Acoustic Materials and Metamaterials

Prof. Sneha Singh
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture - 19
Tutorial on Sound Absorbers

Welcome to lecture 19 on the series on Acoustic Materials and Metamaterials, I am Dr. Sneha Singh, an assistant Professor at the Mechanical and Industrial Engineering Department of IIT Roorkee. So, in the previous two weeks, we have studied about the acoustic materials. So, we studied in detail about porous absorbers, panel sound resonators and Helmholtz resonators.

Now, we will solve some numerical problems. So, this is a tutorial class, we will solve some numerical problems on these materials, so that we get, so that you can get a better understanding of their working.

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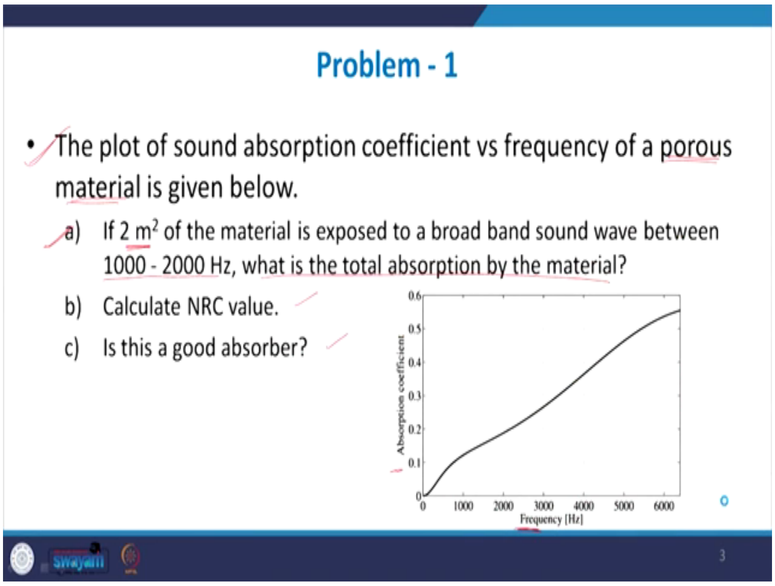

So, let us solve the numericals, the first numerical is from porous materials. So, the problem here given to you is; let a plot of alpha with respect to frequency is given to you for some porous material. So, using this plot some questions have been asked.

So, if 2 meter square of the material is exposed to a broadband sound wave between 1000 to 2000 Hertz, what will be the total absorption by the material? And then we have to calculate the NRC and find out whether it is a good absorber. So, let us first begin with part a. So, here the surface of the, here 2 meter square of this particular material is and the target sound that is incident on it is a broadband sound between 1000 to 2000 Hertz and we have to find what is the total absorption.

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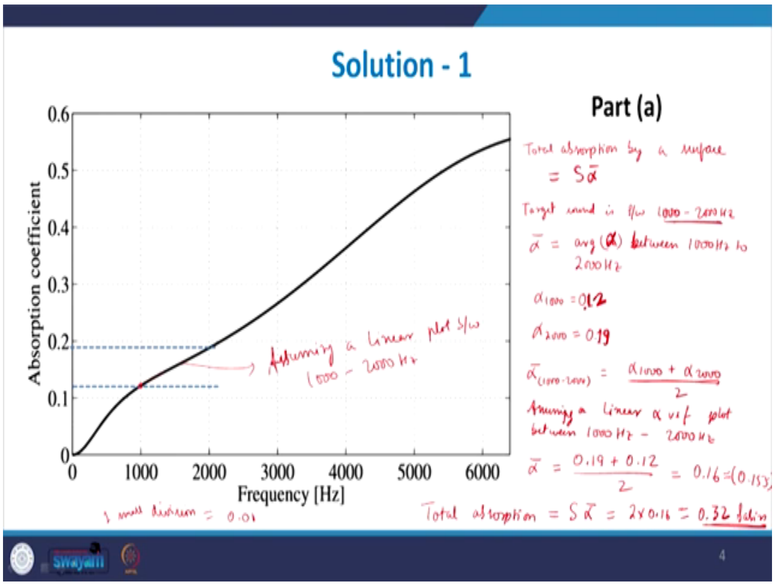

So, here, now we know that the total absorption by a surface is equal to simply the surface area of that material multiplied by the average alpha or the average absorption coefficient of that material. And alpha has got different values for different frequencies. So, here because the target sound is between 1000 to 2000 Hertz, so that is the only excitation that is being provided. So, the average absorption for this particular sound will be taken only between 1000 to 2000 Hertz.

So, your alpha average is simply, the average of alpha between the average of the alpha values between 1000 Hertz to 2000 Hertz; because that is the incident sound. So, let us find what is the average alpha in the domain of the incident sound? So, if we see here at 1000 Hertz it corresponds to here every dot is 10 units. So, here every dot becomes 0.01. So, 1 small division is equal to 0.01. So, this is one and then counting two divisions. So, at alpha what we get is and the curve between them; because it is obviously, very tedious to calculate each and every point, they are infinite number of points between 1000 to 2000.

So, and if you see this let us assume, assuming a linear profile, a linear plot between 1000 to 2000 Hertz. So, as you can see it is almost linear in nature and we have to find an approximate solution. So, let us find the value here which comes out to be 1 point plus 2 divisions. So, alpha at 1000 is equal to 1.2 sorry 0.12 right, 0.1 plus 0.02 two divisions; alpha at 2000 will be what, again we see here it is about one divisions less, so just one small division less than 0.2, so it becomes 0.19. So, you get these two values.

Then the alpha average between 1000 to 2000 is alpha of 1000 plus alpha of 2000 by 2, this is assuming a linear alpha versus f plot between 1000 Hertz to 2000 Hertz. So, we have assumed a linear, this particular line to be almost linear in nature. So, when you assume it is a linear line, then the average will be the midpoint value which we have found as alpha of 1000 plus alpha of 2000 by 2.

So, the alpha bar comes out to be 0.19 plus 0.12 by 2 which is coming out to be 0.16 or 0.155 approximately. Then the total absorption will become, absorption for the given case will be S into alpha bar, which will be it is a 2 meter square material, so if you go back, you can see it is a 2 meter square material. So, by this what we get is 2 into 0.16, which is going to be 0.32 and the units for the total absorption is Sabin.

So, whenever we multiply the absorption coefficient with the surface area of the material, the total absorption that we get we express it in the units of Sabine. So, this is the answer to our 1st problem. Now let us go back to the second one. It has to, we have to find the NRC value or the noise reduction coefficient value and then third part is it a good absorber or not.

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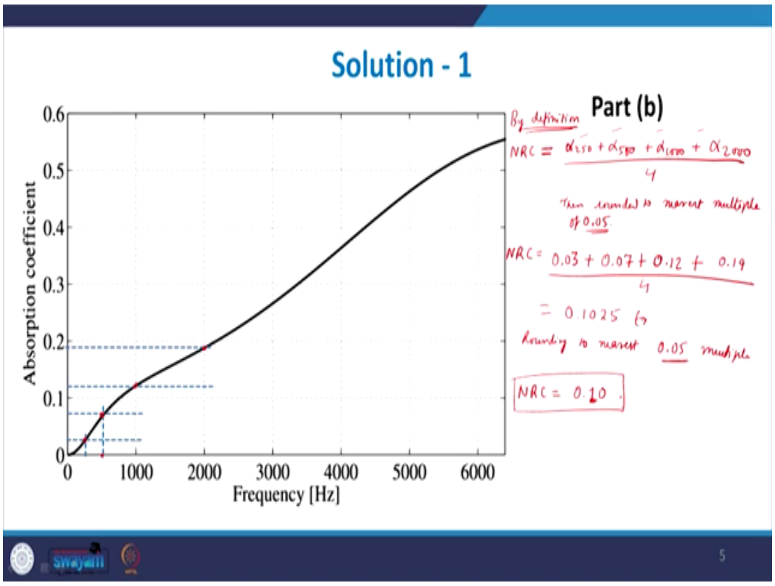

So, if you go back to the plot, let us look at the plot freshly for part b. So, the NRC value has to be calculated and by definition the NRC value we have, it was defined in the class on porous materials that the noise reduction coefficient is yet another metric to measure the performance of a porous absorber which is given by the average value of alpha at 250, 500, 1000 and 2000 Hertz. So, we find these individual values at 250, 500, 1000 and 2000 and then we take the average and the average that we take, then it is rounded to nearest multiple of 0.05.

So, just in the first class of this week we studied about this particular coefficient, thus it is the average value that is rounded to the nearest multiple of 0.05. So, with this definition we can calculate the NRC, for that let us find out these four values. So, we have already found the value for alpha 1000 and alpha 2000 that, was 0.19 and 0.12.

So, this is already known to, this is already this is 0.12 this is 0.19. So, let us begin like this; this is 0.19, this is 0.12 and then let us see what is the value at 500 Hertz. So, if this is approximately at the midpoint. So, at the midpoint what we find is, the value comes out to be 0.07; it is three divisions downwards of 0.1.

So, it becomes 0.07. Or you can simply count the number of dots it will come out to be 7. So, if you count 1, 2, 3, 4, 5, 6, 7; 7th division is this. So, this point we found, this point we have found and this one; and what is the value at 250? This is the midpoint between this and this. So, what the value that you get is again 1 2 and 3; third division. So, this is going to be 0.03.

So, from the graph you can see these values. So, when such questions are given to you; obviously, a bigger and clearer graph will be given to you where every smallest division will be marked. So, you can calculate the particular values at every point. So, you have found these values, you divide and you get the average; the average comes out to be approximately 0.1025, this is the average and then round rounding to nearest 0.05 multiple, because alpha can have the values of so many digits. So, it is usually rounded off to get a more concise value, it is rounded to the nearest multiple of 0.05.

So, if we round this off then the actual NRC value that we get is 0.10. If it was supposed to 0.14, then we would round it off to 0.15, which is also a multiple of 0.05 and so on. So, this is the value of NRC that we are getting.

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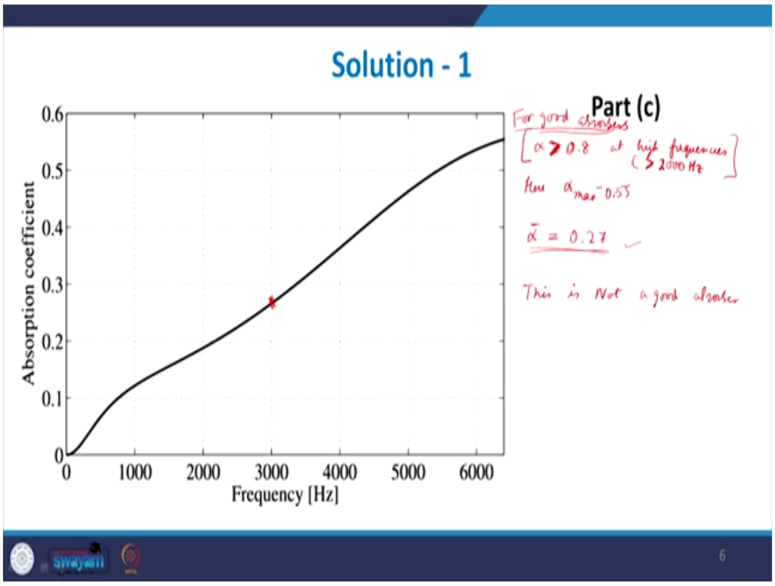

And the third part is just to say is it a good absorber or not. Now as you can see all the absorbers they perform poorly in the low frequency range; but usually beyond 1000 Hertz their absorption frequency increases. And we had already seen up lots of lots of good absorbers and there the alpha would almost be greater than equal to 0.8 at high frequencies.

So, and here you see is the maximum value here the alpha max. So, for good absorbers this is the, this is what the general assumption is that a good absorber should at least provide an absorption of 0.8 or above in the high frequency range approximately. But that is not usually happening; let us say between 2 greater than 2000 Hertz at least it should point provide a alpha value that is greater than 0.8. But here alpha max is coming out to be 0.55, no value is crossing 0.6 and everywhere it is very very less even if you calculate the average alpha.

So, it comes out to be, if you calculate this average alpha then between this, then what you get is somewhere close to this value. So, the midpoint value is here which comes out to be 0.27, even the average alpha is very less. So, you can say that this is not a good absorber, it has very less alpha values. So, it is a very subjective judgment, but in general if among the in the broadband range starting from 1500 to 2000, if it can provide all the alpha values are more than 0.8, you can say it is a good absorber.

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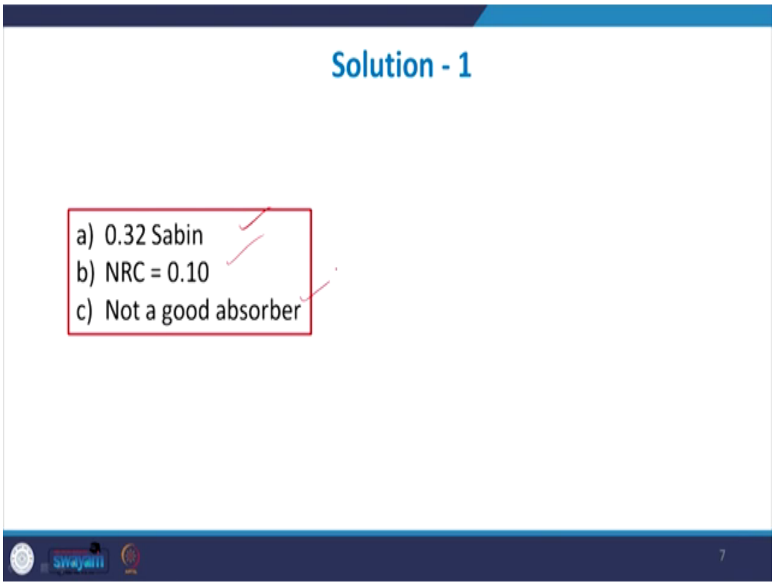

So, this is the solution to the 1st problem, stating it again, ok.

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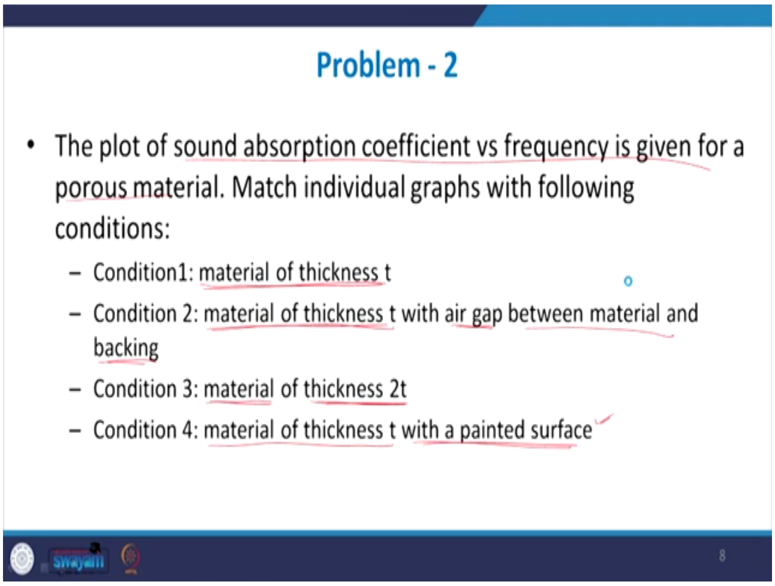

Now, let us solve another problem; now the plot of sound absorption coefficient or alpha versus frequency is given for a porous material. Again of some alpha versus f plot is given to you and you have to match these individual graphs with the following conditions.

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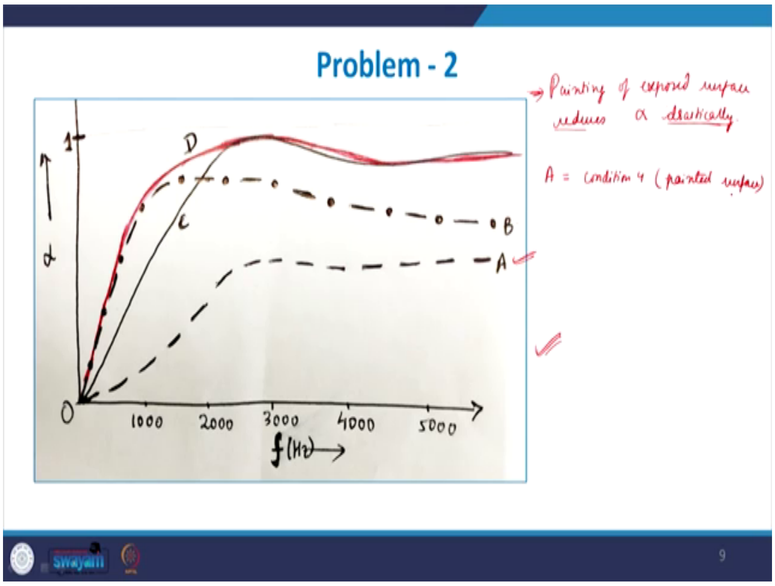

So, the plot is given here in this particular figure. So, you can see this is alpha and f plot and you have this they have four different graphs; graph A, B, this is graph A, this particular thing is graph B, graph C, and the red one is the graph D.

So, each graph corresponds to certain condition for a porous material and you have to match every graph with that condition. So, here the first condition is that, it is a graph of a porous material of thickness t; the second condition is that it is the graph of that same porous material with same thickness, but an air gap is added between the material and the backing. And in the third graph we have, it is the graph of that same material; but now in the thickness is doubled, so the thickness becomes twice of t. And the fourth graph is it is the material of thickness t with a painted surface.

So, the first condition is about the original material; second one suddenly an air gap is introduced; in the third one the thickness is doubled for the original material and the fourth one is when the surface of the material is painted. So, if you see here, then let us solve it one by one; first of all let us see the condition 4, which will be very obvious. The condition is that, material it has a painted surface.

So, when the material has a painted surface; then as we were studying about the porous materials, I told you that when you paint the surface all the pores get clogged. So, in that case the alpha reduces drastically; because the absorption of the material is dependent on the fact that it allows most of the air, most of the sound waves to pass through it and then these waves get dissipated.

So, the more the sound waves can pass through the material more will be the absorption; but the more painting you do, you make it more like a hard reflecting surface, you close down the pores and then the sound waves whatever they wanted to enter will not be able to enter, instead they will be reflected back. So, reflections will increase and alpha will reduce drastically. So, this is what we had studied that, painting of the exposed surface reduces the alpha value drastically. So, this is what we had studied and that is why painting is not done, or evens surface finishing or smoothening of such materials is not done.

So, here you see that, there is just one graph A that has got very reduced alpha compared to all the other graphs. So, there is a very drastic change between A and the rest of the graphs, it is drastically reduced at all frequency. So, A must correspond to the condition 4 which is painted surface, ok. So, A corresponds to this condition we have established. So, the remaining graphs are B, C and D, ok.

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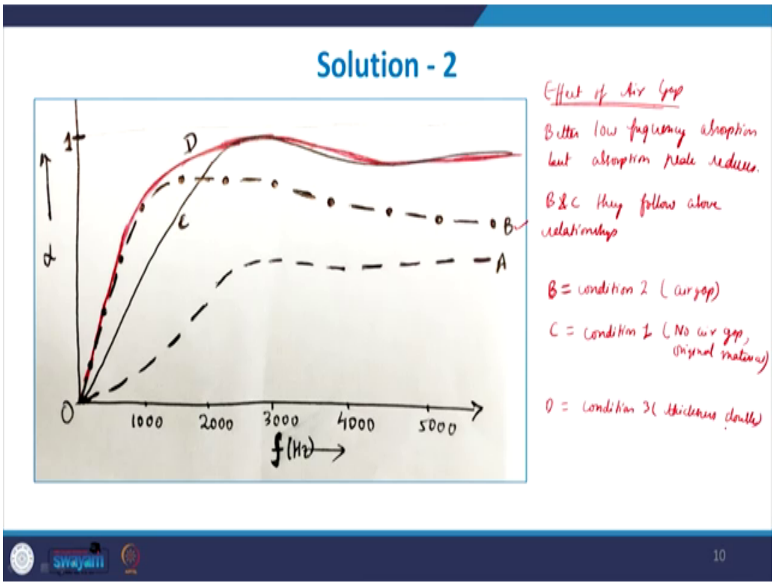

Now, the effect of air gap; let us study how the air gap effects. So, when again discussing about porous material I told you that, when I air gap is introduced between a porous material and the backing; then in that case we studied. So, the exact nature of interactions is yet not known; but experimentally it has been verified and found that, the air gap in general introduces, because the porous materials they are only good at high frequencies, low frequency absorption is extremely less or their poor performance at low frequencies.

So, usually air gap is introduced to enhance their low frequency absorption. And experimentally it has been found that, when you introduce the air gap then the, so the some of the performance at the low frequencies increases slightly; but the overall maximum peak of absorption reduces.

So, better a little relatively better performance at lower frequencies, but the peak of the absorption reduces, that is the effect. So, better low frequency absorption. So, this is the general effect, but absorption peak or the absorption magnitude reduces. So, if you look at this graph, then there is only. So, if you look at graphs, let us say D and C. So, in D and C what you observe is that, this is here the low frequency absorption is increased quite a bit when the peak remains the same. So, this graph is continuously ahead of it.

So, C and D do not represent this condition; but if you look at the graph B here. So, in the graph B, if you compare it with these two gray with this particular graph. So, if you compare this graph with graph C; what you see is that. So, B and C they follow the above relationship; which means that, if you compare this B and C together what you see is that, in the graph B the low frequency absorption has increased, but overall absorption peak has reduced. So, the peak has reduced. So, it is, but the frequency at which the good absorption starts it has increased. So, the low frequency is increased, but the overall peak has reduced.

So, graph B will become the condition. So, if I just go back to the question here ok, the condition 2. So, graph B will become condition 2 which is the air gap condition, and graph C by comparison will become the condition 1, which is the same material same thickness, but no air gap, original material. So, only these two graphs follow this kind of a relationship. So, by default they are left with graph D which should be condition 3, which is thickness doubles. So, let us see if it actually matches with this thickness double condition.

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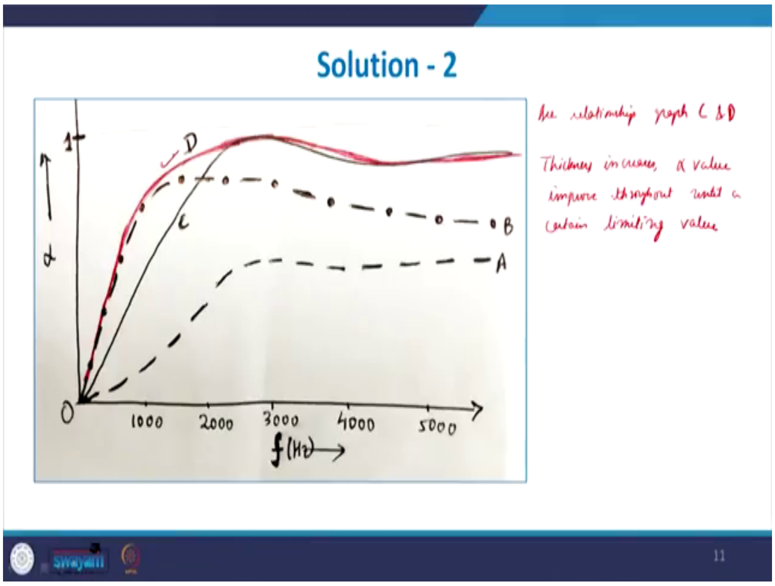

So, if you see relationship between graph C and D; here C we have established is the material, original material no air gap or painting and thickness S t. And D is the condition where same material only the thickness is doubled. So, when thickness increases alpha values improve throughout until a certain limiting value. So, this is the effect of increasing the thickness, so overall as a thickness increases more losses happen; because the sound waves now have to pass through a greater length.

So, overall alpha improves, but after a certain limit or a certain high value is attained; then it becomes almost constant and that is what you can observe in D here. So, D becomes this condition.

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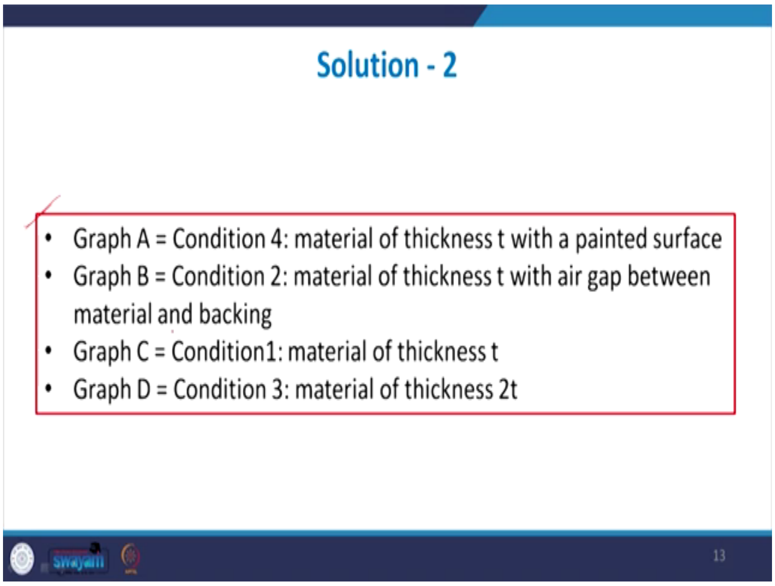

So, to give you these solutions together; graph A is condition 4, B is 2, C is 1 and D is condition 3, ok.

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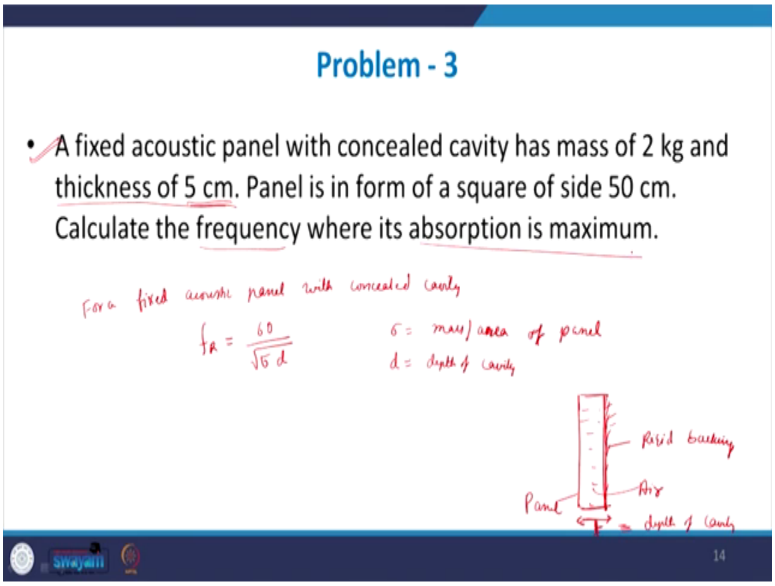

Now, the 3rd problem this is on panel resonators. So, it is given to us is that, a fixed acoustic panel with concealed cavity has mass 2 kg, thickness 5 centimeters and the panel is in the form of a square of side 50 centimeters. Calculate the frequency where it is absorption is the maximum.

So, now, we know that for a, let us solve it here. So, we already know these values that, for a fixed acoustic panel with concealed cavity, the resonance frequency was given by the formula 60 divided by under root of sigma times of d; where sigma is the mass per unit area, mass by area or mass per unit area of the panel and d was the depth of the cavity or how far the cavity is behind the panel.

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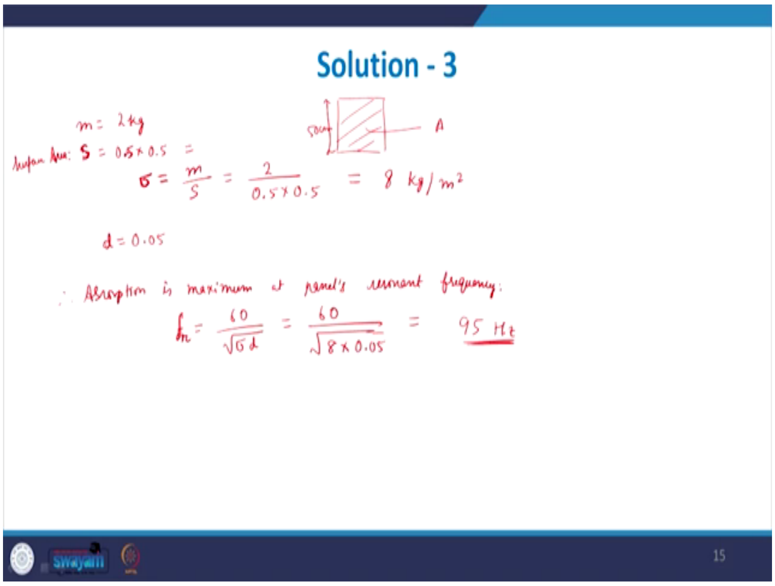

So, what are we given here; we are given, the mass is given to be 2 kgs and the material is in the form of a square of side 50 centimeters. So, the surface area A or S, let S be the surface area; the surface area S then becomes 0.5. So, I am writing everything in SI units, so 0.5 which is equal to 50 centimeters multiplied by 0.5. So, this becomes the surface area. So, sigma becomes mass by the surface area. So, this will give you the net mass per unit area.

So, we get 2 divided by 0.5 into 0.5. So, what we get here is, it is 8 kg's per meter square. So, we have already found sigma and the thickness; if we go here the thickness of, the total thickness of the board is given to be 5 centimeters. So, usually what does the panel resonator consist of? It consists of a thin panel and then some rigid backing and the remaining volume is filled with the air cavity. So, here because the thickness of the cavity in general is not mentioned. So, what we assume is that, this is a thin panel, then we have some rigid backing.

So, the thickness can directly be taken as the depth of the cavity; assuming that the material the backing thickness is negligible compared to the cavity depth, we can take that this thickness will simply give you approximately the depth of the cavity. So, we are taking d as simply the depth of the cavity which is 5 centimeters here. So, it becomes 0.05; therefore, what we have to find is the frequency at which absorption is maximum, absorption is maximum at panel's resonant frequency.

So, whenever the panel undergoes a resonance, the absorption is maximum. So, the frequency of maximum absorption can simply be written as, the f resonance or f natural frequency which is going to be 60 divided by under root of sigma times of d which is 60 divided by under root of 8 into 0.05. So, overall we get is approximately 95 Hertz, this is the resonance frequency which corresponds to the frequency where absorption will be maximum.

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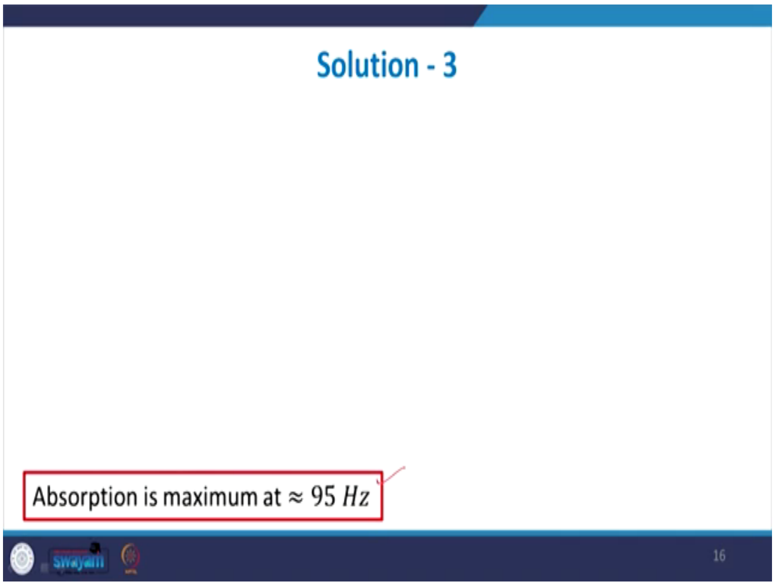

So, that is the value we are getting, ok.

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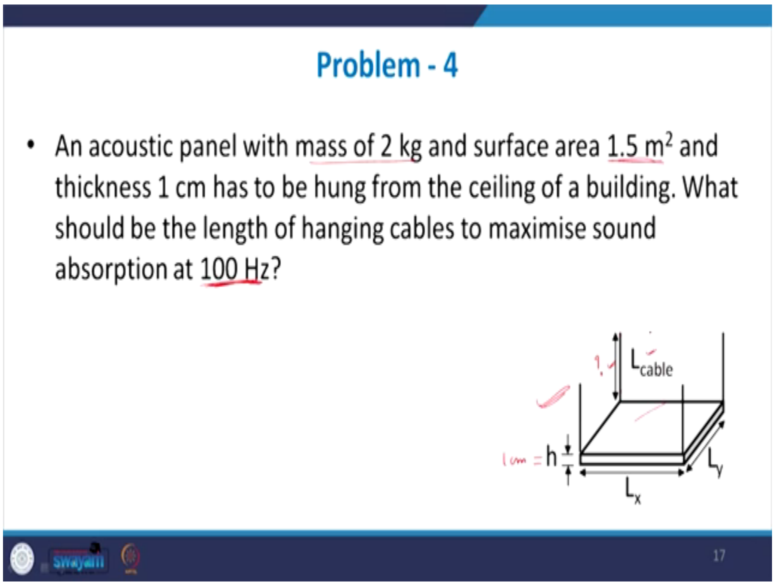

Now, let us solve for another question of acoustic panel. So, this is an acoustic panel that is given to you; this is not a fixed one, but this is a hanging panel or a suspended panel, mass is 2 kg's, surface area is given to you as 1.5 meter square, the thickness is given to us is 1 centimeter. So, this is the thickness ok, this is h is equal to 1 centimeter.

So, everything is given and this is hung from the ceiling of the building. Then what should be the length of the hanging cables? So, this is the length of the hanging cable. So, what should be this particular length, so as to get some maximum absorption at 100 Hertz? Now here a lot of values are given to you, but this is a trick question; we just need one value that is the frequency.

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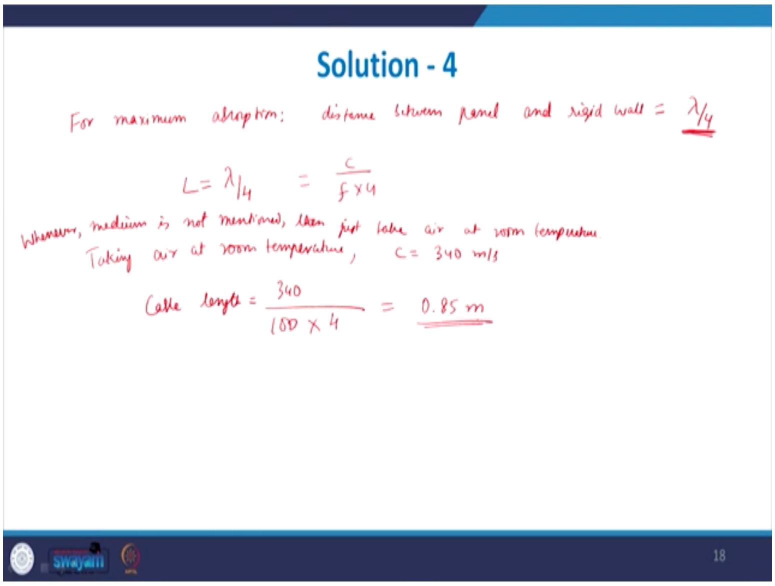

We know that when a panel is backed by a rigid wall, then the distance between the panel and the rigid wall for maximum absorption; distance between panel and rigid wall is equal to lambda by 4. And we had already established; why, because that is where the whenever the moods are set within the room. So, that is where the acoustic particle velocity is the maximum.

And when the velocity is the maximum it will hit the panels hard and the amplitudes that the resonance or the coupling will be further strengthened and therefore, absorption will be maximum. So, lambda by 4 we had this was studied in the lecture on acoustic panels or the panel resonators.

So, we have a target frequency that has to be absorbed is 100 Hertz. So, to maximize the sound absorption, the length of the cable should be equal to lambda by 4, so that the distance between the panel and the ceiling becomes lambda by 4. So, length should simply be lambda by 4, which is going to be c by f times of 4 taking air at room temperature. So, whenever medium is not mentioned, then just take air at room temperature.

So, whenever no specific condition is given to you, we assume the most commonly found medium which is air at room temperature. So, at air at room temperature c is 340 meters per second, this is the value we take; then L comes out to be, the cable length will be lambda which is 340 here divided by the frequency in 100 into 4. So, what we get here is 0.85 meters is the length of the cable.

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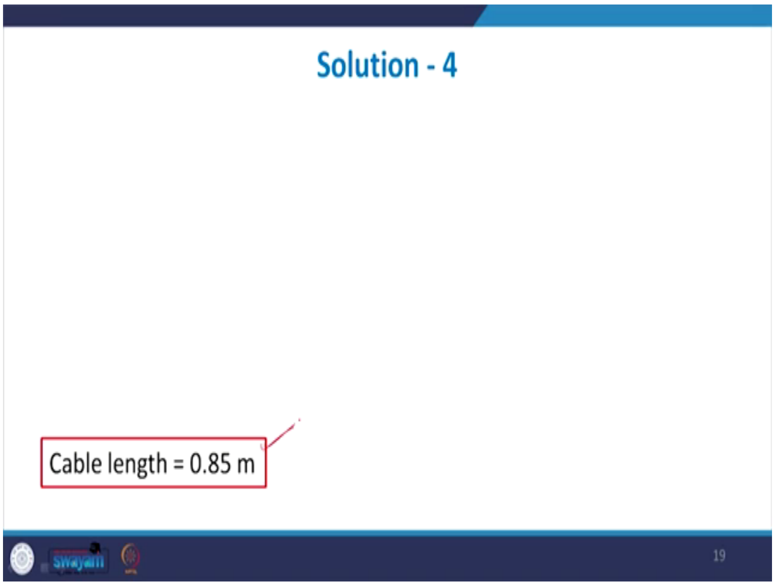

So, that is the solution.

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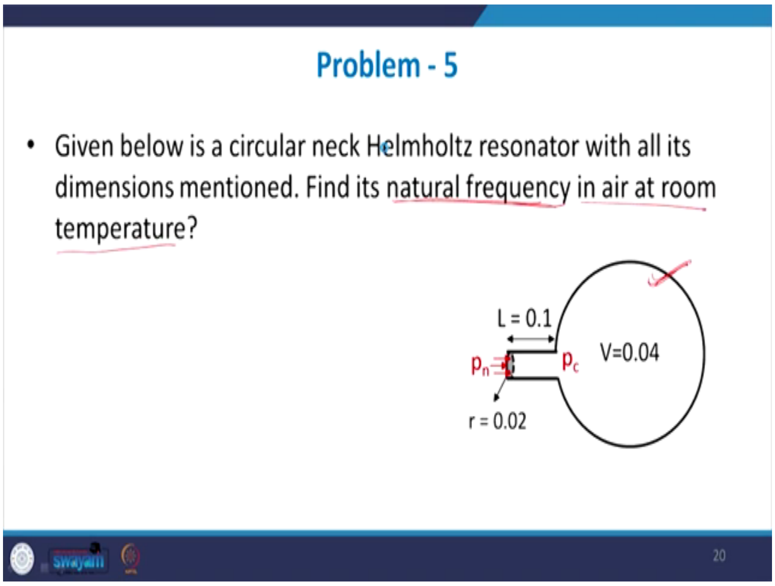

So, our last problem before we close this lecture, this is a problem on Helmholtz resonator. So, here a circular cavity or a spherical cavity Helmholtz resonator is given to us; this is a spherical cavity and the neck is circular. And all its parameters are given. So, neck length is given to us, r is given to us, and the volume of the cavity is given to us. And we have to find its natural frequency in air at room temperature, so medium is also mentioned to us. Now the natural frequency of this Helmholtz resonator is given by c naught solve it in fresh page.

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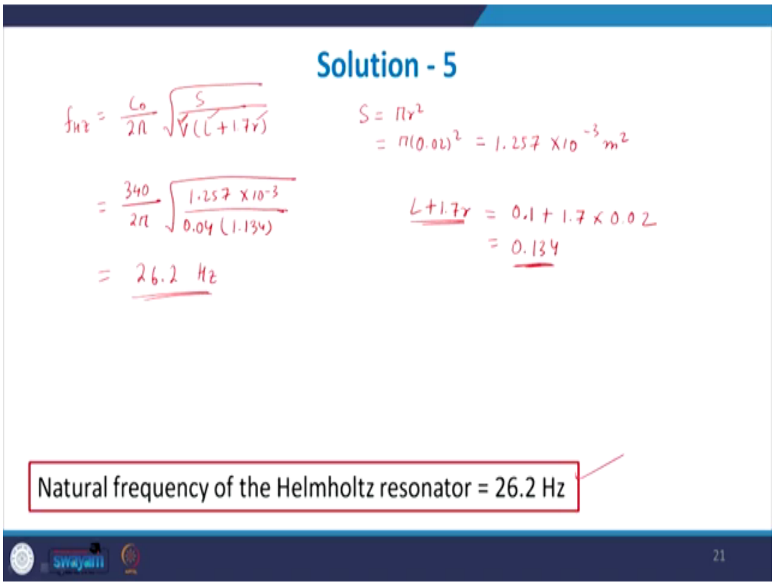

So, the natural frequency of the Helmholtz resonator is given by c naught by 2 pi under root of S by V into L plus whatever is the end correction. Now this is given to us and r value is mentioned to us and L is mentioned to us and volume is mentioned to us. Surface area will be, because it is a circular cavity it will be pi r square, ok. So, this comes out to be r is given to us as 0.02. So, pi into 0.02 square, which comes out to be approximately 1.257 into 10 to the power minus 3 meters square.

So, S we have found. Now let us put the respective values. So, for air at room temperature c naught is 340 divided by 2 pi under root of S which is 1 point this value; the volume of the cavity is 0.04 and the length is given to us as 0.1. So, length will be. So, L plus 1.7 times of r will be what? It will be 0.1 plus 1.7 times of 0.02. So, this is coming out to be 0.134, this is the total length we are getting, the end corrected length.

So, we put this value here. So, this is just a direct question, put all the values given to you and then directly substitute them and you get the resonant frequency. So, this is the natural frequency. So, with this I would like to close this lecture and see you again for the next lecture, where we will begin the discussion on perforated panel absorbers and this is the last type of absorbers we will be studying.

Thank you.