Acoustic Materials and Metamaterials
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Lecture – 17
Panel Sound Absorbers

Welcome to lecture 17 on the series on Acoustic Materials and Metamaterials. So, today's discussion will be on a new type of sound absorbing material which is a Panel Sound Absorber. So, previously we have discussed about porous fibrous materials and the limitations with such kind of materials is that first of all they are not clean. They need timely maintenance because they have lots of pores and fibers which can get contaminated very easily.

So, it is not a durable solution and it is also not able to offer low frequency absorption. So, some of these limitations will be we will try to address here and this is being addressed by using a panel sound absorber.

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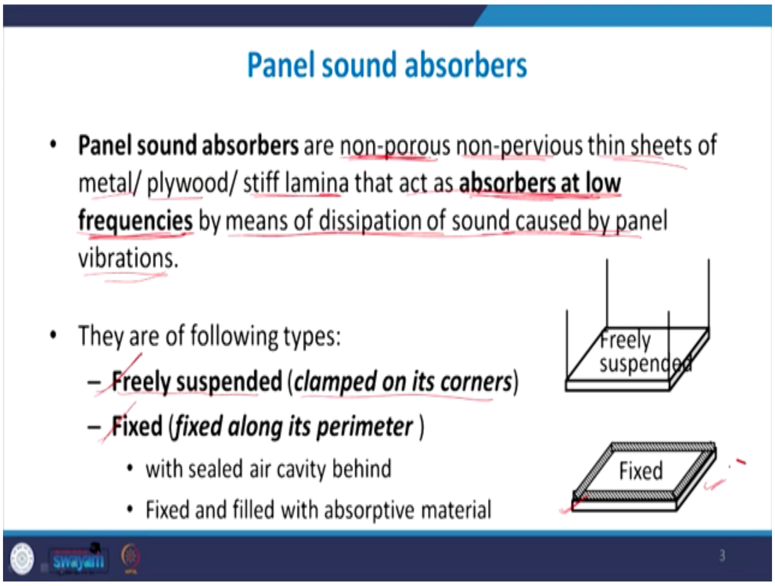

So, let us quickly start with what do you mean by a panel sound absorber. So, panel sound absorbers they are non-porous non-pervious thin sheets of metal plywood or some stiff lamina and they act as absorbers at low frequencies. So as you can see right in the definition what we see is that we are using some non-porous thin sheet of material. It is usually some hard material like metal, plywood or some stiff lamina, but it is thin enough to vibrate. So, such kind of non-porous materials are used so obviously they will be more durable because they would not need timely cleaning because they would not have any pores.

And then these typically act as absorbers at low frequencies by dissipating the sounds by dissipation of sound caused by the panel vibrations. So, we will study what is meant by that. So, typical so typically we have thin panels. So, as the name suggests it is a panel. So, it can be a thin sheet of metal plywood a stiff lamina and they can be used in 2 ways. First can be freely suspended or clamped on its corner.

So, here we have a panel it is the cables some cabe thin cables are used at every corner and it is hung from a ceiling or from any particular ceiling or any particular structure, but in the on the other hand we can also have some fixed acoustic panels. So, here throughout the entire perimeter we have some fixed clamping that is done and then they can be sealed with our air cavity or filled with an absorptive material. So, if as I go into this sub signal go through the lecture it will get the meaning of these clearly.

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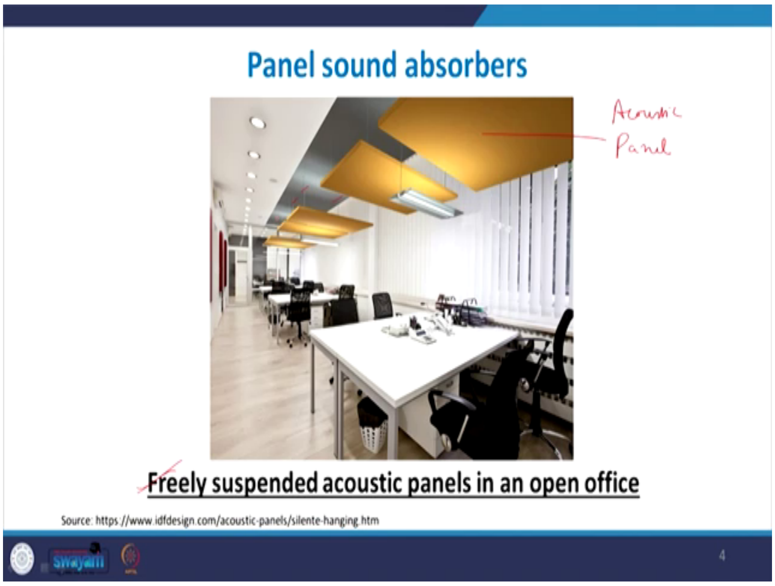

So, to show you these acoustic panels are nowadays being widely used everywhere because they can be painted, they can be used in various shapes and sizes and they are acoustically we are aesthetically very pleasing. So, if you see here this shows you a freely suspended acoustic panel in an open office. So, these are the panels or acoustic panels. So, this is a suspended panel you see you have a panel and this is hanging from the rooftop through these cables as you can see here and it looks acoustically please it looks very aesthetically pleasing.

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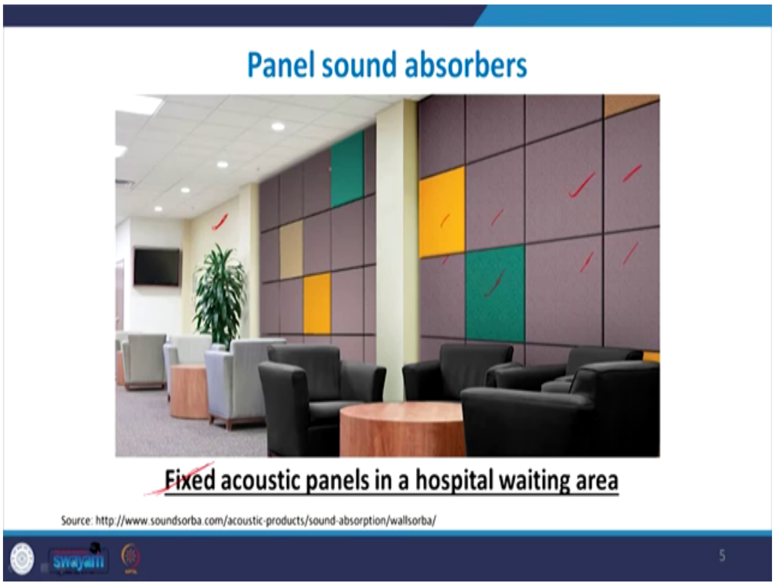

In the same way here this shows the example of some fixed acoustic panels in a hospital waiting area. So, here all these blocks which look like tiles these different colored blocks these are actually acoustic panels. So, we have a this is a typical wall without a panel and then when these panels are sort of fixed to these walls then these become fixed acoustic panels. This is getting even more creative.

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So, here in a coffee area. You have lots of these boards. So, to a viewer it may seem like this is sort of a decoration wall decoration or sort of done for aesthetic purpose, but the main reason for using these panels is to reduce the noise. So, these are actually acoustic panels which two of you and may look like aesthetic elements.

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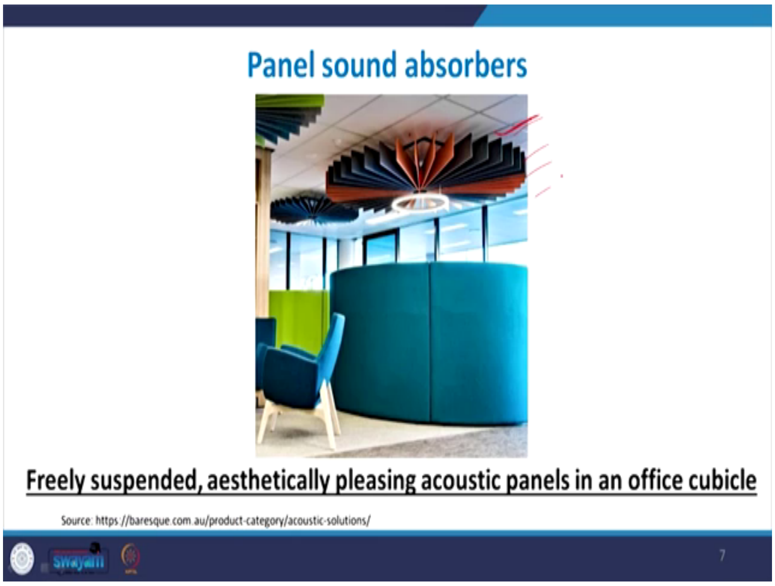

So, as you see it can be used in a wide variety of ways. Similarly in our office cubicle it is this is yet another example. So, we again have a suspended panel. So, here this panel is not suspended from the all 4 corners rather it is suspended from only one side in the form of a fan, but these are all suspended acoustic panels.

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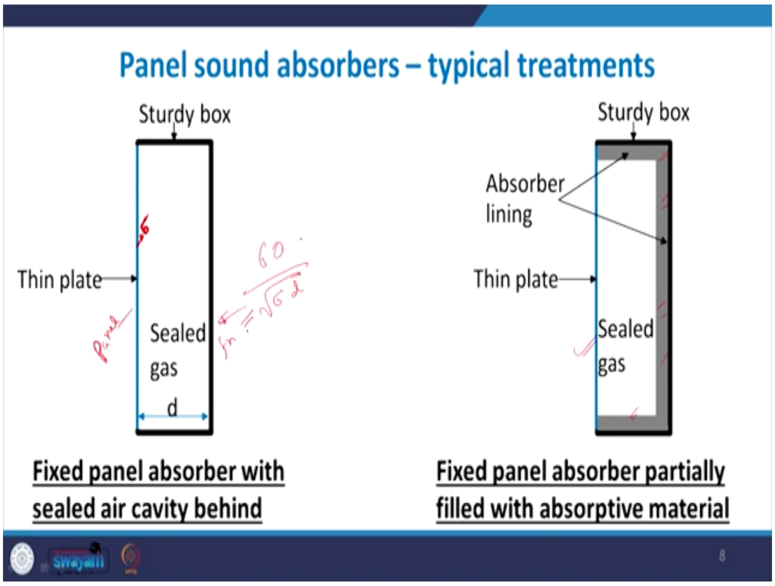

So, these can be used in various different ways. So, now, you already know the schematic for a suspended absorb the suspended panel. So, you have a panel which is hanging from some structure either along the 4 corners or also just from one side as we saw in the last case. And for a fixed panel how does it look like let us see what does a fixed panel look like from inside. So, a fixed panel from inside looks like this.

So, we have a thin material this is the exact panel this is what we call as panel or a thin plate and then it is and we have a sturdy box or a hard material and the panel is placed on the top; on the top of it and there is a sealed gas in between this. So, you have what we have is that let us say we have some hollow structure. So, it is all made of let us say thick wood.

So, we have some hollow box we remove one side and replace that one side with a thin sheet of material and we will have air in between. So, that becomes a typical fixed acoustic panel. In the same way now within this particular hollow structure we can add some absorber lining. This can be another treatment that can be done.

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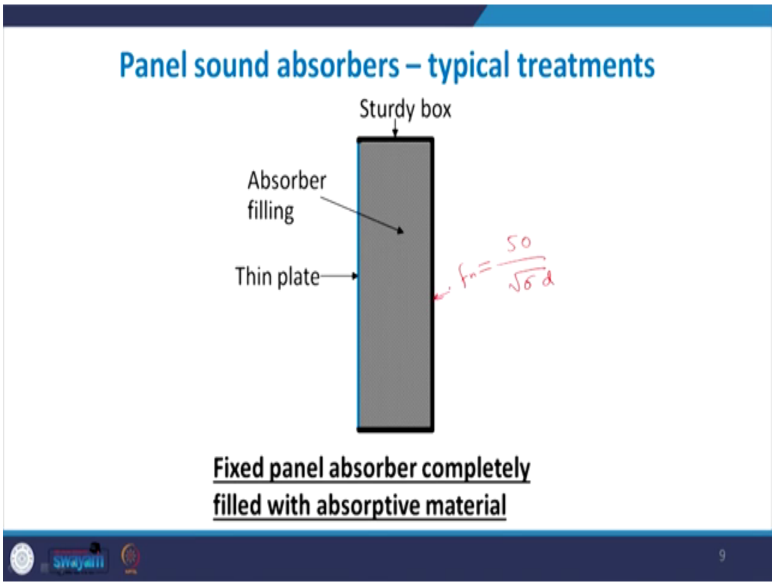

Or we can fill the entire box with this absorbers. So, the absorber is filled inside. We have a study or a hard material box and then we have a thin sheet of material on the top which acts as a panel. So, all of this is a cross sectional view of the material. So, overall just imagine that we have a 3 dimensional box with one of the faces replaced by a panel.

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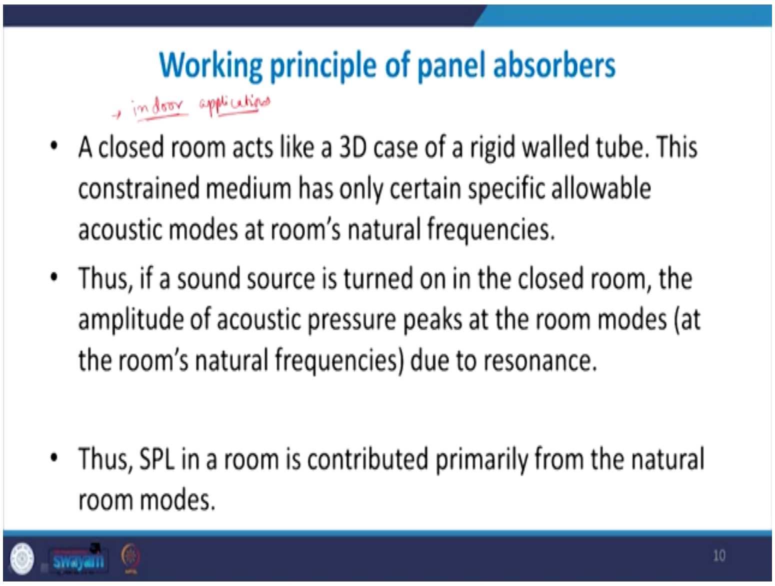

So, that is what you can imagine. So, how do they work. Now we know that now these panels are usually used for indoor applications. So, the first thing you have to remember is that they are used for indoor applications. So, inside a closed room. So, when we were studying about standing waves and resonance. So, we saw that if we have a constraint medium. So, in a constraint medium it will have some fixed modes or some natural frequencies. So, under steady state conditions the sound wave only exists on this fixed modes.

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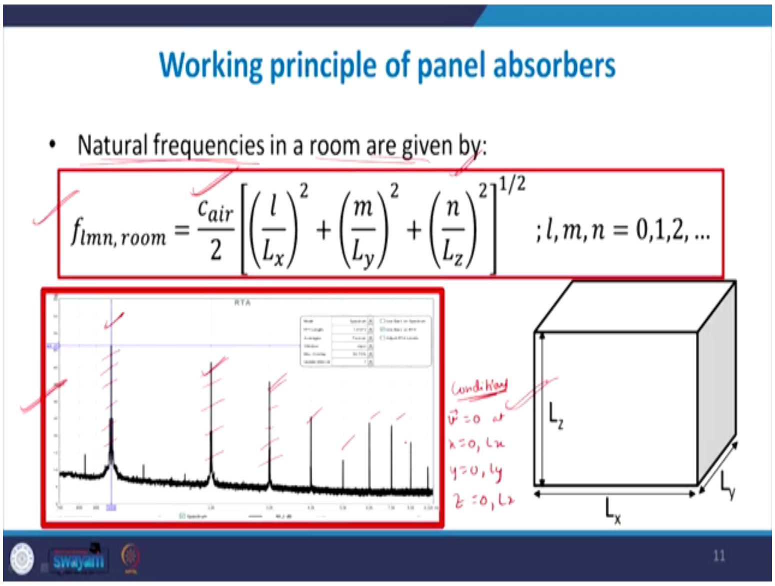

So, when we have a room. So, in a room inside a room the natural frequencies of a room are given by this expression and this can be very easily derived just the way we derived the expression for the sound waves inside a long tube. So, what we assumed there was that both ends are rigid and at the rigid end the particle velocity becomes 0.

So, that was the boundary condition used. The same boundary condition can be used for this 3 dimensional room that is. So, you the boundary conditions here the conditions that can be imposed is that the entire room is made up of these rigid walls and roofs and ceilings. So, v is 0 or the particle velocity 0 at x equals to 0 and Lx at y equals to 0 and Ly and at z equals to 0 and Lz. So, at every boundary this is what is happening and when you solve it you will get this particular expression.

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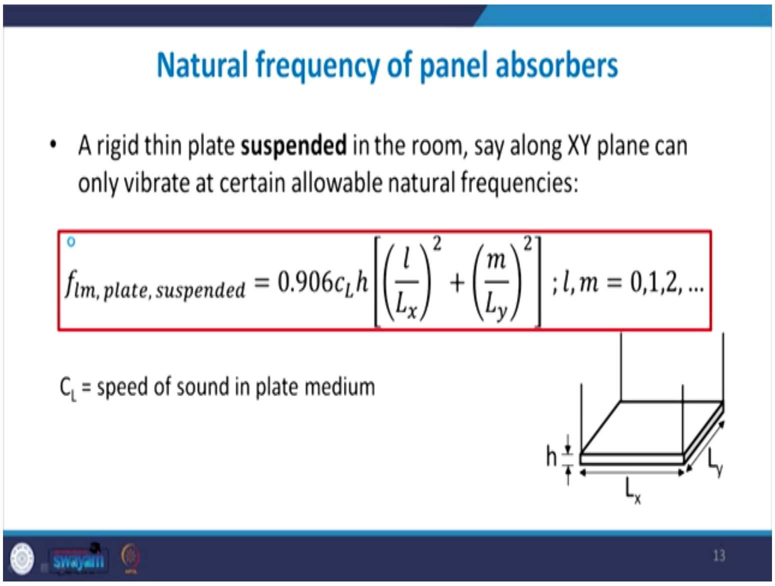

In the same way we have a panel then panel will also have it is own fixed frequency and the frequency for a panel.

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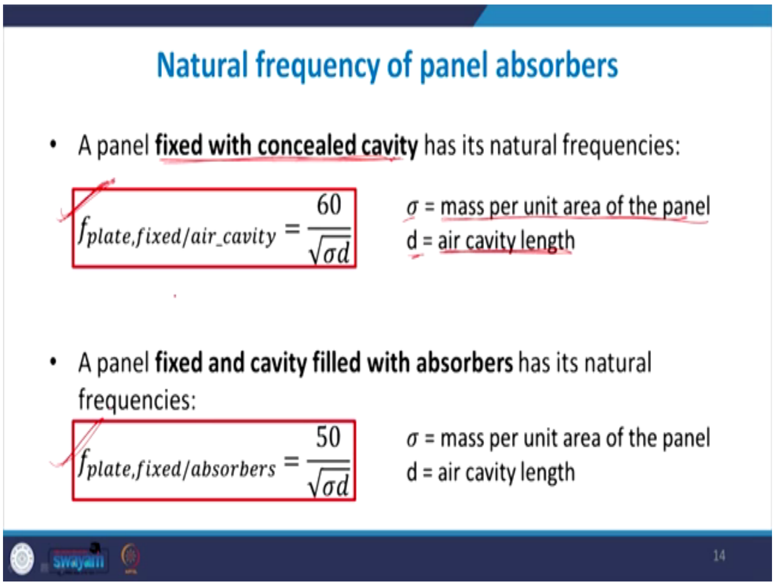

So, I am going to straight come to the approximate solution. So, suppose we have a fixed panel with a concealed cavity which I had showed you. So, the natural frequencies of this panel comes out to be 60 by under root of sigma d. So, this is the approximate this is after calculation an approximate solution is derived. Here sigma is the mass per unit area of the material and d is the air cavity length. So, if we go back to the figure.

So, in this case d was the length of the concealed air cavity the thickness of this air cavity and sigma is the mass per unit area of this particular panel that we are using. This is the mass per unit area of the panel and this is the distance between the panel and the rigid backing or the thickness of the air cavity.

So, 60 by under root sigma d is the natural frequency of this panel and the natural frequency of a panel completely filled with absorber comes out to be this. So, these are the 2 solutions. So, every panel so now, that we have the expression for the what is the natural frequency of in this fixed panel.

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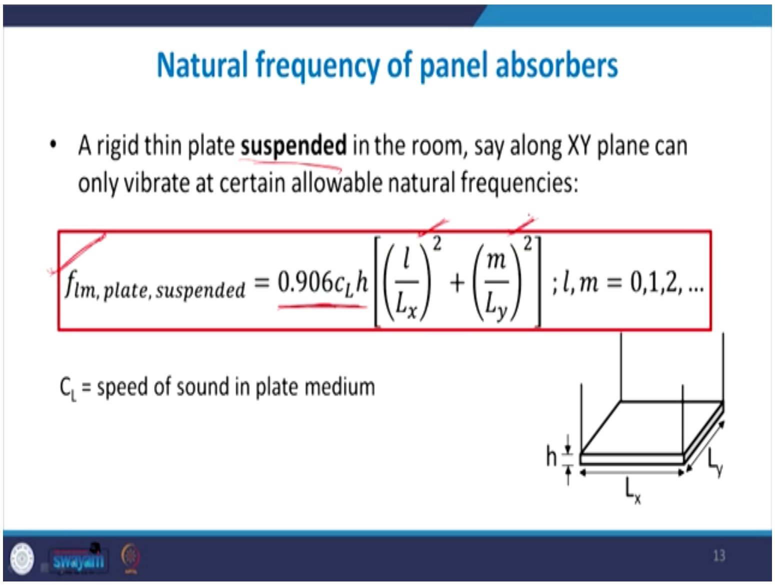

Then the natural frequency of a suspended panel can be given by this equation this is the equation which we get if we solve it. Anyways the cell the derivation of this is not within the scope of this course. So, only the working of these materials and their advantages and limitations are. So, I am directly giving you the expressions.

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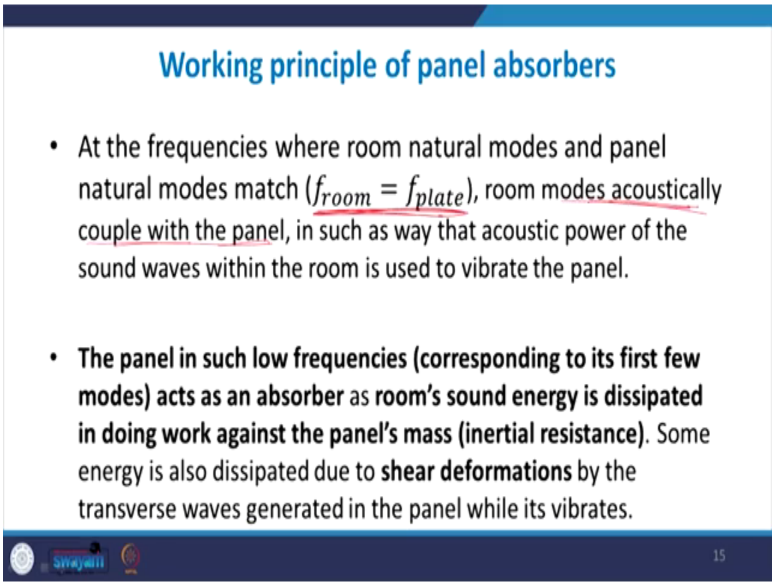

So, how does this panel absorber work. So, whenever we have placed the panel inside some room or any closed area and some sound is generated within that room. Then now we know that the room itself has it is natural frequencies and therefore, these sound waves will be the sound the SPL will be the highest at these natural frequencies because that is where the resonance will take place and a heavy amount of vibration the particles will oscillate with almost infinite amplitude.

So, the SPL within a room can exist only within it is natural modes. So, if I show it here this is a particular example I am giving it here. This was the SPL measured for a particular room. So, as you can see overall the decibel levels remain very slow and then they suddenly jump whenever a mode of the room comes.

So, whenever they jump whenever we have like f1, f2, f3. So, they jump whenever it matches with the natural frequency of the room. So, if we can mitigate the noise just add these particular natural frequencies. So, overall noise can be reduced to a much larger extent because the remaining is very very low the maximum magnitude is only at concentrated at some particular frequencies.

So, if we know some we already know these are the predator these are the frequencies at which the maximum acoustic intensity is present then we can selectively cut these cut the noise at these particular frequencies and that is what this panel absorber can do. So, how does it act we can design a panel absorber and we know that the natural frequency of a panel absorber is given by these expressions.

So, we can select the value of sigma and d such that the natural frequency of the panel absorber matches with the natural frequency of the room because that is the frequencies where we desire the noise control because all the sound is contained within that frequency. So, in that case so whenever this happens a panel is designed and the natural frequency of room matches with the plate which means that the sound waves that are coming in at that frequency they couple acoustically with the plate. So, this is called as acoustic coupling.

So, acoustic coupling takes place. So, in this situation what happens is that the sound wave that was generated in the room is now being used to vibrate this panel because the panel vibration frequency is the same as the frequency of the incident sound wave. So, the sound wave is now trying to vibrate the panel and therefore, the sound wave is now doing work in vibrating the panel. So, most of the sound energy gets lost in doing work against this panel.

So, this is the main principle of dissipation that is followed by a panel resonator. So, as you can see is that in a panel resonator we can design them to have particular natural frequencies. So, whenever a target sound at the same frequencies incident then it will lead to large amplitude vibrations or in this case and the sound waves that are being incident on the panel will affect.

So, what happens there is actively now doing work to move the panel to end flow and they are doing and at resonance they do more work because at resonance the panel vibrates more. There is a strong acoustic coupling and all of the sound power that is being incident is now being used to drive the panels to and froth.

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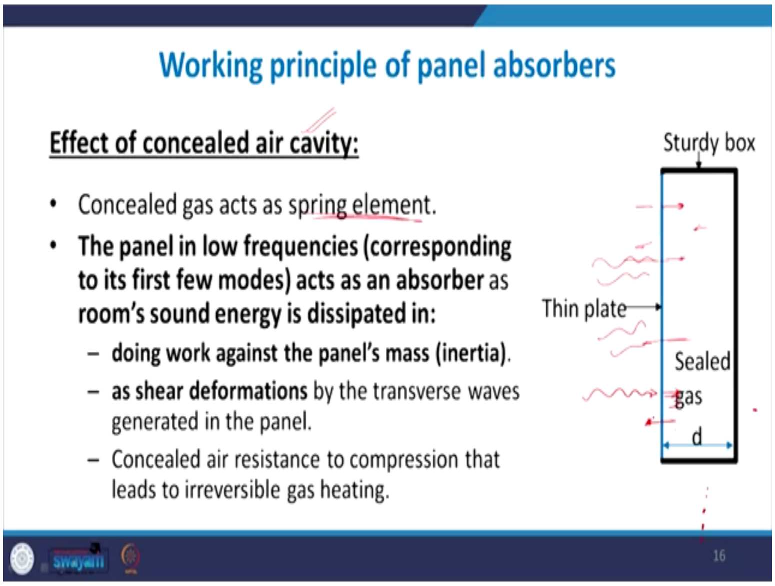

So, overall what happens these become good absorbers at their natural frequencies. And what is the effect of a concealed air cavity. The concealed air cavity is simply acting as a spring element here which means that it is acting as a restoring force. So, when the sound waves they are incident on the panel, the panel starts to vibrate at it is natural frequency and the lot of work is being done to vibrate it and the sound energy is getting lost. So, as it vibrates to and flow it tries to compress this sealed air and expand the sealed air.

So, because of the resistance to compression the expansion they mainly act as a restoring element. So, suppose this panel is being pushed this side let us say the sound energy is incident here and the panel is being pushed to this side then it will compress the air, but the air does not want to remain compressed because it is resisting the compression. So, it will push the panel on the other way around.

So, the panel will get pushed. So, it will become a to and froth motion, enhance the panel gets pushed the air will expand and again it will try to bring it back to compress it and bring it to equilibrium position. So, this is more like a restoring force to make sure that the oxidations of the panel continue.

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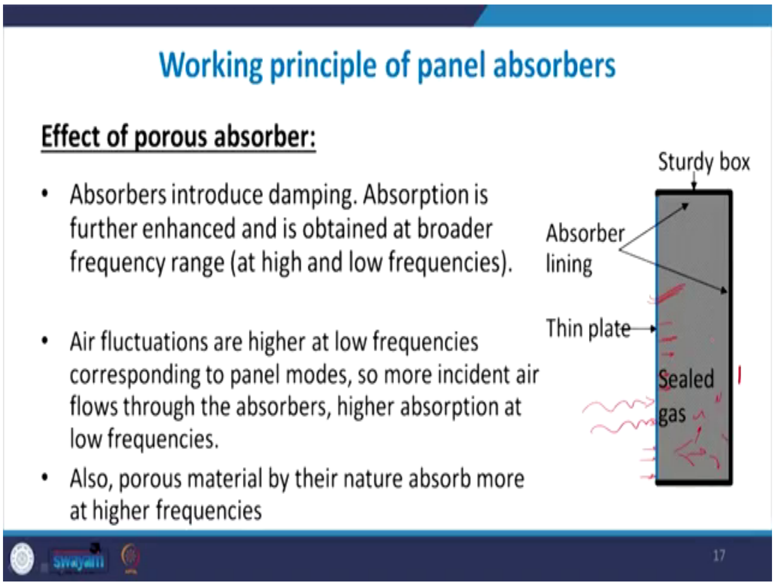

So, that is what happens. Now, if we fill this panel with the absorber material then what we are doing here is that sound wave is being incident on the panel. The panel starts to vibrate to and froth and as the panel is vibrating the air within the. So, we know that this was a medium which had some air and then the porous medium was put inside. So, this porous medium will also have air inside and as the panel is vibrating it is causing the air and the exposed force to start vibrating with the panel. So, the panel vibration sort of.

So, effectively what happens here is there is layers 2 way acoustic coupling. So, first of all a longitudinal sound wave was vibrating to and froth in the room. This was the noise. It is hits the panel and it does work on the panel to vibrate it to and froth and then the panel itself does work on the air particles of the porous medium and the air particles in the porous medium also vibrate to and froth and as they vibrate to and froth and pass on the sound energy then some energy is also lost due to viscosity and friction as we have studied in the previous case.

So, in a porous medium when the air molecules they start vibrating longitudinally and pass through a porous medium then most of the sound energy gets dissipated because of viscosity, friction as well as due to structural vibrations and also due to other such resistance. So, losses will also happen. So, here in this case some energy will be lost due to doing work against the panel and some energy will lost while the sound waves pass through the porous material.

So, there will be 2 more 2 way losses and we know that this is a typical low frequency absorber. The panel is only a absorber at it is own natural frequency. So, whenever the target incident wave is equal to it is natural frequency then the coupling takes place and work is done to vibrate the panel. But at other frequencies also the porous medium can act as a good absorber. So, it can broaden the absorption characteristic.

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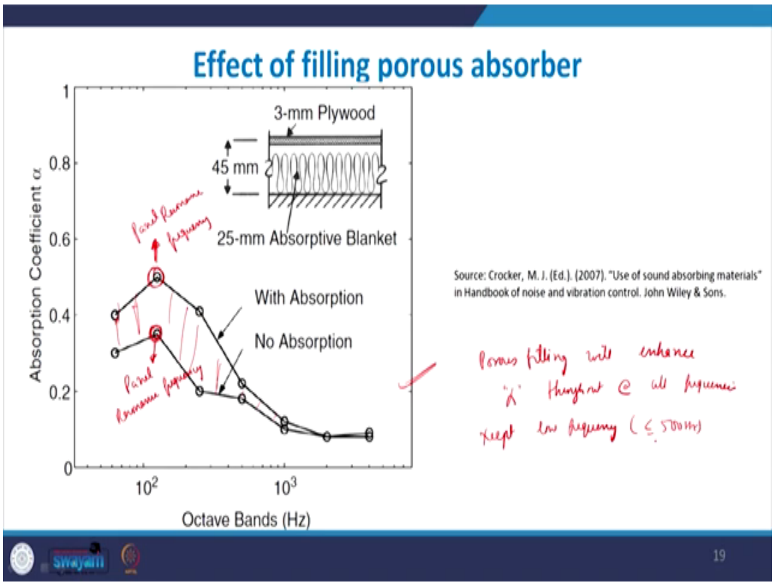

So, this shows this graph shows what is the effect of adding a porous material. So, let us say we had a fixed panel here, no porous material and this is a typical peak. So, this may be this peak corresponds to the panel resonance frequency. So, the frequency at which resonance happens is the frequency at which maximum power will be lost. So, maximum absorption will take place at that frequency and now also the because we are using the same panel. So, we have the same natural frequency approximately same.

So, now also it is happening at it is resonant frequency, but the overall magnitude of absorption has increased because now we have; we have; we have one loss due to doing work in vibrating the panel and the other loss is happening while passing through the material. So, there are 2 way losses enhance the overall absorption enhances throughout. So, this is the effect of adding porous material.

What we get is that porous material porous filling will enhance alpha throughout at all at almost all frequencies except obviously, at low frequencies because at low frequencies very low frequencies less than let us say 500 Hertz porous materials are ineffective, but at higher frequencies in their zone of operation they will just add more to the absorption.

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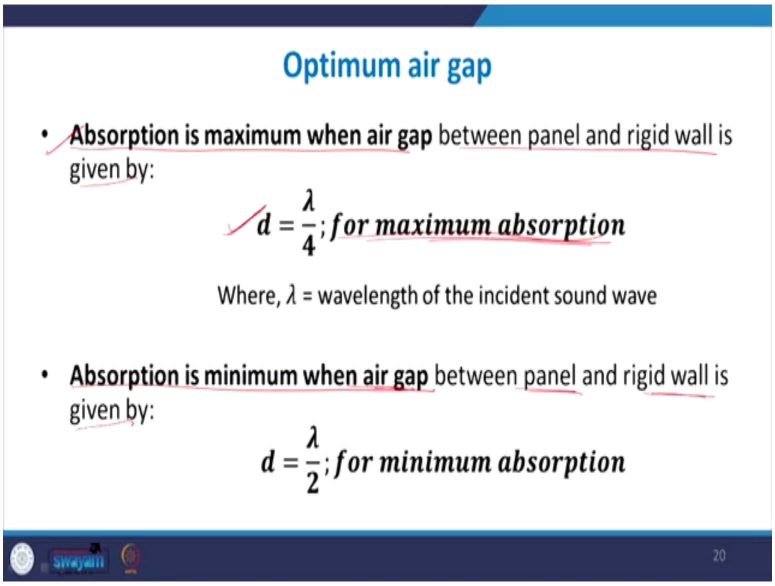

I am giving you 2 statements here. The absorption is maximum when the air gap between the panel and the rigid wall is given by d equals to lambda by 4. So, maximum absorption takes place when the distance between the panel and it is backing is lambda by 4 and the absorption is minimum when the air gap between the panel and the rigid wall is lambda by 2 and this holds true for both a fixed panel and a freely suspended panel. So, the distance between the panel and the wall if it is lambda by 4 maximum absorption and when it is lambda by 2 minimum absorption and the reason for this is that let us see a room here.

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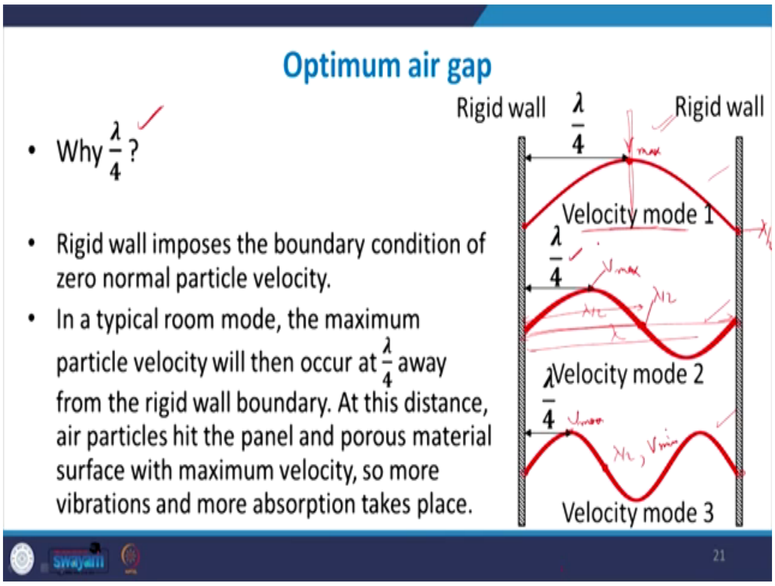

So, let us say we have this room and these are the 2 opposing facing walls of the room. So, whenever the sound wave is being generated in the room, it will follow this sort of pattern because at the rigid wall at the this is the velocity mode. Let us say the these are the velocity modes or this is this shows the function of the velocity. So, the condition of a rigid wall is that the acoustic particle velocity becomes 0 at a rigid wall because it does not allow any further waves to pass through.

So, the particle oscillation suddenly has to stop at a rigid wall. So, v becomes 0 at the rigid wall. So, if you put this condition then the various shapes we can obtain is this. Let us say we either obtain a shape here where this is the minimum this is the minimum, this can be the second mode, this can be third mode and so on.

And at any such modes what you observe is that at a distance of lambda by 4. So, this entire distance is lambda right one full cycle is going to be lambda. So, this distance from here to here is going to be lambda by 2 and this distance is going to be lambda by 4. So, at every such mode at lambda by 4 we get maximum velocity v max.

So, v max is obtained at lambda by 4 and if we know that the if. So, if a panel is placed at this particular distance. So, which means that when the waves are generated in a room then at that distance they will hit the panel with the maximum velocity. So, if the if they are hitting the panel with the maximum velocity then obviously, first of all panel vibrations are going to improve as well as when it and the same velocity is now getting transmitted to the porous material. So, the maximum sound the maximum velocity is at this place.

So, maximum oscillations maximum vibrations and therefore, maximum work will be done in vibrating the panel and the porous material. So, at lambda by 4 we get maximum absorption and by the same logic whenever the distance is lambda by 2. So, this is lambda by 2 in this distance, this is lambda by 2, this distance again is lambda by 2, this distance again is lambda by 2 and so on. So, at lambda by 2 v is going to be minimum. So, minimum velocity is available. So, minimum work is done.

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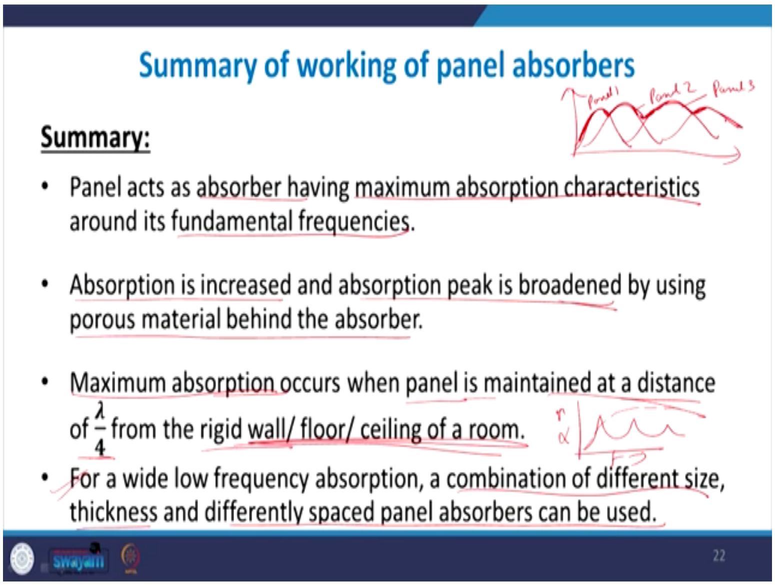

So, to summarize the panel absorbance they act as absorber having a maximum absorption characteristic at its fundamental frequencies and this absorption can be increased and the peak can be broadened if you use some porous material behind the absorber. And the maximum absorption is obtained when the panel is maintained at a distance of lambda by 4 from a rigid wall or a floor or a ceiling whatever and because this panel it has some fixed resonant frequencies.

Therefore, the absorption characteristic is going to be very sharp which means that if this is frequency this is alpha absorption can be like this and so on only happening maximum at it is resonant frequency and then again decreasing sharply. But to obtain a more broad frequency absorption what we can do is that we can then we use a combination of different sizes and thickness of differently spaced absorbers.

So, usually in all the examples that I showed to you where acoustic panels were used you saw that not a single panel was used, but there was a set of our collection of different panels. Why because one panel will only have one fundamental frequency. So, it can only have a peak around one particular frequency, but to get a broader absorption we can have a lot of panels.

So, let us say panel one gives this one. This is due to panel one, this is due to panel 2, this is due to panel 3 and so on. So, overall we can get the overall reduction that we get is this. So, it is more broader and across all the frequency ranges. So, to get a broad absorption we can have some differential and we can have a combination of different panels with different resonant frequencies.

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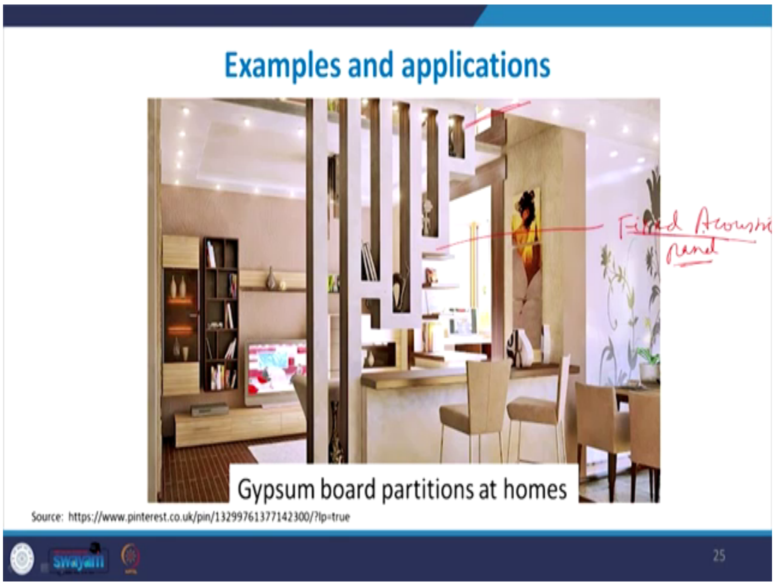

So, to show you some examples here I am going to show you.

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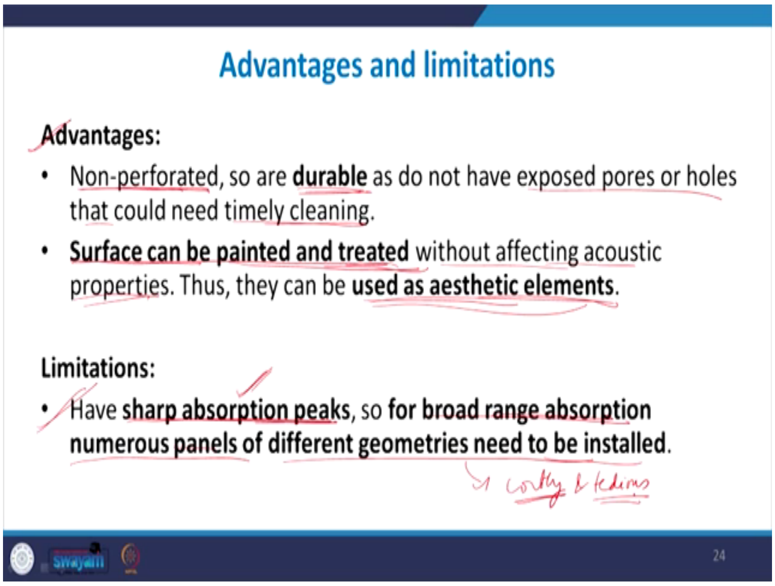

So, before I proceed with some of some further examples the advantages and limitations are given by first of all as we already know they are non-perforated. So, they are more durable they do not have any exposed pores or holes which would need some timely cleaning and maintenance and these panels can therefore, be painted and treated. Because porous medium we cannot paint because it will block the pores and the particular material will become ineffective it will deflect, but this panel here there is no such limitation.

So, here we can paint these surfaces, we can have different shaped surface, we can paint them and treat them whatever we want without affecting its acoustic properties and therefore, they can be very aesthetic and they can be used in a variety of phase in a building to add to its beauty. The limitation however, is that the porous material it gives a more broader way of a broader range of absorption in the high frequencies, but this particular panel it will only give you absorption around its fundamental frequency. So, it will be very sharp.

Broad range is possible only when we have a numerous panels of different geometries which will become very costly. So, broad range absorption can become costly and tedious. So, with these advantages and limitations let us see a few more examples. So, here in the house we have a gypsum board.

So, this shown this looks like it is sort of some partition added for the beauty and to separate the 2 sections of the house, but this is a hollow structure and this is actually a fixed acoustic panel. So, inside this what we have is that we have the face is made up of thin sheets of gypsum which act as the panel and then we have rigid backing and then we have a concealed air cavity. So, there also able to reduce noise within this room.

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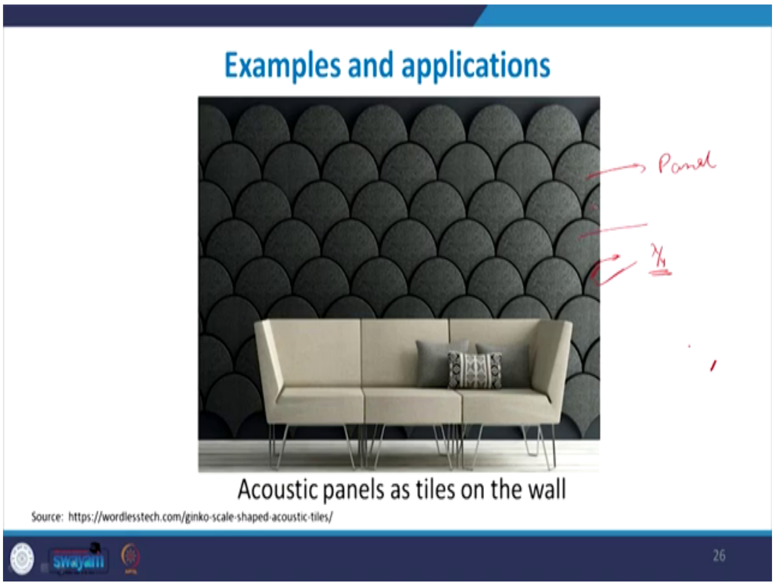

Similarly, in this room also you can see they can be easily integrated with the room aesthetics. So, all of these are panels that are fixed to the room and if you and usually what happens the designer can design. Suppose we have some particular area where we know what is the frequency that we have to in control. What frequency noise we have to control then the distance between this panel and the backing can be adjusted to be lambda by 4 to get the maximum absorption at that frequency. So, all of these are individual panels.

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Similarly, we have these panels hanging around in the office like that and the cubicles.

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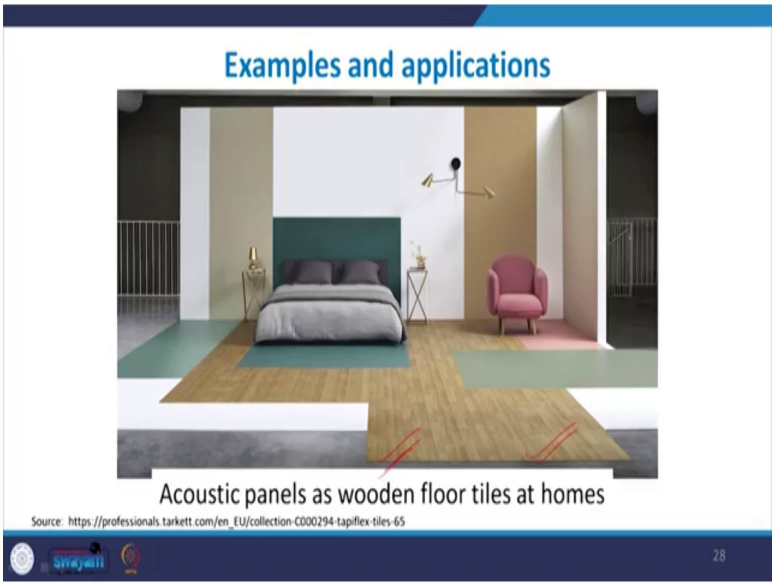

So, it can be used in a lot of forms. It can also be used as wooden floors or tiles at the homes. So, these are the various examples for it can be used. So, today we studied about panel resonators these are resonators that offer very selective absorption and their fundamental frequencies and a combination of them can be used to get some broad absorption and they are very aesthetically pleasing. So, they can be used in a lot of applications indoors. So, with this I would like to conclude my lecture.

Thank you.