Acoustics
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Lecture 03
Module 3
Leakage in Walls, STC Ratings, Octave Bands

Hello, welcome again to this lecture on acoustics. In our last lecture we had developed several relations for transmission of sound through partitions or walls. So we will continue that discussion today and specifically what we will cover today is A, what happens if there is leakage in these walls? So in all the discussions which we had done early we had assumed that these walls are solid, there are no (ca) cracks in the walls and also there is no leakage path between the wall and the sound source except through the wall itself.

So that is one thing which we are going to cover today and the other thing about walls we are going to cover is what happens if we have two walls adjacent to each other, double walls. So again we will develop some mathematical relations for these types of configurations and finally we will close today's discussion by introducing a term which gets very frequently used in the industry and that is called STC that is sound transmission class.

So with this we will conclude today's lecture. So these are the three things we are going to cover today. So our first aim will be to explore what happens if there is leakage? So let us say I have a wall and there is some sound and there is some incident energy and then some sound gets transmitted, so that is transmitted energy. And if I know the value of T L that is transmission loss and if I know what is the value of incident energy then I can clearly figure out what my transmitted energy is going to be.

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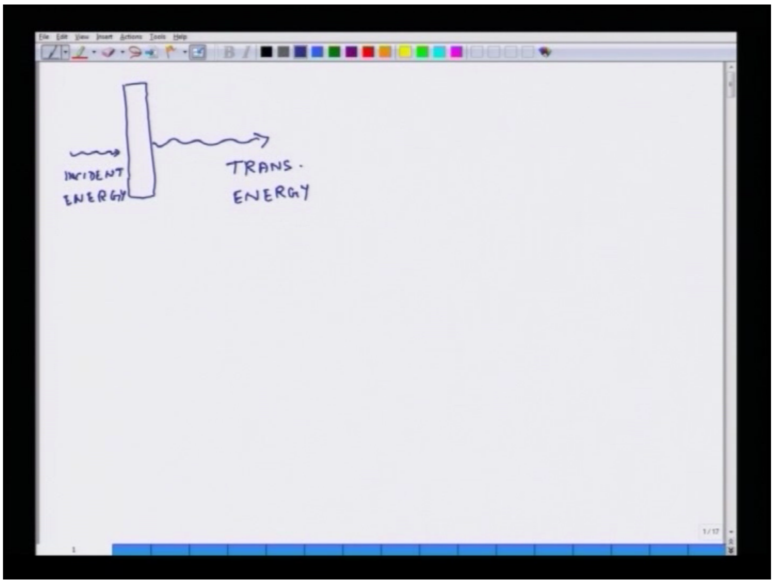

So we will do an example. So let us say we have a wall and the incident sound energy is such that there is 100 decibels of sound power level on this side and on this side it is 70 decibels of power level. And so because of this we know that T L is equal to 100 minus 70 that is 30 decibels. We can look at this number in another way. We can say that the reduction in power which is experienced on this side can be calculated and that is nothing but transmission loss if I raise it to the power of 10.

So this is 10 and then I divided by 10, okay, because we know that when we were calculating transmission loss in decibels it was transmission loss equals 10 log of some quantities. So that is why I am dividing it by 10 and I am raising it to the power of 10 because transmission loss is calculated on a log 10 scale.

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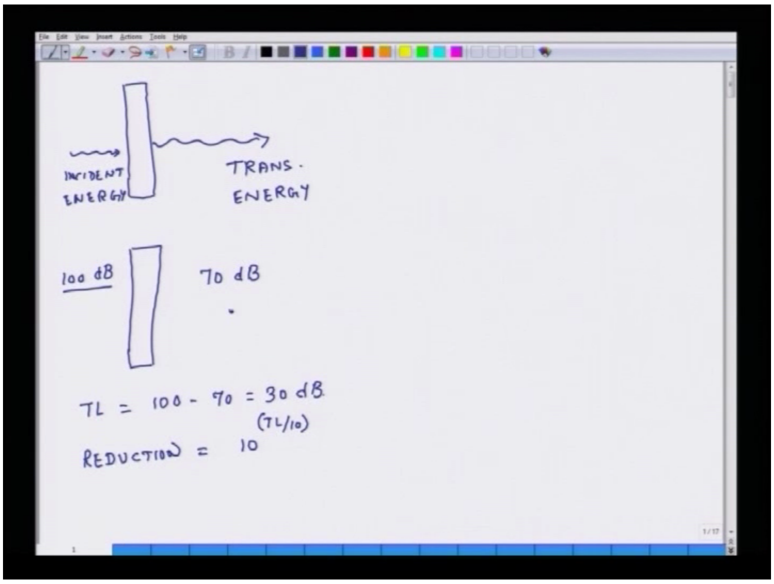

So because our transmission loss in this particular example is 30 decibels so reduction is going to be 10 to the power of 30 divided by 10 is equal to 10 to the power 3 that is 1000. What that means is that if I have this wall and it is a solid wall which has no leakages present then if I impinge it with let us say 1 watt of energy then on the other side I will get 1 watt divided by 1000, so many watts of energy which will get transmitted to the other side of the wall.

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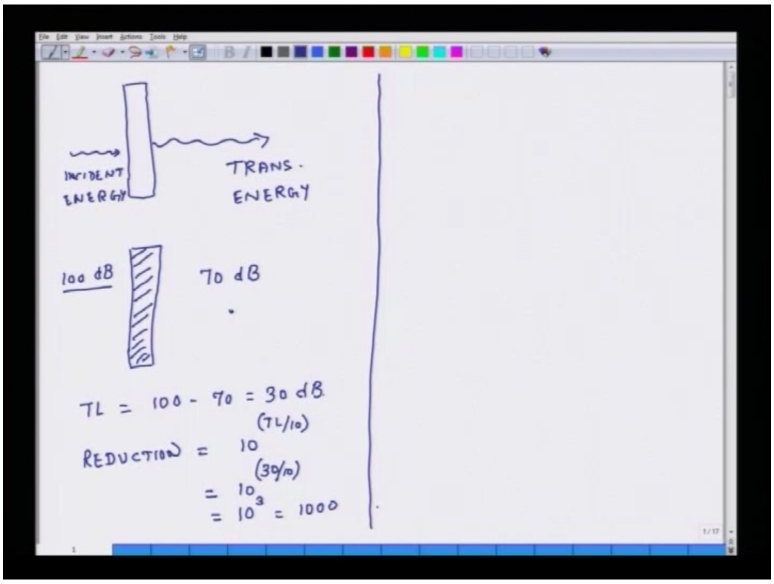

So I will not call it energy I will call it power. If my incident power was corresponding to 100 decibels then that would mean that 100 decibels would correspond to 10 to the power of 100. This is from decibels divided by 10 and then times P REF. And we know that for acoustic system this value of P REF for air is 10 to the power of minus 12 watts. So that equals 10 to the power of 10 times 10 to the power of minus 12 is equal to 0 point 0 1 watts of power.

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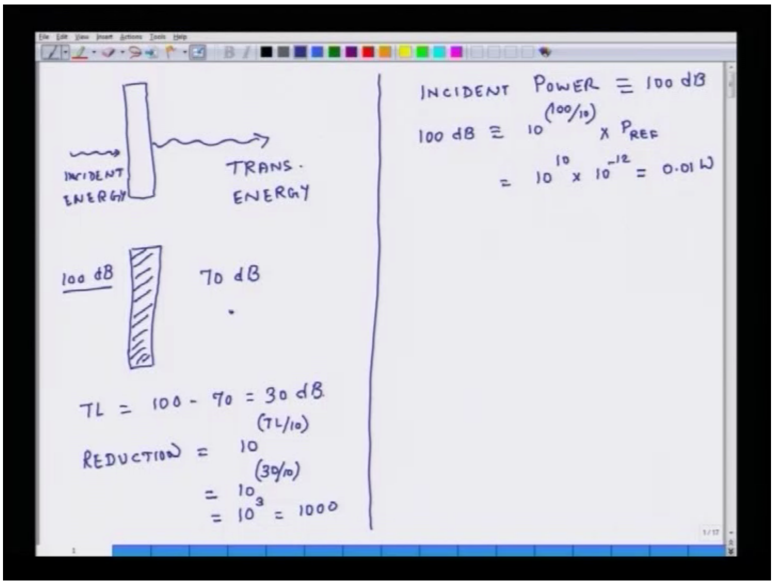

And then transmitted power again it corresponds to 70 decibels. So that means 10 to the power of 70 divided by 10 times P REF and that is 10 to the power 7 times 10 to the power of minus 12 and that is 10 to the power of minus 5 watts. So once again the ratio of incident power and transmitted power is 1000, okay.

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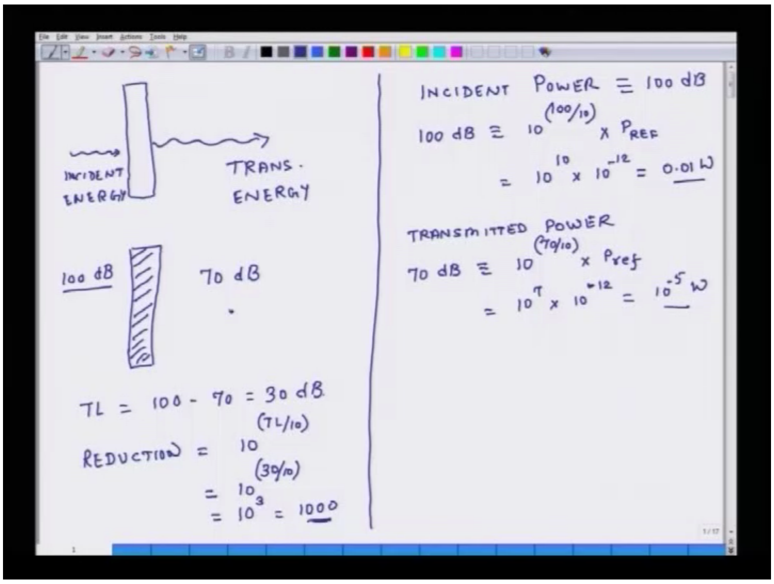

So now all this calculation was done on the presumption that there is no leakage path in the wall or adjacent to the wall. So sound can get to the other side of the wall only by getting transmitted through the wall itself. Now what we will do is we will conjure up a scenario and let us assume there is a leakage. So what we are going to do is that assume leakage and we will put a number on this leakage. We will assume that the total amount of area through which sound is leaking is roughly equal to 1 percent of total wall area, okay.

So through 1 percent of the area sound just goes in an uninhabited way and then the remaining 99 percent you have a real wall which is arresting the transmission of noise by certain extent.

So what we are going to do is that we are going to find out what is the amount of wattage or power which gets transmitted directly through this leakage path and then how much sound is getting transmitted through the wall itself and then we will figure out how the total overall transmission loss number in the case of the wall with leakage compares to the wall where we have no leakage, okay.

So, transmitted power through open area is equal to incident power times leakage fraction because there is no resistance no impedance to propagation of sound through the leakage path. So, all the energy or all the power which is going through this just goes to the other side without any attenuation. So incident power we had calculated was point 01 watts and leakage fraction is 1 percent. So 1 percent is 1 over 100 and that comes to 10 to the power of minus 4 watts, okay.

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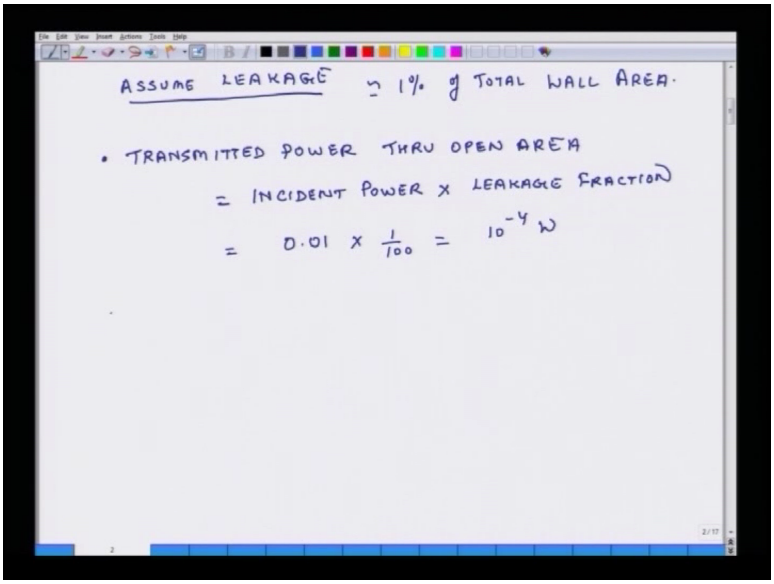

Then there is some sound which is going though the wall itself. So, transmitted power through wall and that is equal to incident power on wall times attenuation, okay. So what is incident power? Incident power is the total amount of power which is on the other side is point 01 watts and then the total wall area is 99 percent of the overall original wall area, okay. So this is 0 point 01 times 99 percent. And then attenuation is 1 over 100. We have calculated this 1 over 1000. So we have to reduce it by that factor, okay.

So what that means is 0 point 0099 over 1000 and that comes to 9 point 9 times 10 to the power of minus 6 watts, okay. So total (trans) power transmitted equals this number and this number so it is 9 point 9 times 10 to the power of minus 6 plus 10 to the power of minus 4 and that is equal to 0 point 0001099 watts, okay.

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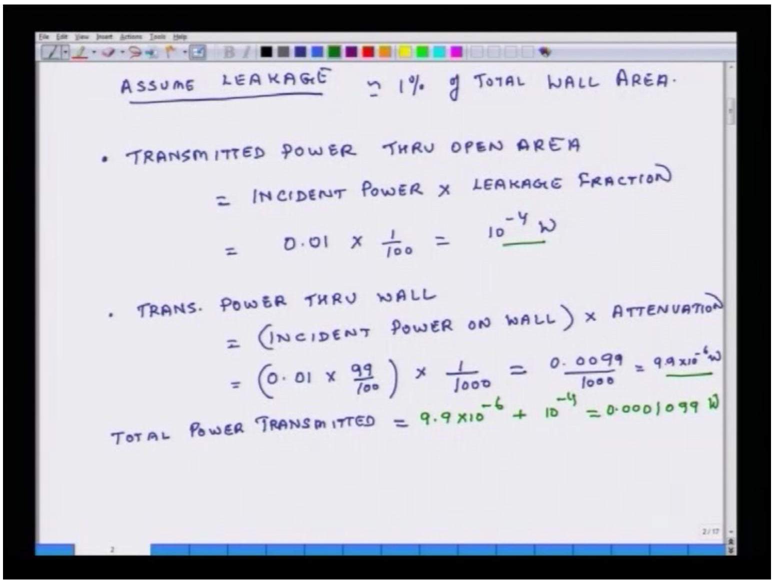

So this is the total power which is getting transmitted on the other side. And the total incident power we had calculated earlier was 01 watts, 0 point 01 watts. So that is 0 point 01 watts. So in that case our transmission loss will be 10 log 10 of point 0 you know this number three 0s 1099 divided point 01. And then I take a negative because the more I have transmission loss the lower is the amount of energy or power getting transmitted to the other side.

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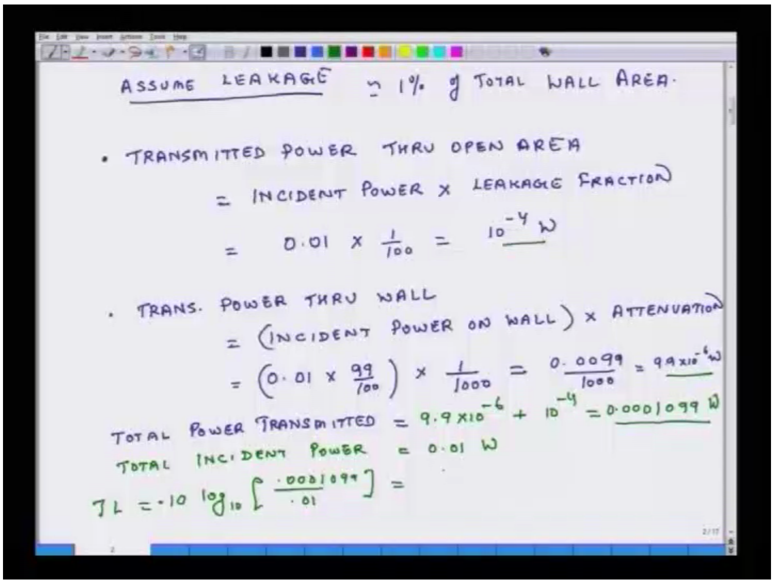

So I will not calculate transmission loss at this stage but rather I will find out total decibels on the other side. So total transmitted power in dB is equal to 10 log 10 times this number point 0001099 divided by reference power, 10 to the power of minus 12. And if I do my math correct it comes out to 80 point 41, okay. So T L for a leaking door is incident power in decibels minus transmitted power 80 point 41 and that comes to 19 point 59 dB.

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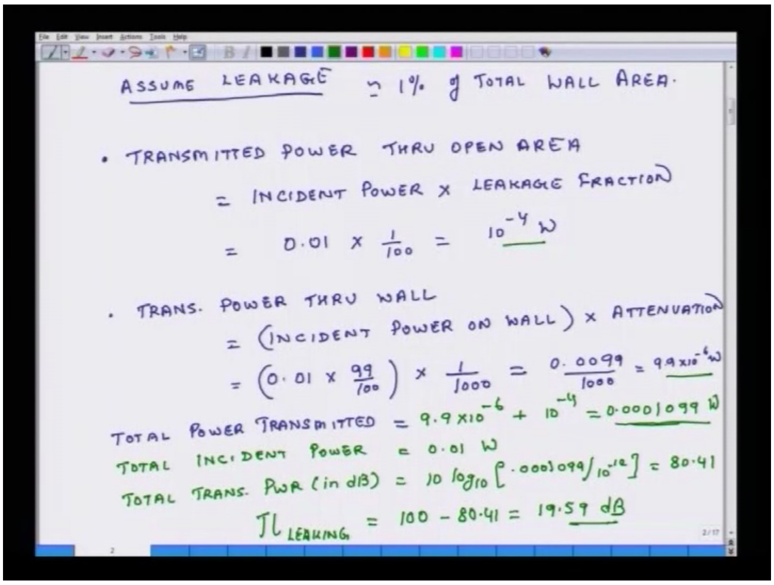

So just what I am trying to explain here is just a very small fraction of area is having a leak. Just 1 percent of the total door area or a wall area or a panel area and just that 1 percent is sufficient to reduce my transmission loss from 30 decibels to about 20 decibels, 19 point 59 decibels to be precise. So what this shows is that the transmission loss is extremely sensitive to leakage variable.

So as we are designing doors or panels or walls to arrest sound it has to be kept in mind that leakages should be minimized to the maximum possible extent. So to further illustrate this we will do one more example and this we will do very quickly. Now let us assume suppose leakage was approximately equal to 0 point 1 percent. So earlier we assumed it was 1 percent. Here we are assuming 0 point 1 percent.

So in that case if we do the math correctly in the way I had explained earlier then total transmitted energy or power we calculate it comes to be 19 point 99 times 10 to the power of minus 6 watts. And if I do the decibel calculation then at this corresponds to 10 log 10 divided by 10 to the power of minus 12 and this comes to 73 decibels. So T L becomes 100 minus 73 is equal to 27 decibels. So again point 1 percent of leakage causes a reduction in my transmission loss from 30 decibels to 27 decibels, okay.

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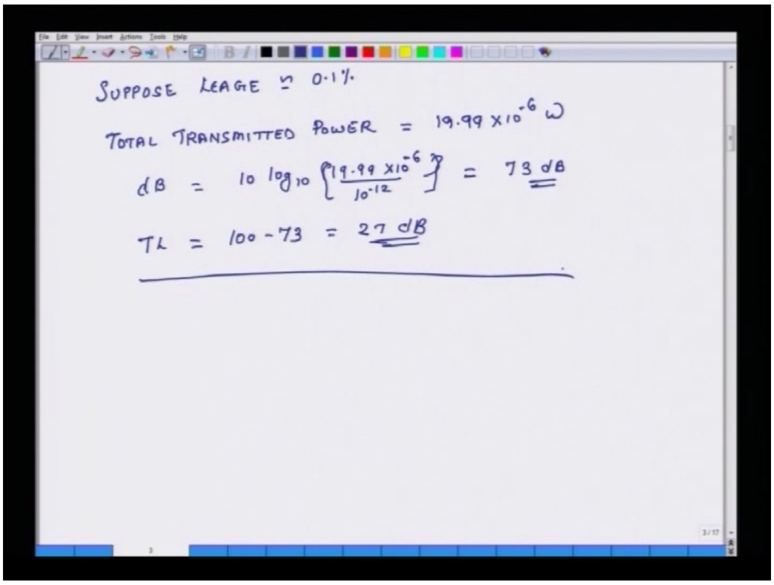

So this closes my discussion on the leakage part of you know what happens if there is a leakage in a wall or in a door or in a partition which has been design to arrest noise. So another related topic which I am going to cover is what happens if I have two walls adjacent to each other and noise is incident on the wall to the other side. So let us say this is one wall, this is another wall and area density of this wall is M 1, this is M 2.

Distance between these two walls is d and then what I am interested in finding out is that if I am having sound impinging on this wall, so this is incident power, then what is the magnitude of transmitted power? Okay.

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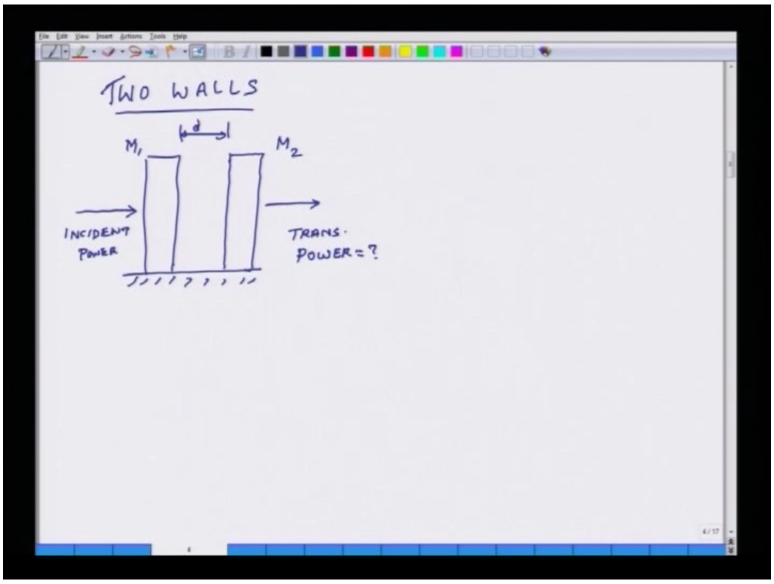

So based on the current state of knowledge and mathematical calculations and also empirical data which I will not be discussing in this particular lecture for purposes of gravity, I will just present results for this problem. So what people have found is that the answer to this problem depends on the magnitude of this term d. So d could have change then the answer may change.

So there are three scenarios and based on what is the value of d and then depending on which scenario we are into we will have a different answer. So first one is case 1. These walls are very close and theoretically they can be as close as a situation where the distance between these two walls is exactly 0. So if these walls are extremely close and we will quantify in a little while what is the meaning of being very close. Then these walls behave in such a way that they have a total combined thickness of wall 1 and wall 2 and the mass.

So they just behave as a single wall. That is what it boils down to. So if these walls are closed then my transmission loss is 20 log 10 of specific mass 1 plus specific mass 2 plus 20 log 10 of frequency minus 47 point 3. So everything is in decibels, okay.

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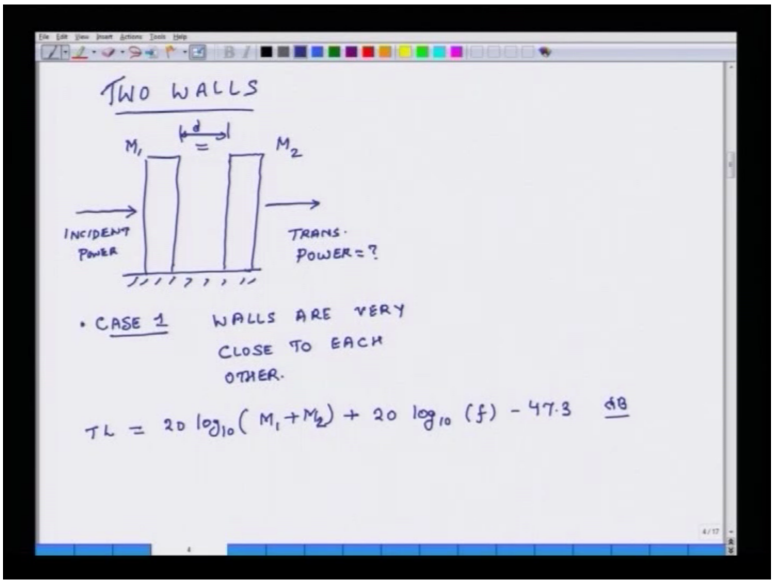

So what you see here is that this relation is more or less identical in a single wall situation. The only thing we have done here is that I have replaced M 1 by M 1 plus M 2 which is basically a sum of two specific mass values. So this is what happens when these walls are very close. Now what is the meaning of this term called walls are very close? Walls are very close in the sense that this term rho C over pie M 1 plus M 2 is less than f is less than f 0, okay.

So I have to calculate the frequency at which I am trying to assess the value of transmission loss. And as long as the value of f is less than this term and also it is less then f 0, and I will again define f 0 in a little while, then walls will be deemed as fairly close to each other.

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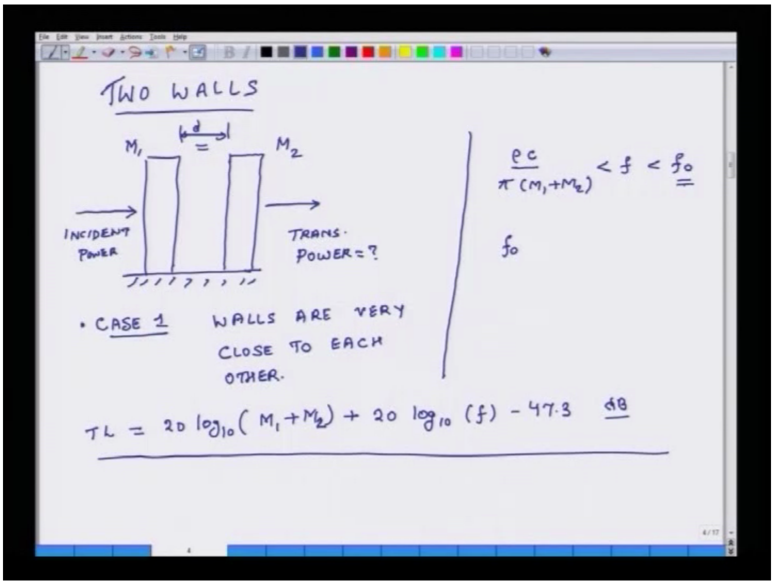

Now f 0 it depends on the value of d. So f 0 is actually related to the resonance of the system. So f 0 equals C over 2 pie, C is velocity of sound, times rho over d, d is the distance between these two walls, rho is the density of air in ambient conditions, times 1 over M 1 plus 1 over M 2 and then I take the whole thing to the power of half. So what you see here is that f 0 depends on d. If I increase my d, f 0 becomes less. If I reduce my d then f 0 becomes more. So I know from this I can find the value of f 0.

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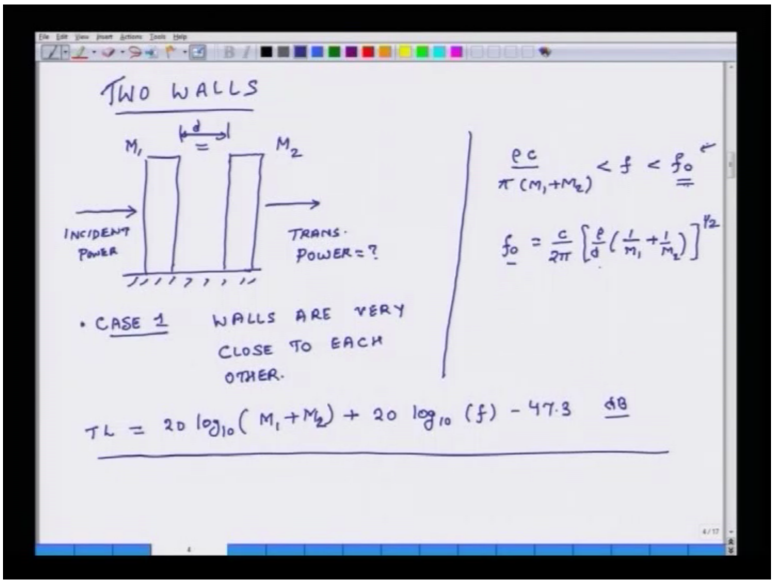

And as long as the frequency of the sound which is getting transmitted through this dual wall structure is between these two numbers rho C over pie M 1 plus M 2 and f 0 I will consider that the walls are fairly close to each other and then in that case the transmission loss across this dual wall structure is defined by this relation.

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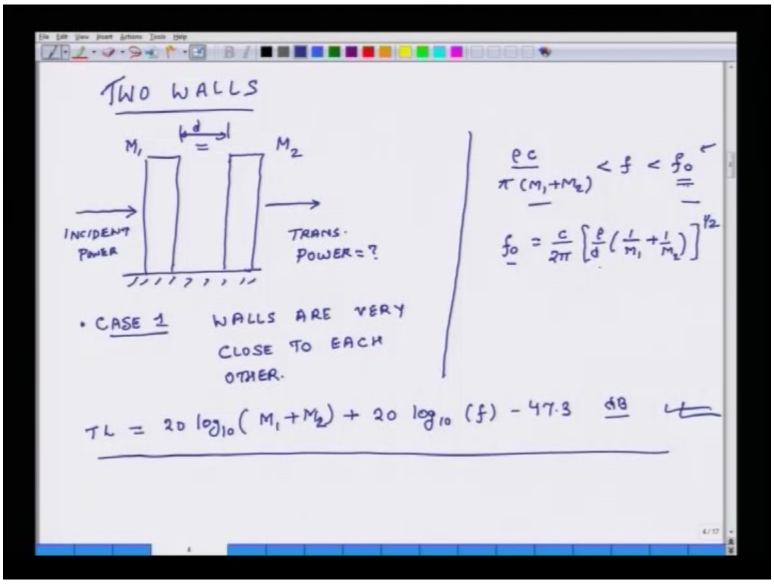

One last thing in this context I wanted to point out is that this term basically relates to the condition that I am operating in the mass operated region and we had defined and we had explained the meaning of this term mass operated region in our previous lecture. So this is case 1.

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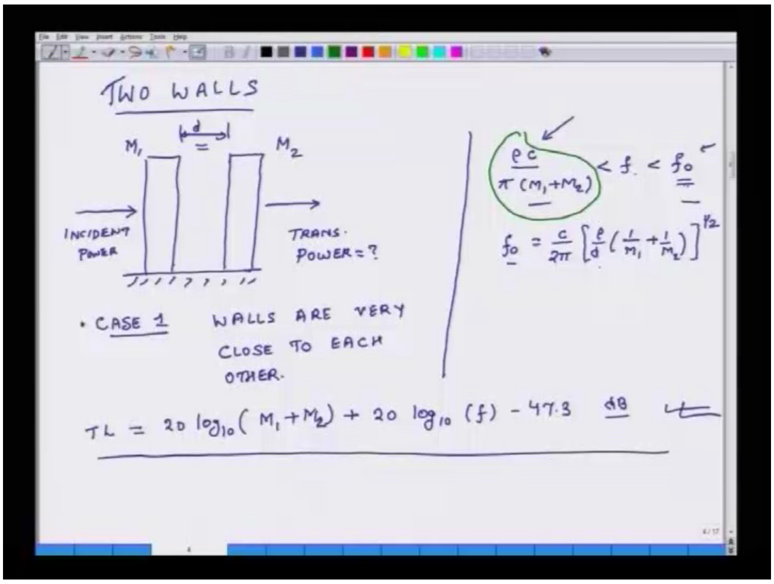

So then obviously the case 2 will be when the frequency exceeds f 0. So case 2, frequency is exceeding f 0 and then again there is upper bound to this frequency. So if the frequency is between f 0 and C over 2 pie times distance then the coupling between these two walls is of a moderate nature, it is of a moderate nature. So if this is true then standing wave gets developed between walls, okay.

So in that case the relation for transmission loss is T L equals T L 1 which is transmission loss for this wall alone. So this is wall number 1, this is wall number 2.

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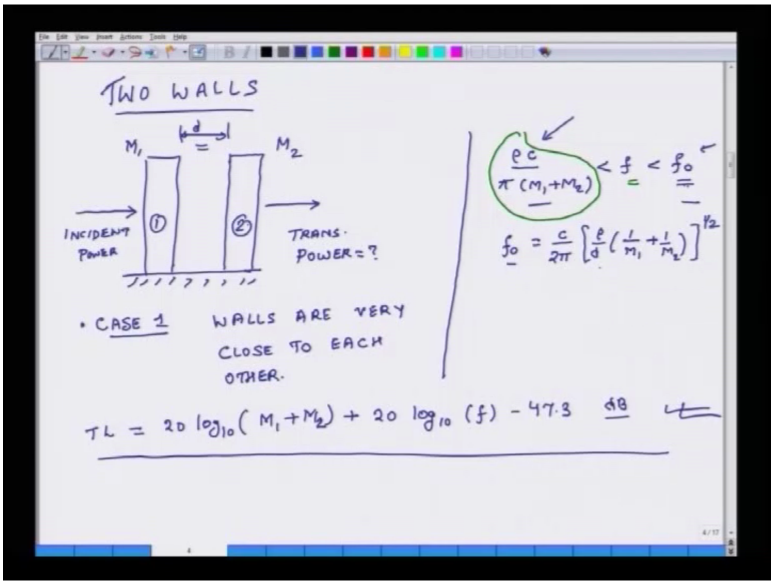

So T L 1 plus T L 2, you see these walls are not getting decoupled. So, T L 1 plus T L 2 plus 20 log in this 10 times 4 pie f d over C, okay. So this is the transmission loss equation for the second case when my frequency is between f 0 and C over 2 pie times d, d is the distance between these two walls.

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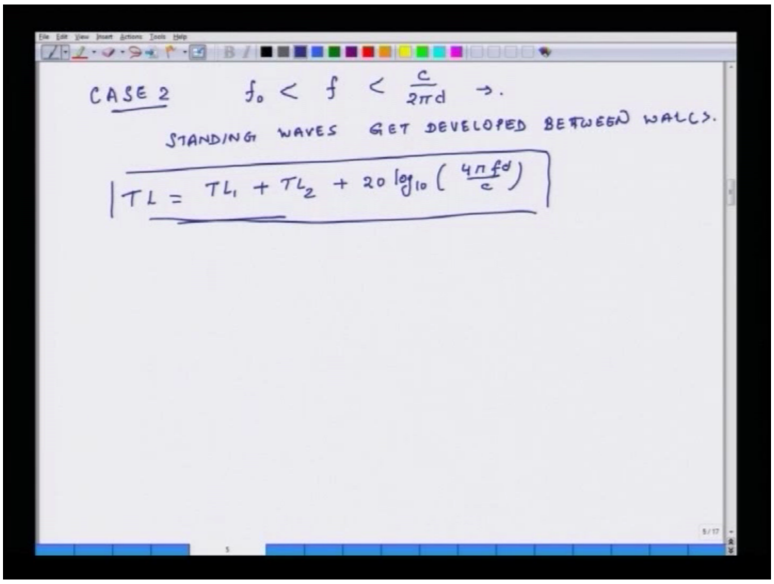

And then the third case is when the walls are extremely far with respect to each other. So that is case 3. Walls are far from each other. Now in this case what starts happening is the walls which are extremely far from each other then the distance between these two walls start behaving as some sort of a small room. And once we have that kind of situation then one thing which also starts becoming important is that overall absorption of sound between these two walls. So that absorption of sound also starts becoming important.

So in that situation transmission loss equals T L 1 plus transmission loss 2 second wall by itself plus 10 log of 10 over 4 plus 1 plus 2 over alpha where alpha equals surface absorption coefficient. And this is a dimensionless number. It changes with respect to frequency and the value of this number also changes with respect to the type of material we are talking about.

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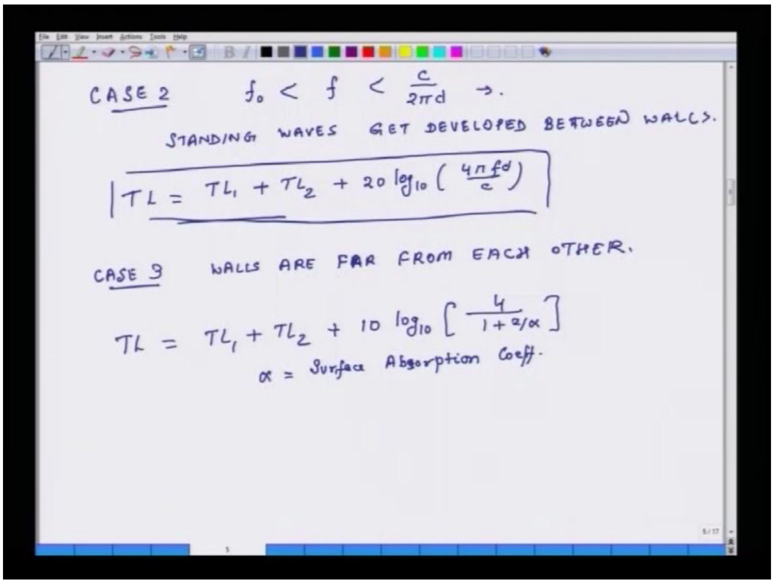

So you have a brick the value of alpha at 125 hertz may be significantly different then let us say if you have glass and the value of alpha for glass at 125 hertz. So alpha, it depends on material and it depends on frequency. So there are catalogues and books which have recorded the value of whole range of materials at different frequencies and from there we can get the value of alpha, plug it into this particular relation and you can figure out what is the value of T L when walls are far from each other.

And once again the meaning of the term walls are far from each other is when f is large compared to C over 2 pie d. So this is good for this particular condition, okay.

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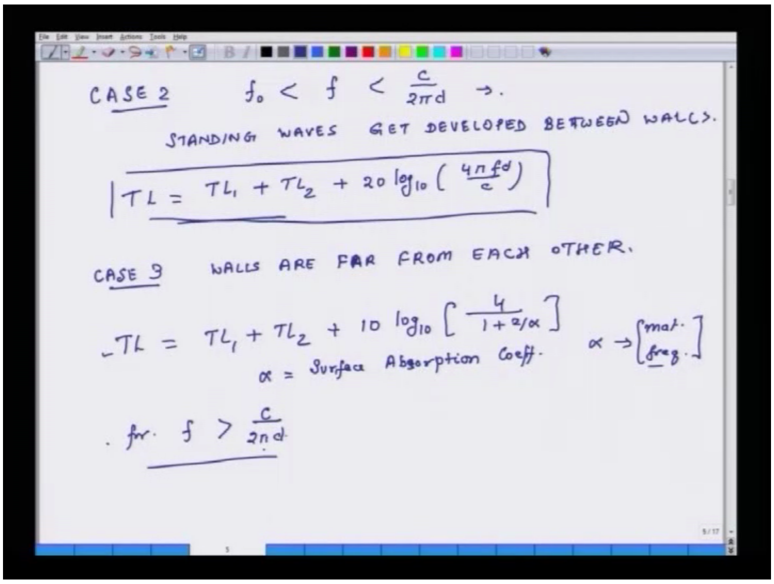

So we will do a small example and I have done these calculations earlier so I am just going to just replicate some of the numbers here to provide you some perspective. So we will do an example that M 1 equals M 2 such that it is equal to 30 point 48 kilograms per square metre and this value of M 1 and M 2 corresponds to an acrylic panel which is about 25 millimetres thick. If acrylic so about 1 point 18 to 1 point 2 so I have put those numbers in and this is what the value of M 1 and M 2 comes out to be, okay.

Now for this situation then I also assume that d is equal to 1 centimetres that is 0 point 01 metres. So based on this I find that value of f 0 is 153 hertz using this relation and then f 2 which is the second frequency, cut off frequency and which equals C over 2 pie times d and that comes out to be 5490 hertz, okay.

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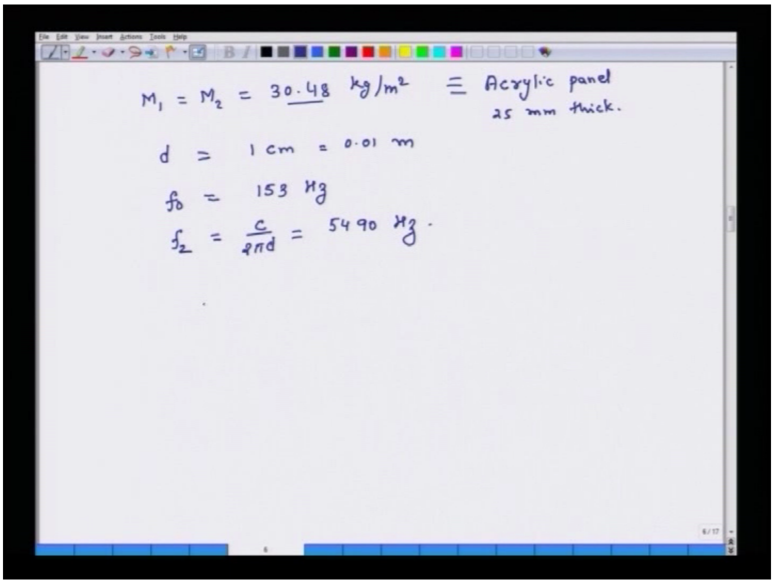

So for this kind of structure I am going to plot my transmission loss on vertical axis and frequency on horizontal axis and I am going to have 2 breakpoints in terms of where the slope of the curve is going to change. So first one is f 1 equals 153 hertz and then the second one is f 2 equals 5490 hertz. The slope of this curve is going to change at these two individual frequencies because I jump from one zone to the other zone.

So below value of f 1 as long as I am in the mass controlled region my slope line is going to be something like this. Then at f 1 I have a drop in transmission loss and then the value of (transmit) transmission loss it rises very rapidly and keeps on going up till you hit f 2, okay.

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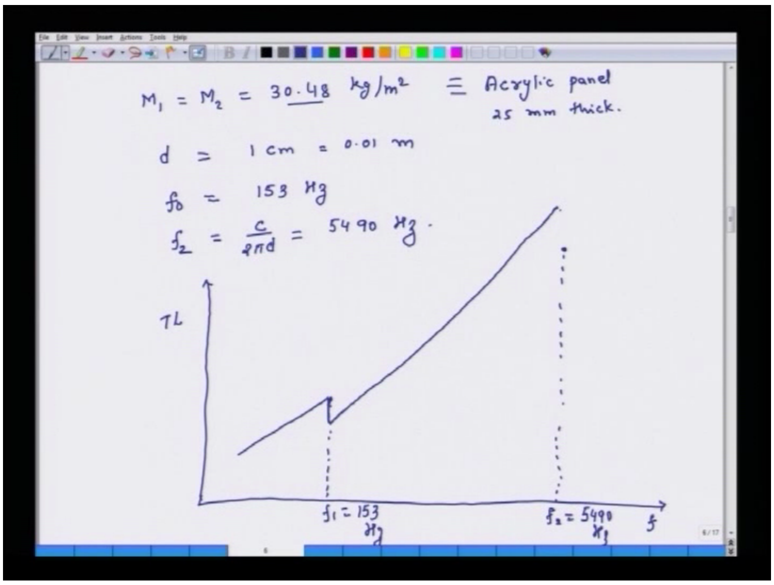

And at f 2 if I do the calculations I find that once again I have a drop in the value of transmission loss and after that, this is probably not that steep, again the value of transmission loss starts increasing. So this number I did some math and it is approximately equal to 5 point 8 decibels. This drop is approximately equal to 30 decibels and the slope here this equals 12 decibels per octave.

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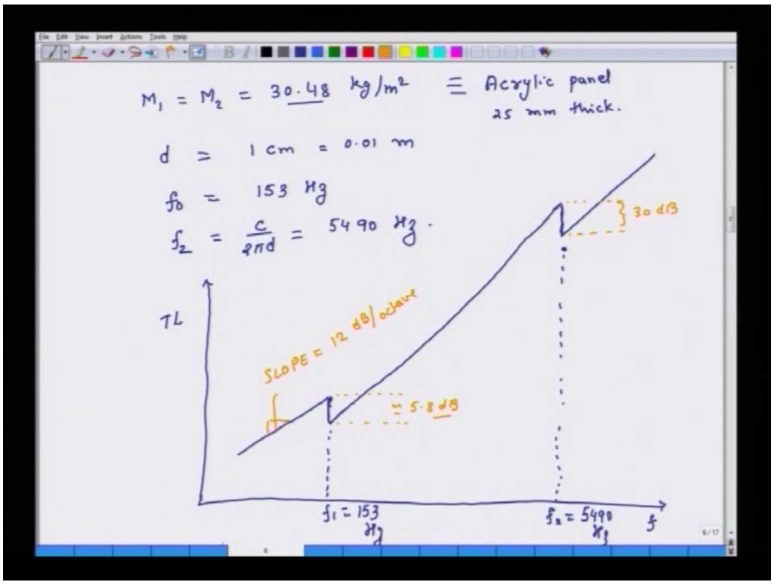

Why is it 12 decibels per octave? Because initially these walls if I have, I am sorry this is 6 decibels per octave. The other thing I wanted to mention is that if I plot another line and this corresponds to T L for M 1 alone and I know that here M 1 equals M 2 equal 30 point 48, then this gap between these two lines is about 6 decibels. It is actually exactly 6 decibels, okay.

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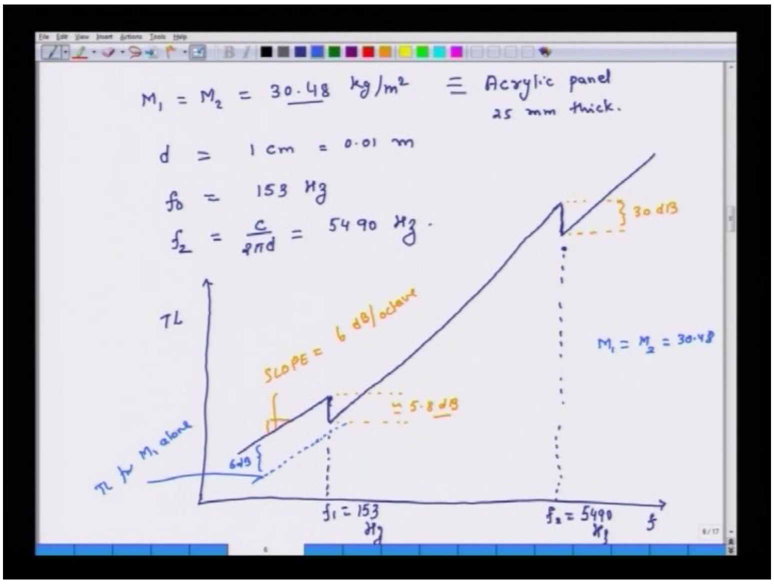

So what this curve shows us very clearly is that below the value of f 1 if I have two walls separated by small amount of distance their transmission loss will be more or less same as that of a wall which is twice as thick. Then at the value of f 1 this transmission loss will shrink and it will more or less disappear.

But then as I move into the intermediate range where walls starts kind of getting decoupled then my transmission loss for this dual wall structure starts rising very significantly and I have a really very large amounts of transmission losses happening across the dual wall structure till I hit another frequency which is in this case 5490 and it relates to this term C over 2 pie d.

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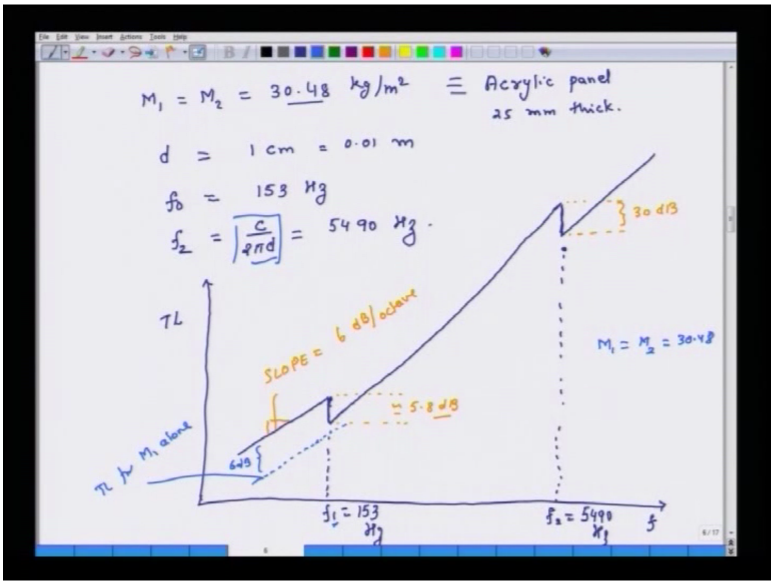

And at that point once again I have a reduction in transmission loss and it is primarily due to this factor alpha because what is happening is that this term in the parenthesis 4 over 1 plus 2 divided by alpha is less than 1, this whole term. So the logarithm of this term in the parenthesis is a negative number and as a consequence I have a drop in transmission loss.

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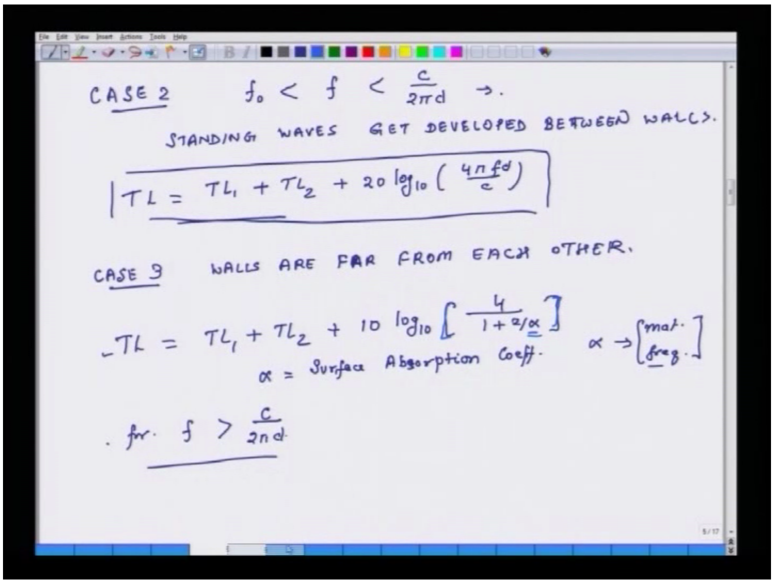

But once again once that has happened then as I keep on increasing my frequency further because T L or transmission loss of a standalone wall increases with frequency, so once again I start having this increment

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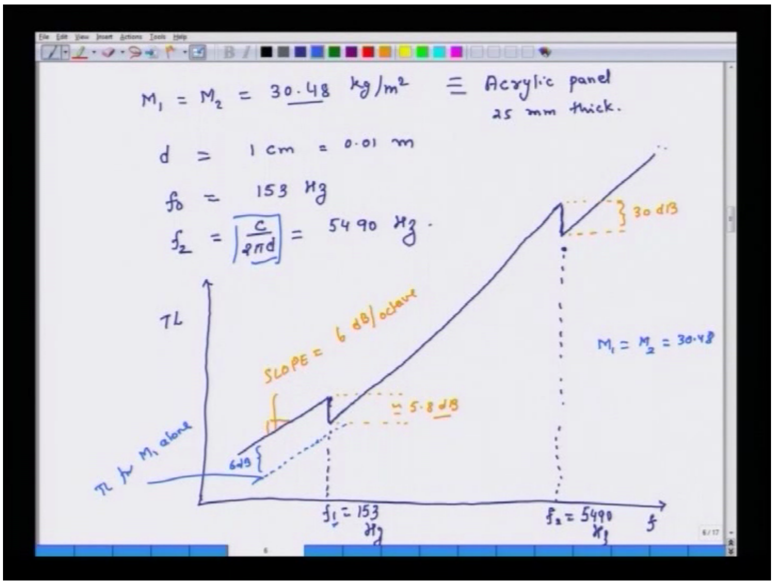

So till so far we have covered sound propagation through dual wall structure and also through a wall which has a leakage path. So now I will be moving to the last topic for today's lecture and that is sound transmission class. So but before I talk about this I will introduce another terminology called frequency bands. Now you can have a frequency band between two frequencies F 1 and F 2 and whatever frequencies are between these two bands that is called a frequency band.

But for purposes of standardization the international standards organisation has defined a set number of bands which are now used across the whole industry of acoustic industry and research community whenever results are analysed, recorded and presented. So these are known as ISO frequency bands, okay.

Each of these bands they have four components. The first one is a band number. If I know the band number then mathematically I can very easily calculate other parameters of the band which are upper frequency, center frequency and then lower frequency.

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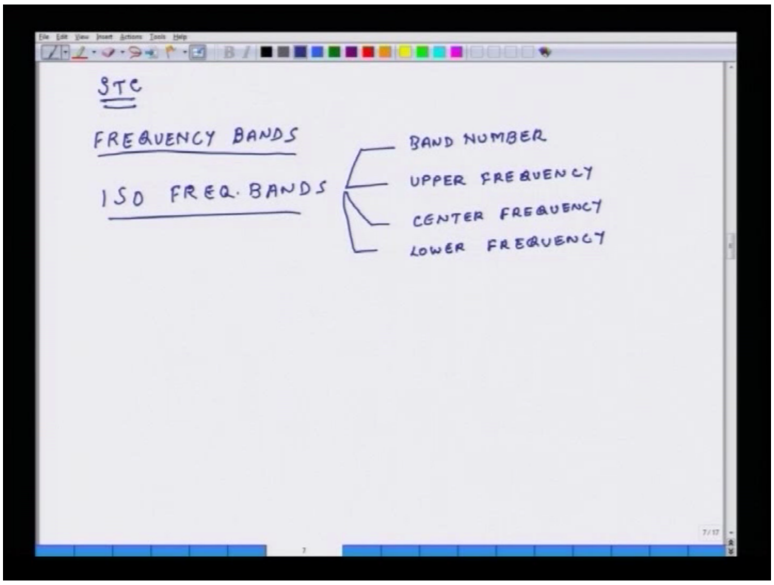

So band number is B N. If I know the value of B N it could be and it is an integer. So it could be 1, 2, 3, 4 whatever. Then from that number I can very easily calculate what is going to be my upper frequency f u? What is going to be my center frequency f c? And what is going to be my lower frequency f L? So please note that the relationship between f u, f c and f L is such that it meets our log scale standards. So it is not that the difference between f u and f c same as f c and f L, okay.

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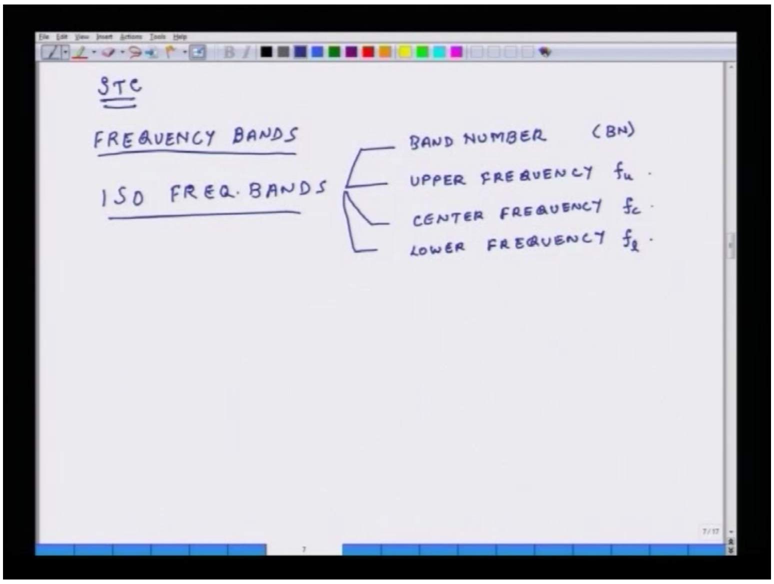

So now I will just cite some of these relationships. So if I know the band number then I can calculate the (va) value of center frequency through this relation. Also the center frequency is related to upper frequency and the lower frequency through this square root relation. The math for all this stuff is oldest fairly trivial so will not go into proving out these relations but I just wanted to put this on record so that you are familiar with this material.

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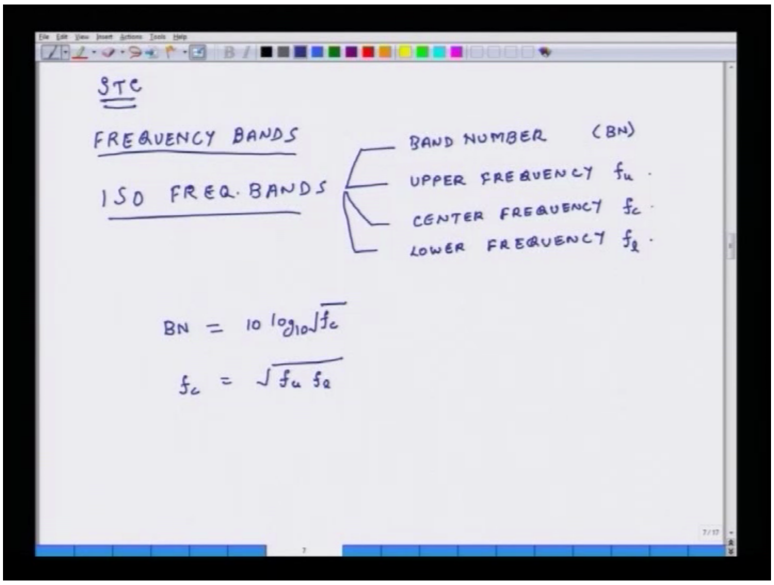

So f c is a square of f u times f L and then finally f u over f L is 2 to the power of 1 over N where N could be an integer. So it is 1 if the two frequencies are separated by an octave. So if my upper frequency and lower frequency are separated by an octave, for instance let us say 125 hertz is my lower frequency, 250 hertz is my upper frequency then in that case I will call

N to be 1. So N is 1 or N could be also 3. So this is for octave bands. And in case of N being 3 these bands are known as one third octave bands, okay.

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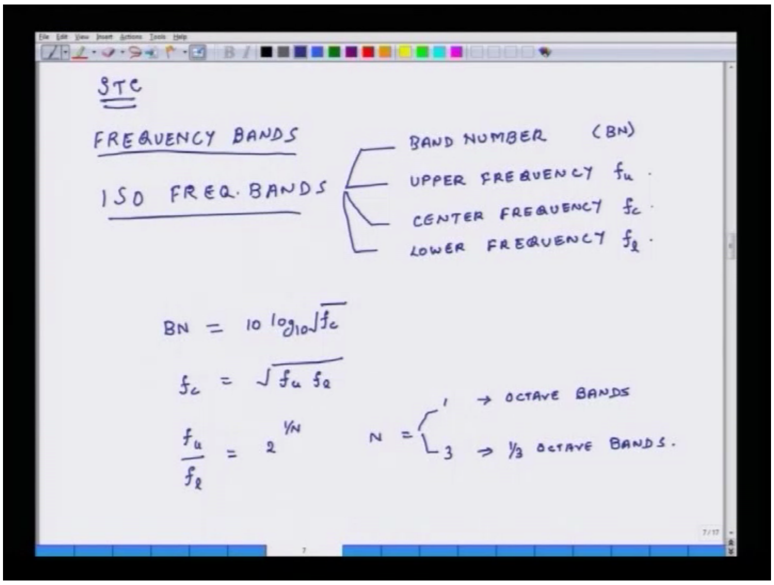

So if I have a lot of noise or sound related data let us say starting from 10 hertz to 20000 hertz and I want to break it into specific bands then I can break it into bands. It will be good if I and consistent with these ISO frequency bands and if I break it into bands where each bands bandwidth is defined by these relations which I have shown here. So I just wanted to show you some of these bands, exact value of these bands. So what you have here are in this table are columns.

So first column is band number, band number is 12, center frequency is f c and then from the center frequency I can calculate my f u and f L from the relations I explained. 13 band number center frequency is 20. So one thing I wanted to mention is that relationship between B N which is the band number and the center frequency is not an exact relationship because band number is always used in an integer sense.

So these relations are approximate because if I take 10 log 10 of 16 it will not come out to be exactly 12. But it will be fairly close to 12. So I am making some approximation. But this is how ISO has defined it and people have been following it very consistently for last several decades now.

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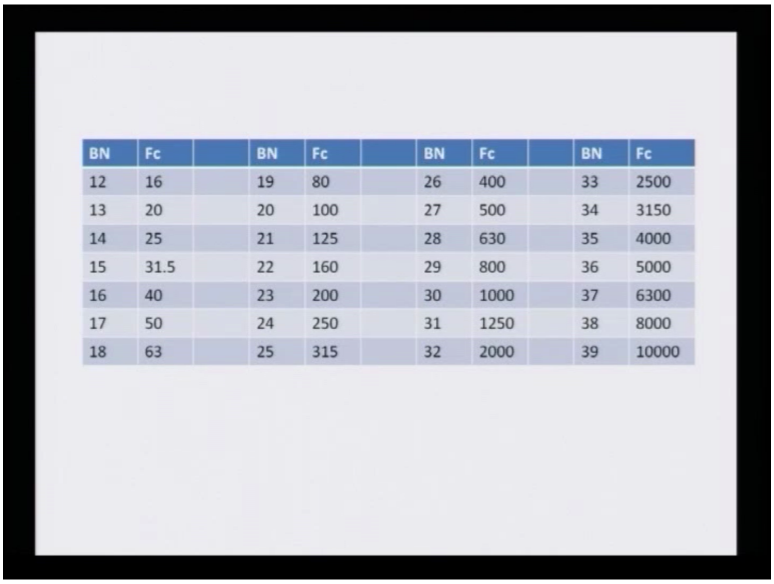

BN	Fc	BN	Fc	BN	Fc	BN	Fc
12	16	19	80	26	400	33	2500
13	20	20	100	27	500	34	3150
14	25	21	125	28	630	35	4000
15	31.5	22	160	29	800	36	5000
16	40	23	200	30	1000	37	6300
17	50	24	250	31	1250	38	8000
18	63	25	315	32	2000	39	10000

So I have band numbers going from 12, 13, 14 to 18. Then I have another set of band numbers starting from 19 to 25, 26 to 32 and actually this goes on further. So in case of band number 32 my center frequency is 2000. If I go to band number 39, center frequency is 10000 and it keeps on going down further. So one thing you may want to again observe is that let us look band number 13 and the center frequency is 20 hertz.

Then if I skip two bands so I go to 14, 15 and then 16 band is 40 which is two times that of 13. Then again skip two bands, so 17, 18 I skip 19th band is 80, again it is a factor of 2. So every third band is an octave higher than the earlier band.

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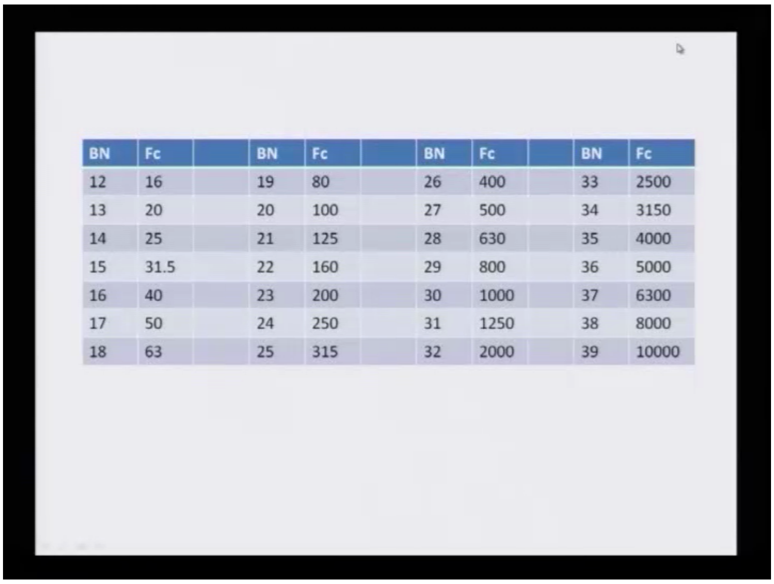

BN	Fc	BN	Fc	BN	Fc	BN	Fc
12	16	19	80	26	400	33	2500
13	20	20	100	27	500	34	3150
14	25	21	125	28	630	35	4000
15	31.5	22	160	29	800	36	5000
16	40	23	200	30	1000	37	6300
17	50	24	250	31	1250	38	8000
18	63	25	315	32	2000	39	10000

This is what I wanted to show about bands. So now going back so now will talk in very brief about STC, sound transmission class. So this is an acronym for sound transmission class and STC is a single number. It is a single number which helps us get quantitative feeling of what is the transmission loss across a wooden panel or a glass door or a wall or whatever. So this is what sound transmission class is.

Now we have seen till so far how we can for relatively simple configurations calculate transmission loss across a rectangular panel. It turns out that in actual applications some of these panels may have more complex designs. They may have ribs, they may have holes, they may have different types of materials, they may have varying mass properties from point A to point B based on their structure. So analytically finding out transmission loss across real panels or real walls becomes difficult.

So in a lot of cases people experimentally measure these transmission loss values at different frequencies because we have seen that the value of T L or transmission loss varies very strongly as frequency changes and then they shrink all that data into a single number and that number is called sound transmission class number. In this particular context the data is captured in the frequency range of 125 hertz to 5000 hertz.

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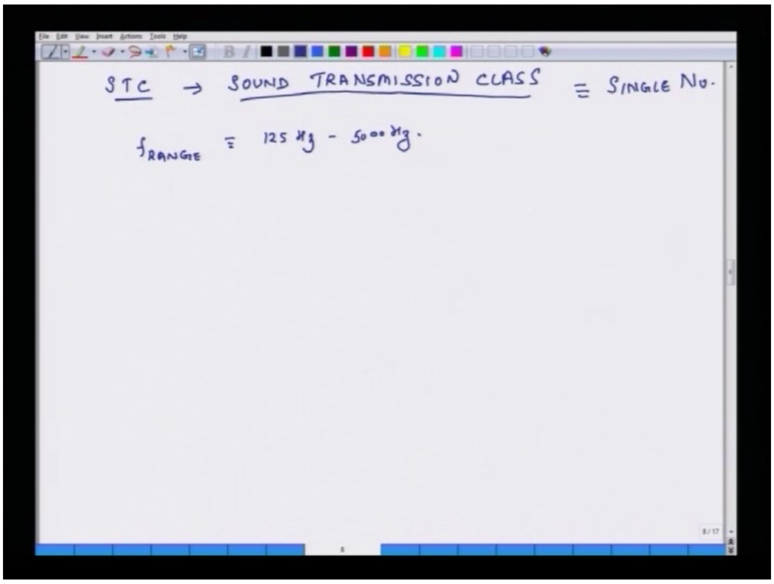

So people measure the value of transmission loss in this bandwidth using this one third octaves and they measure the value of transmission loss at all those individual frequencies between 125 hertz and 5000 hertz using one third octave strengths. And then they shrink all that number into a single number, all these numbers into a single number which is known as STC.

Now the reason this bandwidth is used is because most of the sound we hear in day to day activity whether it is audio, for instance in radio, TV, speech, in office spaces. Most of this noise or sound lies in this bandwidth. So this is why data is collected for this bandwidth and STC number is calculated.

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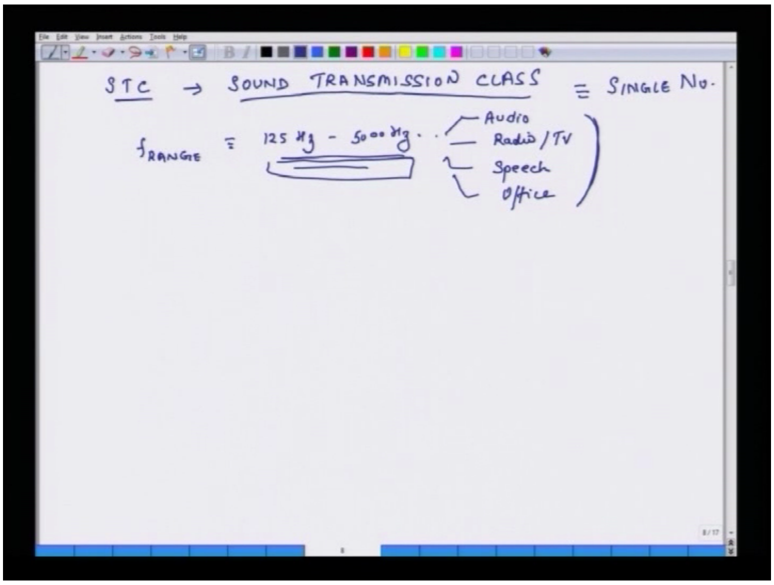

And how is STC calculated? So what people do is that first they collect all these numbers and then they compare all these data to a standard curve which has been defined by ISO and then from that they compare it with the standard curve and then there is an algorithm for shrinking data to single number.

So we will not discuss this algorithm today but I think for purposes of this lecture it will suffice that people measure the value of transmission loss at different frequencies which are separated with respect to each other by one third of an octave and this frequencies lie between 125 hertz and 5000 hertz. And then they shrink all these data using this algorithm to single number. And while they are shrinking this thing they are using some standard curve to do this shrinking process.

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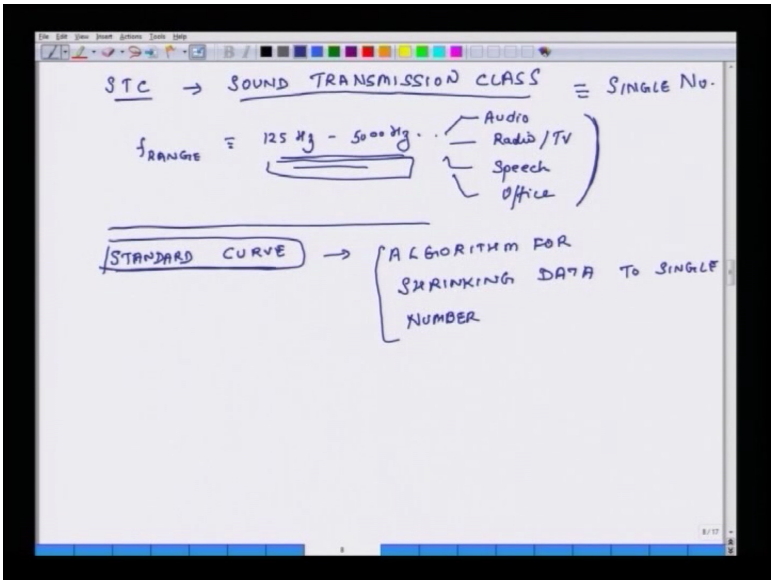

What is an ideal attenuation or transmission loss you would like to have if you are sitting in a room or you are in a bedroom? So that is what I will show in the next slide. So this chart or this table shows some typical design values for STC or sound transmission class and these values they have been catalogued in this reference but several other agencies also have done similar work.

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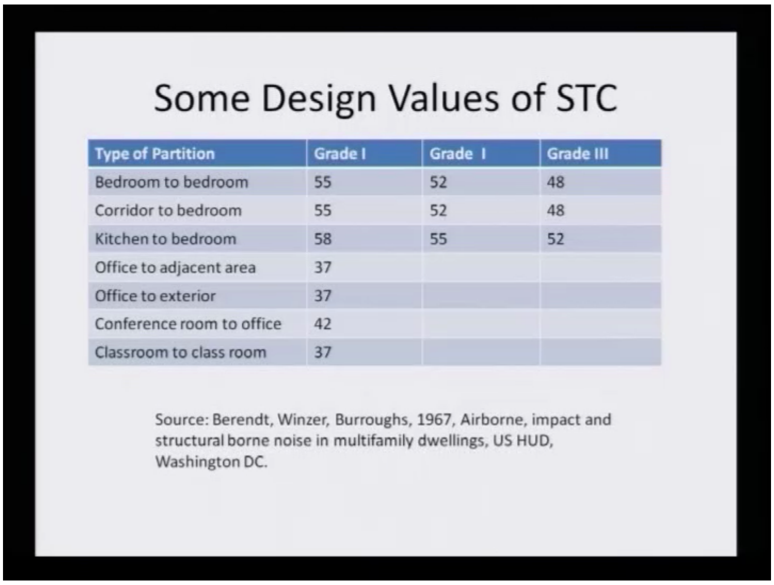
Some Design Values of STC

Type of Partition	Grade I	Grade I	Grade III
Bedroom to bedroom	55	52	48
Corridor to bedroom	55	52	48
Kitchen to bedroom	58	55	52
Office to adjacent area	37		
Office to exterior	37		
Conference room to office	42		
Classroom to class room	37		

Source: Berendt, Winzer, Burroughs, 1967, Airborne, impact and structural borne noise in multifamily dwellings, US HUD, Washington DC.

So suppose you are in a bedroom and then there is an adjacent bedroom and if you have to design a partition between these two bedrooms then top grade design would have some sort of a 55 STC partition. So this should have been grade 2. So grade 2 would be 52 decibels, grade 3 would be 48 decibels and so on and so forth. So there are some target values of STC so this helps an individual go out in the market or to an acoustic consultant and get specific partitions with specific performance parameters which will suffice his or her needs.

So I think this completes our discussion on sound attenuation through walls and also our today's lecture and we will start talking about loopholes and propagation of sound in radial direction in our next class. Thank you very much and look forward to seeing you in the next class. Thank you.