Energy Efficiency, Acoustics & Daylighting in building
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Lecture – 45
Auditorium

So, look into auditorium design and you know that is what I was telling you in the last class that we need adequate loudness throughout and clear viewing because good viewing means good listening and if it is dramatics and facial expressions are important.

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So, 22.5 meter is a distance what people can you know visualize, this is not this is not the this is not, I mean you can view faces and things like that because it depends upon the adequate the angle it sets what we will call visual equity we will see that later on, but that is for small letters you know. So, the distance, the angle that the expressions you know create. So, 22.5 meters is considered to be the appropriate distance and should not have external noise right and free of certain defects. So, most important is the proper reverberation characteristics that is part of the auditorium.

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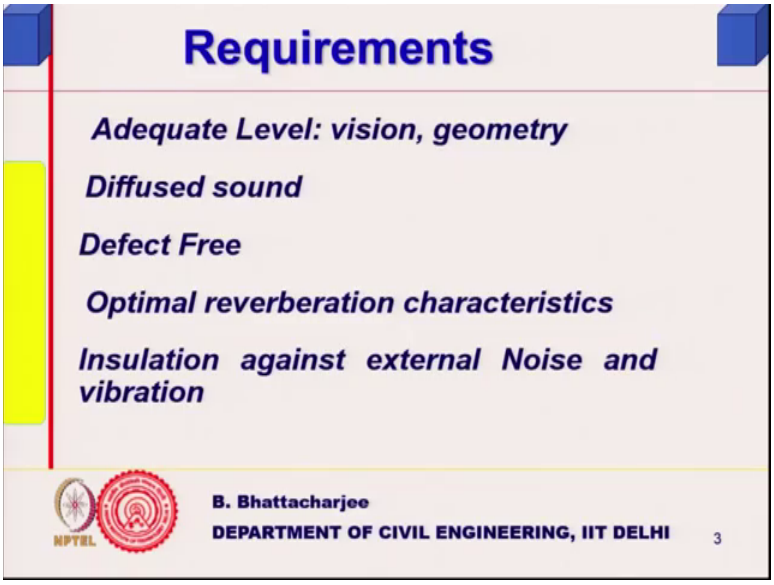

So, let us look at it, first thing adequate level vision and that is done by geometrical design, geometrical design the shape, profiling on the ceiling, wall shape and all that they and sound should be as diffused as possible; that means, you must have sufficient reflected sound right and should be defect free as I said we will define what are the defects possible in an auditorium and of course, optimal reverberation characteristics. So, to make a diffuse sound you will have absorbers or reflectors in appropriate places right, optimal reverberation characteristics you remember the formula we had again it is related to s alpha bar.

So, again the absorptions and so on related to that and for outside noise course insulation which you have discussed so far.

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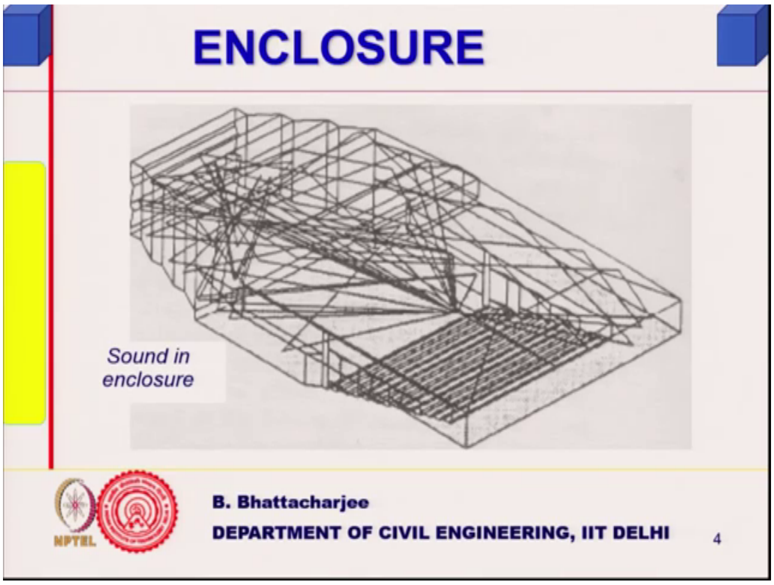

So, this we have remember, you remember the enclosure scenario.

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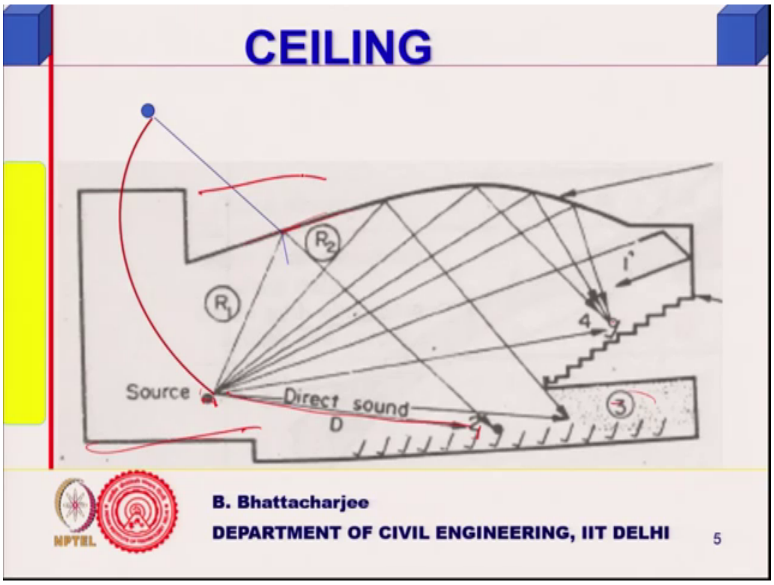

This was the enclosure scenario now this exactly the same thing, you know that you have a source then you have a kind of give the source somewhere there in the stage then you have the you know may be balcony or something of that kind. So, from the source infinite number of reflections will reach the receiver depending upon the position we have, it is important to have ceiling reflection because if you see this is the profile of a of an auditorium typical proscenium is here, you know stage.

Now, the source could be somewhere here direct sound to this audience let us say it reach like this, now several reflected sound will reach right several reflected sound will reach you know. So, this reflected sound difference you know this reflected several reflected sound that reaches that reinforces the direct sound especially at distances which are away from the source. So, rear of the auditorium reflected sound should reach that is the idea, but then this diagram also shows some of the defects.

For example you know this area is sound shadow, I will come to that later on, but let us see how do I design this profile, it depends upon this profile how much reflected sound will reach to the rear. For example, if I have a flat, you know if I have a flat reflector its ceiling is flat, let us say it is flat like this, then what will happen?.

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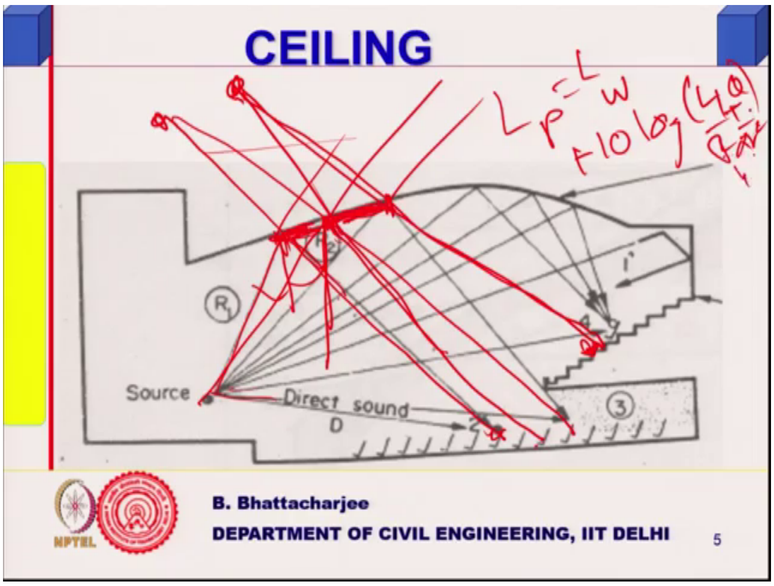

From here angle of incident is equals to angle of reflection. So, it will reach here only, this will also reach here only, but I should have the ceiling profile such that it actually directs it away that is the idea.

So, geometrically this you can do, geometrically you can do very easily for example, assume the source as shown and I want to find out the reflector, reflector you know profile here, reflector profile here. So, what I do this point I consider and this is my receiver and this point here I want to find out the reflector. So, I just divide this angle by 2 bisect it. So, this is the angle of incident, this is the angle of reflection and my profile should be normal to this right, reflector profile should be normal to this. So, I draw a normal profile here you know if I if I remove all this, if I remove this erase out everything I will see the normal profile somewhere the red coloured shown, my virtual source then I if I extend this line this will be the virtual source from geometrical optics or geometrical you know acoustics from geometrical consideration because if I draw an arc like this extend this line, this arc cuts this line here. So, that is the virtual source.

So, if I extend this, you know if I extend now the reflector profile such that I, I want it to reflect up to this point then just extend this reflector profile to profile up to that you know like draw the line from this point to this point, this is the profile of the reflector. So, this reflector will reflect the sound from here to this one and sound from this point it will come to this. So, this will reinforce the direct sound the reflector sound, this portion of the ceiling will actually direct sound from this source reflected sound from this source to this zone.

Similarly, let us say if I want to extend beyond this point, now I will have you know and I want to, I want it to reinforce let us say somewhere here. So, again same thing again divide this divide this into 2 parts equally bisect that angle, extend this point and accordingly you can go on extending the reflector. So, profile would be something would look something like this. In fact, you can do a geometrical profiling section by section. So, you have this portion of the reflector, there is another portion of the reflector and if you join them together you get.

So, what you see for example, you see here this reflects here to the rear seat and then this portion will reflect somewhere there. So, every portion you can actually geometrically decide, what is the principle? Consider the point of your interest, consider the point of your interest which is at sufficient height from the source I am talking on the ceiling this is not the roof, roof is above. So, sufficient height this is the point you join and you pre decide where your reflection should go, first set.

So, the lets say this is the reflection, you know this is the point where I want reflection to go, reflection to reach then join this line divide this into 2 parts right normal to this will be my reflector profile, extend this you get the virtual source and what is the length of the reflector. Supposing I say that this profile will reinforce the sound up to this then join simply this much this will be the profile then next you want to get this profile here and you say that for this point I would like it to reinforce the sound between this point. So, join like this divided into 2 parts draw a normal to this and extend this virtual source somewhere there and I say the last point where it should reflect is up to the balcony. So, profile will be something like this. So, step by step one can actually design this profile and length of the, first you have to decide up to which point it should go the reflected wave should reach from that profile. So, you will have its something like this, you know if this is where the source is it is something like this I am taking the cross section.

Now, the length is, see for example, here the virtual source. So, I have decided the last point where my reflection reflected ray should reach is this. So, from virtual source I simply join this point, this is the because that normal already I have normal to this I have already drawn wherever it cuts the normal there is a length of the or width of the reflector you can say. So, it will look like this you know in this direction it will look like this. So, hole of this profile will be something like this, that will ensure that you get sufficiently reflected sound on the rear portion because direct sound will reach to the front portion, rear portion is the one which will not get direct sound it will get less and less direct sound as the distance increases because you know L p is equals to L w plus 10 log 4 by R plus q by pi R square you know q by pi R square pi R square.

So, as R increases direct sound reduces right was it pi R square or I pi R square I think 4 pi 4 pi R square, yes 4 pi R square. So, as the distance increases as the distance increases that sound reduces. So, you need to reinforce the rear of the auditorium by reflected sound. So, you can design the profile for example, this is not a very good design this is. In fact, fairly bad, but then this is not meant for it is not a very large auditorium either it has got all absorbers at the top perforated as you can see.

So, it will actually it will largely dependent on the direct sound, what they have done is they are putting speakers right and having speakers at the rear is also not a very good thing, it is a small space is fine you know the speakers positions are also to be designed because that can create defect and electronically also it is a problem it can cause feedback. You know if you have you know like you know the mic microphone is somewhere here it the reflected wave sound comes there could be problem of those kinds. So, that is that is sort of scenario ok. So, this is how it decides ceiling profile, the ceiling profile is decided in this manner.

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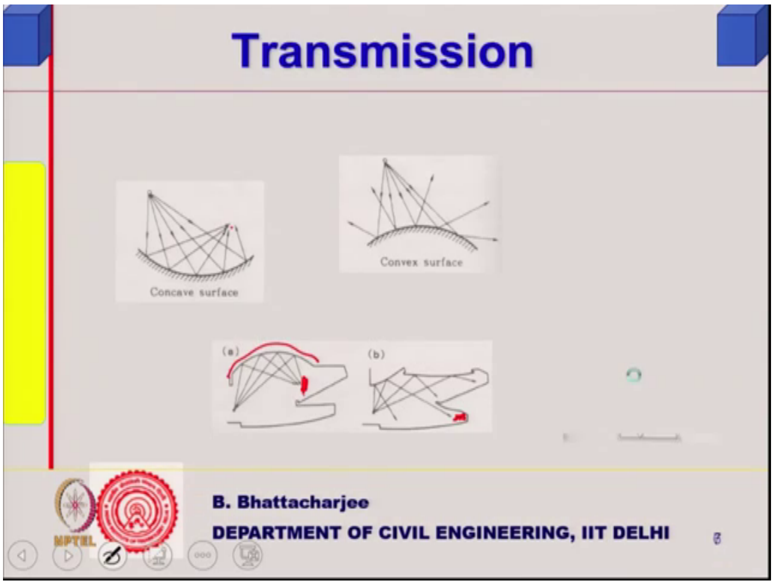

Then these are some kind of you know profiles which convex surface will have a tendency to diffuse it, any convex surface will have a tendency to diffuse it. Any concave surface will tend to focus it somewhere and in an auditorium if you have this concave this will have a tendency to focus the sound here, create a hot spot and you will have less sound elsewhere. So, this can results in what is called a defect focus formation sound concentration as we call it this is this can be a sound shadow region, this can be a sound shadow region where sound does not reach for example, this is the sound shadow region this 3 sound reflector sound is not reaching direct sound also will be less right.

Now, this can form a sound shadow region. So, shapes are important from that point of view, shapes are important from that point of view right.

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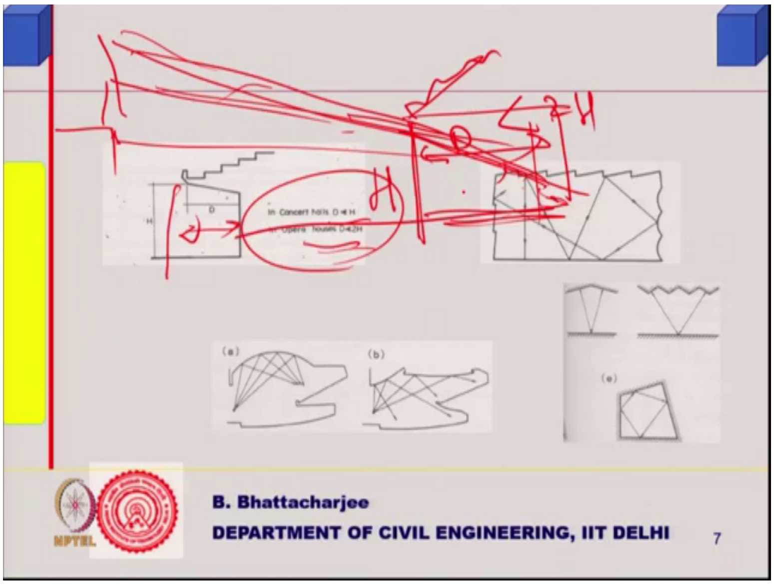

Basically this distance depth of the, depth below the balcony right this depth that we are talking about this you know this, this portion this D should be less than, D should be less than twice H, this should be less than 2 H. In opera houses D should be less than 2 H, in concert hall D should be less than H where H is this height. So, this is the height of the balcony for example, this was this was the balcony steps, this was the depth you know and your source was somewhere here. So, from source who said that sound shadow of formation takes place, that 3 that I was showing if you want to avoid sound shadow if this is height is H this D should be less than 2 H for opera houses or should be less than H for concert halls we would for.

So, this D should be. In fact, good idea, we keep that D less than height, height of the balcony well basically you should it should you know the direct sound will source to this is an there is a kind of idea of base, a thumb rule sort of thing not really, but the idea is that direct sound should reach to the last one. So, if this is H and this yours 45 degree then this is also is equals to H, but if the source is at somewhat lower level right then it can go a little bit deeper it can go a little bit deeper. So, if you have opera house where actually human performances are also there, human height is less concerts it you know the reverberation aspects are also there.

So, this is based on really thumb rule, but idea is this 45 degree angle fine it can reach up to the last seat, but if it is, if this is angle is less than that then can go a slightly more so, but never more than 2 H, they should not be more than 2 H. In fact, it is usually good to have it as less as possible, these goes to H possibly is a good idea, 22.5 meters of maximum distance you can see. So, your capacity increases viewing becomes difficult because the length will become more then you provide with the 22.5 meter you put it a higher level. So, that is where you need right ok.

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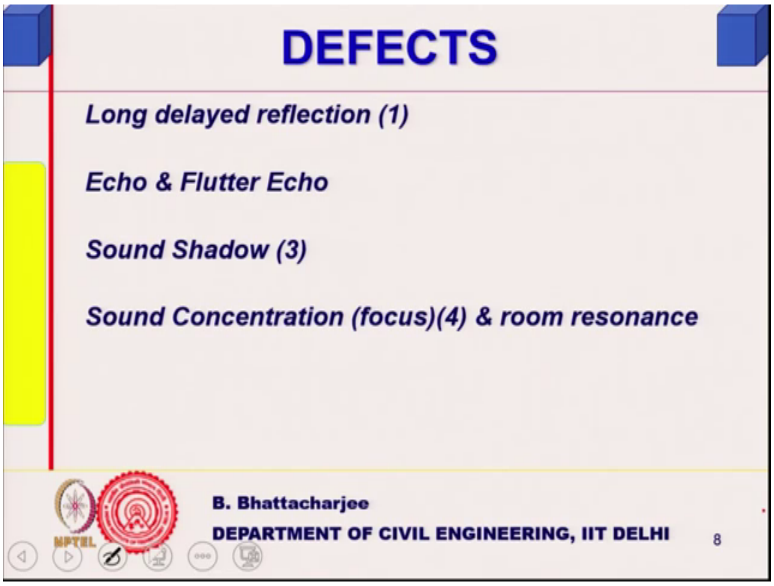

So, one long delayed reflection is other kind of defect, echo flutter echo, sound shadow and sound concentration and room resonance these are kind of defects that you can find in the auditorium.

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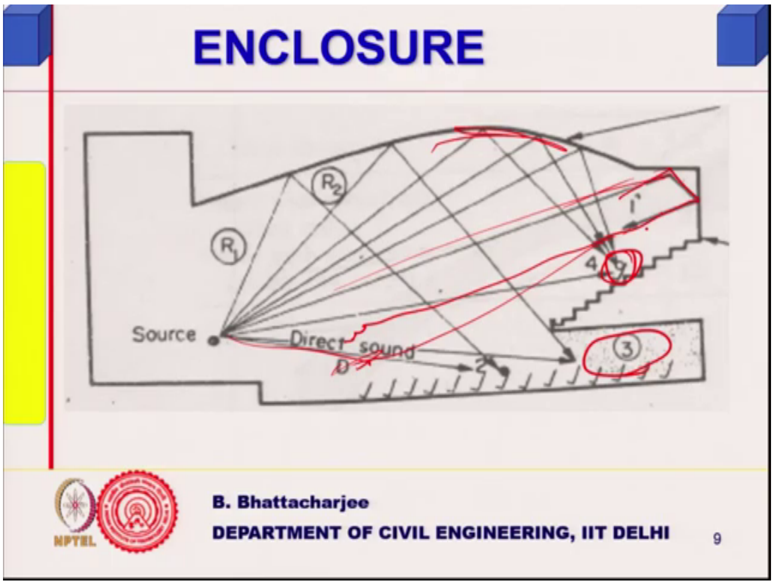

Let us see this is where it shows the same diagram back. So, this is what sound shadow, one was long delayed reflection now if I have something like this will come and reach here, you know somewhere the audience it will reach somewhere here, now look at the travel path it is too long. So, direct sound will first come and reflected sound will come much later it will block the direct sound that is reaching. So, long delayed reflection is above you know one should avoid. So, there is a the time delay between direct sound reaching the audience and reflected sound reaching the audience that should be minimal, depending upon type of performance.

So, I will just talk about that I will just let you know. So, this is called long delayed reflection right, then shed the sound shadow I said if this is ferrical or concave it can cause a focus here, a hot spot we do not want such a hot spot then you know you will have high sound here nowhere elsewhere there will be no sound know there are it is not diffused distribution will be affected. So, you know this is also not desirable, this is not desirable right flutter echo is this.

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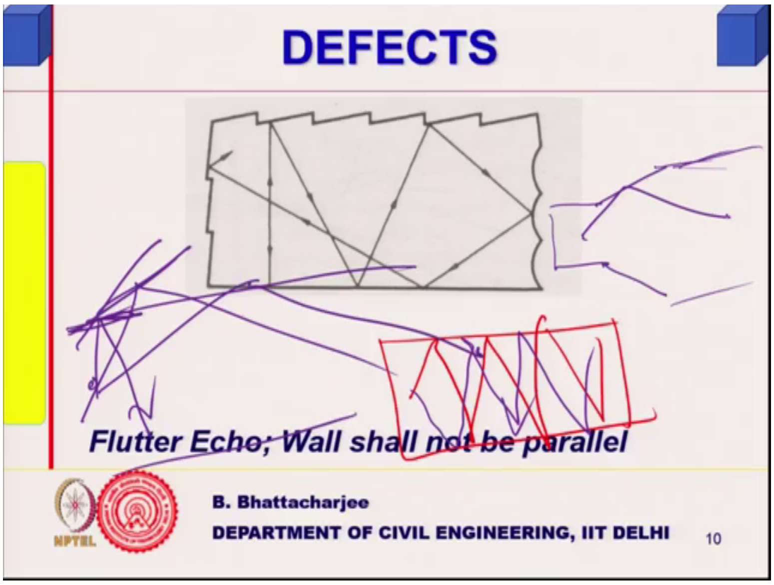

When you even your parallel, you know when you have parallel for example, this is your parallel wall. So, what will happen, it will reflected wave will travel like this and the other reflected wave other reflected wave might travel in like this, this causes a fluttering sort of an effect. So, when your parallel wall close to the proscenium or stage source they tend to cause a reflection back and forth, parallel walls because angle of incident will be small. So, will be the angle of reflection.

So, you have and that cause a kind of a fluttering somewhere in this front seats. So, that is called flutter echo and not a desirable thing. So, what you do either put absorber near the stage so that you know nothing is nothing comes back from there it only reflects from for example, if this is the source and if it goes there then it will go somewhere like this, but if it goes here then it will be reflecting back. So, these portions you can put in absorber or at least keep it inclined, you know make it inclined then this will different direct it to the rear.

So, best shape is actually a fan shaped, best auditorium shape is fan shaped something like this, this is your stage right and then of course, you can make it whichever way you like. So, this will reflect away, a fan shaped one is a good shape near the stage it should be inclined right and if you cannot inclined it for some other reason because space is not available or whatever it is put absorber switch our code also says we will look into that. So, flutter echo to avoid flatter echo you do this. So, flutter echo is you know like parallel walls reflecting from both the sides near the stage, they cause us a kind of flutter. So, this is not desirable, what is the distinction between echo and flattery?

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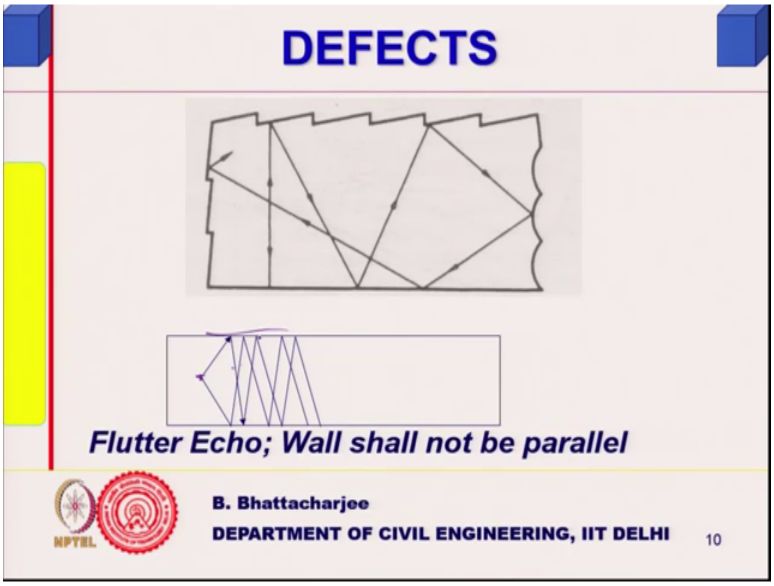

I mean echo and long delayed reflection, long delayed reflection does not I do not hear distinct sound for example, you know in hills as you know if you hills you like something you utter loudly after sometimes it saying sound comes back distinctly you can hear it second time. In case of long delayed reflection you do not hear it second time, but your direct sound and reflections out there overlap as a result it get distorted completely. So, long delayed reflection generally occurs from the rear of the auditorium as I have shown in the diagram and this is what is flatter echo this is what is flatter echo this is what is flatter echo? You know so this source is here. So, this parallel walls are it should be avoided to have flutter echo get rid of flutter echo.

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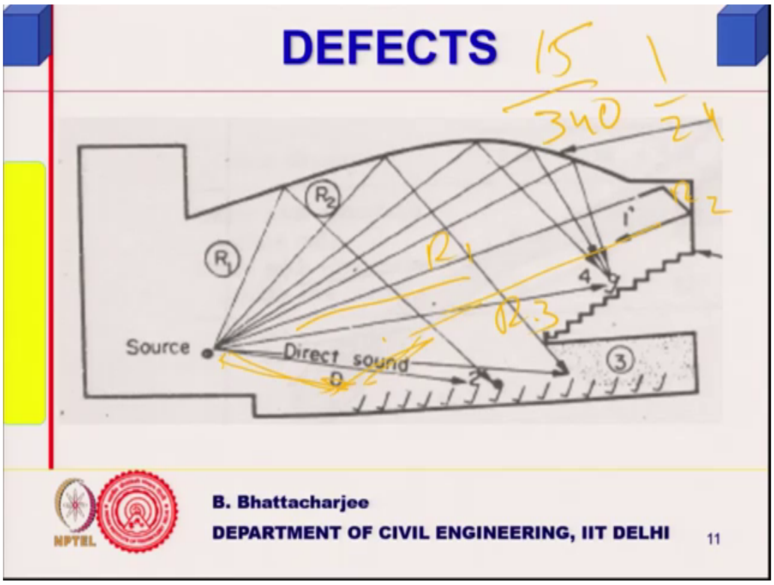

So, focus is this, this is.

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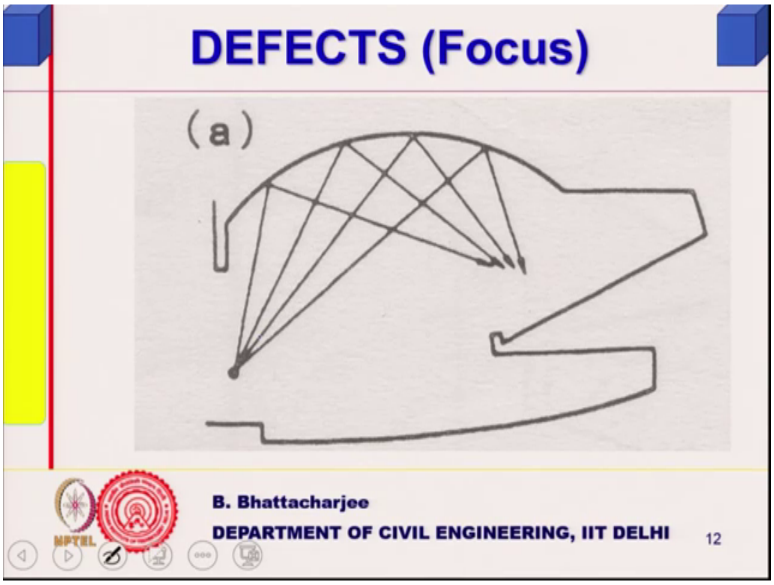

For focus formation and room resonance can occur.

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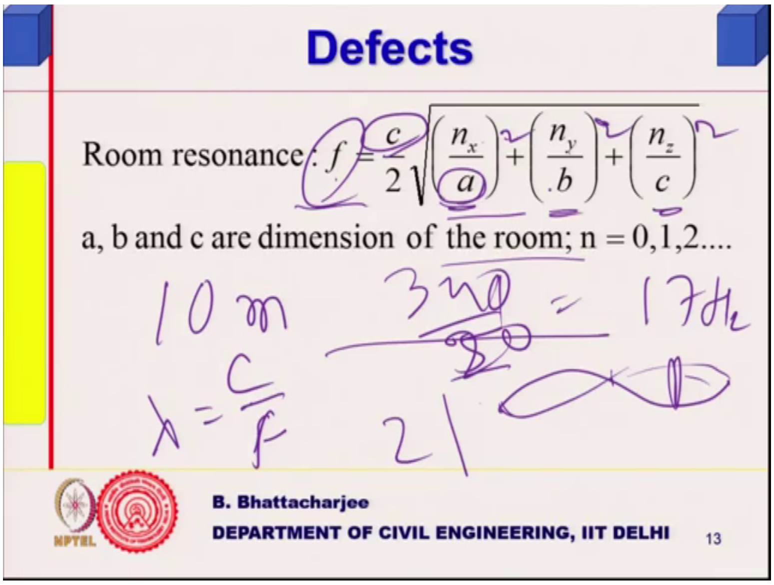

Standing wave formation can occur within the room itself for example, direct sound and reflected sound if they superimpose constructively then it will have some points where you will have very high sound some points you will have dead spot or low sound. So, hot spot and dead spot can form depending upon the wavelength of the sound or frequency of the sound and room resonance formula is given like this, c is the velocity of sound this is the frequency at which room resonance will occur n x n y m z are numbers they are simply 0 I mean 1, 2, 3 you know integers they are integers a b c are the dimension of the room, a is may be length dimension this is the width, is the height.

Now, just for the sake of it lets understand let us say n y is equals to 0 and z is equals to 0 n x equals to let us say one. So, if that the frequency one over the length of the one over the length you know that the frequency or half wavelength, what is the lambda? Lambda is equals to C by F lambda is equals to C by F. So, what is the f is this. So, what is lambda C by F this will be lambda will be equals to 2 n x was 1. So, basically there is a square there is a square I think this is a mistake the sum of square it should be square. So, when wavelength matches with the room dimension it will have, it will have these points actually they will cancel each other some points they will add each other.

So, this is I think this should be square actually then under root. So, it can occur in this direction longitudinal direction, there can be a standing wave formation in the transverse direction there can be a standing wave formation depending upon the wavelength comparable to the dimension. It can occur in this diagonal, floor diagonal of the floor or occur in the 3 dimensional you know the diagonal from this corner to the other corner. So, depending upon the values of n x, n x n x. So, it is only when room dimensional is comparable to the wavelength room resonance can occur usually you see if it is let us say 10 meter, it is a dimension of the room some side and what is the frequency then 10 meter is a wavelength I mean room dimension. So, lambda by 2, 5 meter right and 340 divided by 5, 340 divided by 5, lambda by 2 sorry 20 let us say lambda by 2 is 10 meter let us say.

So, 340 divided by 20 is how much. So, it is about 17 hertz. So, at some low frequencies this can over 17 hertz is usually not, but one can see that check that those frequencies are matching based on this formula based on this formula on my check that if it is actually room resonance can occur or not at certain frequencies you have predominant frequencies. So, at some lower frequencies this can occur where room dimensions a lot if it is free meter then at higher frequency you know resonance can occur.

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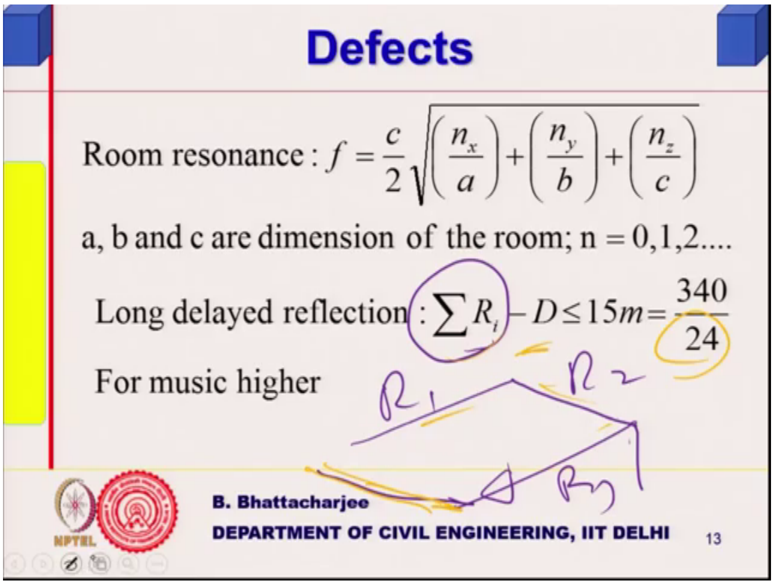

So, this is the formula one can use and find out the room resonances.

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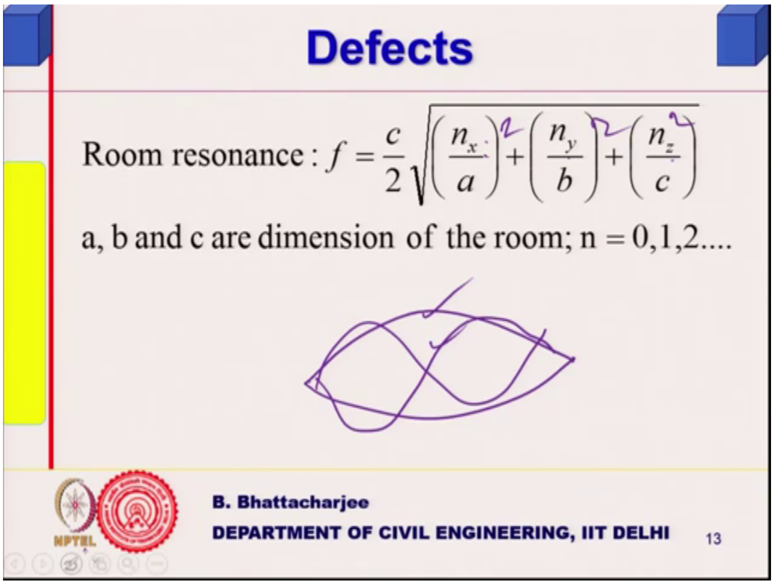

Resonance can occur, standing wave formation can occur supposing the it is something like this or something like this. So, the wave length is multiple of you know wave length and the room dimensions, if they are matching except one case it can this case or next case or similarly 3 waves are contained you know standing wave tube if you remember standing wave tube is a something same thing. So, standing wave formation can occur in this direction, this direction or this direction or diagonal directions. So, if all 3 are 1 this is 1 this is you know n x is 1, n y is 1 and z is 1; that means, is occurring in diagonal direction.

So, one check one can do this check one can do this check basically, long delayed reflection the all the sum of reflected path you know because reflected path will go like this first reflection might reflect again from the rear. So, R 1, R 2, R 3 third reflections and then direct sound might reach from somewhere from direct sound might reach somewhere something like this. So, this sum total of all the reflected path reaching to the audience minus the direct path if it is less than 15 meter right then wrong long you know if it is less than 15 meter long delayed reflection will not occur right because the time would be the is basically for speech 24 seconds it is more important for speech actually.

So, 340 divided by 24, 24 340 is a velocity 24 the time delay you can distinguish the sound depending upon the time. So, 24 is I think 24 seconds is one of the high guidelines. So, 340 divided 15, 340 divided by 24 is how much it is around 15 am I right. So, 10 100 divided by 100 divided by 24 is 4.

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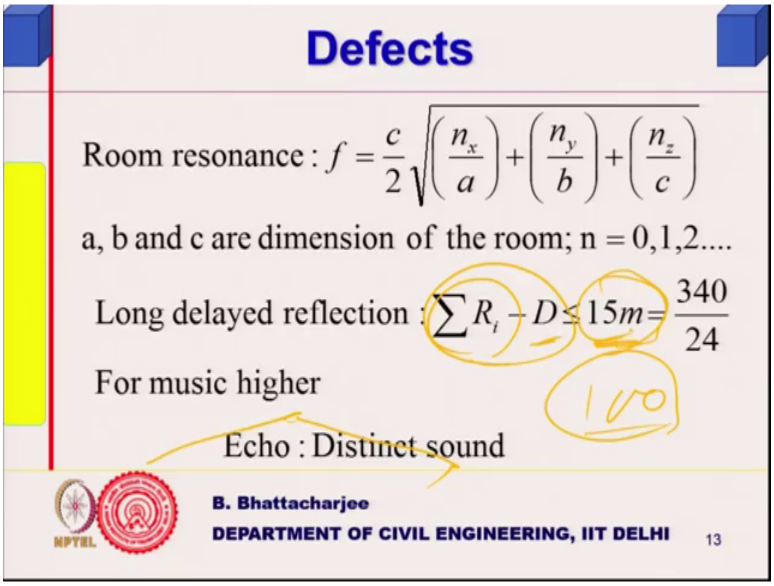

So, about 14 15 meter, so as long as this condition is satisfied you know if it is if this distance between this is more compared to this sum total of all the reflected path, sum total of the distance of all the reflected path if it is more than direct or the difference between them is more than 15 meter then sound will reach later. If the distance you know this is first reflected path, then second reflected path just for the sake of the example for this one you remember that is what we I think here it is there it is this one. So, this is R 1 this is R 2 and this R 3 let us say coming to the audience somewhere there R 3.

So, R 1 plus R 2 plus R 3 it should be, it should not be too much different than this direct path, then it will reach much later if this difference is more than 15 meter then it will reach as a distinct sound or it will disturb the first sound, it will disturb the first sound right, how late it will reach supposing it is 15 meter. So, velocity of sound is 340 meter per second right. So, 15 divided by 340 is how much? 15 divided by 340 1 by 24. So, 1 by 24 is a time for speech, 1 by 24 is the time right. So, velocity multiplied by time gives me the distance. So, 1 by 24 seconds if it comes less than 1 by 24 seconds then it is fine, it will reinforce it if it comes more than one by 24 seconds then actually it will disturb it and if it comes too far late then it will be totally distinct sound echo.

So, echo could be totally distinct for speech this is 1 by 24 seconds is the time within which it should you know because sound will some for some time it persist in my ear, hole of the cinema is based on similar kind of concept because the eye retains this image for certain very minor time. So, by the time 1 image has gone good old days you know even, even Thomas Alva Edison’s filaments you know that kind of thing may be video due to those days. So, 1 frame to the another frame, if the time delay between 2 frames are too small then you will see as a continuous movement, you see a picture frame to frame this was frame to frame actual or is you know.

So, every frame to every frame if the time delay is small you will see it as a continuous thing because your eye or brain retains it for certain period same thing in the town sound it has come, but it retains very for a very small second time. So, if the reflected sound comes within that period of time then you will persist it a continuous or same sort of things. So, 1 by 24 seconds is the time you know 1 by 24 seconds is the time for which speech. So, it should not be 1 by 20 or 1 by 10 seconds, 1 by 24 seconds is the time within which it which comes is fine, that is why the 15 meter, that is why this 15 meter.

Now, for music it can be retained I do not mind having it coming a little bit later because music passes for a longer period of time. In fact, we would like it to be a little bit higher. So, echo is distinct sound that is what I said you do not like to have echo. So, that is how it is.

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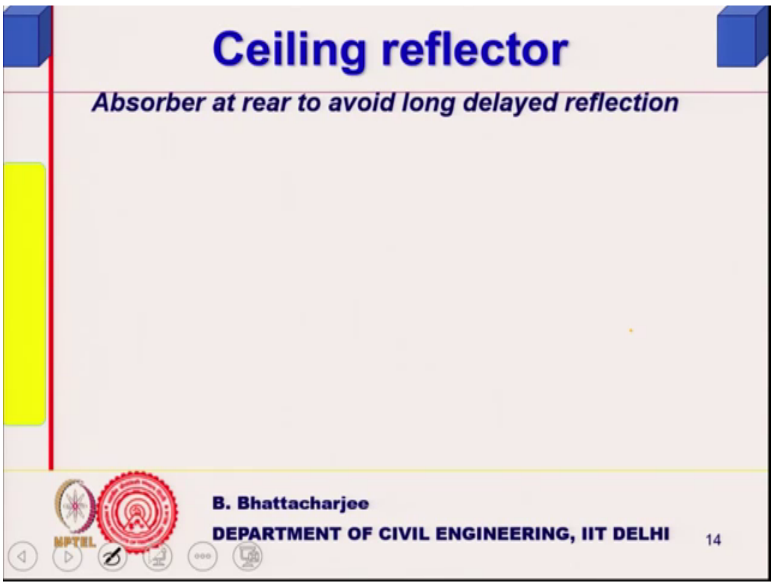

So, you know that is that is how it is actually. So, we can you know we can avoid some of this, let us see how we take care of them. So, we will you know just after the break after the break if you have any questions I will take it.