NOISE CONTROL IN MECHANICAL SYSTEMS

Prof. Sneha Singh

Department of Mechanical and Industrial Engineering

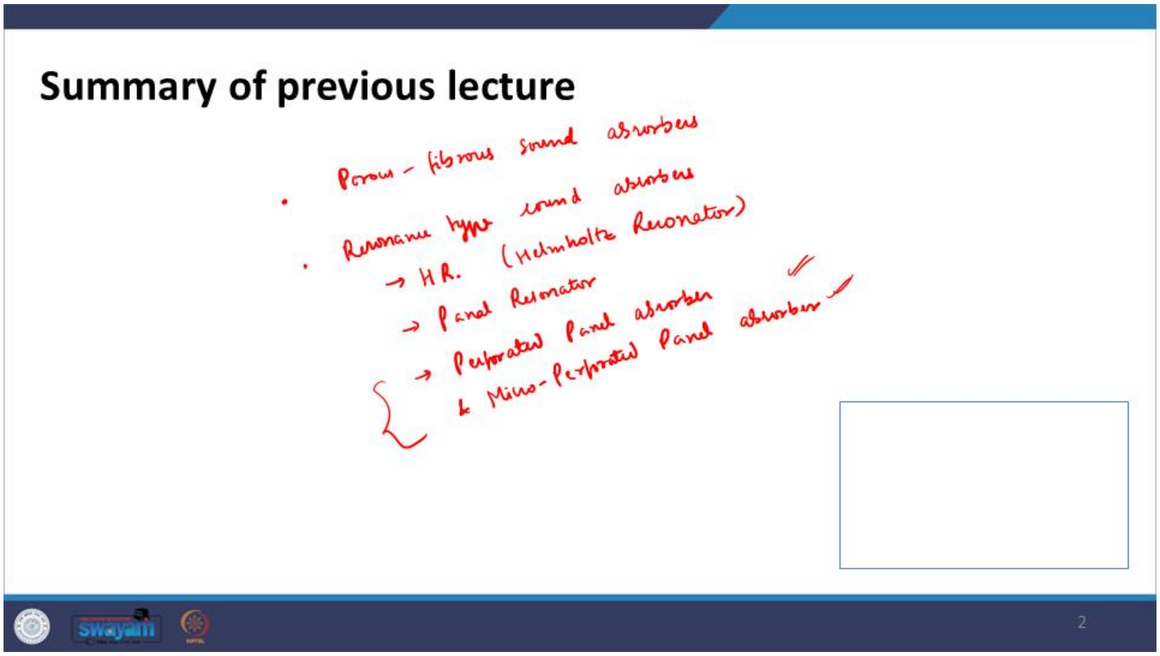
IIT Roorkee

Week:9

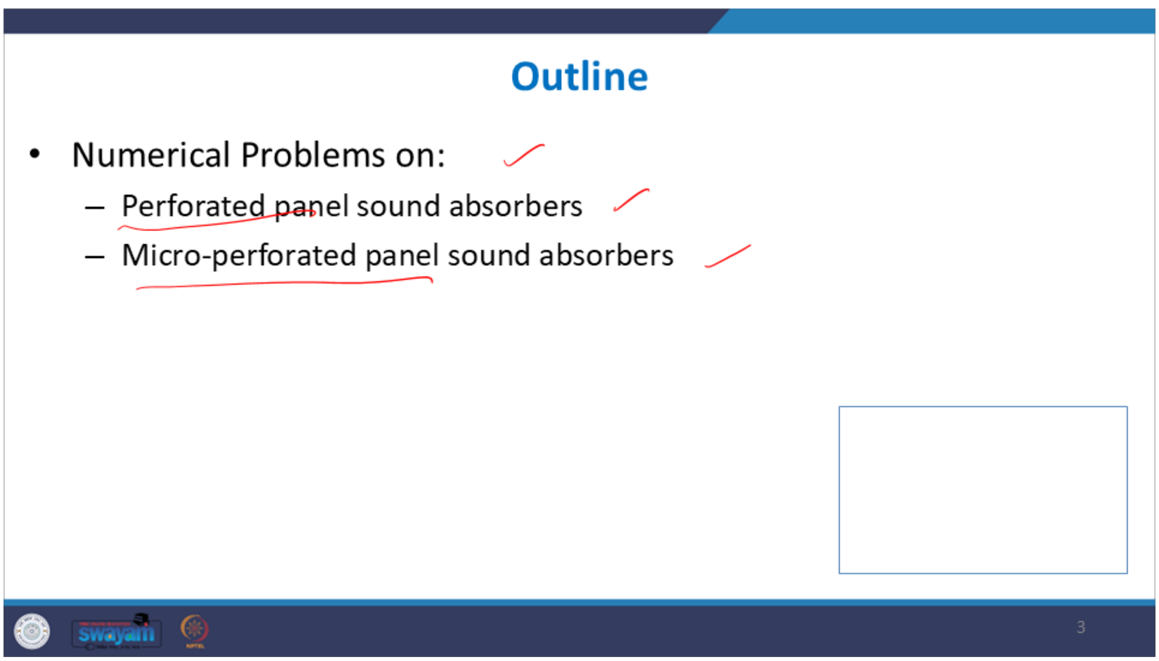
Lecture:045

Lecture 045: Perforated & Micro Perforated Panel Sound Absorbers Numerical

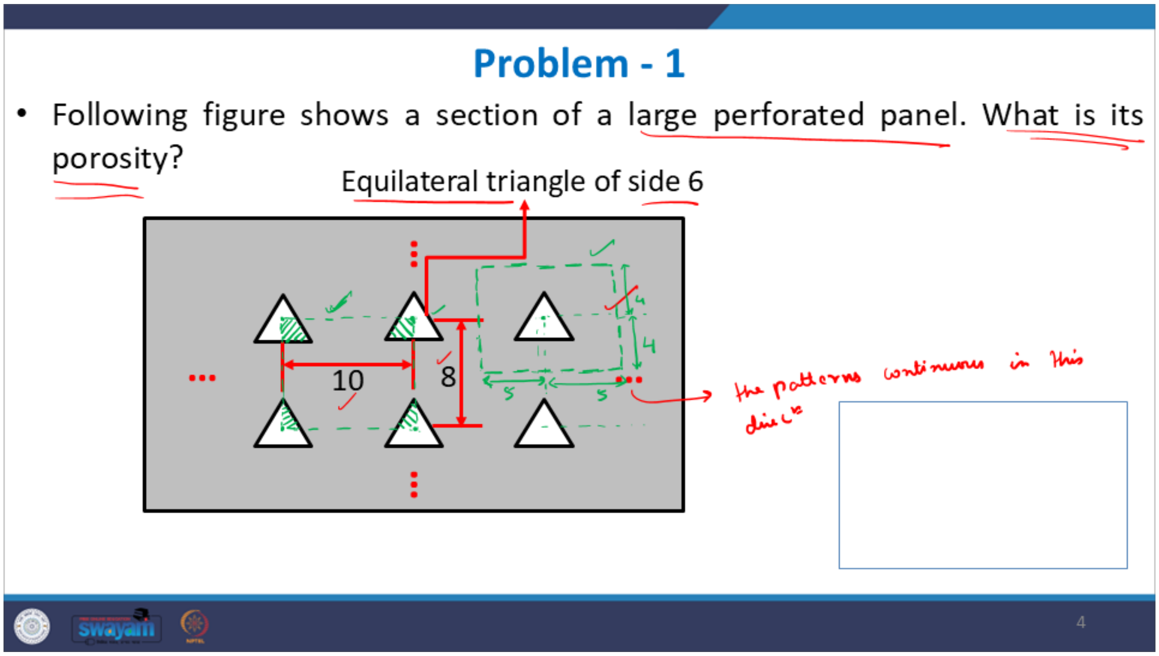
Hello and welcome to this lecture course on noise control in mechanical systems with me, Professor Sneha Singh from IIT Roorkee. We have been discussing sound absorbers that could be used for noise control, and in that we have studied various porous fibrous sound absorbers. And then we have studied some resonance-type sound absorbers. Among those, we have the Helmholtz resonator, and we also have the panel resonator or panel absorber. Then we have the perforated panel absorber and a more advanced version of it where the holes or the perforations are at the micro-level or in the micrometer range, which is called the micro-perforated panel absorber. We have already studied the theory, the advantages, and the limitations of these.



Let us do some numerical problems based on the perforated panel and the micro-perforated panel absorbers. Let us start. That is the outline for today's lecture.

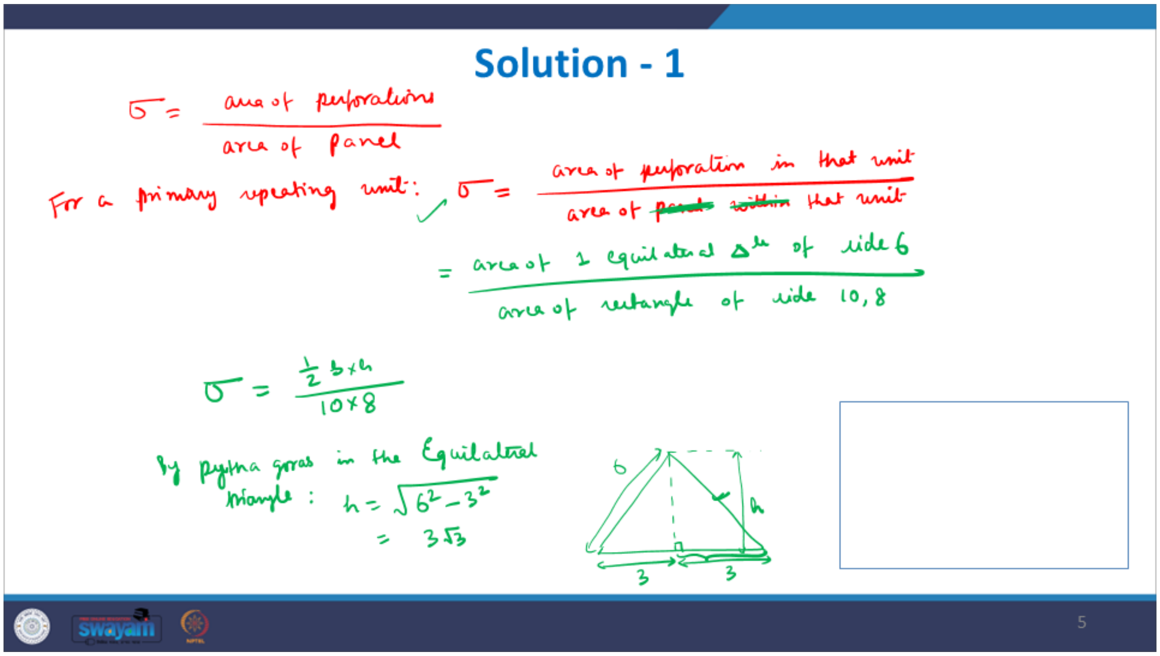


We will do the numerical problems on these two types of sound absorbers: the perforated panel and the micro-perforated panel type.



Let us see here some kind perforated panel is given to you. It is a large perforated panel, and just a small section of this is given. This here means that, this pattern continues in this direction, or the pattern continues over the four directions, as in we have a very large two-dimensional perforated panel, and a small section of it is given to us in this figure.

What you see is that here the perforations are equilateral triangles of side 6. And the spacing between them is such that in the horizontal direction, the spacing between the centroids of these perforations is 10, and in the vertical direction, the spacing between the centroids of any two adjacent perforations is given to be 8. The units are not mentioned, but it is not required because, anyway, when we calculate the porosity, we have to find the porosity of this panel. When we calculate the porosity, it is the area of the holes divided by the total area of the panel. Which can be boiled down to one primary repeating unit and say that within that unit, what is the total area of the hole or the perforation divided by the total area of the panel. And if one unit can give you the porosity, then you can sort of repeat it to get the full panel and find the porosity of the entire panel. Anyway, the numerator and the denominator will have area, which will get canceled. The units, as long as all these dimensions are in the same units, which unit you are considering will not matter. If you see here, by definition, the porosity is the area of perforations in the panel divided by the area of the panel. We can then make a primary repeating unit, and we can simply find the



$$\sigma = \frac{Area\ of\ Perforation}{Area\ of\ Panel}$$

porosity of the area of perforation in that unit divided by the area of the panel within that unit. or the area of the solid phase of the panel.

Over here, if you see, let us take one repeating unit. You can take it either this one. I would represent it by the green dashed lines (Slide 4). This could be your one repeating unit. Mark the centroids and simply join them. And you will see that this unit repeats to make the complete microperforated panel. This requires more practice, if you practice, then you can very intuitively guess which would be the primary repeating unit. If you keep repeating these units in all four directions one by one, you will get the full panel. this is one primary repeating unit. Another one that you can think of is this. You can mark a midpoint over here and a midpoint between them. Either this you can take or this repeating unit you can take. As your primary repeating unit, and then you can derive your porosity for both. From this, you can see that within a single primary unit, we have one equilateral triangle of side 6, which gives you the area of the perforation. The area of the panel material is given by over here, we are taking it midway between four. Over here, this length is going to be so from this to this, it is a total of 10 units from this one to this one, and this is midway of that, so this will become 5. In the same way, this will become 5. If you think about it from here, the spacing between two adjacent holes is 8 units, and this is halfway of this, so this becomes half of 8, which is 4. And in the same way, this would be 4 for the next adjacent hole. The area of the panel would be a rectangle of side 10 and 8, that would be the area of the panel. In the same way, if you examine in this unit al here you can straight away see that the total area of that primary repeating unit. I do not want to say this is the area of the. this would be the area of that unit. The complete area of that unit will be the porosity. Here the area of the primary repeating unit, the net area, is simply a rectangle of side, this is 10 and this is 8. It is a rectangle of side 10 cross 8, and if you think about it, within one primary unit, how many perforated holes you can get. These are the regions within that unit which are being occupied by the perforations. If you combine them, you will get the full equilateral triangle. If you think about it, these are the four parts of that equilateral triangle. When they are combined together, the complete equilateral triangle can be formed.

Either you consider this unit or this unit; with both, you will get the same answer, and that would be the area of the perforation is the area of that one equilateral triangle of side 6, and this is the area of rectangle of side 10 and 8.

$$\sigma = \frac{area\ of\ that\ one\ equilateral\ triangle\ of\ side\ 6}{area\ of\ rectangle\ of\ side\ 10\ and\ 8}$$

Then, simply, the porosity can be found as: the area of the rectangle you can find. Let us see how you find the area of a rectangle. Suppose this is your triangle of side 6. All of these are of side 6. Drop a perpendicular to the base. Due to symmetry, it is going to cut it midway, so each of these would be 3. It would be half into the base into the height, and the base is 6.

$$Area\ of\ triangle = \frac{1}{2} \times b \times h$$

What is the height of the equilateral triangle? You can find it using Pythagoras' theorem. In this case, this is your height of the equilateral triangle. It is by Pythagoras' theorem. this is your porosity.

$$\sigma = \frac{\frac{1}{2} \times b \times h}{10 \times 8}$$

by Pythagoras' theorem, in the equilateral triangle, what you get is this height would be

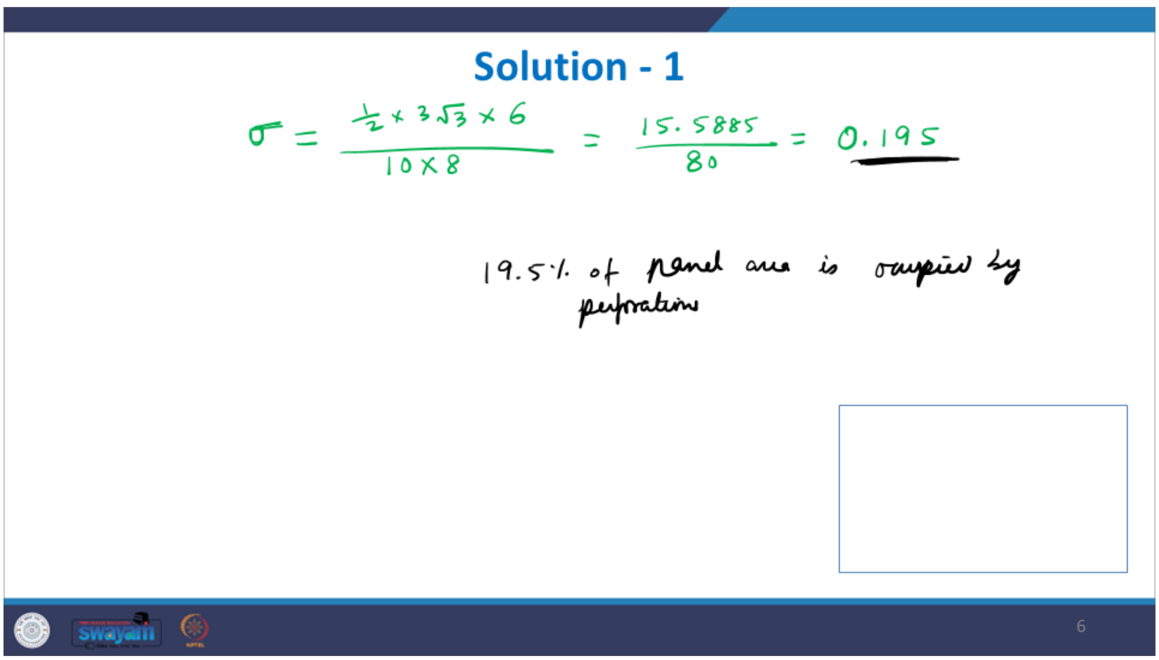
$$h = \sqrt{6^2 - 3^2}$$

$$h = \sqrt[3]{3}$$

Let us solve for the porosity. It comes out to be

$$\sigma = \frac{\frac{1}{2} \times 6 \times \sqrt[3]{3}}{10 \times 8}$$

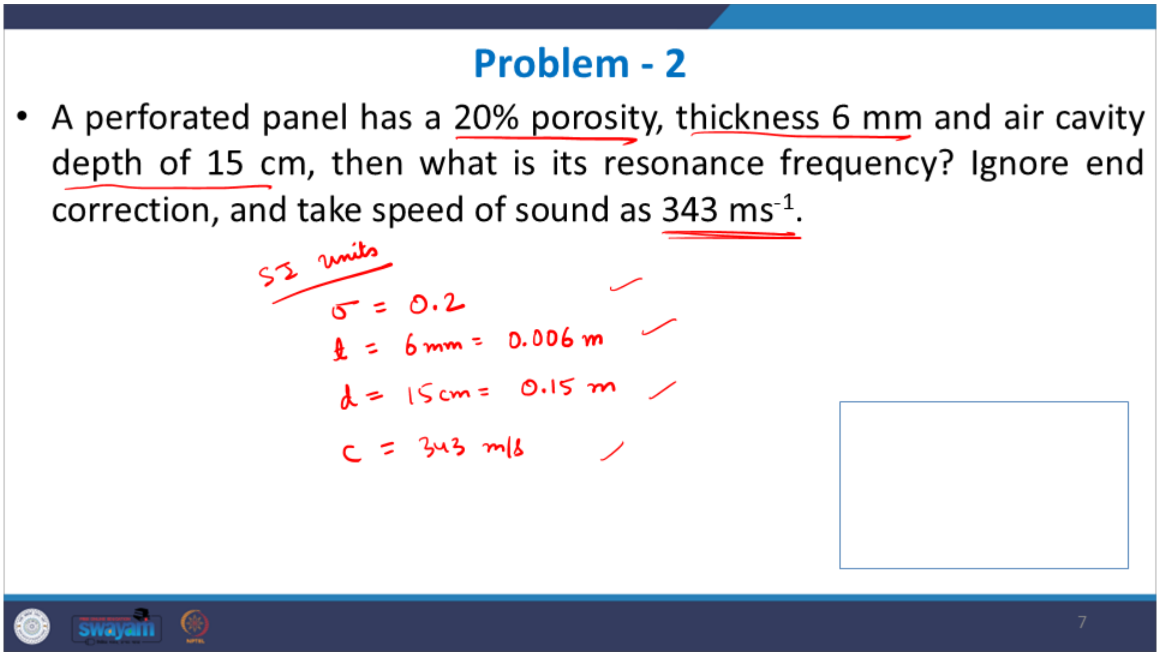
Ultimately, you will get the porosity of 0.195. That becomes your answer, okay. almost 19.5 percent of the area of the panel is being occupied by perforations. That is the implication of this word. 19.5 percent of the panel area is occupied by the perforations, or 19.5 percent of its area is empty.



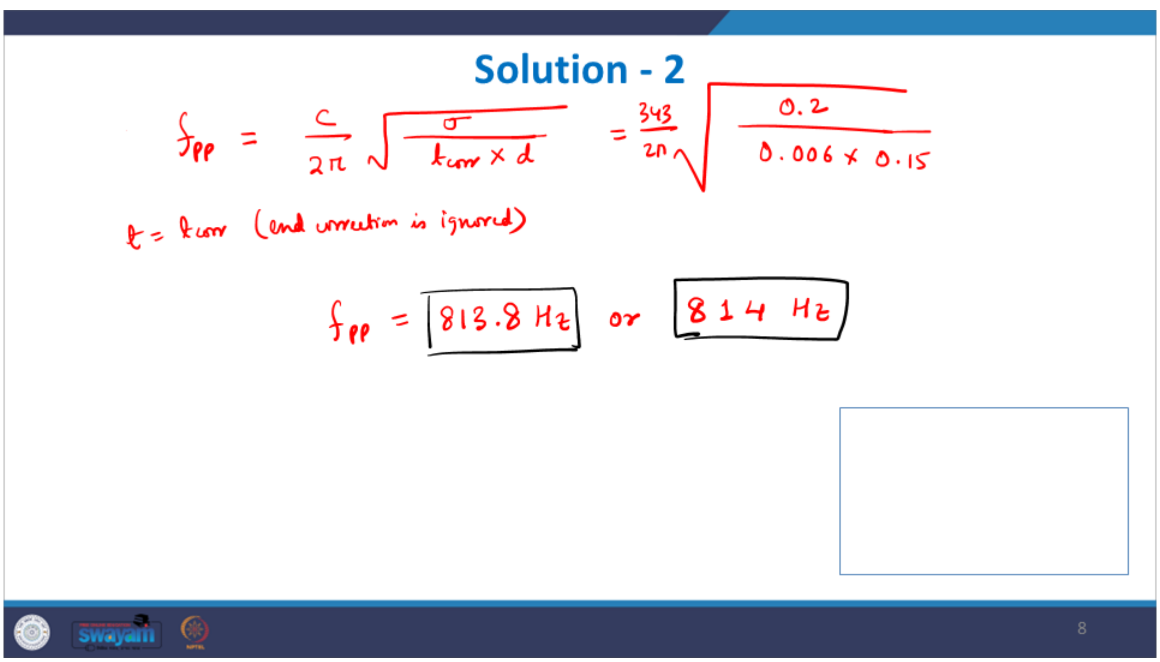
Let us see problem 2. A perforated panel has 20% porosity and a thickness of 6 mm. various values are given to us. Porosity is given, the thickness is given, and the air cavity depth is given to us. What is its resonance frequency?

Here, you can ignore the end correction and take the speed of sound as 340 meters per second. Let us take account of the things given. Sigma is given as 0.2 because we take the porosity not as a percentage but as a fraction.

When doing the calculations, 20 percent is simply 0.2. The thickness without the end correction is 6 millimeters, which is 0.006 meters. Let us write everything in SI units. The



air cavity depth is 15 centimeters, which we can write in SI units as 0.15 meters, and the speed of sound is already in SI units. these things are given to us.



We know that so as taught previously the fundamental frequency or the resonance frequency of a perforated panel is given by this formulation.

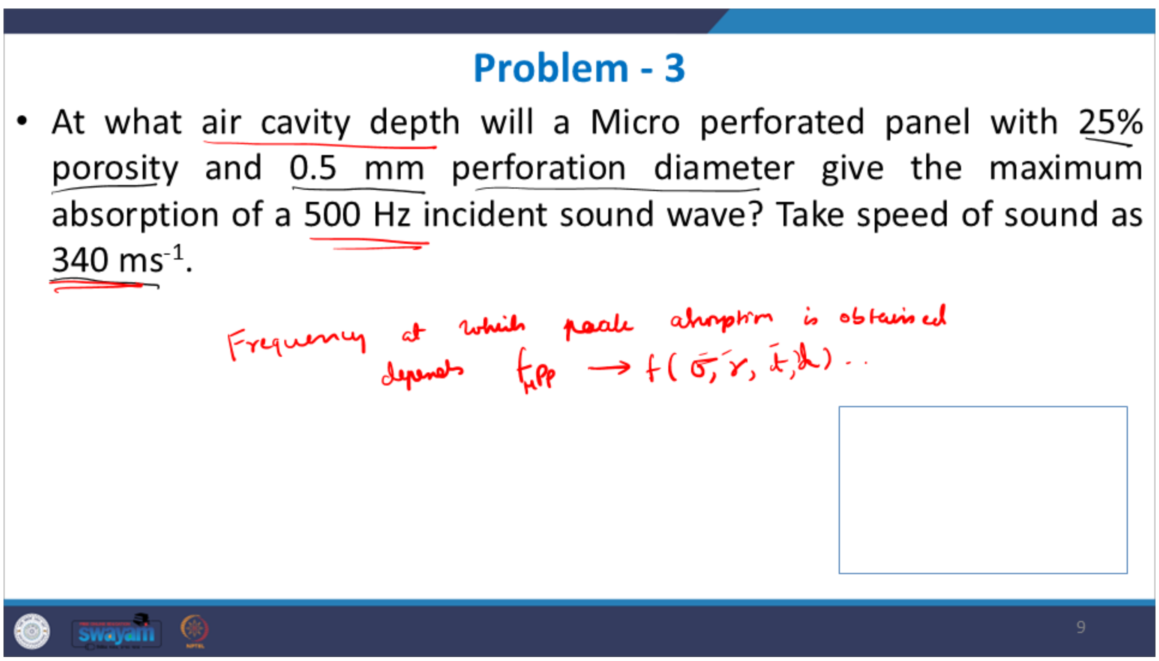
$$f_{pp} = \frac{c}{2\pi}\sqrt{\frac{\sigma}{t_{corr} \times d}}$$

Now, we are ignoring the end correction. here t we can take as t corrected because end correction is being ignored.

Then you can directly punch these formulas here.

$$f_{pp} = \frac{343}{2\pi}\sqrt{\frac{0.2}{0.006 \times 0.15}} \cong 814\ Hz$$

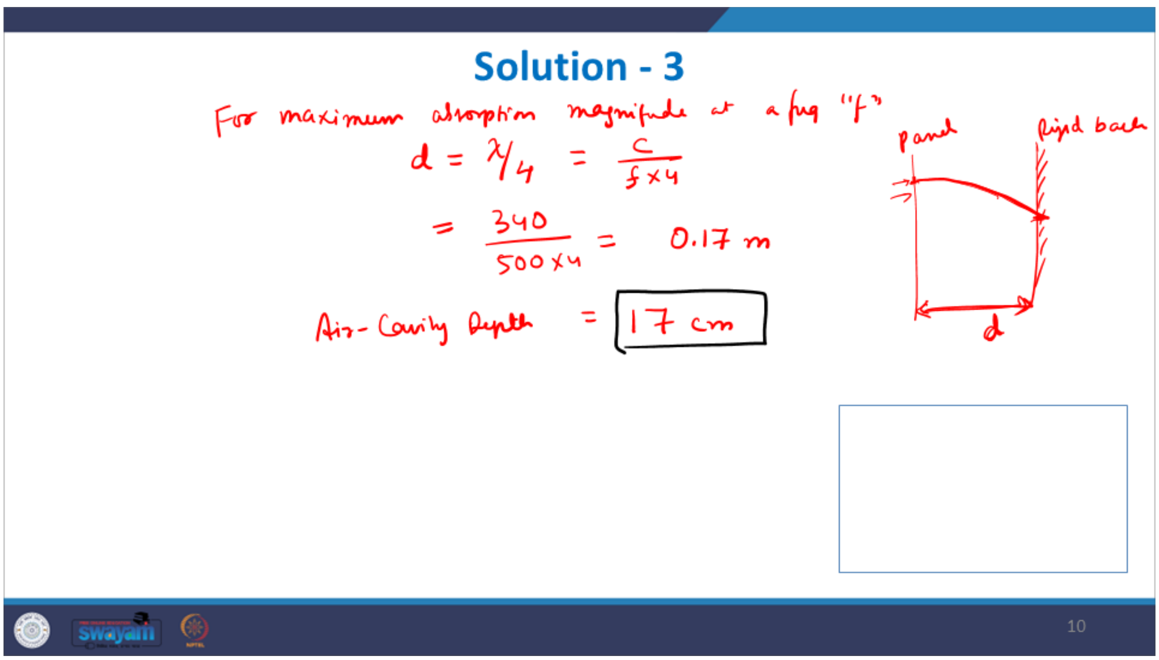
All the values already given to us, we directly punch it in the formula here and we can find out the answer. The fundamental frequency comes out to be If you solve this you will get this value. Usually, we express frequencies without a decimal point because very few measuring instruments measure the fractional frequencies. we can directly write it as 814 approximately the frequency. This becomes the frequency of your panel either this or this both answers are acceptable.



Now, let us see a third problem. at what air cavity depth will a micro perforated panel with 25 percent porosity, 0.5-millimeter perforation diameter gives the maximum absorption of a 500 Hz incident sound wave take the speed of the sound is 340 meters per second.

Now that the frequency at which the absorption is obtained okay so here i would like to state that the frequency

At which peak absorption is obtained. That depends on the fundamental frequency of the MPP, which depends on, it is a function of sigma, the hole diameter or the radius, and then the thickness of the panel, the air cavity depth, and so many things. Your frequency will depend upon these parameters. It is already given that the frequency is maximized at 500 Hz, but at what air cavity depth will we get this? what is the effect of air cavity depth? Because, again air cavity depth will impose a rigid boundary condition.



As we already taught in the theory, for maximum absorption, the acoustic particle velocity should be maximum when they hit the panel, and for maximum absorption magnitude. At a particular frequency, at a frequency f, let us say, the depth, air cavity depth should be.

$$d = \frac{\lambda}{4}$$

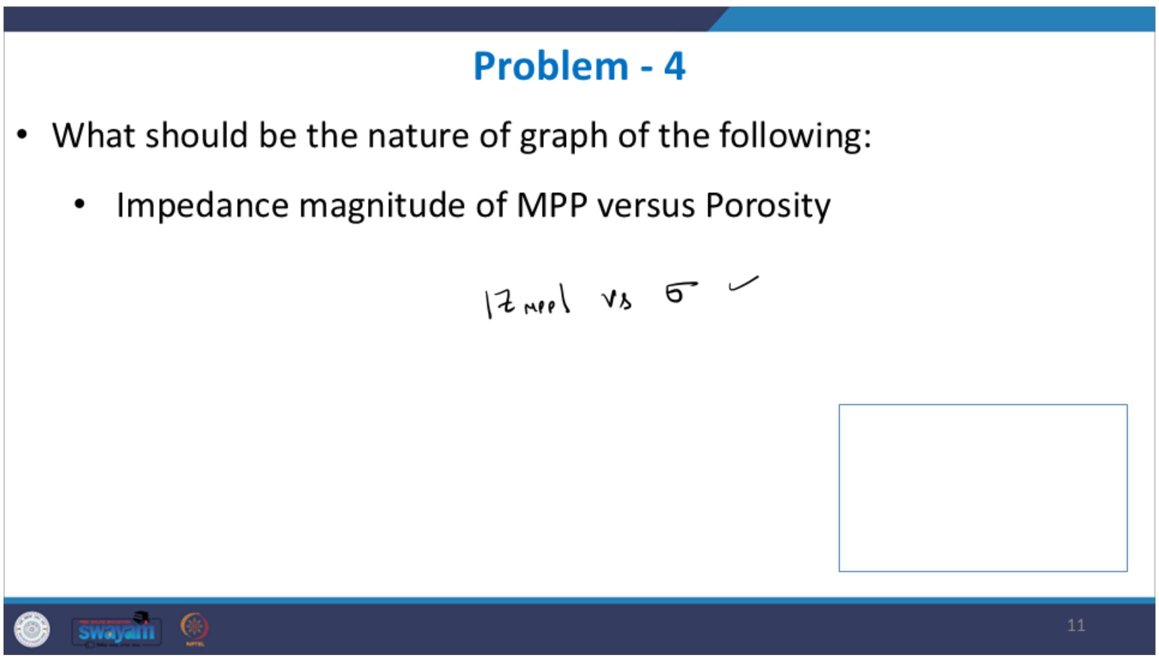
For example, this is your panel. If this is the rigid boundary condition and this is your air cavity depth, then this is your panel and this is your rigid back. And this is your air cavity depth d, then here it should hit with the maximum acoustic particle velocity.

this could be at $\lambda/4$. If this is the wave function of the velocity, it reaches zero at the rigid boundary. Basically, in this case, the other parameters will not affect. It is a trick question.

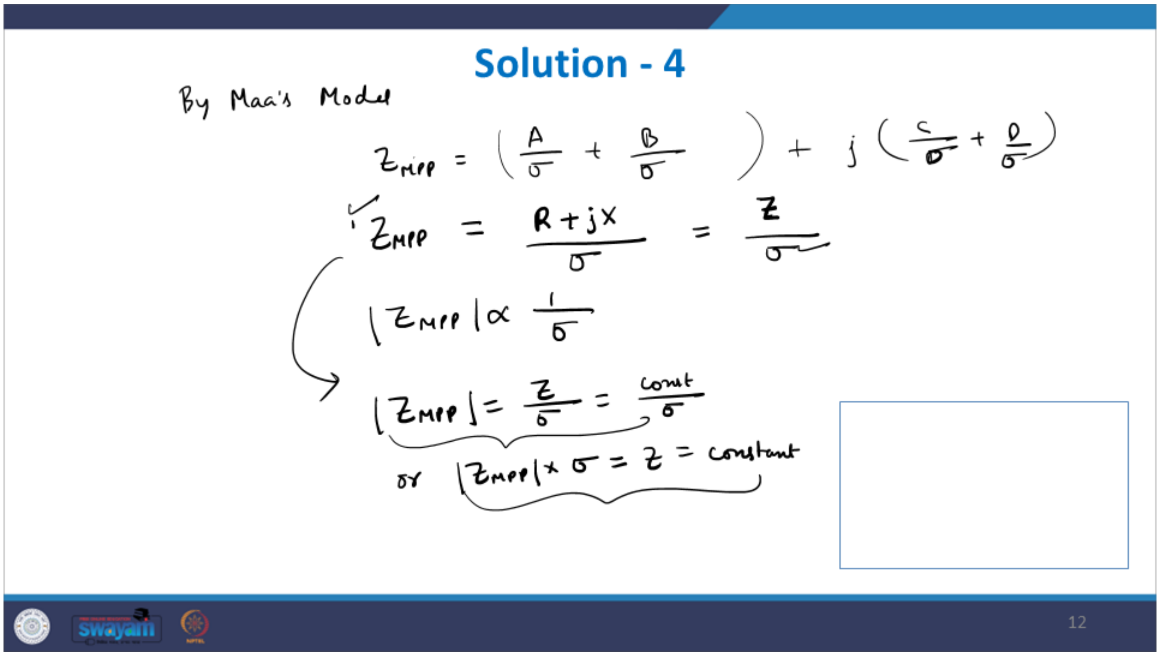
You just need to take into account the frequency of the wave, and these will not come into use. Simply, you can write this. Here, the speed of sound we have to take as 340 meters per second, as given in the question.

$$d = \frac{\lambda}{4} = \frac{c}{f \times 4} = \frac{340}{500 \times 4} = 0.17\ m$$

ultimately, what you get, the answer that you would get, is 0.17 meters, which is 17 centimeters, should be your air cavity depth.



let us see another problem. What should be the nature of the graph of the following: impedance magnitude of an MPP versus its porosity Which is the mod of the Z MPP versus the porosity—this is what we have to find. In the previous lecture, when we were discussing MPP, that is a micro-perforated panel, we saw that by the Maa's theory or Maa's model—the Z of an MPP is given by some complicated expressions. It has a real part plus some imaginary part, and in both these expressions, The porosity comes at the denominator. We have some constant expression— by sigma, some constant expressions, then some constant expressions by sigma, like that. This kind of an expression was there.



Which means that the Z of MPP was some $R + jX$, let us say, which is some complex number divided by σ or the porosity. This is how, by using the Maa's model and that equation, we can simply take all the other complicated terms, which are independent of porosity, together as a constant and just see how it depends on porosity. All other parameters we will take as constant. What we will get is some constant complex number divided by the porosity—that is your Z of MPP.

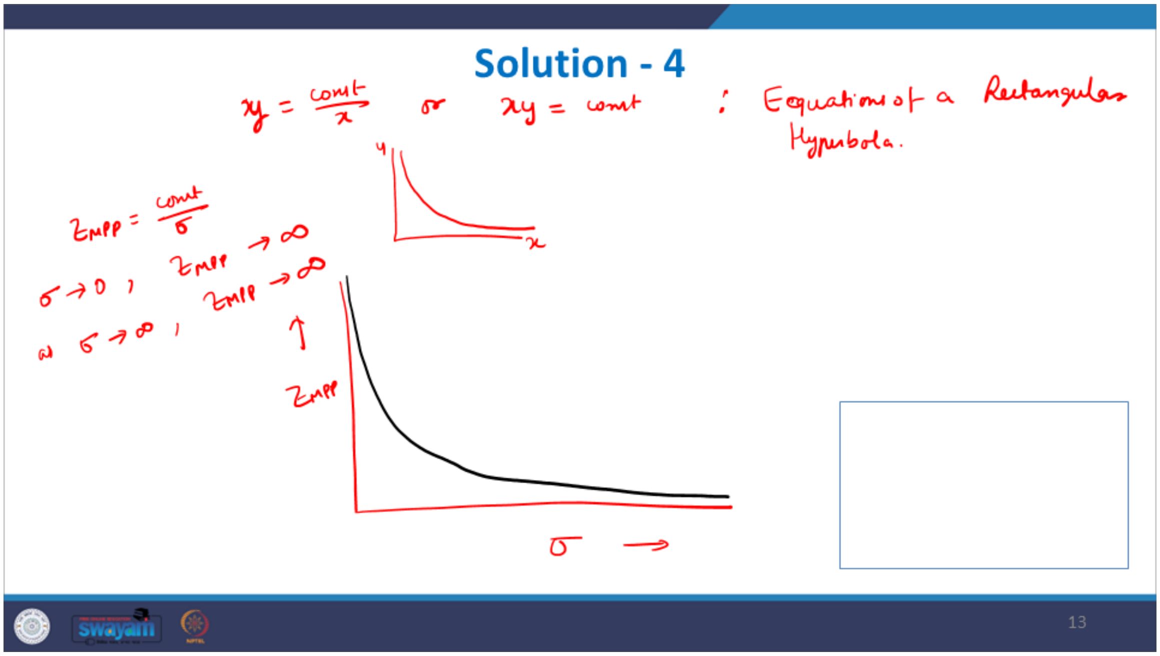
What you see is that Essentially, Z of MPP is inversely proportional to sigma.

$$Z_{MPP} \propto \frac{1}{\sigma}$$

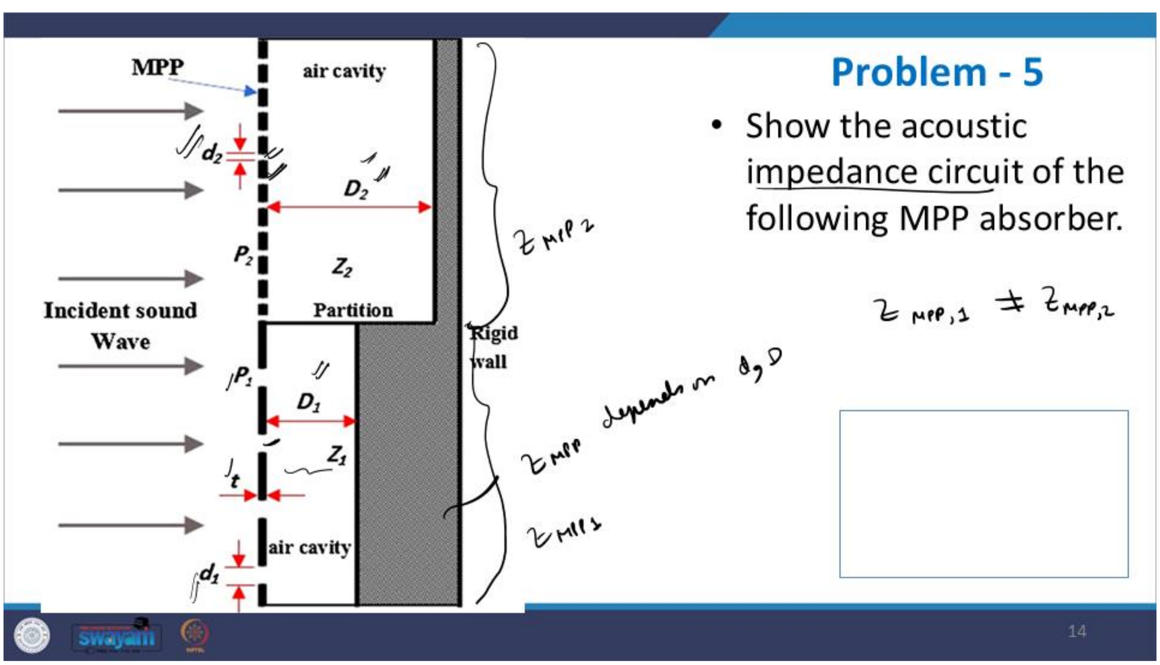
This is some constant number. We can write this equation like this also. we have to draw a graph between this and this, okay, these two variables. And Z of MPP is some constant Z by sigma or the Z of MPP multiplied by sigma is equal to Z. which is some constant any two formulations you can use.

Now, if you recall suppose we have two variables x and y then y is equal to some constant by x

$$y = \frac{constant}{x} \; or \; xy = constant$$



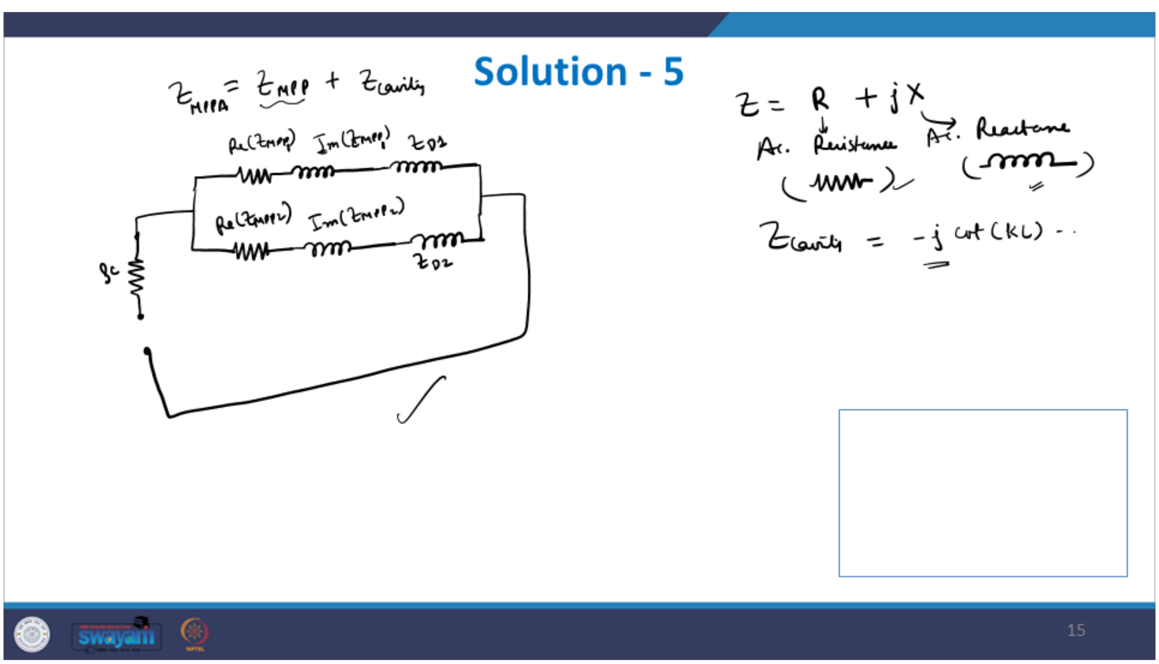
these are what this corresponds to the equations of a rectangular hyperbola; this is the relationship between them and for this the graph comes out to be like this x and y it is an asymptotic graph like this. In the same way same kind of graph will be their Z of MPP is equal to some constant by σ. What it means is that if you have an axis for σ, and an x the vertical is for the z of MPP. As sigma tends to 0 z of MPP. over here let us write it in the same equation. As sigma tends to 0 z of MPP tends to infinity. And as sigma tends to infinity, Z of MPP tends to 0. This is an asymptotic relationship. the graph would be simply like this, reaches here infinity, this shows the graph of the magnitude of this ZMPP with sigma. Here if you do mod then this is what will happen some constant yeah.



The last question for this lecture is that again some MPP absorber is given. And to enhance its absorption response different to some kinds of changes have been done. What we have here is that we have the second half of the MPP. which has a smaller air cavity.

Here the lower half of the MPP has an air cavity depth of D1 and the perforations they are of the diameter P1. The perforations have a diameter small d1 and the air cavity depth is capital D1 and the upper half of it is another perforated panel but here both the air cavity depth has increased and the diameter of the hole has decreased. Basically this could be treated as a separate MPP absorber, because the Z of MPP depends on the diameter of the hole as well as the air cavity depth.

Here for this part, it would be some Z of MPP1 and for this part the acoustic impedance would be Z of MPP2 and Z of MPP1 should not be equal to Z of MPP2, because these parameters are changing in general, they will not be equal. Basically, what we have here is that two MPPs are there ok with two different acoustic impedance because of the changing parameters of small d and capital D. And they are connected in parallel because the sound waves are incident and these are not connected in series which is one after another but rather these are the impedances connected in parallel. What is an impedance and impedance is made of resistance term and acoustics resistance and a reactance term. When we have to show an electric circuit diagram or an impedance circuit diagram. It derives from the electric circuit analogy.



The resistance is simply represented by a resistor this simple and the reactance is indicated by an inductor. This is the symbolic representation of acoustic resistance and acoustic reactance when represented using the electrical circuits we represent it simply as a resistor here and this part or the complex part is represented as the inductor. What you have here is you can represent this circuit as follows. You have the sound wave incident on it. First of all, they are travelling from a characteristic medium which has got a characteristic resistance there is no complex part ρc that is where the incidence is happening and then it is passing through two MPPs okay that are connected in parallel.

We know that the total Z would be Z of MPP for every absorber, which would be Z of MPP plus Z of cavity. We will first have the acoustic impedance of the panel, then followed by the acoustic impedance of the cavity. For each of these parallel MPP absorbers, the panel and the air cavity depth of it are in series. So here in this case, this panel and this— They are in series, and in the same way here, this panel and this air cavity depth are in series, but the two absorbers are in parallel. You can have a parallel combination of each of these MPP absorbers, where first we write the Z of MPP, which has both the real term and the complex term. This belongs to the real part of the Z of MPP, and this belongs to the imaginary part of the Z of MPP—this inductor. And then, after we have taken into account the total acoustic impedance, we will have the impedance due to the cavity, and we know that the Z of cavity is given by

$$Z_{MPP} = -j\cot(KL)\cdots$$

The cavity depth only has this complex term. It only has reactance, no resistance. the cavity acts as a reactance, again a reactance to it, which is the Z of the cavity1.

We will represent it by capital D1. the first air cavity depth. The Z due to capital D1— And in the same way, in the second parallel connection, we also have an MPP absorber. This is for MPP1. Similarly, we have the real part of Z of MPP 2, which contains both real and complex terms, followed by just an inductor indicating the complex term due to the Z of the cavity depth D2, and they are connected in series and parallel. This is how we complete our circuit. This becomes your electrical circuit for this model. with this, I would like to close this lecture. Thank you for listening.

Thank You