**Energy Efficiency, Acoustics & Daylighting in building**
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**Lecture – 46**
**Auditorium (contd.)**

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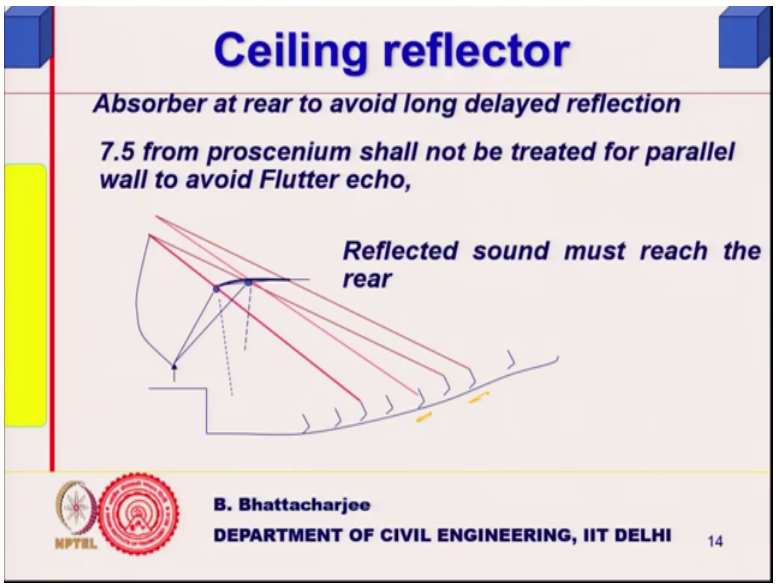


So, sealing reflectors absorber at rear to avoid long delayed, you know that is what it is. If you put absorber at the rear, long delayed reflections will be taken care of and 7.5 meter from the proscenium shall not be treated for parallel wall to avoid flutter echo, not treated with reflector, you can put absorbers. If it is a brick wall it will automatically be observed that is what I am saying 7.5 meter from the face of the prostate or proscenium you know. So, that is what it is. So, that is what it is showing this is a reflector again the reflector design I am showing again right.

So, this is a we designed do the ceiling reflector and this is I am just repeating. So, this is the length of the first reflector, then the second reflector I wanted to decide it, I i decided to actually reinforce from here. So, is I, what I do is, I join this line divide this and then normal to this and I decide that the reflected sound should reach there. So, its just same thing drawn again and this is my profile then, and you can carry on this manner to get the right kind of ceiling profile.

So, that ceiling reflectors actually and this is also reflected, sound must reach the rear from the ceiling, it must reach the rear or even from the near the procedure proscenium wall it should reach the rear, should not come back. So, therefore, no parallel one right so that is what it is floor shape.

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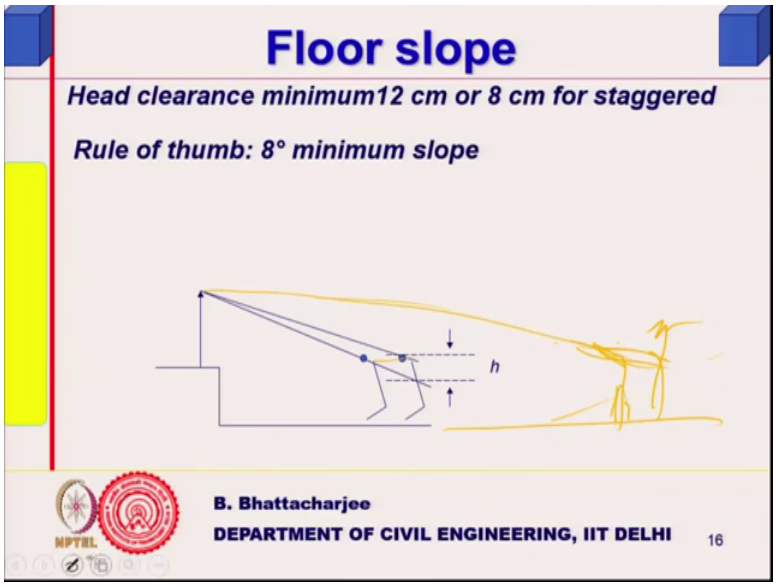


Floor shape is an important issue, because if you if you are not like this diagram will make it possibly clear. Supposing this is my source height and this is my sources you know receivers. Now, the ray from the source passing over the head of the front seat and ray passing over the head of the rear next set, I need sufficient gap between these two; otherwise I will see only the backside of the head, the angle reduces as I go far away this angle. So, this is called head clearance, this is called head clearance. Now head clearness if this is my floor is flat this angle will reduce.

You know here for example, somewhere here somewhere here from the same source and somewhere here from the same source this angle will simply reduced and if I go far beyond I would not see, the person on the rear would not see anything, because the head will come and block it. So, I need sufficient head clearance. So, what we do we provide therefore, slow raise this point up, so that this head clearance increases. Now there is formula for this and there is algebra behind this actually, so I will just talk about that. So, this is called head clearance. Is it clear, what is head clearance; head clearance is the

difference in height between the ray reaching the front seat and the next, just next rear seat right. So, this is the height see.

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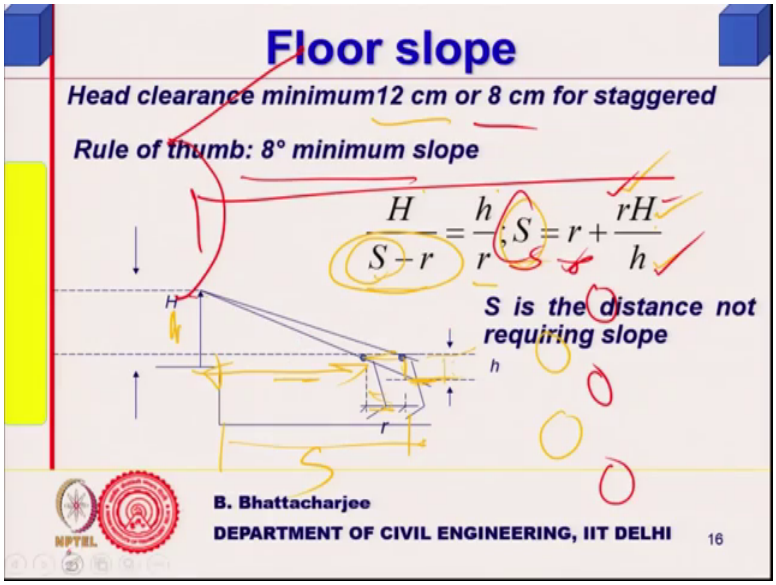


This is from the front seat rear is coming from the front seat and this is coming to the next seat. So, this is called head clearance H and this is the height of the source. So, simple geometry this is the distance between two row. So, H this H you know these two triangles similar triangles. So, this is r, this is distance is the head clearance, this is the spacing of the row. So, H minus H divided by S is this distance S minus you know. So, this h by r, this is h this is r is equals to S is the distance not requiring slope. First is S is the distance not requiring slope.

So, if the head clearance is sufficient, I would not need the slope, I leave the slope. So, I want to find out what is the value of S up to which I do not need any slope, it can be flat. For example, here they are provided a slope right from the beginning, I am not very sure this was necessary right. This is just intuitive sort of without going into the thinking part of it ok, it looks nice that is not a problem, but you can avoid providing slope up to certain distance right

So, this distance is S where, because S is the distance up to which I do not need slope. So, up to this distance let us say I do not need slope, S minus r is this distance S minus r divided by H must be goes to r divided by or you know S H by S minus r is equals to h by r, where S is that distance up to which I do not need raising of the flow.

So, this is a formula. So, S is given by r plus r H by h, where r is the spacing of the seats right H is the height of the source typical height of the source and this is a head clearance and these values are actually given in the code. So, this is S as I said, and these values are given in the code actually or guidelines are available,

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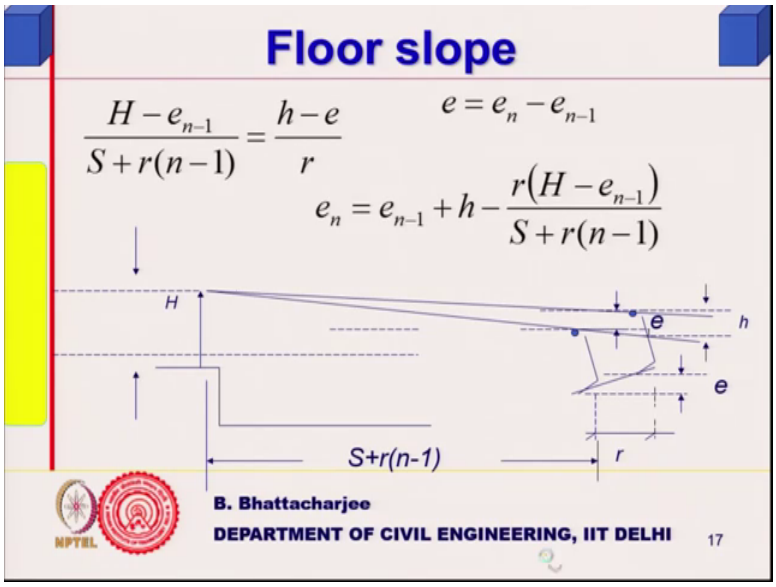


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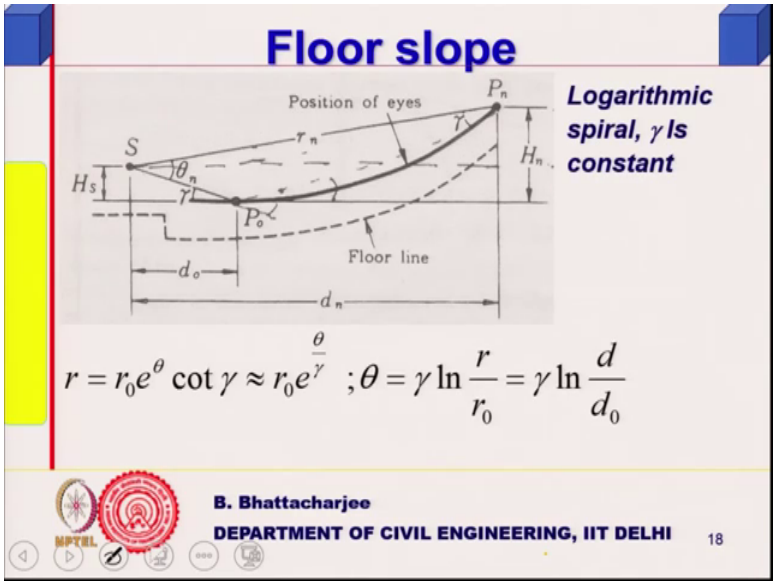


Let me see I will come back to this algebra part of it later on, but let me see there are two formally I will come to that, but let me give you the value first typically 8 degree is good, typically 8 degree is supposed to be good.

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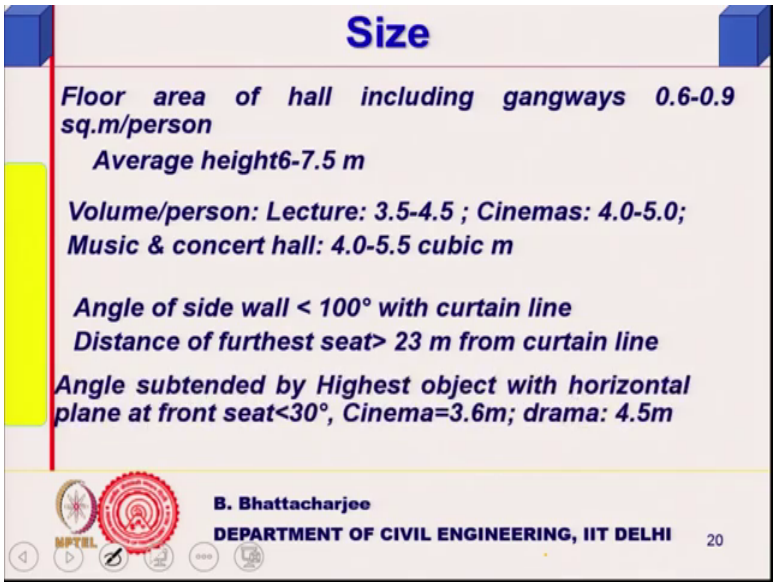


Let me see if I have somewhere written it down.

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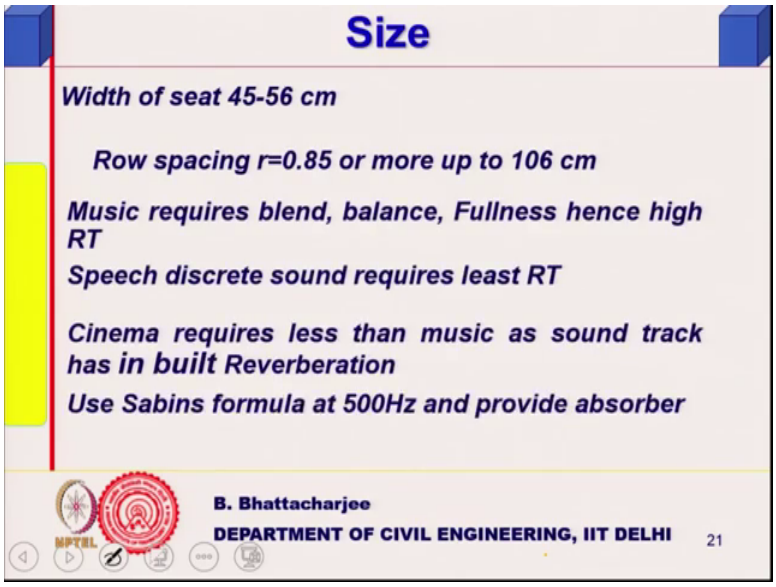


Their head clearance should be no I think I have missed it, or may be its there somewhere I will find it out 12 is written, 12 centimetre minimum for sits one behind the other, but if I have staggered sitting arrangement in plan like this, you know a next row is, next row is something like this staggered sitting arrangement, then I can go for 8 centimetre as a head clearance. So, minimum head clearance should be 8 centimetre or 12 centimetre and a rule of thumb is that 8 degree minimum slope, 8 degree minimum

slope, 8 degree should be the minimum. We do not need because it will be the uncomfortable, even going through the steps if it is more than that. So, 8 degree is one thing rule of thumb, but you can actually design, this as we shall do right now right

So, 8 centimetre staggered. So, this is what it is. So, this formula we already we have talked about up to yes. So, you can calculate out if you know the spacing, spacing is decided based on row, spacing is decided based on what kind of city. Well what sort of comfort you want to give for example, in you know like you want to give lot of space then, but minimum should be 0.85 sent it 8, you know 8 5, 0.85 meter I will come to that, I will come to that later on. So, this is minimum you want to give a lot of comfort then you increase it right H we have said 12 or 8.

So, r we are talking about and height of the source would depend upon performance. Now as I said you know the white other day I was just saying; that is kept the speaker somewhere on 5 meter height, it is all ridiculous, you do not need to have 5, you know why do you need 5 meter you if you put it somewhere there it will go some as a sound it goes somewhere there, unless you want to send the sound away and it was also convex like this, which means that this will sound will go somewhere, its not going into the auditorium its actually misuse of the whole energy, you are not using the energy properly you know no idea basically. So, this is this is not required, this is not required number one, this is not required, so this is the formula. So, we can actually calculate it out.

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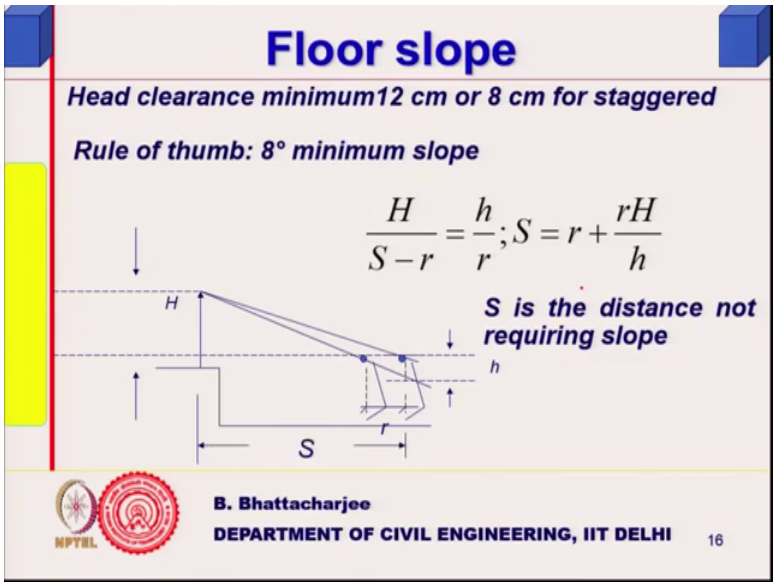

Now, to find out a formula, there are two ways we can find out the formula

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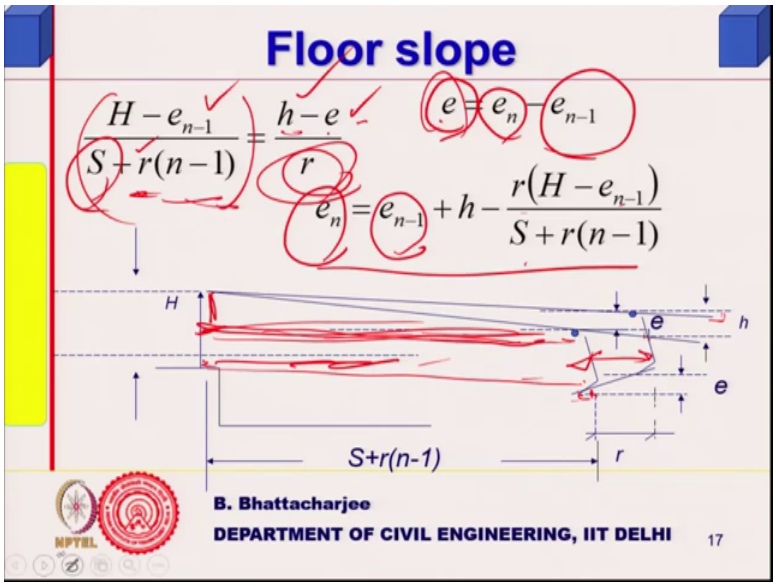


One consider at point up to S you do not need any rays of the flow. let us say consider two points where I need some rays of the floor. So, this is my ray from the source and this should be the head clearance, and this is the, you know this line, this is the this is a normal head level without any rays, head level will be somewhat higher its a head level we are talking of head level, because hearing at this level you know.

So, head level eye level etcetera etcetera generally we talk of head level. This is the elevation of a set e is the elevation of the set, h is the head clearance height of the source is h from the proscenium or you can you know you can. So, this is your, this itself is e. So, if I draw a line like this parallel line, horizontal line at the head level this is e. So, therefore, if I extend this spacing is r and H is this h minus e is this distance, h minus e is this distance this small distance, h minus e is small distance. So, h minus e divided by r you know this triangle, if you look at this triangle this is H and h minus e is this distance h minus e is this distance.

So, h minus e divided by r is equals to, its similar to this triangle which will be H minus raise of the previous one has been already raised to e n minus 1. I am interested in e n elevation of nth row, elevation of n minus oneth row after up to certain row I would not require any elevation, but after that row number 1 row number etcetera n minus oneth row has the elevation e n minus 1 and nth row has got the elevation this.

So, difference is e, this is the e, the elevation of the nth row over and above n minus oneth row. So, this is what it is. So, h divided by h minus e divided by r you know this small triangle as you see this is r this is h minus h minus e divided by r; that is equals to this height divided by this length, this height is h minus e n minus 1, because is the elevation of this row, this was h this whole thing is h and this much is a elevation of this row is an e n minus 1. So, the reduction originally there are up to the floor level there is no like height from the normal head level I am talking of.

So, this is the h in e n minus 1 S plus, and this distance is how much S plus r, because r is the spacing and n minus oneth row is this row. So, r into n minus 1 S plus every row spacing is r n minus 1 row which required elevation the previous row is r n minus 1. So, this from geometry I can actually arrive at, this h is known to me which will be at the 12 centimetre or 8 centimetre, r spacing is known to me and S is known to me which I have already calculated earlier, the row up to which I do not require any elevation. So, for each row after that. For example, first row for the first row n equals to 1 this value is 0 and you know this is simply S. So, I can go on calculating step by step, elevation of difference in elevation of each row from the previous row.

So, e n will be given by this e n minus 1, because easier from this formula you know this is e equals to e n minus 1. So, I put here e n minus e n minus 1, I get this sort of an expression, because r multiplied by whole of this, r multiplied by whole of this plus h. So, this is the expression I get.

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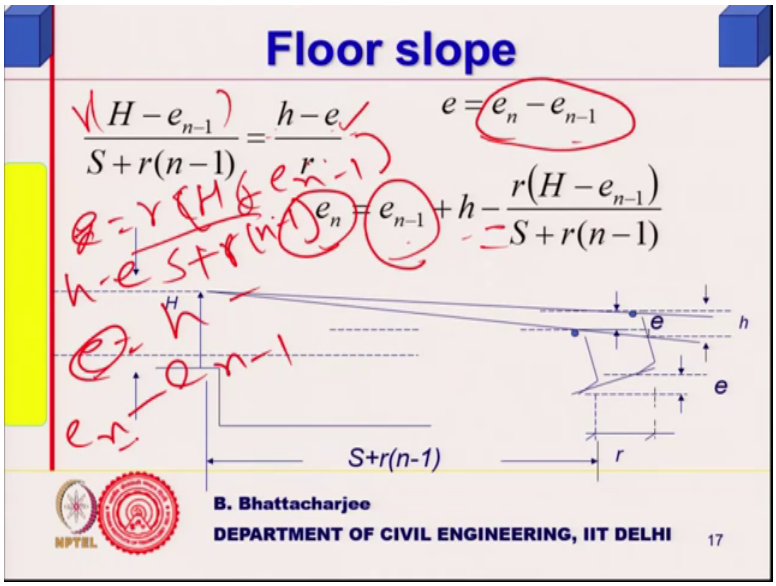


So, for e n elevation of nth row elevation of n minus oneth row H because this will be multiplied here by r and then e will go H will e will go to the other side H minus this comes in right H by r. So, this r I have already multiplied. So, and e is nothing, but e n minus e n minus 1. So, e equals 2 I can find out e from this you will be simply e will be equals to r into H r into h minus e n minus 1 divided by S plus r into n minus 1 e and e, then I write is you know and this sorry e will be equals to no H r h, h minus e will be this.

So, e will be equals to H minus all this and e is nothing, but e n e n minus e n minus 1. So, I can get an expression for e n equals to e n minus 1 plus H etcetera etcetera. So, this is known step by step I go first I find out from the first row requiring elevation then find for the second row requiring elevation and every steps will be different, well for construction purposes you might like to make it as close as possible steps cannot be two different, but just you know, but this is how you one can calculate out the full slope. So, that is how one can actually calculate out of the full slope, but there is another way of calculating it also using principle of what is called logarithmic sphere logarithmic spiral

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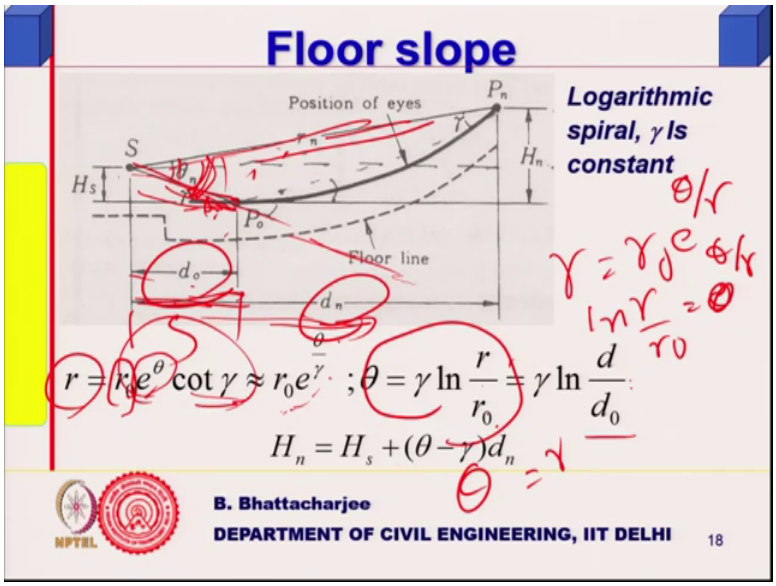


Spiral, where this angle this angle is constant, this angle gamma is constant you know angle it makes. So, anywhere for the last set it makes this angle the slope this line and this angle and here also this line and this flow line from the source to the point head level, if I join with the headline the angle it makes is gamma and here again in the flow line the head you know. So, this is my flow line this is the headline. So, this angle is gamma this is constant this called logarithmic spiral.

Now, if this angle is constant then I will be able to see all the time everybody will be able to see that will corresponds to 12 centimetre or 8 centimetre, gamma is such that it will corresponds to 12 centimetre, every time the angle is constant. The last seat you know last seat the curvature this angle and angle is the source this angle is constant its because of this angle which we drawn earlier and then try to geometrically find it. So, this called logarithmic spiral, gamma is constant remains constant and gamma is nothing, but H S by S, this is nothing by my S d 0 which does not require any elevation right.

So, the gamma is simply H S height of the source normal height without floor raising height of the source. So, gamma is simply H S divided by S, H S divided by H S right and that is that is one, and in this otherwise I will have to basically at any distance the distances r n. So, I can I can actually get an expression like this; so the r which will maintain, the distance this r which will maintain this constant gamma or for equation for logarithmic spiral is given by this r 0 e to the power theta cot gamma right.

So, what is theta, theta is shown is this as angle. So, theta 1 theta 2 theta n for any point nth row first row it will be theta 1 first row requiring elevation value is theta 1 second row theta 2 and theta. So, its given as e to the power r 0, this is r 0 e to the power theta cot gamma, this maintains constant gamma angle if it is this given by this curve and it can be approximated to r 0 e to the power gamma by theta. You know this one can be approximated to r 0 e to the power gamma by theta by gamma.

So, theta 1 can write by taking l n both sides, theta by gamma is equals to l n r by r 0, because r equals to r 0 e to the power theta by gamma; that is actually approximate equation of logarithmic spiral right. So, logarithmic spiral satisfies this requirement of maintaining a given has head clearance. If the gamma angle remains constant it will maintain constant head clearance. So, if I take l n of both sides l n r by r 0 is equals to e to the power theta by gamma. So, what is it, so sorry this will be theta by gamma simply. So, theta will be gamma l n r by r 0

Now, what is theta this angle we take same as this angle. So, which is simply you know theta is distance divided by, theta will be this theta theta n is, theta n would be can be written as d divided by d 0 d is a distance at any point, horizontal distance by any point. So, if this is you know this theta I am interested in theta n I am interested in any theta for that matter. So, theta is given by l n d, you know r by r 0 is r by r 0, what was r, r is this distance.

So, this an r 0 is this or d 0 is this distance, r 0 is this distance, r 0 is this distance. This approximately same as the ray in the ratio of the horizontal distance d 0 by d n is equals to r 0 by r n; that is what we are saying. So, r 0 you know r by r. So, that is what we are writing. So, theta is written as gamma n, l n r by r 0 and what is theta theta is H S divided by, because just let me just clear it up a little bit more theta n is this distance, this angle is same as this distance.

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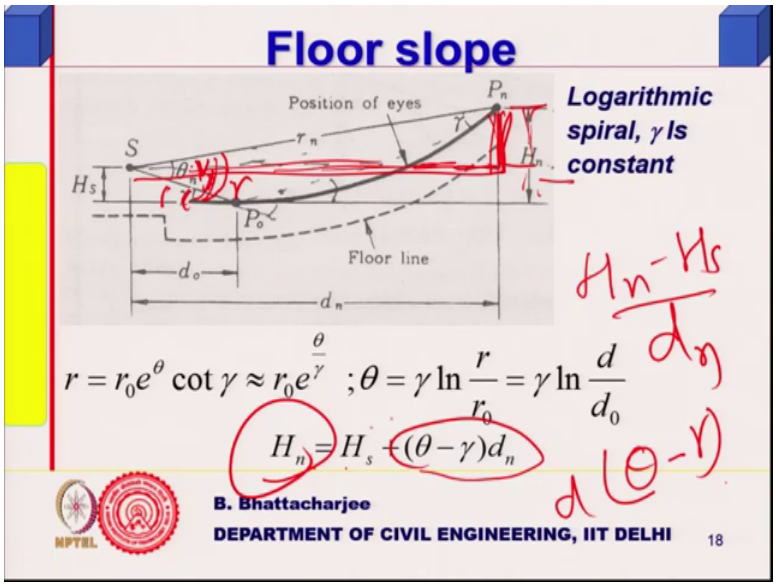


So, this is gamma; so theta minus gamma, theta minus gamma into d. So, this is, if I draw a horizontal line, horizontal line at any point, this corresponds to a this angle is same as gamma, this angle is same as gamma. So, theta minus gamma is this angle which is nothing, but this height H n, you know H n height of the elevation height minus H s. So, H S this is, this you know this is H n is the elevation height minus H S, H n minus H S is this height.

This is equals to this divided by d n, this divided by d n this length is equals to theta minus theta minus gamma, theta minus gamma. So, from this it follows d n into theta minus gamma is equals to H n minus, you know approximately one can write H n is equals to H s plus theta minus gamma into d n.

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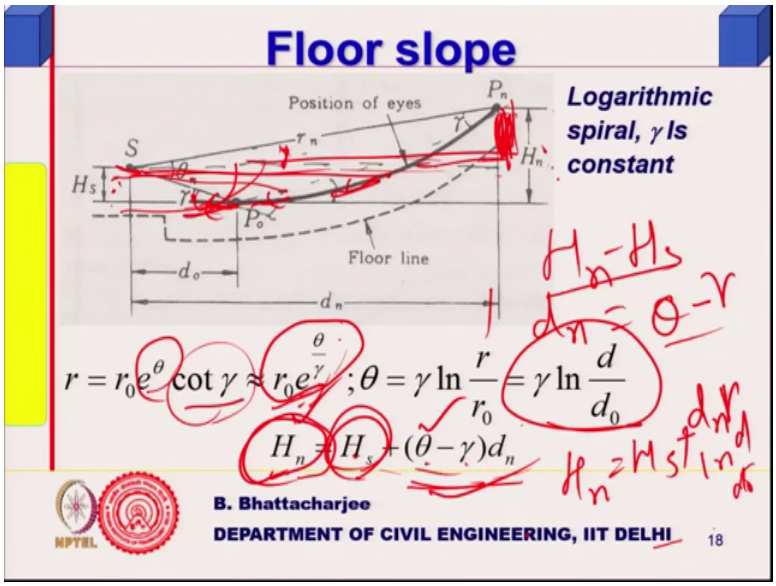


How, this line I draw a horizontal line this angle is same as this angle. So, this is gamma, how much is this angle theta minus gamma. So, this height is how much H n minus H S, height of the source minus the height elevated height of the head you know head level. So, H n minus H S is this height. So, this height divided by d n is equals to, this is d, this this, you know this this by d n is equals to theta theta theta minus gamma, this height divided by this distance is equal to theta minus gamma. So, this is H n, H n minus H S, H n minus H S is equals to you know H n minus H n is equals to theta minus gamma divided by d n of course, d n, this distance total distance is equals to theta minus gamma from these it follows here.

So, therefore, H n I can find out. So, essentially height head height of a nth row is given by this formula, where H S is the head height of the height of the source without you know height of the source from the, from the head level, basically height of the source from the normal head level normal head level in the without requiring elevation. So, height of the source over and above normal at level is given as H S. H n is a head level or elevation, actually H n minus H S is actually the elevation of this row, this elevation of the nth row. So, that can be obtained from this, this formula, where what is theta. Theta can be obtained as H S divided by d 0, theta can be obtained as H S divided by d 0.

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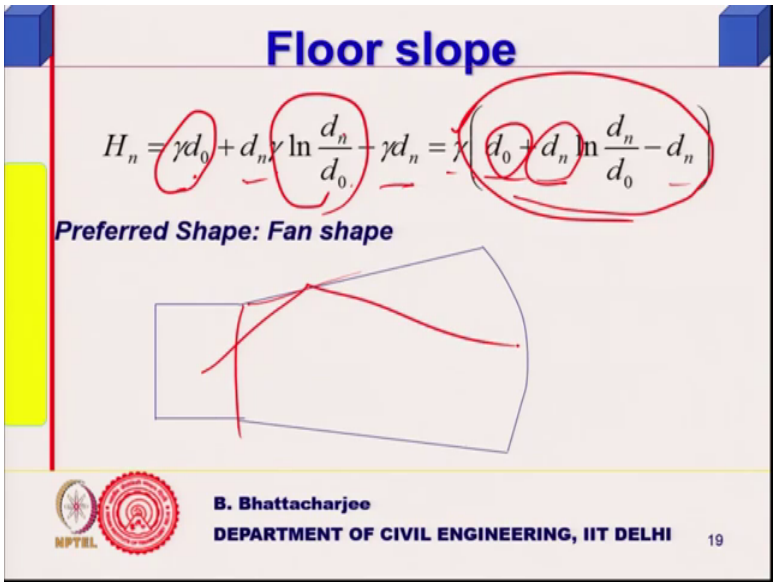


Let us see I think we are. So, H n is equals to you know the if you if you go back here, gamma is gamma is H S divided by, because the slope here, this is slope, at any point this angle remains same gamma, any point you measure this slope this angle is gamma. So, here the gamma is H S divided by d 0 or you know s. So, a gamma is H S basically this was H S which is gamma d 0 and this is d 1 l n because, because from this one it follows theta is equals to gamma l n d by d 0.

So, I put it here theta equals to gamma l n d by d 0. So, I will get H n equals to H S plus theta is d n multiplied by gamma l n d by d 0 plus gamma d n you know. So, this is what is done here. So, d n gamma l n d n by d 0, because this theta minus gamma d n. So, gamma can be taken out from everywhere and you get something like this gamma into d 0 d n etcetera. So, gamma required for the head clearance that you can find out, that would be height of the source divided by first row or not requiring any elevation, height of the source divided by you know i. So, from that actually.

So, S, d 0 is nothing, but S and d n is distance of the row from the source and everything else is known to us we can actually find it out. So, one can actually use this also formula to find out the floor shape, one can use this to find out the floor ok. Quickly just rounding it up, preferred shape is fan shape this is my proscenium this fan shape, because everything will be reflected back word.

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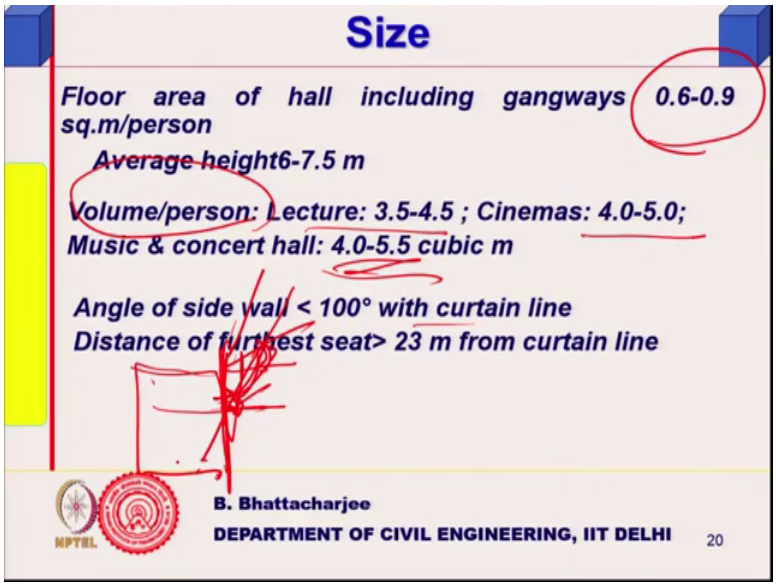


Floor area of hall including gangways this is given in the for you know per unit area for considering general type of auditorium 0.6 to 0.9 square meter per person are going to mix and everything put together including else movement and things like that. Average height should be 6 to 7.5 meter and volume per person depends upon, because volume controls are reverberation. So, volume per person for lecture, all theatre it is lecture halls it is 3.5 to 4.5, cinemas 4.5 to 5 4 to 5 and music and concert hall it become more,, because reverberation time t is a function of 0.16 v divided by S alpha bar, if you remember that.

So, higher the volume better is a reverberation, it will stay remain in the space for longer period of time reflected sound will come later right. So, being free path and all that that we discussed about. So, therefore, music you need more per person. This is given in codes actually 2526 I S code also gives the same and angle of the side wall this wall, because you know side walls for example, this is my stage right. Now this angle should not be this, you know this angle should not be angle of side walls 100 to the curtain line. So, this is my curtain line, let us say this is my stage, this my curtain line, this angle should not be more than 100 degree.

If it is more than 100 degree means it is going to be flutter like this which means that visually somebody is sitting here would not be able to see anything. You know if it goes like this somebody sitting on that corner will miss the other corner of the stage. So,

viewing becomes difficult. So, within 100 degree you can see that. Distance of the rear more seat should be not more than 23 meter from the curtain line for viewing; otherwise you provide balcony.

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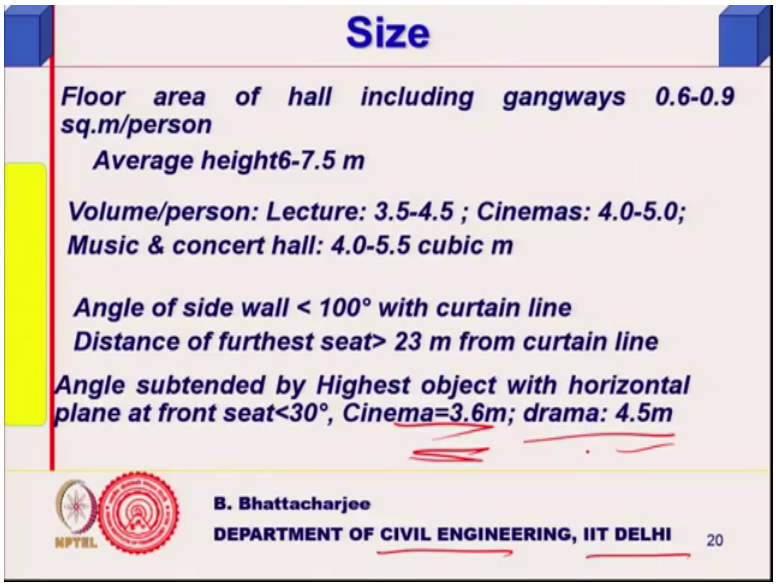


So, angle subtended by highest object with horizontal plane at front seat should not be more than 30 degree. You know like otherwise you have to look vertically up very uncomfortable. So, in case of cinema this is very important, the top of the screen and the headline of the first seat that should not make more than 30 degree; otherwise somebody will have to raise their head and see, this very uncomfortable seeing all the time like this or moving your head during this manner.

So, this should not be. So, therefore, cinemas should be 3.6 meters, top of the screen should not be more than 3.6 meters and drama, because here drama is also you view people know drama you view people; therefore, 4.5 meter is a you know seat distance minimum distance of the seat. So, minimum distance of the seat is 3.6 meter 4.5 meter, because 4.5 meter, because you know like in case of drama the height is less, you know whatever it is.

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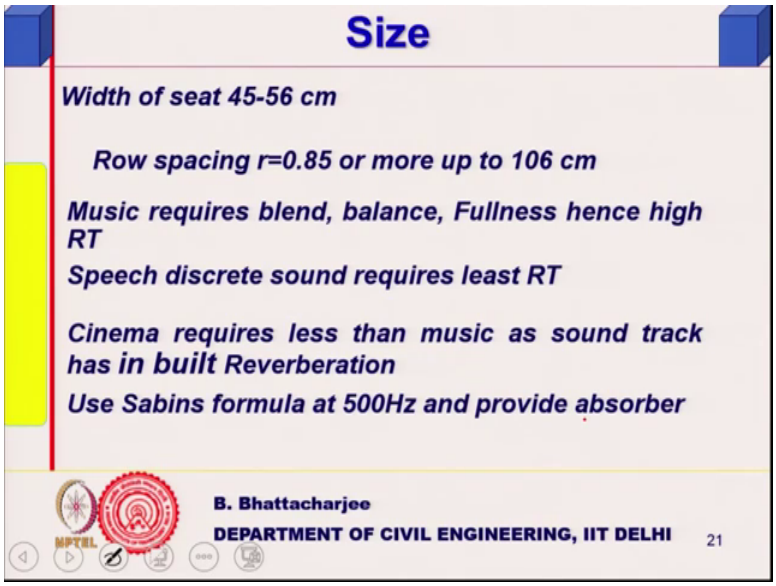


So, it is related to that actually width of the seat 45 to 56 centimetre, row spacing 0.85 or more 106 for uphold which are said giving lot of comfort. Music requires blend balance fullness, I told you already hence high reverberation time and speech discrete sound requires less reverberation time, cinema requests less than music, because there is some amount of reverberation built in the soundtrack itself.

You know if you have seen a film of good old days you will find on the corner there is a soundtrack, blank spaces right. So, those soundtrack already has some reverberation built in and one can use Sabine's formula 500 hertz to provide observer

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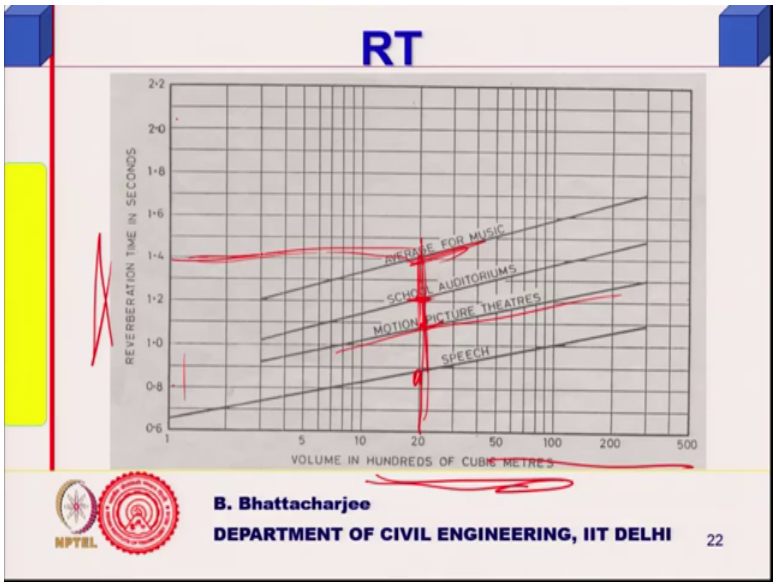


So, the last of the slide is. This is from I S code straightway, it gives you the desirable reverberation time in seconds volume in 100 cubic meters as a function of volume of cube you know. So, average for music is higher reverberation time, orders are 1.4 seconds for 20 meter cube 20000 meter cube 2000 2000 meter cube 2000 meter cube, because in volume in hundreds of cubic meters. So, 2000 means 2000 meter cube you need around 1.4 seconds desirable reverberation time.

For speech you require much less, because speech is discrete sound which I told you earlier, you do not want sound to persist for a long period of time. In fact, it can distort. School auditoriums are generally meant for multipurpose you know sometimes speech, sometimes drama, sometime music, so it is a compromise somewhere in between. Motion pictures have both speech as well as music. So, it should be something close to the school auditorium, but it has got built in reverberation. So, therefore, this is kept somewhat below. So, this curve is something like this, in log scale as you can see the order of these times are from about point you know 0.8 seconds to 2 seconds and so on.

These are order of the reverberation time. So, you know that desirable reverberation time you can calculate for without any treatment and which treatment you can calculate out what is the reverberation time required and you know the formula is known to us we just use Sabine formula at 500 hertz. So, absorption at 500 hertz is taken typically that is what is checked for most of the auditorium and that is that is what is done, and you see

that it is close to this value if it needed put some additional absorbers. Preferably every observer should be placed at the rear right, but try to distribute them as best as possible.

So, that you get diffuse sound or absorber should be placed close to this wall, close to the source to avoid flutter echo that sort of situation. So, judiciously one can place the absorbers, but otherwise if absorbers are not require reflectors are required, you do not you know polished you can place polish things. So, quite often people add observe or depending on the situation, makes a calculation without the observer with without any treatment.

Then calculate the reverberation time, if it is satisfying fine if it is not satisfying then find out how much is the additional total absorption required or reduction in absorption required and accordingly, then you design your observer place them as you want. This will be random noise absorption not you know, one thing is random besides that they will be you know coming from all angles. So, specific or not necessarily specific frequencies, unlike the one that we talked about like Helmholtz resonators or similar sort of thing which has specific frequency for noise control, if I know the frequency here, it could be all kind of frequencies. So, such absorbers which can absorb at various frequency broadband that is what one should be selecting

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Sound reinforcement somebody was asking about mics, where do you I mean speakers where do you put them. You can put them in appropriate places be using this concepts

that I talked about, there will be additional sources and if you put additional sources, if you put them on the wall face to face that will caught flash flutter echo. So, put them in such a manner and you know such that that it reinforces the direct sound as much as possible or the number 1 speaker as much as possible conference rooms slightly more complicated, because you have more number of sources not one, several sources.

So, if you are doing rate diagramming you have to do 4 number of sources, and open air theatre external noise is anyway there adequate loudness level is important, because in open air theatre you will have no absorption, no absorption at all, because it is all open space and therefore, adequate sound level is important, adequate I am saying not excess. So, that is related to auditorium.

I think going stop here.