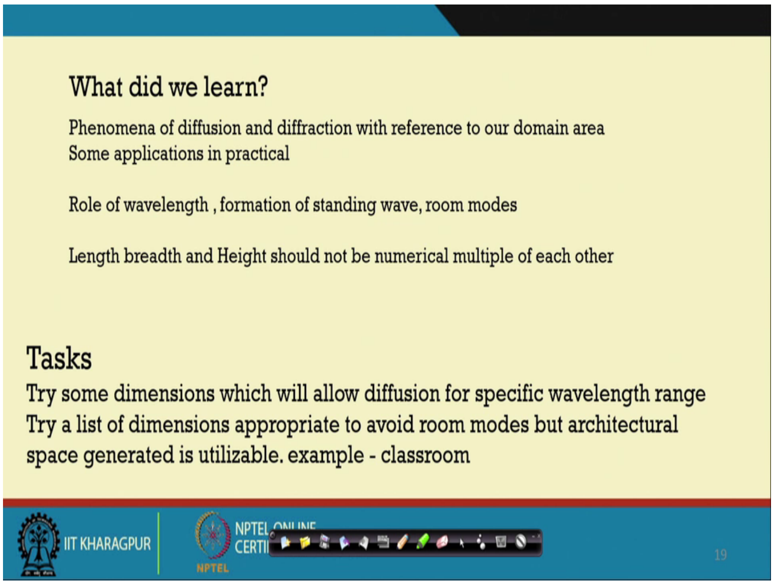

The phenomena of diffusion, diffraction with reference to our domain area, we have also talked of some application in practical, we understood that the role of wavelength is so very important in the formation of standing waves and room modes, it is also very important in the phenomena of diffusion and as well as diffraction. But that was not much of important when we were dealing with reflection.

So, length breadth and height should not be numerical multiple of each other. That is the very important lesion which you learn and which will be one of the tools. You have also understood that reflector length, diffusion length, diffuser length, and diffraction length are also with order of their wavelengths. And you can also try out some dimensions which will allow diffusion for specific wavelength range, you can try out to list of dimensions appropriate to avoid room modes.

But architectural spaces generated so that the architectural spaces generated is utilizable. Say for a class room: what should be the proportion? We are having the height which is a constraint for us. So, if you are designing the class room you know the height, but you can change the width and the length proportion to avoid such standing waves. Nowadays we are not having windows in class room we are having a C class room. So, this kind of this kind of situations of having standing waves within the room will happen in near future.

So, you must be very careful. In our classrooms we have windows, we have doors sometimes it is open and some of the sound can move out. So, we do not experience this if you say in practical terms. But, if you have an air conditioner classroom the doors will remain closed, the windows will remain closed and it will actually behave as a closed tube. So, if sound over there is of the order of the wave; the wave length of the sound is of the order of the room dimensions you will really encounter such problems.

So, with all these learning we will move to the next lectures.

Thank you for now.