NOISE CONTROL IN MECHANICAL SYSTEMS

Prof. Sneha Singh

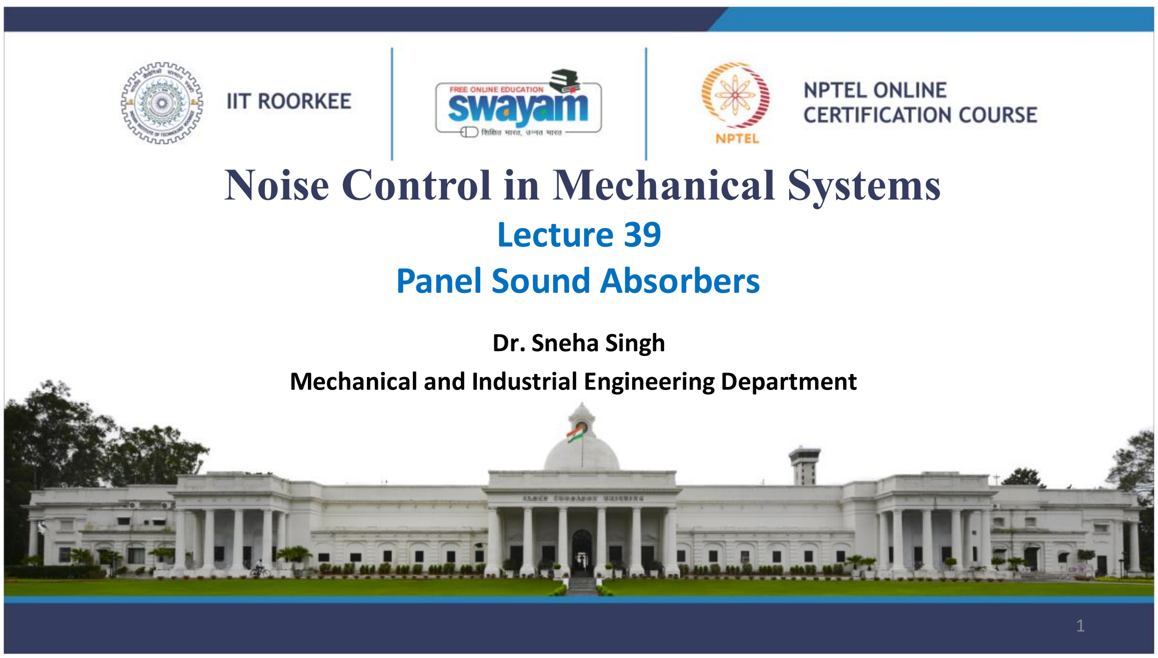
Department of Mechanical and Industrial Engineering

IIT Roorkee

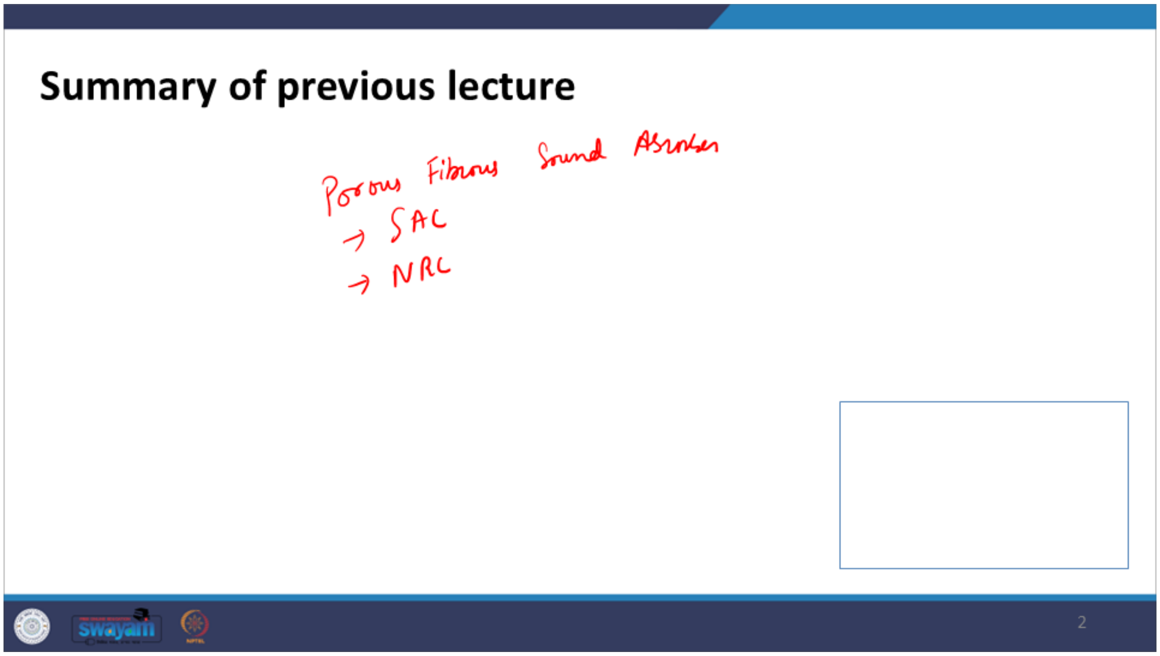
Week: 8

Lecture39

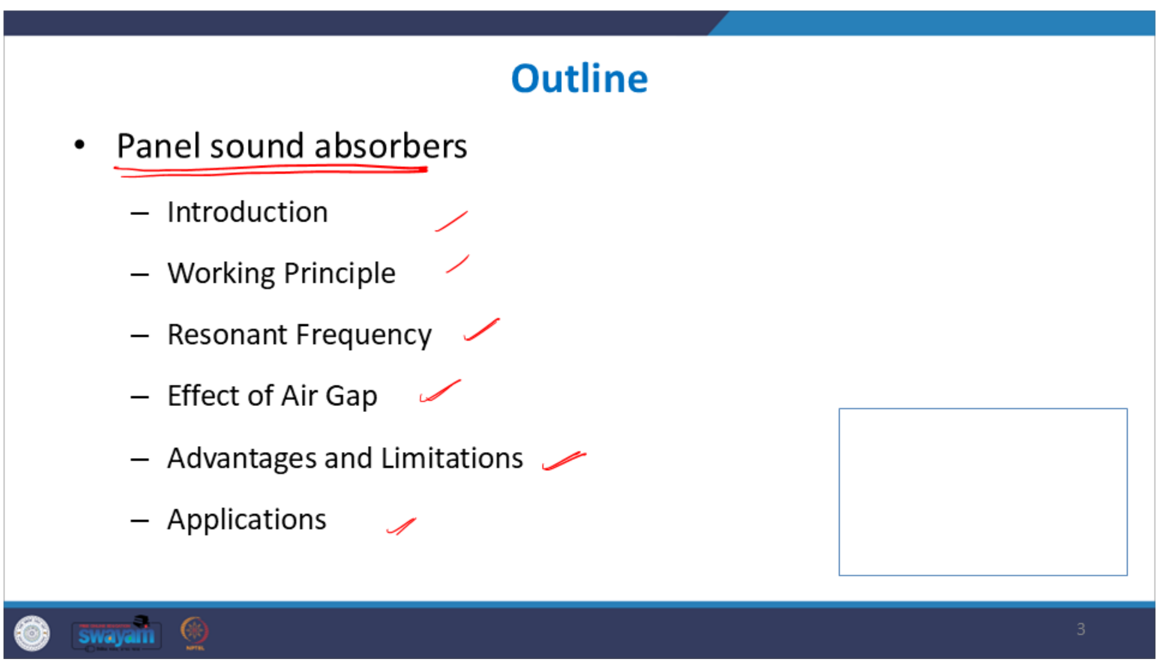
Lecture 39: Panel sound absorbers



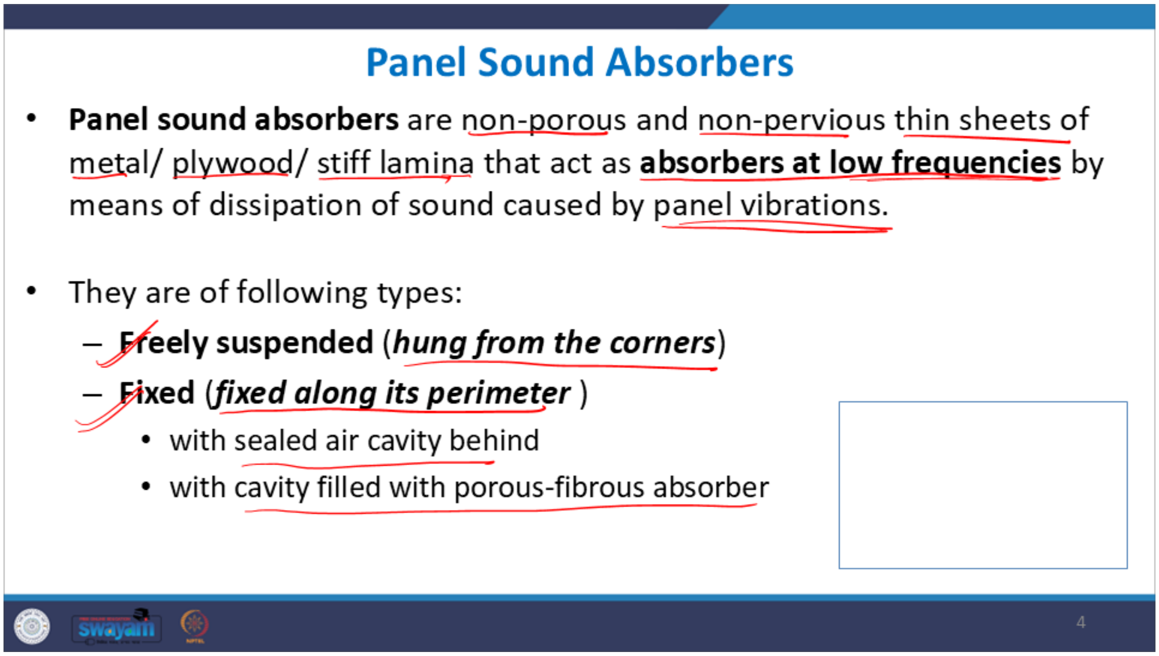
Hello and welcome to the lecture series on noise control in mechanical systems with me, Professor Sneha Singh from the Indian Institute of Technology, Roorkee. We have been discussing sound absorbers, and today we had a discussion on porous fibrous sound absorbers. So, this is what we have been discussing. And how their sound absorption coefficient is measured, what is NRC—the noise reduction coefficient for these absorbing materials.



But sound absorbers can be classified into many groups, such as porous fibrous sound absorbers, panel sound absorbers, perforated and micro-perforated panel sound absorbers, Helmholtz resonators, and metamaterials.



So, we will see the next type of sound absorbers, which are the panel sound absorbers, in this lecture. We'll just give the introduction, the working principle, and the resonant frequency for this absorber. What is the effect of the air gap, which plays a very crucial role in the functioning of this absorber? What are the advantages, limitations, and applications of these kinds of absorbers? So, let us see, as the word suggests, panel sound absorbers.

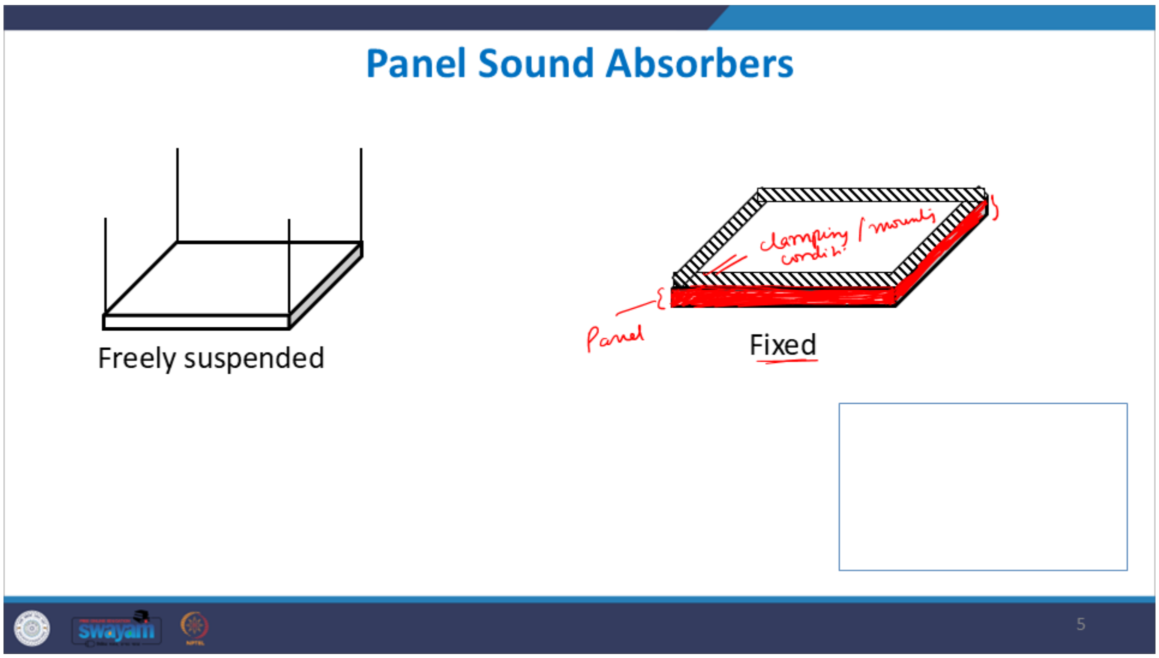


So, you know, what is a panel? In mechanics or in the field of mechanical engineering, typically a panel is anything which is a thin plate of metal or a thin plate of wood. So, basically, a thin plate which is not pervious and non-porous, and it is stiff enough that it acts like a rigid body. So, it is not like a rubber band. A stretched rubber band would actually become a membrane, but it is rather like a thin sheet of metal or a thin sheet of wood.

So, in the field of the noise control because before this we studied about porous fibrous absorbers there we there they have got a lot of pores you know holes and perforations for the sound waves to enter into the material. but after the porous absorber in the panel we have no holes and pores okay so this is a non-porous and a non-fibrous absorber so basically these absorbers are non-porous and non-pervious thin sheets of metal or thin sheets of plywood or any kind of stiff lamina that you can examine it could be any material like a metal a plywood a gypsum board but it has to be non-porous, non-pervious and thin sheet of stiff lamina. And then when they are configured in a certain way inside a closed indoor space, they behave as an absorber at low frequencies. Okay. And they dissipate the sound energy by the means of the vibrations of these panels itself.

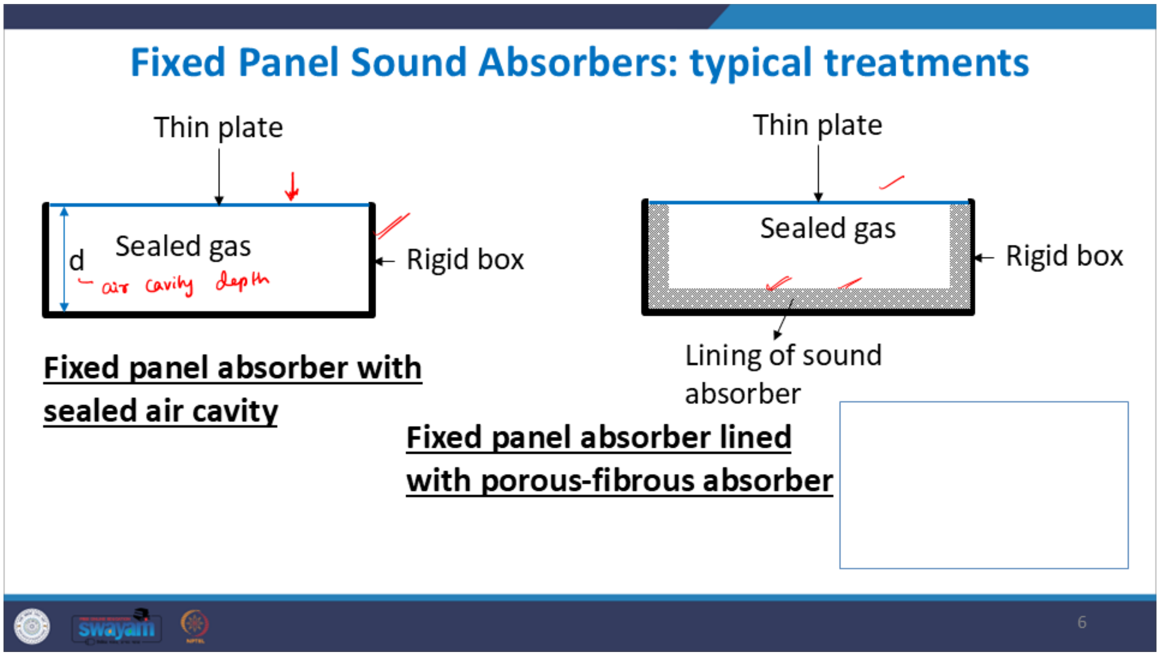
So, there are two types of these panel sound absorbers. The first is the freely suspended which is hung from the corners and then we have the fixed which is fixed along its perimeter and within the fixed type we can say that it also has a sealed air cavity and the cavity could be filled with some other absorbing material.

So, let us have a look at them to see what is freely suspended and fixed. So when you have got a you know kind of a panel and from its corner you are hanging it okay that becomes a freely suspended absorber and you have seen a lot of false ceilings you know and where these panels are just hanging on the top of the ceilings they are freely suspended panels and then the fixed panels means you know sometimes on the walls you have these panels installed or in the roofs as well. So, they are fixed all along its perimeter they are not hanging freely from the edges.



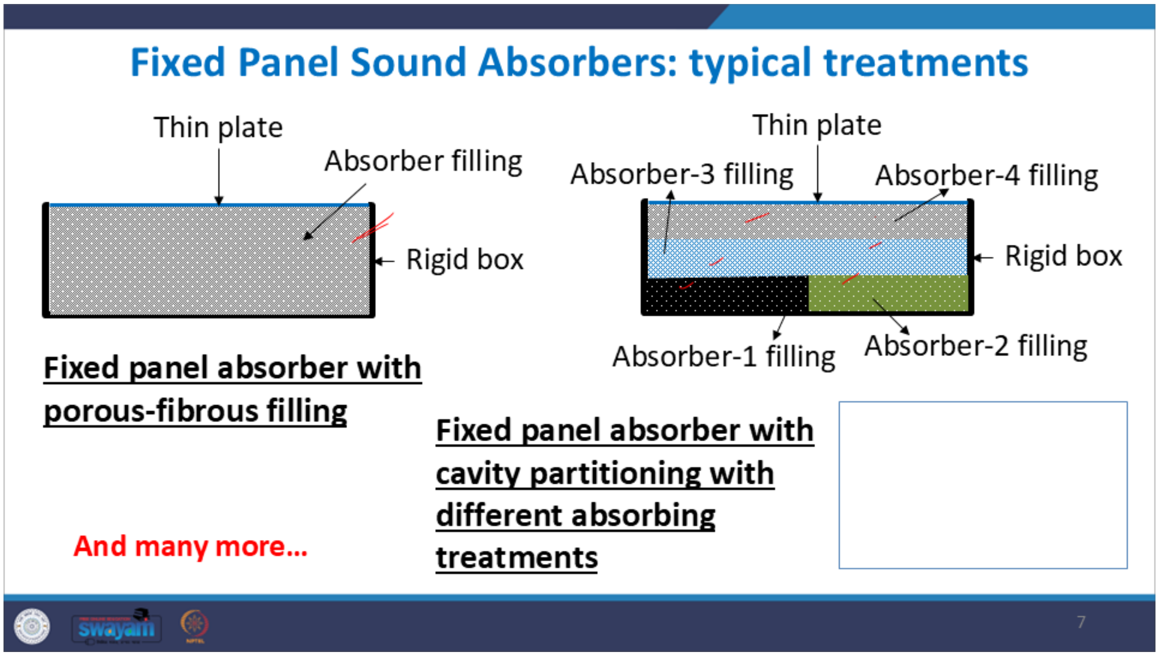
So, again see this is a fixed panel and this is your panel right this is your panel this part it is a panel and then this shows the clamping condition or the mounting condition which means that All along its perimeter it has some adhesive has been applied or some kind of welding has been done, but through some mechanical means this particular panel here this thing here the one that is that I am sort of coloring with a red. This panel here through some means is being firmly fixed to a rigid wall ok. So, what goes on inside this particular panel in the fixed panel. So, this shows the inside view of this red portion.

This is the red portion here, which is your panel. Ok. This is your panel. What is there inside? You can see that it is made up of a thin plate because it is a panel-type absorber.

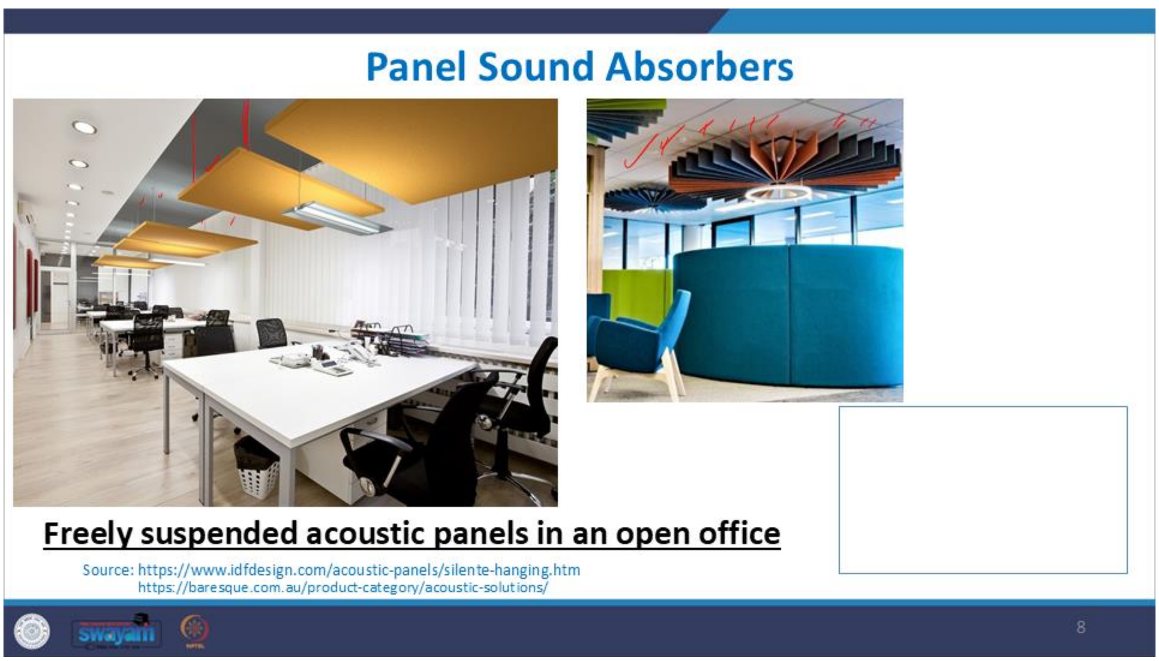


So, you have a thin plate, and then you have this thin plate attached to a rigid box. And there is some sealed gas behind it. Some depth d is given, which is called the air cavity depth. Okay, so it's as simple as that. You know, you can either have a stiff panel hanging from the roof or you can have a panel attached to a rigid backing. And how do you attach it? You make a box kind of a structure. And you attach it to that rigid wall with this structure, where you have this panel which is free to vibrate and it is being backed by a rigid box which contains a confined gas or a sealed gas. Ok. The gas has no means to escape. So, whenever the panel vibrates, the gas would try to oppose the vibrations by means of its own bulk modulus.

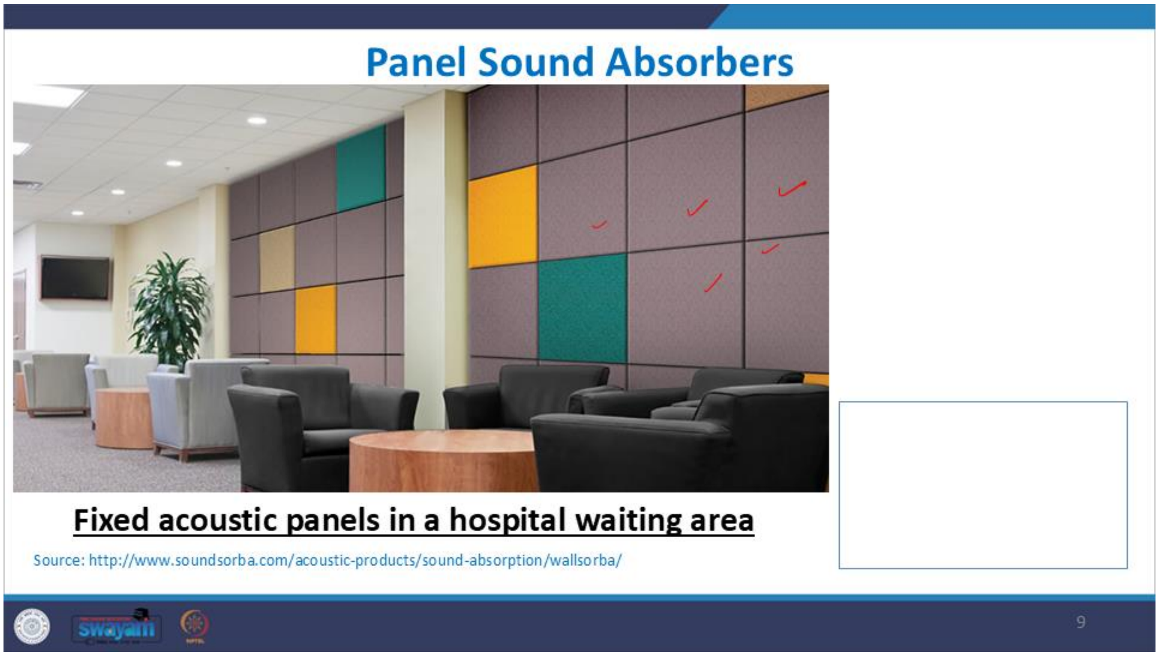
So, this is one where, you know, you just have a gas being sealed behind the panel or the plate. The other configuration would be that within this rigid box, you can also have some lining of absorber material because typically what we find is that the panel absorbers absorb at low frequencies, but the high-frequency absorption is not as great. So, why don't we combine, you know, the advantages of porous fibrous absorbers, which perform really well over a broad range of high frequencies, and we combine it with a panel? So, the general practice now for noise control engineers has become that when you make these fixed panels, you have a panel, then a rigid box, and a sealed air, but with some absorber lining as well to further enhance the absorption characteristics. Sometimes, you know, the entire cavity itself is filled with the absorber, and sometimes what happens is the cavity is partitioned. So, multiple different absorbers of different volumes are kept inside this sealed cavity.



So, this shows some of the examples here. You can see an office space or open office cubicle and these hanging panels. You know, this is the wire. I do not know if it is visible

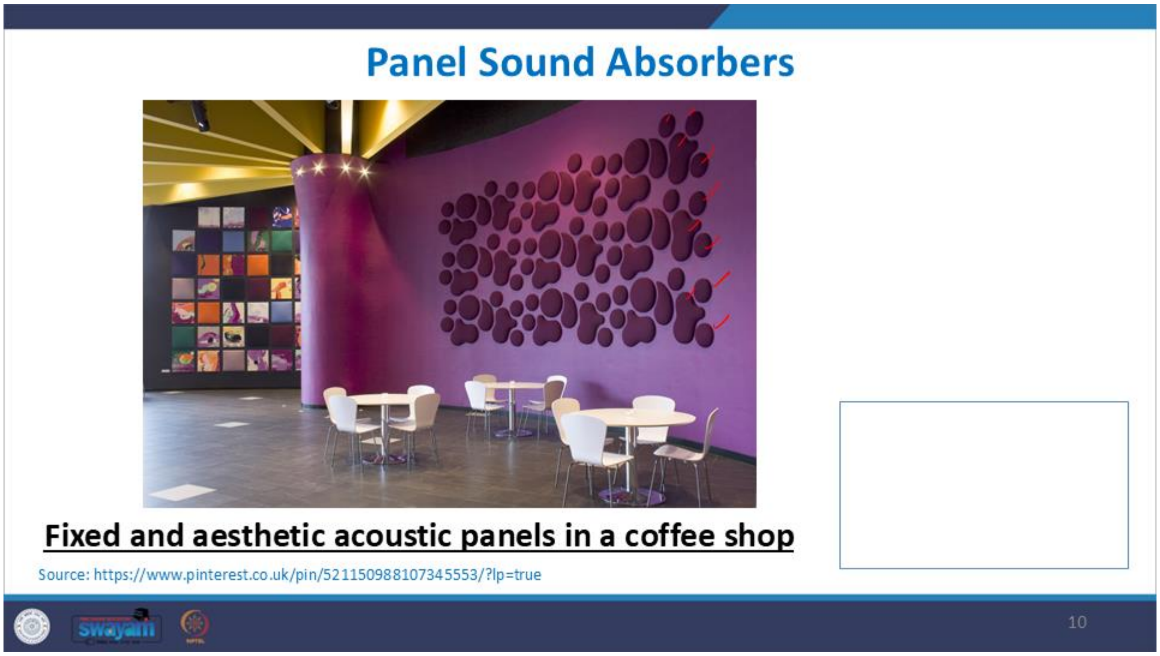


or not, but these wires are there, and they are hanging along its corners through these wires, and they are held there. So, why are they there? They are not really, you know, although they really act to the aesthetic quality. Because, you know, they are nice, glossy, and shinily painted, okay? They have a nice glossy surface, very good painting, but they are actually added for acoustic purposes, okay? So, they're added to enhance the acoustics inside this indoor office space. They act like panel absorbers and try to absorb the irritating low-frequency noise. In the same way here, also, you can see these panels.

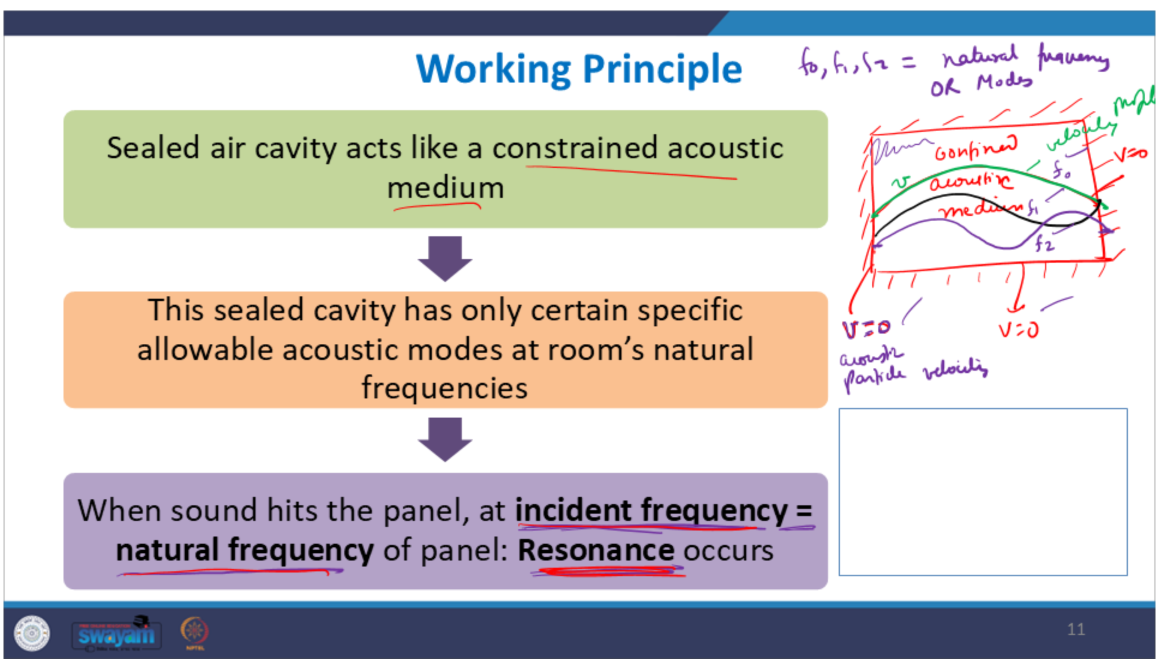


You know, they are sort of hanging from the ceilings, and they are adding to the aesthetic quality also, but they are serving the purpose of enhancing the acoustics of this environment. Over here, you can see some fixed acoustic panels in a hospital waiting area. So, you see, it looks so beautiful. It looks like some architecture, you know, installed these, you know, colorful tiles just to, you know, just for the purpose of, you know, enhancing the beauty of the structure, but— Enhancing the beauty or the aesthetics is a secondary, just an added advantage. But the primary purpose of installing these tiles is to provide, firstly, some kind of thermal insulation and also to provide some sound absorption and enhance the acoustics. So, they are usually installed to enhance the thermal insulation and to enhance the acoustics of the environment. And they can be beautifully painted, beautifully cut, and lined along the walls.

So, the aesthetics becomes just an added advantage to the actual primary functions of these particular fixed acoustic tiles. Here also, you can see in the coffee shops, it seems like they are adding so much of aesthetics, but they actually serve the purpose of again absorbing the sound.



So, what is the working principle behind this? You know, in the panels, you have got some sealed air cavity. It acts like a constrained acoustic medium. So, whenever you have got any kind of acoustic cavity, any kind of cavity with an acoustic medium such as air, and it is confined on various places. So, at every rigid wall, you have a condition that, you know, the sound pressure, okay.



The velocity suddenly changes when it hits the rigid wall; the particles cannot go beyond the rigid wall. So, the velocity has to become 0 at the rigid walls. So, whenever you have some kind of medium within confined rigid boundaries, it has to satisfy the condition that the sound waves will reach their minimum velocity at the boundaries. And in such a confined medium, what happens is that they can only allow the sound waves to exist at certain frequencies, ok, because they have to satisfy that condition.

So, let us say something like this to explain this: this is the rigid wall. And we have some confined acoustic medium, some confined acoustic medium. So, here the particle velocity has to become 0 on all these walls. So, what kind of wave can you observe? You cannot have any random wave; maybe you can have a wave like this, or you can have a wave like this, so this shows the velocity profile.

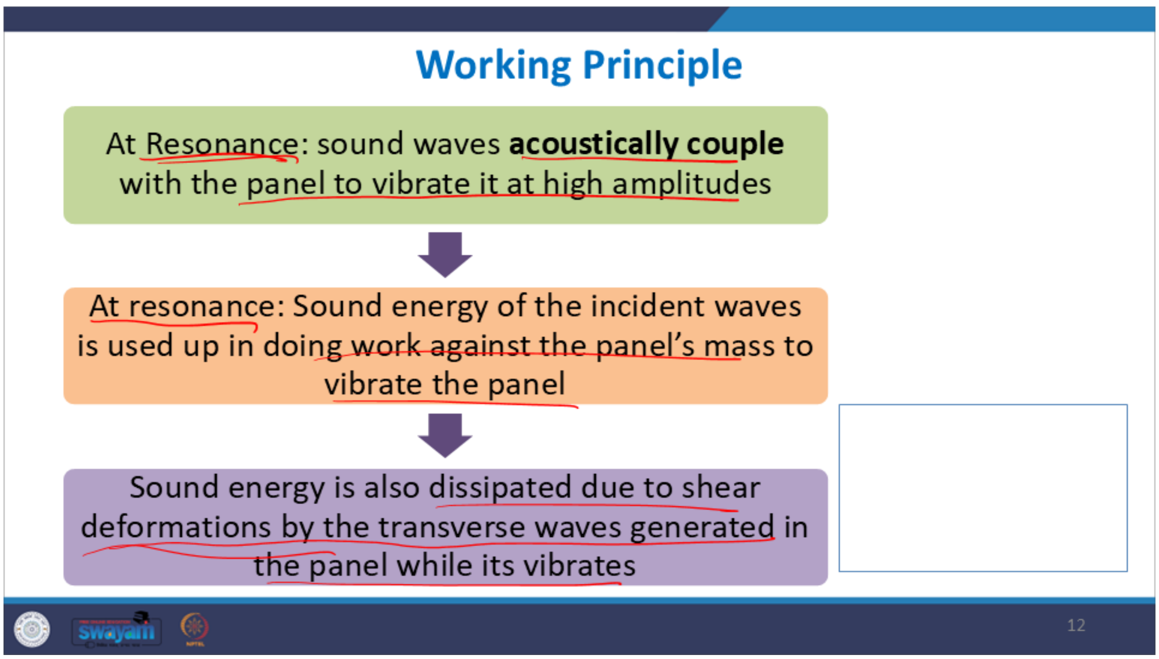
Okay, so this shows the acoustic velocity. It can reach a zero value. So, one wave could be like this. Then you can have a wave like this. Then you can have a wave like this.

And so on, so always the condition has to be satisfied that, you know, at the end points, the V has to become 0. So, you cannot have any frequency you want; you can only have waves of a certain frequency, you know. Certain frequencies—only certain frequencies—can exist within such a confined acoustic medium that is surrounded by rigid walls because, at the walls, the acoustic velocity has to be 0. At the rigid walls, acoustic velocity or particle velocity becomes 0, and to satisfy that, your velocity wavefront has to reach a 0 value at the end points. So, the shape cannot be arbitrary; I cannot have any arbitrary shape as I want. It has to reach a certain 0 at this point. So, only certain allowable frequencies can exist. So, with this understanding, what we come to know is that if a panel has got a constraint—

A sealed cavity can only allow certain frequencies to exist within it, which means that only at certain frequencies, if the sound is hitting the panel, will the air cavity inside the panel get excited—not at all frequencies. It will only get excited at certain frequencies that match with the allowable frequencies of its medium. Which satisfy this particular condition here, and only at those frequencies, whenever the sound wave is hitting, suddenly the acoustic medium is going to get excited. The sealed cavity will undergo a large amount of pressure fluctuations and particle velocity fluctuations. So, whenever this happens— So, those frequencies which are allowed within this constrained medium are also called as—

These frequencies which are allowed—these are also called the natural frequencies, which means only—or the modes. Which means that these are those discrete frequencies of sound that can exist within this medium. Other sounds get automatically dimmed because they cannot exist within this confined medium. So, whenever your sound wave inside some room—with an acoustic panel installed in the room—matches with one of these natural frequencies of the panel, then the phenomenon known as resonance occurs. What happens in resonance?

So, whenever this happens—so in that case, because the panel absorber is the first kind of resonance-based absorber—the phenomenon of resonance needs to be understood.



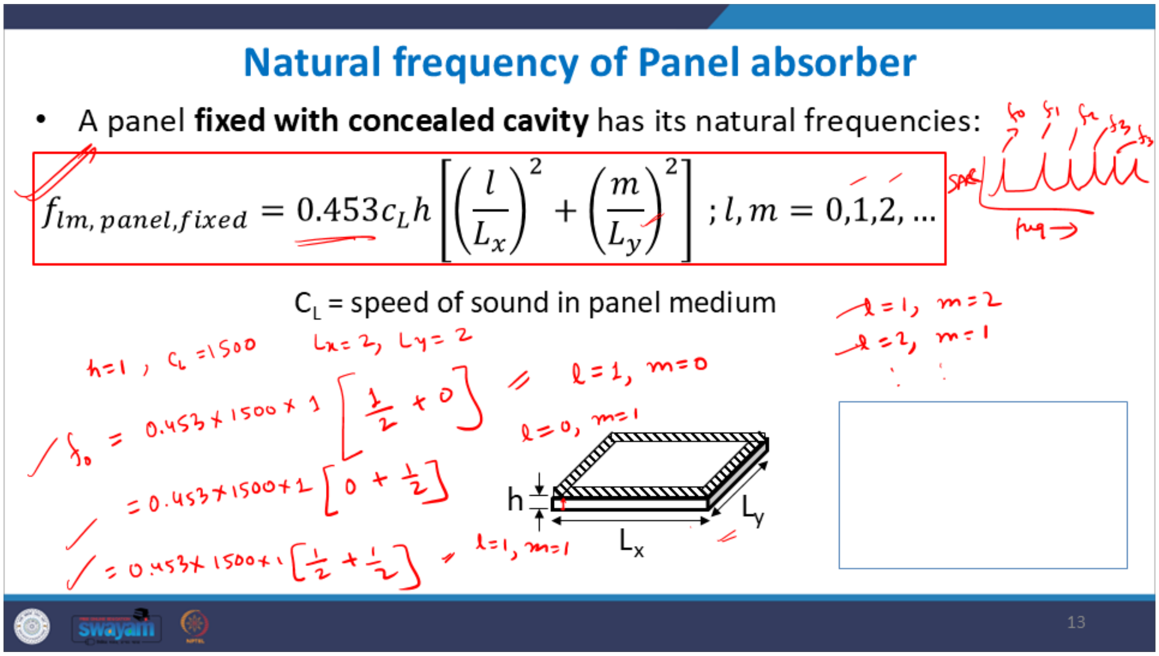
What it means is that we have some kind of an acoustical medium where only certain certain sounds with only certain discrete frequencies can exist. So, whenever your incident frequency matches that allowable discrete frequency or the natural frequency, then suddenly, the medium is going to get excited at a very high level. There would be an acoustic coupling or resonance, which means that suddenly you will have sounds with very high amplitude or vibrations with very high amplitude—whatever is getting excited. So, a very high level of

excitation will happen in this case because it is hitting the panel, and the cavity inside is getting excited. So, the panel itself will start vibrating largely. The panel is going to vibrate at a high amplitude at this particular resonance, and now whatever sound wave is being incident it is somehow using up all its energy to drive the panels. So, the panel is a stiff panel with a certain mass. Suppose you have to vibrate the panel. You have to fluctuate the panel.

So, initially, the panel was at rest. But then, due to the incident sound wave hitting that panel, the panel is now getting excited. So, initially it was at rest, and now it starts vibrating heavily. So, to vibrate itself, the acoustic energy or the sound energy is getting used up. Okay. It is doing work against the panel mass in order to vibrate it, and this causes the dissipation of the sound energy.

So, what you can say here is that in a very crude way you can say that you know suppose I am in a room I am there is some kind of noise source and there are these acoustic panels installed. So, whatever my sound wave I am creating or whatever the noise source is whenever the frequency of the noise source matches with the natural frequency of that panel then that frequency can create resonance which means that it can help acoustically coupled with the panel or may be another way of saying that that frequency when the noise source is creating a frequency which matches with the frequency of the panel then at that frequency you know whatever sound waves are coming out of the noise source they will actually get used up in driving the panels to vibrate at high amplitudes. So the noise is going to go down but the panels will be set into vibration.

So basically the energy going into the room is now getting sort of absorbed into the panel and is used and is going into that confined space of the panel to vibrate those panels. And the dissipation happens because the work is being done to vibrate them. It also happens because you know whatever vibrations are created they create shear deformations because of the vibrations that also uses up a lot of sound energy. Now, so you know that the natural frequency of the panel that becomes very important because it is at that frequency it behaves as an absorber, okay. It can absorb the sounds at its natural frequency.



So, what is it for a fixed medium with a concealed cavity? The natural frequency is given by this formulation here. So, which means that Lx is one dimension of the panel Ly is the other dimension of the panel and you know that a set of discrete frequencies can exist. So, the natural frequencies they can be a set of discrete values.

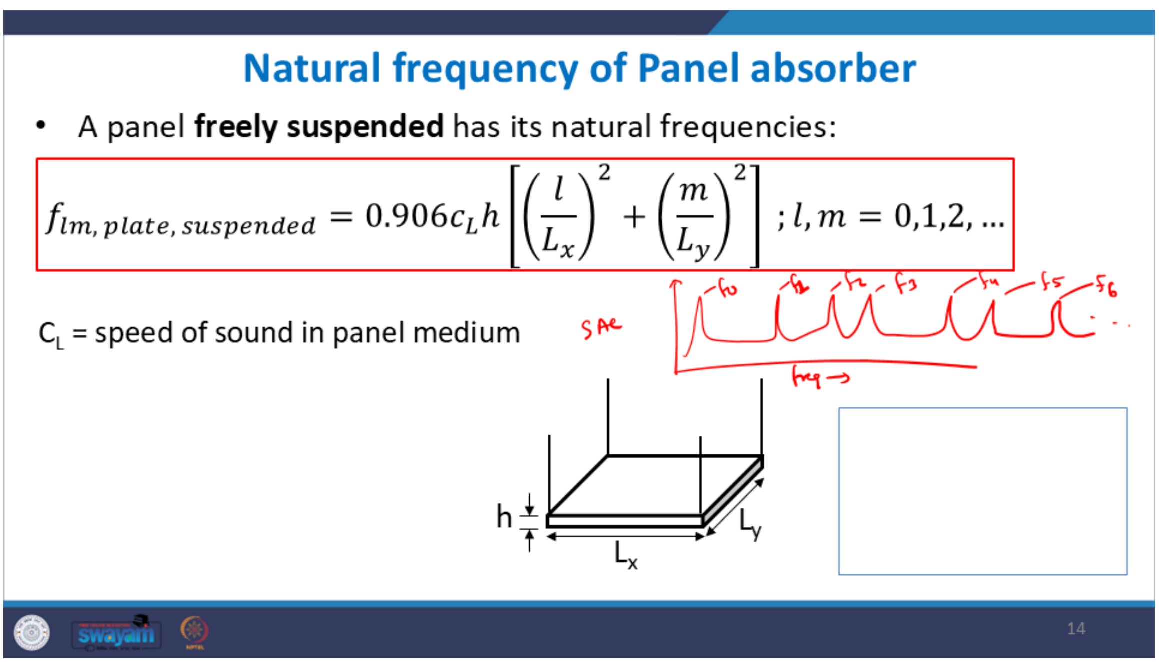
So, h is the thickness of the panel or the thickness of the concealed air cavity within it this one. So, what it means is that let us say for example, if h was equal to 1 and the speed of the sound in the panel medium was somewhere let us say 500 or 1500 like that and your Lx was let us say 2, Ly was also 2, then what it would mean is that the very first natural frequency or f0 would come at this particular value. L would be if L is 0 m is 0 then the value becomes 0 you do not want a 0 value. So, you will start with L as 0 and m as 1 like that.

So, let us say I make 1 as 0 and 1 as 1. So, this is 1 by 2 plus this is 0. So, this will be your first frequency where L is 1 and m is 0. Then if you the next frequency you can get by putting l as 0 and m as 1 and in this case it would be the same value because both Lx and Ly are same okay.

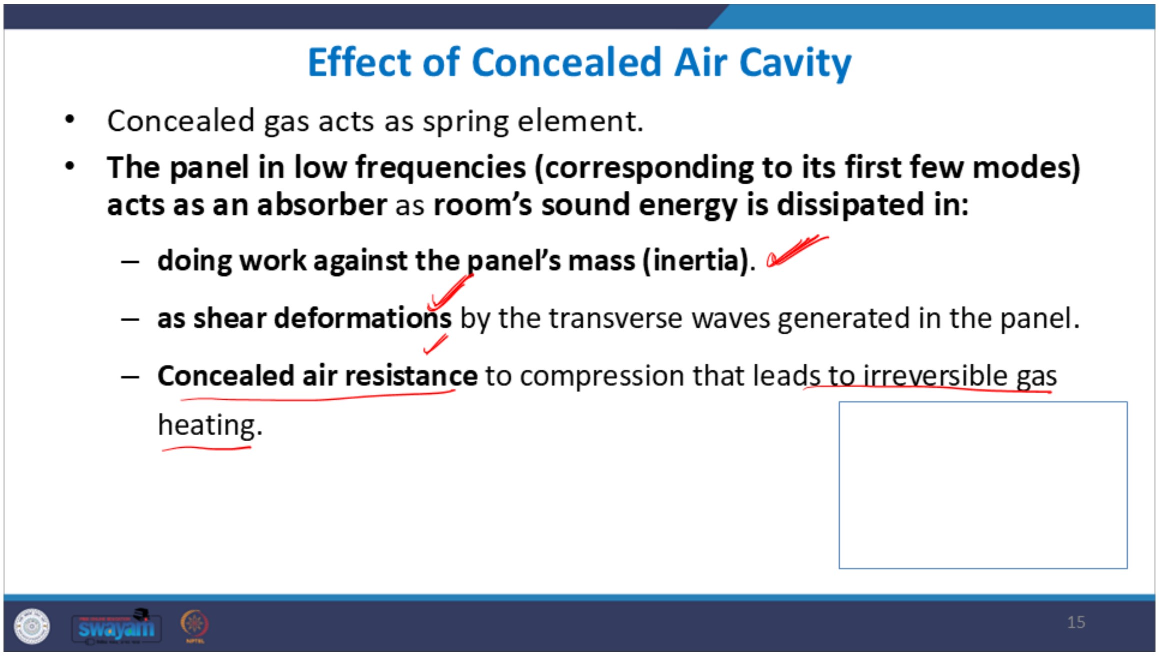
And then you will have the mode where l is 1 and m is 1 and you will get yet another frequency ok, a different frequency and then you can have another mode where l is equal to 1 and m is equal to 2, l is equal to 2 and m is equal to 1 and so on. They can take these discrete values and for each value you will get a certain For each of these integral values of l and m, you will get a certain frequency value. So, a lot of discrete frequencies are there and these become the set of natural frequencies of the panel.

So, whenever the incident sound wave has a frequency same as one of these values, one of these values that you are obtaining, then it will act as an absorber. So, obviously, the absorption characteristics would have a peak like this. where each will correspond to a certain mode of the panel okay. So, this is how the typical you know absorption characteristics with respect to frequency should look like okay for the panel. because it has a set of discrete natural frequencies corresponding to an l and m mode in the same way for a freely suspended panel we have similar kind just it is twice of whatever value you obtain for a fixed one

and once again you can put l is equal to 0, m is equal to 1, m is equal to 0, l is equal to 1 and slowly putting these different integers you can get the different set of discrete frequencies which are the natural frequencies of the panel and if the incident frequency is any of these natural frequencies then the panel will act as an absorber. So, once again its absorption characteristic should have multiple peaks. corresponding to whatever its natural frequencies are. Ok. So, f0, f 1. So, we will get a set of different frequencies for the different l and m values and corresponding to that we will get a multi-peak sound absorption curve. Ok.



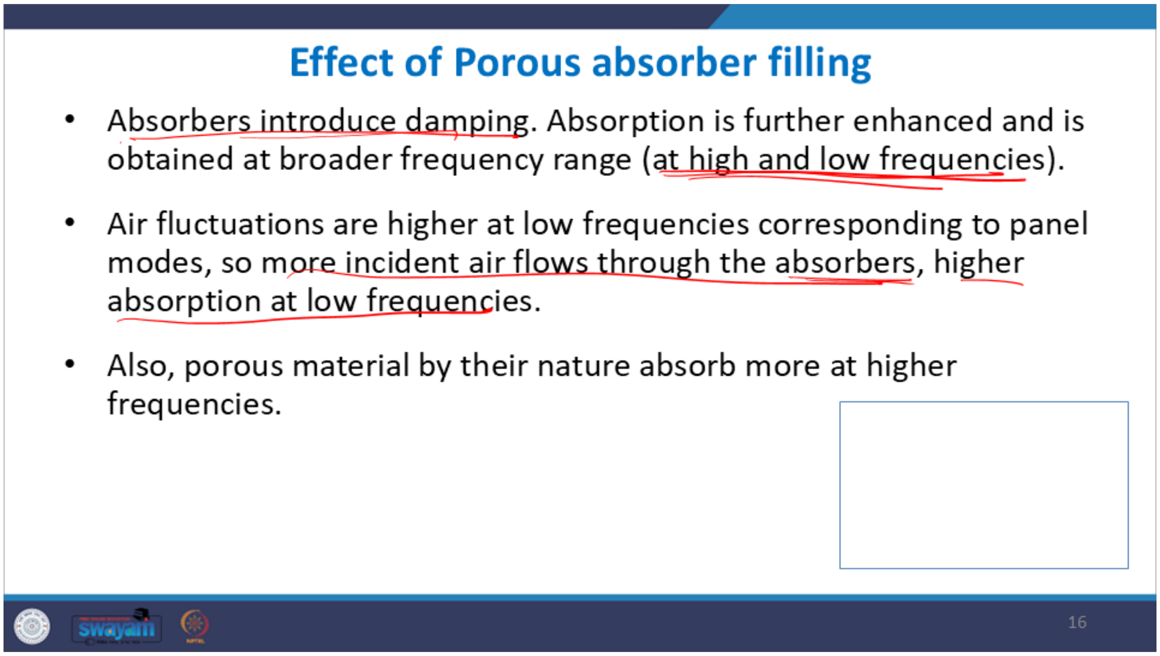
So, what is the effect of this concealed air cavity? So, here we know that a lot of energy is getting dissipated to vibrate the panel. So, some work is being done against the panel



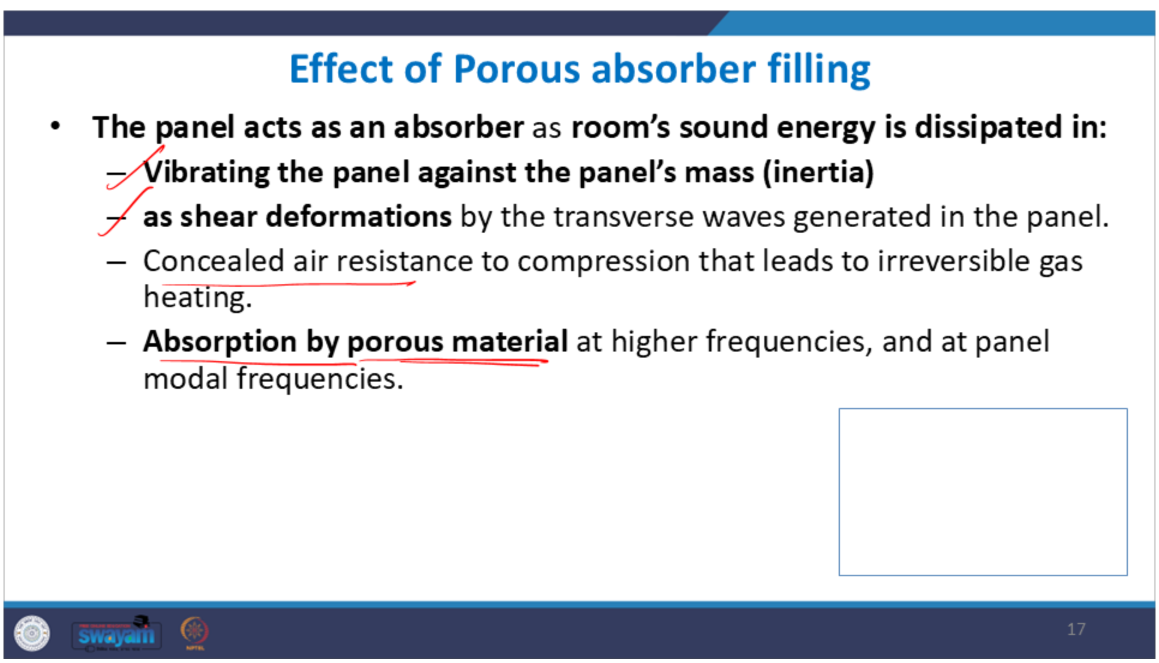
mass or inertia and also due to the shear deformations which are caused when the transverse waves are being generated in the panel. But in addition to that we have a concealed gas. Then suppose we just had a hanging panel, these two mechanisms would operate and dissipate the sound. Ok.

So, in the case of freely hanging panels which do not have a concealed cavity within them, these two mechanisms take place. But just in case we have a concealed cavity, then there is additional absorption due to the resistance faced by this concealed cavity or the concealed air resistance.

Because here, when the panel is vibrating, it tries to compress and expand the concealed air cavity, and this leads to irreversible gas heating and the loss of sound energy.

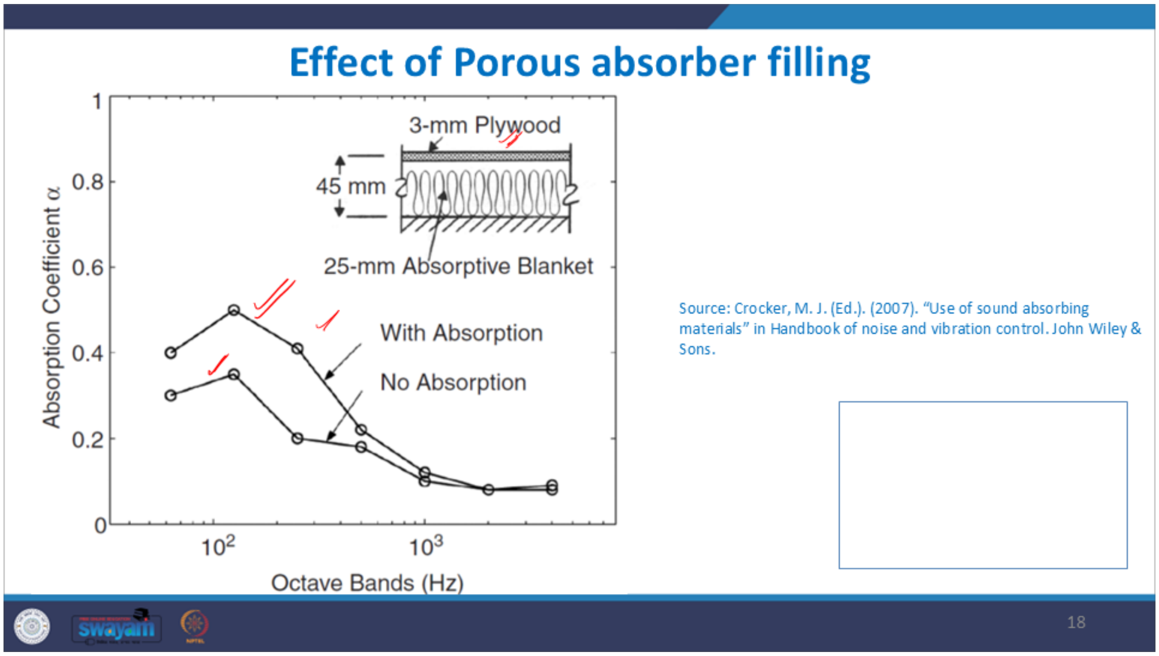


So, there is an additional mechanism that comes into play because of the concealed air cavity. Suppose instead of a concealed air cavity, you now had porous fillings. So, what would happen again? You know some energy is used up because of the panel vibration. So, the first two mechanisms for the dissipation of sound are definitely the same.



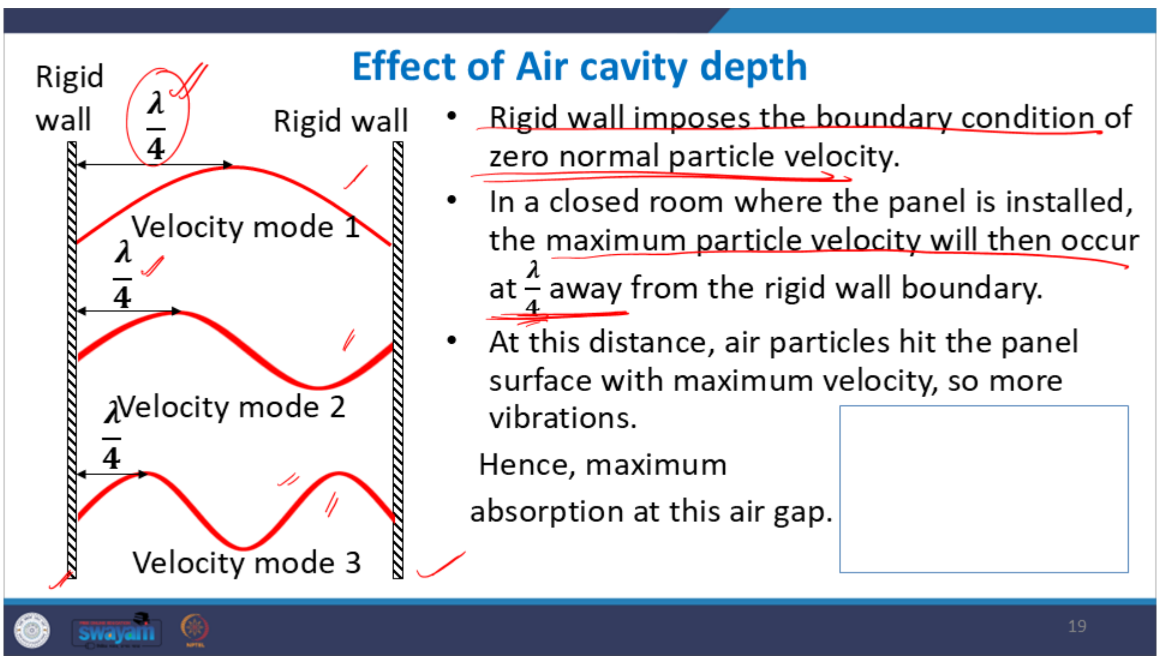
And then, if there was a concealed air cavity, there would be concealed air resistance as well. Suppose it is an absorbable lining, and now that you have a porous material, the absorption would have an additional mechanism, which would be the absorption by the porous material. It would enhance its absorption at the higher frequencies or the panel modal frequencies.

So, let us see, you know, and see experimentally what we have found. So, the effect of porous absorber lining: suppose you have some panel, and inside it, this is your panel, and then it is backed by a rigid concealed air cavity, rigid and filled with, you know, a porous absorber blanket. So, once when there is no absorber filling, this is the sound absorption coefficient. But with the absorber filling, what is happening is that now the absorber is helping both in the low and the high-frequency zones. So, it does not matter whether it is low frequency or high frequency; it will help both ways. While if you introduce an absorber, it adds additional damping, okay?



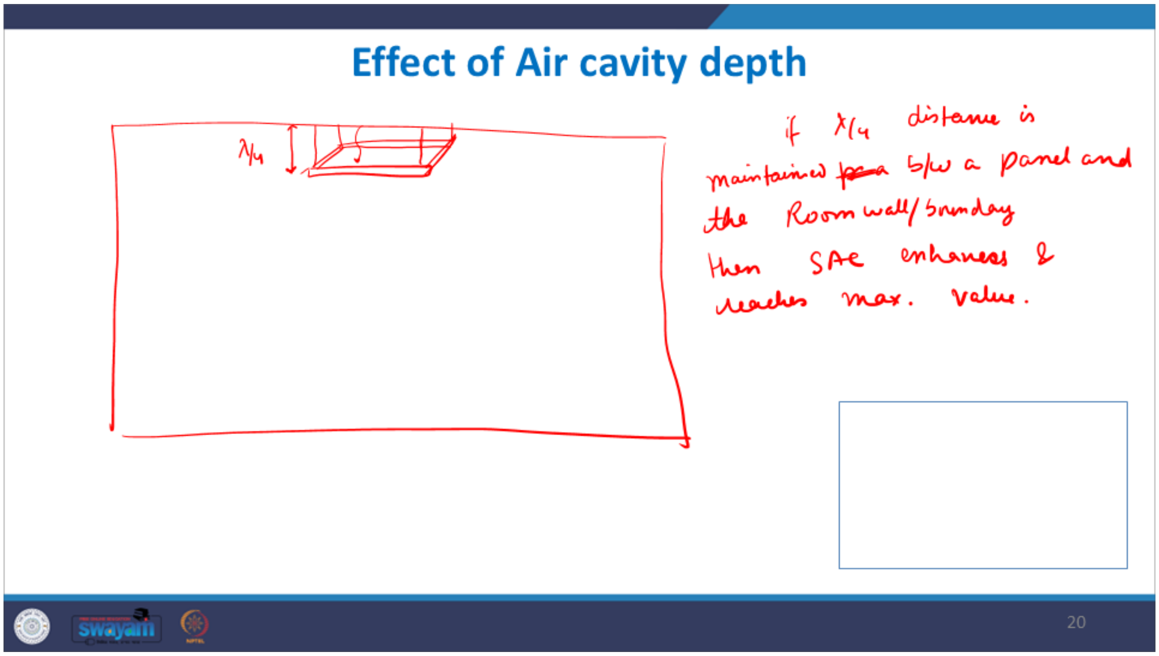
So, the frequency—so typically, the absorption values get enhanced because you know that at resonance, particle velocities are the maximum as they are flowing through into these absorbers, and hence a higher level of absorption is taking place at the resonance. So, wherever you are getting the peak essentially. So, without the absorber lining, whatever peaks you were getting, if you add the absorption, you will get the same peaks because at those peaks, your acoustic particle velocity is the maximum. You are having the maximum vibrations and the maximum fluctuations. And hence, this highly vibrating—you know, this large amount of acoustic velocity with which particles are vibrating—they will enter into the absorber filling. So, they will enter at a higher velocity into the porous material.

And the viscous losses would increase because of the increased particle velocity. So, even at lower frequency, you are getting a peak, and then you have introduced an absorbable filling; then, the thermo-viscous losses will also rise at those high particle velocity regions, and the peaks will get enhanced even at low frequencies, okay? Like this, so the peaks get enhanced. Now, what is the effect of air cavity depth? So again, I was saying that, you know, suppose most of the time these panels are used in closed indoor spaces having rigid walls. So, in closed indoor spaces with rigid walls, the condition again has to be that, you know, the particle velocity has to reach 0 at all these rigid walls. So, only certain levels of wavefronts can exist, as you can see here and so on, because the velocity has to be 0 at both ends.



So, this is, suppose, the opposite walls of some room. So, only certain allowable frequencies can exist within this room. Now, you see here that the velocity is maximum at lambda by 4 away from the rigid wall. So, if this is, if the wavefront is something like this. At lambda by 4, you have got the maximum velocity away from the rigid wall.

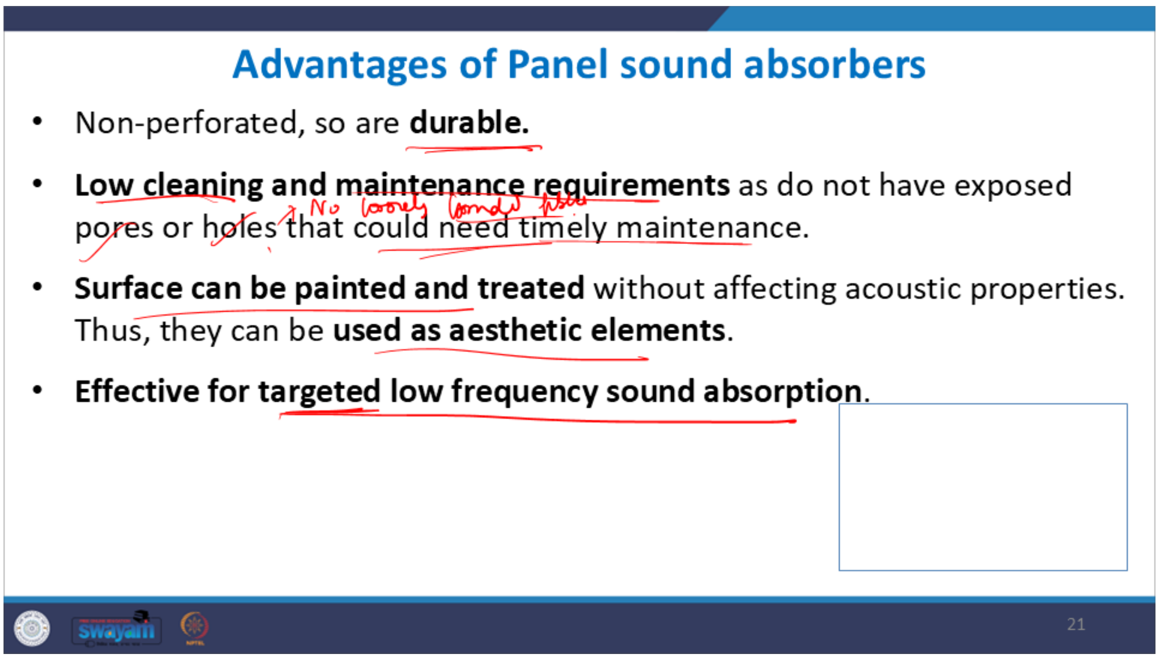
Even if the wavefront is like this, again, the nearest distance from the rigid wall where we are getting the maximum acoustic velocity is lambda by 4. Even if we have this kind of mode, or the wavefront, the nearest, you know, distance from the rigid wall where we get the maximum acoustic velocity is lambda by 4. So, at lambda, maximum particle velocity will always occur at a distance of lambda by 4 away from the rigid wall boundary condition. Hence, let us say, with this knowledge, we have got some confined room.



And let us say we are hanging the panels in that room. So, what if we keep the length as lambda by 4 for these cables? What will happen? Then the panel—then we know that the particle velocity reaches a maximum at lambda by 4. Okay. So, if the panels are kept at a distance of lambda by 4 from the rigid wall of the room, then the particle—whatever, you know—the waves generated in the room will hit the panel with the maximum velocity here. So, basically, the sound waves will be incident on the panel at the highest velocity, and due to this, the losses will be higher.

So, if the lambda by 4 distance is maintained for a panel between a panel and the room wall or the room boundary. So, if you maintain a distance of lambda by 4 between the panel and the boundary of the room. Then the absorption enhances and reaches the maximum value. Why? Because at this point, the sound waves will hit the panel with the maximum acoustic velocity, and whatever phenomenon we were absorbing will get further enhanced. The higher the velocity with which they hit the panel, the more energy gets used up in vibrating the panel. And the more energy gets used up in going into the absorber filling and getting dissipated as heat. Okay.

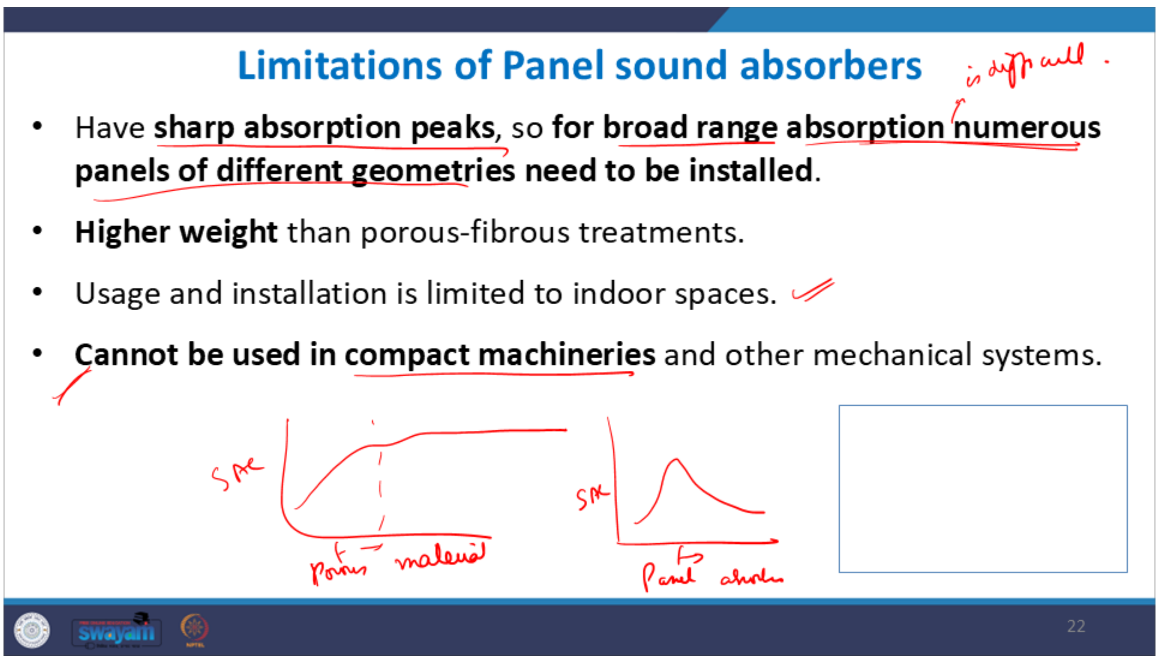
So, if you maintain the panel—whatever, suppose you are having a hanging panel or you just have a fixed panel—and you are thinking, 'Where should I install it to get the maximum benefit?' Whatever is your frequency of interest—suppose you want to curve down a frequency of 1000 hertz—then you would first find out what is the lambda corresponding to that 1000 hertz. So, it would be 343 by 1000. So, the value of the lambda that you get—you do lambda by 4—that would be the best distance to keep your panel away from the rigid boundary of the of your room because, at that place, the absorption by the panel would be the most effective. So, this would be the distance at which the panel will work the best. Okay. So, some advantages of these panel sound absorbers: they are obviously non-perforated.



and non-fibrous. So, all the limitations of the porous fibrous absorbers are now getting solved. So, they are more durable they do not have that high maintenance requirement. So, even with low cleaning and maintenance they work because they do not have any exposed pores or holes and no such loosely bonded fibres ok. No loosely bonded fibres that can fall off it is a stiff lamina

So, that kind of maintenance is not required no need for these maintenance. So, low maintenance and cleaning requirement compared to porous fibrous absorbers and more durable because they do not get clogged up due to the continuous usage and then the surface can now be painted and treated without affecting its acoustic properties and hence they can be used for as the aesthetic elements. And they are effective for targeted low frequency absorption. So, basically whatever limitations you had with the porous fibrous absorber. The porous fibrous the limitations was that low frequency absorption is quite poor ok at the low frequency they are not able to absorb properly.

you cannot do surface treatments on them because then you know the pores can get blocked up and the absorption can go down with the continued usage the air contaminants and the dust particles in the air can again block up the pores and the fibers and they can still make the absorption go down so they were not durable also and lot of cleaning and maintenance was required so all of these limitations are now avoided by using a panel sound absorber what are the limitations now although they can give you targeted low frequency absorption i mean target it means that only at certain range so typically the absorption peaks they are very sharp in nature okay for a porous material let us say your this is your absorption it looks like this very broadband after a certain frequency range poor at low frequencies, but for a panel absorber SAC looks like this sharp peak at low frequency.

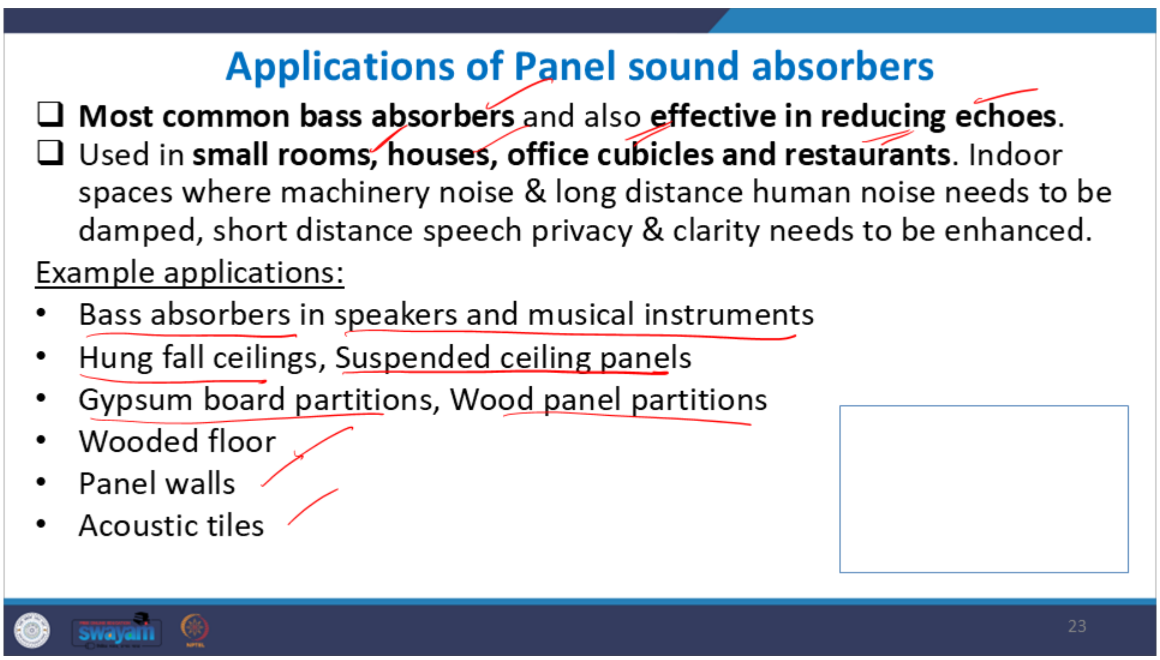


So, which means that broad range absorption again becomes tricky and difficult. For that you need to have numerous such panels with different geometries each of them giving a peak at a continuous different frequency and combining them together which again is not practically feasible.

So, broad range absorption is very difficult. Then they have much higher weight compared to the porous fibrous treatments because essentially porous fibrous they have lot of air spaces and voids and their velocity and their you know density is very low. They are very low weight low cost solutions but panels they are stiff lamina they are higher weight and higher density. Their usage and installation is also limited only to some indoor spaces. They cannot be installed just anywhere in compact machineries because of the shape that they have to maintain, the air cavity depth that they have to maintain and their mounting conditions.

So, because of their construction and their design itself, they cannot be used in machineries with complex contours, whereas absorbers just can be lined anywhere in the machinery.

Some applications, the panel absorbers, they are the most common bass absorbers, effective in reducing most of the echoes. and specially used in the indoor spaces like small rooms, houses, office cubicles and restaurants where you can find them in the form of suspended ceilings, hung fall ceilings. So, whatever fall ceilings are there, suspended ceiling panels are there in these office cubicle spaces, restaurants and various other buildings. They are panel absorbers, then the gypsum board partitions and the wood partitions inside the houses, they also serve as panels.



The wooden floors, the acoustic tiles, the panel walls, then the bass absorbers in the speakers and the musical instruments, they are all panel sound absorbers.

So, some pictures, this is a gypsum board partition at home which is acting as a panel absorber. And also adding to the aesthetic value and creating a partition between two living space living space.

Here you have got these wonderful acoustic tiles acting as absorbers.

You have these hung freely suspended acoustic panels on these in this office cubicle.

Then you have again these various kinds of wooden tiles on the floor, which act as panel absorbers and so on.

So, thank you for listening.