Architectural Acoustics
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Lecture – 34
Structure Borne Sound Transmission

Welcome to the NPTEL certification course on Architectural Acoustics. Today we are in the seventh week and this lecture number is 34. This is the fourth lecture on the seventh week of this program of Architectural Acoustics. And today will discuss about the structure borne sound transmission in general. This as you remember in the lecture number 31, 32 and 33 or on a borne sound, 34 and 35 is on the it will be on the topic of this to a will be on the 34 and the 35 is structured-borne sound.

So, the learning objectives are the.

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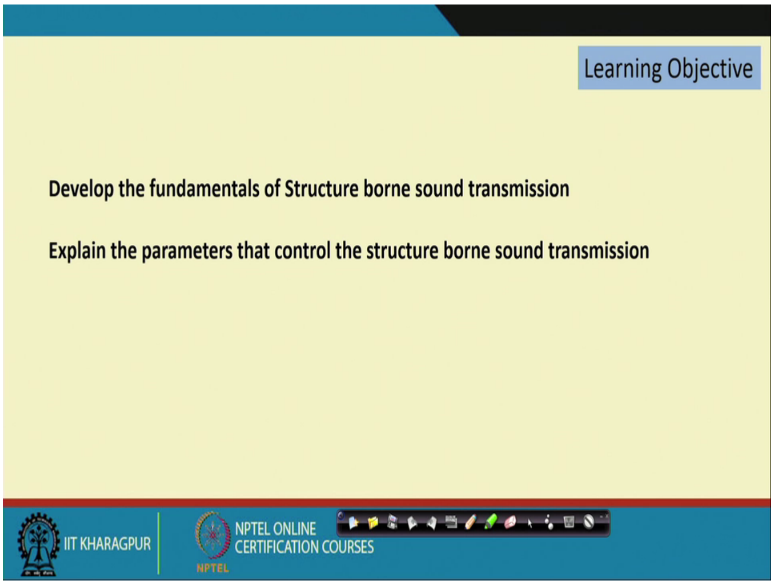

We will develop a kind of the fundamental understanding of the structure-borne sound, transmission of the structure-borne sound, and also will going to explain what are the different parameters that actually influence the structure borne sound transmission.

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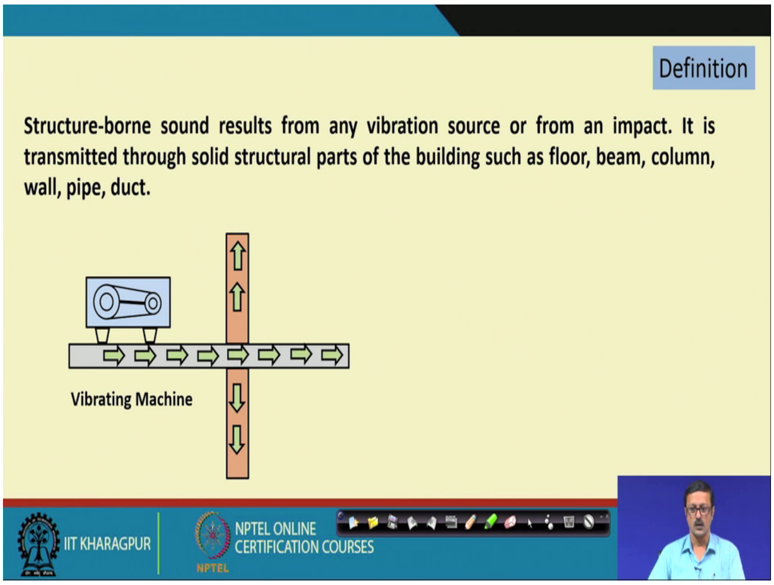

The structure-borne sound by definition is as we already discussed in lecture 31 is a there are two way a sound propagate from one place to another; one through the air which is the borne sound transmission and for that we need to develop some kind of a transmission loss. Suppose from source room to the receiver room, some sound is propagating.

So, the transmission loss of the in between partition wall is one of the important criteria where as for the structure sound of propagating through various due to some kind of the vibration of some kind of various impact. And that will actually propagate through some of the structural members and the some of the structural member which is embedded into a building system. Those structural members are suppose the floor, suppose a beam, column or maybe a slam or maybe a some kinds of metallic pipelines, some duct all those.

So, we will try to see the what are the ways it is propagate and how we can control this particular vibration and that is a mechanical vibration of course, but this mechanical vibration propagates the sound from one place to another, and from your basic physics, you must know that the velocity of the sound in solid is much faster with compared to the air. So, that is another issue.

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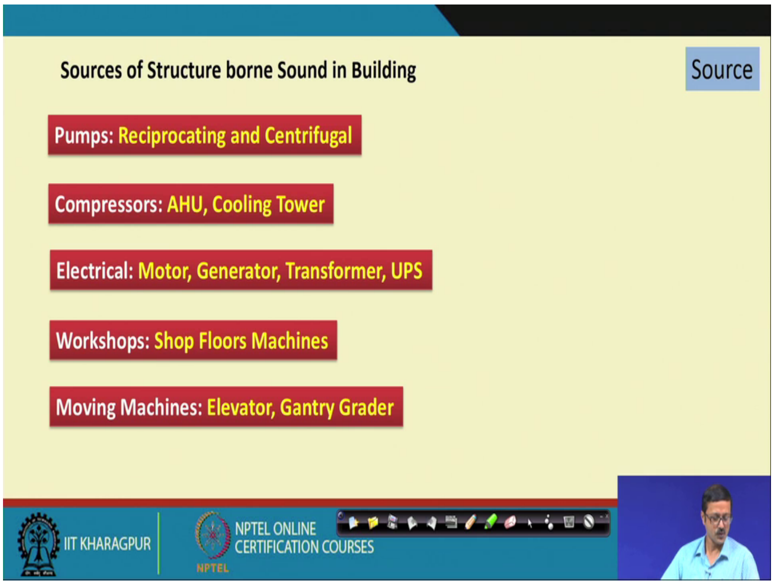

So, what are the different source of the structure borne sound in a building?

Let us see one after another; the first one is some kind of a pump, pump is a integral part of any the building or maybe a building complex ,it may be some kind of a reciprocating pump or centrifugal pump. There are compressors for the cooling towers or for the air handling units for air conditioning system, there are electrical motors and generators or another part of a particular building or par particular site where there are group of buildings. Yes, there are workshops are there also a part of industrial building or maybe some kind of the institutional building the workshop is one of the common criteria the space criteria. And then there are some kind of machines and the shop machines and also so that also create some kind of a vibration or some kind of structural borne sound, and moving machines like elevated gantry graders also are the sum of the sources of the structural-borne sound.

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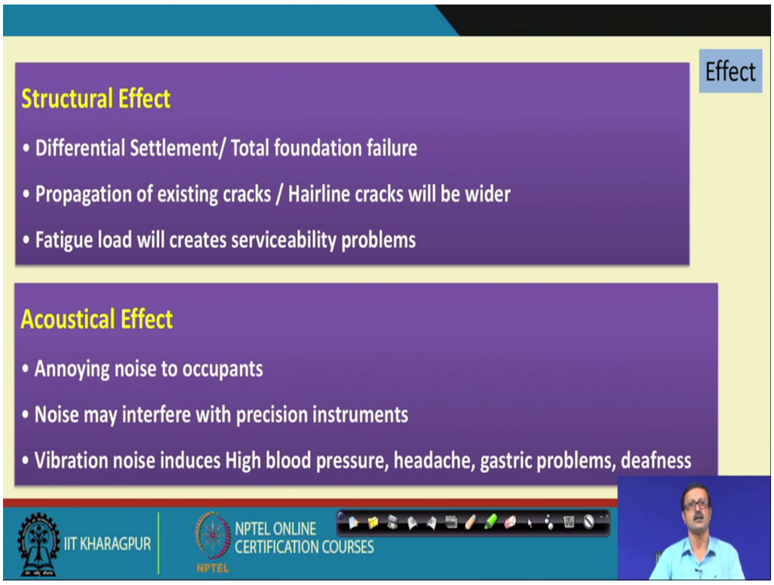

Now, what are the effect of the structure borne sound also. I have to categorize the structure borne sound are this is vibration effect into two the broad category. One is the structural effect which is actually because of some kind of differential settlement may occur, because of the vibration there may be some kind of a crack which is existing in a building, because of the vibration this crack will be initially maybe hairline crack that may be wider or maybe that maybe elongated or there are some kind of a fatigue load.

Fatigue load is something like a reversible kind of a load applied in a particular structural member that create some kind of a serviceability problem. But we are interested to know about the acoustical effect of the structural borne sound which is actually a kind of a annoying kind of a noise in a occupant, because the structure borne sound vibration has a typical frequency band and that is sometime is very boring in that sense and it is create a some kind of a the negative sensation in human brain.

So, that has to be stop, that has to be actually eliminated from the from the source room to the receivers area. The noise may be interfere with some kind of a precision instrument or so. Suppose there are some kind of the instrument in a hitech laboratory where a particular measurement is taken for some kind of in the nano or there could atomic range measurements or so.

So, those kind of structure borne vibration or noise may hamper that particular reading also. There may be some error involving in that particular the output in from that particular instrument. Structure borne noise also individual lot of the physical problem like headache, some kind of the high blood pressure and the deafness and all those kind of a thing; so this is one of the area which generally people ignore, but lead to be address properly by an architect.

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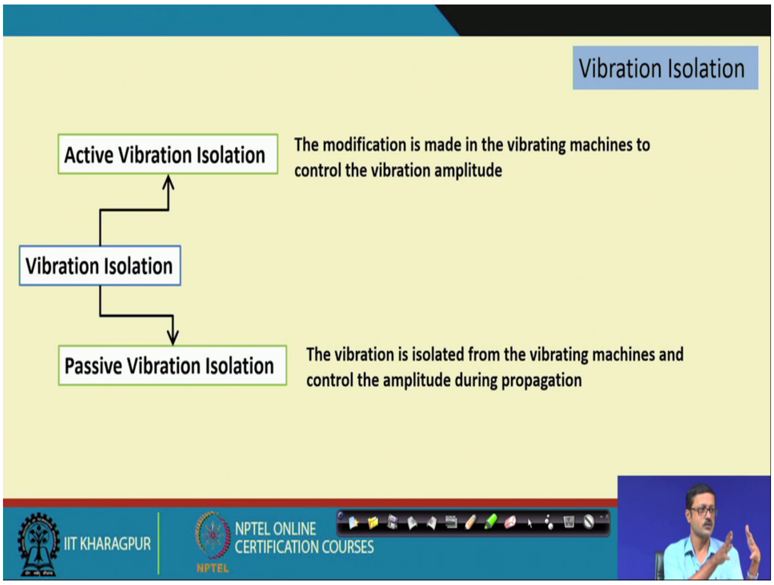

So, as I understand are as probably, you also understand in this particular structure borne sound regarding that area, it is actually the initiated due to some kind of vibration of a mechanical vibration of a machine. So, this vibration has to be isolated and there are different techniques and if those techniques is group together and again try to classify those to techniques, there are two such classification.

The first classification it is called the active vibration isolation. In active vibration isolation architects may not have a role to play it has kind of a area which a mechanical engineer or may be the electrical or electronics engineer may have a much more the role to play over there. What is that? That is nothing but the modification has to made in the vibration control by virtue of some kind of a amplitude modification, vibration amplitude modification.

So, as you know, the amplitude is if it is a high amplitude is having a the power of the emission is much more. So, we if we can modify that if we can reduce that particular modify the amplitude, then probably the vibration, the effect of the vibration will be less. So, the control of the machine, the effective utilization of the some of the component of the machines or the new technology, new development all those are involved in active vibration isolation. So, it is all about the machine itself, it all about the integral part and the design of the machineries also. So, the architect does not have any role in that part. The second one which is a passive vibration isolation yes we have a much to play in, have a much bigger role to play in that the vibration is isolated from the vibration machine du I mean during the propagation stage.

So, a architect in definitely not going to touch the machines and the machine at a part, but he has to actually think about how this particular propagation, will minimize from source room to the receiving room by virtue of some changes in the building configuration, some structural configuration of the buildings and all other.

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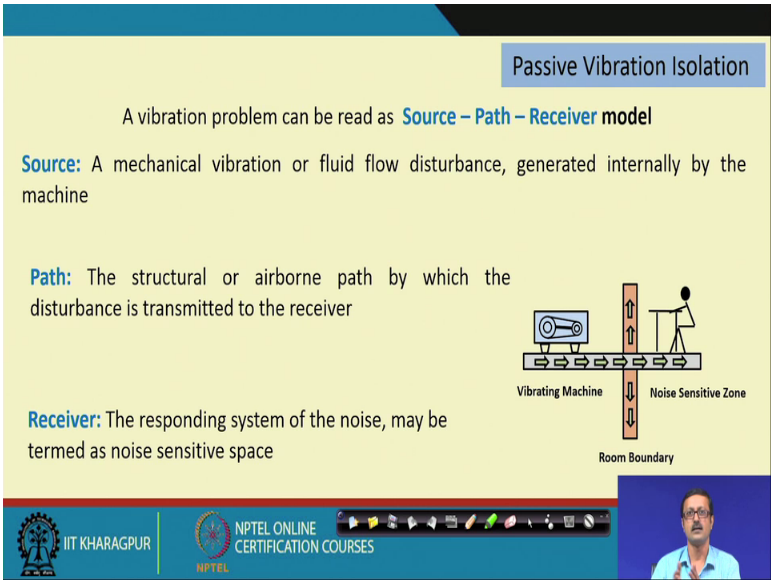

So, here let us see what are the different way us see find out from the vibration pro identify the problem of this propagation and the passive isolation. So, here we have a path system where a source is there and a receiver is there, in between the source and receiver there is a path. So, these three areas we can actually touch and actually control. So, the first one is a source. The mechanical vibration of source of the this the structural vibration is by a mechanical vibration or any kind of a fluid flow disturbance that may generate in the machines or maybe generate in the some part of the machines and while it is propagating.

Suppose if you take a pipeline, suppose you take a building pipeline that the water is flowing or the waste water is flowing, that vibration or that kind of the structure borne noise is because of the disturbance in the fluid flow. If there is a laminar flow, the it will be much less the much less amount of vibrational produced and your control will be much easier where as if there is a turbulence in this particular path of the fluid, the amount of vibration also will be high and your amount of afford to control the vibration is also going to be heavy.

So, that is one. And fluid flow may not be always going to be the fluid flow like the water are many any kind of fluid it may be the airflow also, sometimes in the building is central air conditioned and from that point of view the air the cooled air or the return air comes from through the ducks and also there also some kind sometimes disturbance and there is a fluctuations of the pressure that by deals and all those. And the disturbance and this kind of the laminarity of the flow is an all will create lot of vibration problem.

Next is the Path. Path is the structural borne sound or maybe airborne sound has a kind of a path it. Sometimes it is through the structure and sometimes it is through the structure plus the air. So, it this path has to be taken into account. So, how it will actually moving from the source to the receiver; and finally, it is a response system where a particular measure area or a designated the noise the sensitive zone is mark and I am going to isolate that particular receiver area from the source of or the path of the particular vibration.

So, the there are some solutions has been the short it or solutions has been the thought of.

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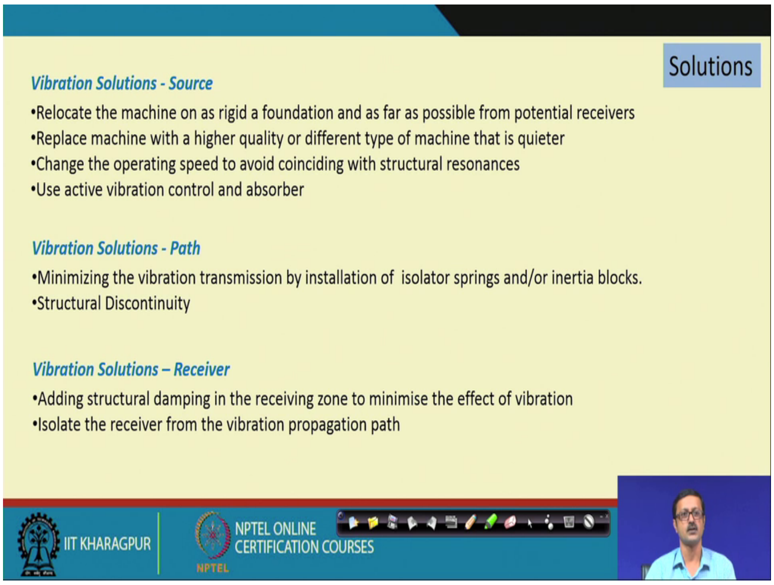

The first kind of solutions are the relocation of the machines and the foundation system in a rigid kind of a the system is can be thought of control over the vibration. There are replacement of the machines of the part of the machines that is another issue. This is all about the source, source is that the has to taken into the consideration because that if you minimize the vibration from the source, your it is a great duty great job, I mean in that way itis a kind of a the reduced propagation of the structure borne sound in a great way. Sometimes we can change the operating frequency of the machines or sometimes we can change the natural frequency of the machines also to reduce the impact of the vibration or the propagation of the structure borne sound.

Next is, we can have some kind of a solution from vibration solution from the path. So, we can actually think of some kind of a system where the spring and some kind of inertia block is placed on the machines. So, while it is vibrating, it may vibrate the source may vibrate it is own, but while it is going to I mean taking a path through some kind of a the structural element in a building. So, it will initial it will be taken kind of some kind of a filter of, so with that particular spring or some kind of a inertia block. So, there are some kind of mechanism happen and because of that particular mechanism, there will be some amount of energy is actually absorbed. We can also think of some kind of a discontinuity in the structural member too just stop the propagation of the sound in the path

The finally, the receiver; so, adding some kind of a damping in the receiving zone is always going to be a beneficial, it is always going to be a minimize the effect of vibration we can isolate the receiver from the propagation path with a some kind of the making some kind of a special arrangement where it can actually not entertain any kind of a outside vibrations or so. So, we will go in one by one, and all the details.

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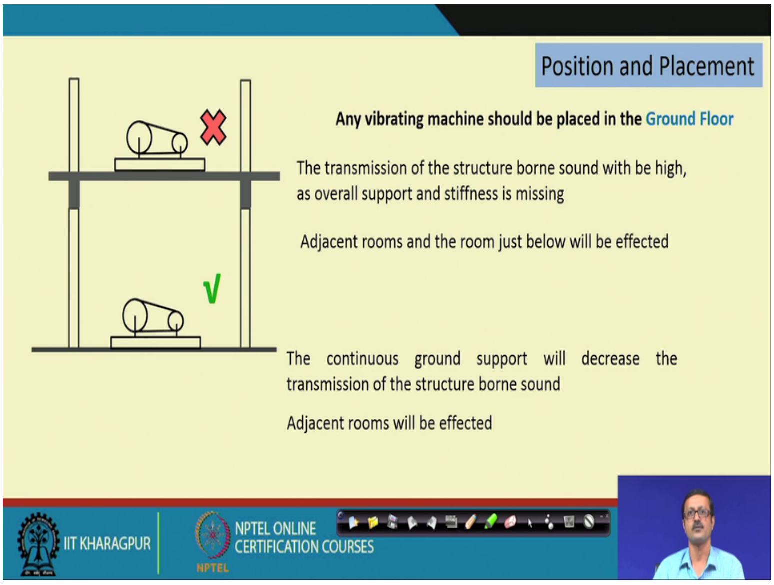

The first one as I told that the source has to be taken very carefully. So, the position and the placement of the source is very very important. Any vibrating machine should be placed in the ground floor that is one of the important criteria, but why? Suppose a machine is vibrating machine is in the top floor or the not in the ground floor, when because of the placement and you know the this, because of the placement of the machine in the first floor or may be the some other floor, it is actually rules some kind of a the stiffness, because if it is in the ground, then it has a wide verity of the suppose system. Because the ground below the ground floor there are the there are some soil or the there are some kind of a solid base and continuity in the base is available which add a kind of a stifling to this particular ground floor.

So, automatically the vibration will be stopped or vibration will not going to be propagate from that particular machine to the other component. Of course, which will propagate, but not in a form that it actually the way propagate in the upper floors or so.

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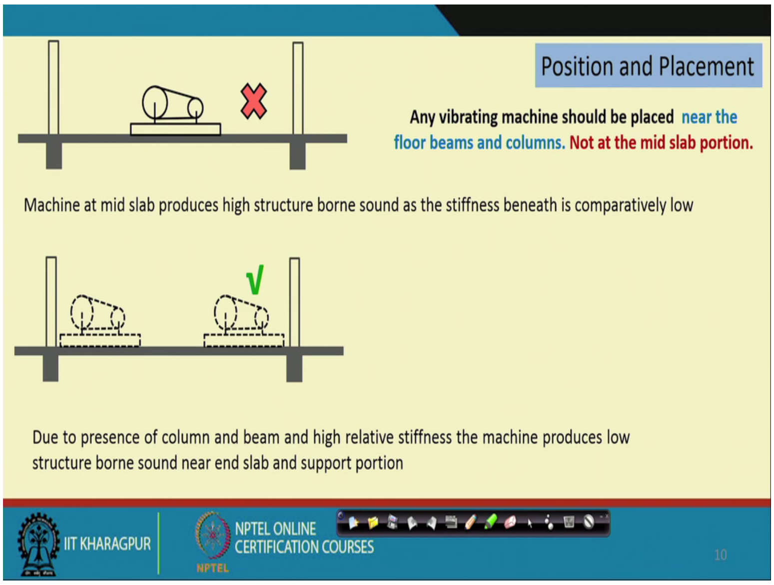

The next one is that the vibrating machine should not be placed in the center of the slab, I mean if at all you want to place it in a in a in a upper floors because many times we cannot aware that particular vibrating machine to be suppose a choose or each and every floor you have to give some kind a choose and which is have been some kind of a pump or some kind of a the diffuser.

So, those has to be in the different floor, but if it is also placed in the upper floors, you should not be exactly in the central span of the slab because the central span of the slab is having less stiffness. It should be either the where corner, where there is a beam or maybe another corner where there is a beam or columns are available beam surrounded by surrounded least the two side or at least one side, because of this beam column association in a particular area. And if you place the vibrating machine need to that, the added stiffness made by this beam and column will give you some kind of the reduction in the propagation of the vibration.

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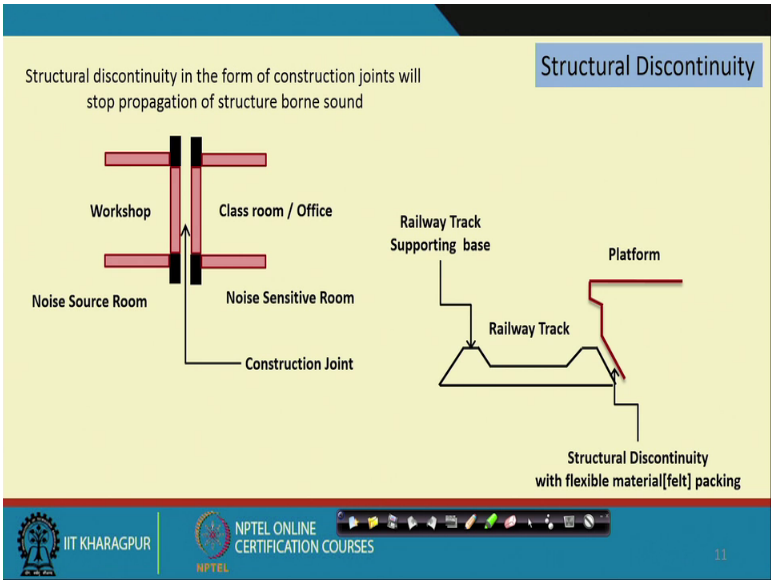

So, next is the structural discontinuity. This is one of the easiest way to control about the vibration propagation, the structural discontinuity suppose there is a workshop and there is a classroom or may be some kind of office, it is a very common the space arrangement in anys the college or may be an engineering college or so. There is a workshop and there is a classroom or maybe some kind of the noise sensitive area, we can provide a structural discontinuity in a form of construction or expansion joint. And definitely the noise will not vibration noise will not going to propagate because there is a discontinuity also. We can do it in this particularly in the railway track and the platform maybe in the metro railway or may be any kind of the urban areas where there is a railway track and a particular the platform and associated with that, there are some office buildings and some kind of a the noise sensitive zones are there.

So, we can introduced a gap over there, structural discontinuity and we can actually field is structural discontinuity some kind of a flexible material packing like the felt or the us felt are those kind of a here maybe the rubber or may be the cork sheet those kind of a material through in this gap. So, structural discontinuity is also going to help us to minimize the propagation of the sound.

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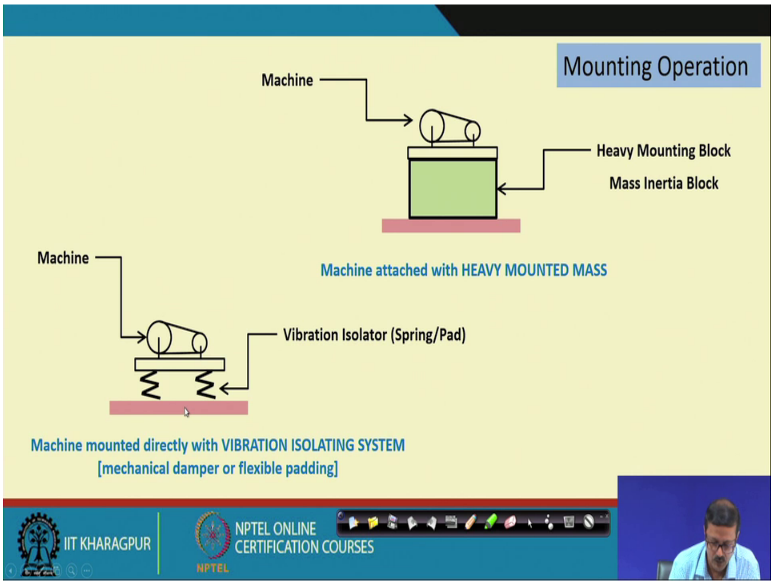

The next one is the mounting operation, this mounting operation is also wonderful because this mounting operation is almost essential to take into stop the; or the to reduce the vibration isolation, to reduce the vibration propagation as such. What happened is that, a machine is actually placed over inertia block or heavy mount block by concrete or maybe the brick machinery and this heavy mount will be after that. And if you just put it in some kind a anchor bolt and all the rigid rigidly fixed with this particular inertia block, this inertia block plus this machine will now act as a unit system, has a integral system and vibration of that particular machine will be reduce down.

So, the sometimes, we can also provide some kind of a spring the steel spring or some kind of a the steel pads or metallic pads, metallic strips or flexible pads kind of thing below the machines. So, which will again going to arrest, which will again going to observe some amount of vibration and the propagation through this red colour slab will be minimize.

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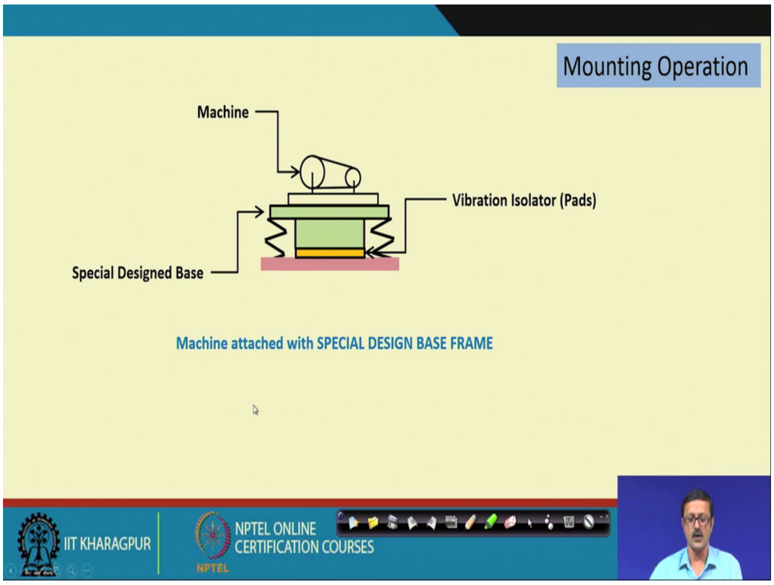

We can also go for a some special design base spring where a mounting base a concrete mounting base this green colour, also this top green colour is the mounting base and this is the some kind of the flexible padding and also a kind of a side springs are also I design carefully with some kind of the from the vibe vibration equations and all and it will definitely going to minimize the propagation of the sound, vibration sound or the structure borne sound. So, those are your mounting operations this types there are various types and these are very much adopted in practice.

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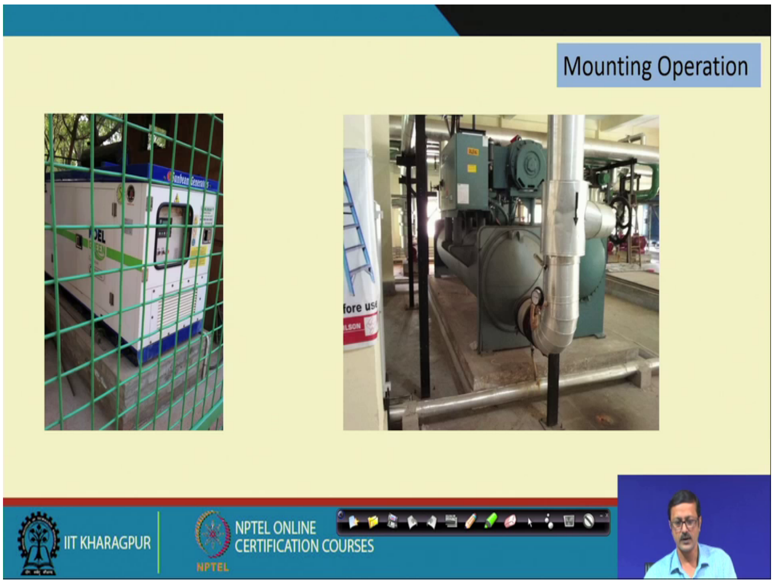

Now, I have two photograph taken from our IIT Kharagpur campus where one diesel said this is a diesel generators. It is on a inertia block say this is inertia block which will also help in other way around, it will also leaf this particular machine. So, working on the machine will be easier and also it will sometimes the area may be flooded because of the rainwater also.

So, those are the associated the advantage but basically this is another machines machine which is a air condition central air conditioning system machine which is placed again in a classroom complex near to our IIT in our, IIT campus, Kharagpur campus where you see there are this inertia block is having two split; you see there is a black line that is two split. So, the inertia block is a two, is spitted into two part the top and bottom and the central area sand which a part sandwich area is filled with a felt or the co cork sheet layer. So, this is a kind of another arrangement where the mounting or the inertia arrangement with some kind of special criteria is taken care of.

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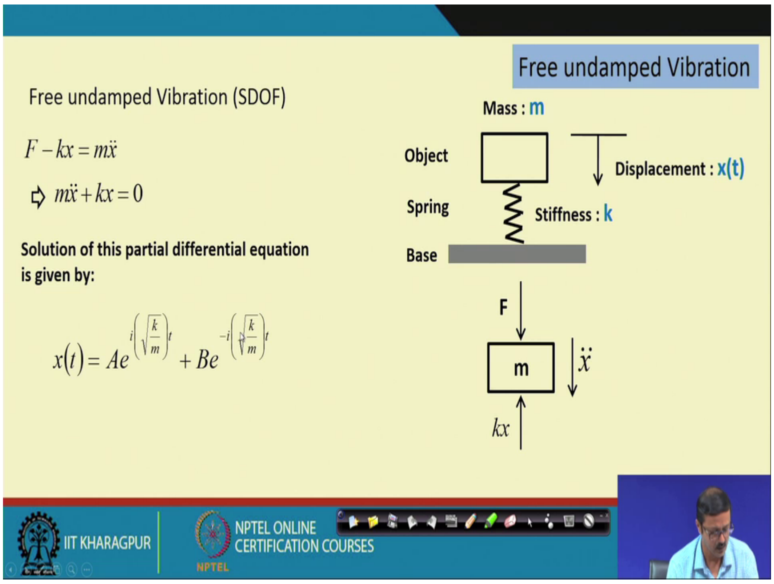

Now, let us see some kind of a fundamentals from and applications and mathematical applications of this the vibration and the vibration isolation. So, as you know as you know from you are basic physics is that a mass a vibration is a basically problem of a mass and stiffness. And a mass of suppose object is having a mass m and this is having a kind of a stiffness of k and then if there is a kind of a force applied on this particular mass, then we can see that there is a rebound or there is a kind of a the resisting force from the spring which is k into x k is the stiffness of the system which is measured in Newton me, Newton per meter also and k x is that is placement. So, if you just multiply k into x that is a again in force Newton and which will be actually this force will create some kind of a vibration, vibration mean there is a acceleration it is a time bound accelerations or the displacement also and this is a sinuso I mean the SHM, that is the simple harmonic motions kind of a thing.

So, the force in the body will be m into d d x 2 d t 2. So, that is the acceleration. So, the d x 2 d t 2 that is your the double differentiation of x with respect to t is also noti also written as the x double dot. So, I can use this particular equation fundamental equation as this f minus k x is must be equal to this force of force that exacted in for this mass m is into a acceleration. And finally, we can find we can use this particular rearrange this your equation like this and this is a the second order differential equation. In the second order differential equation is a solution of in this form can have a exponential form and this in exponential form, there is a imaginary roots also the minus 1 under root. So, and from that

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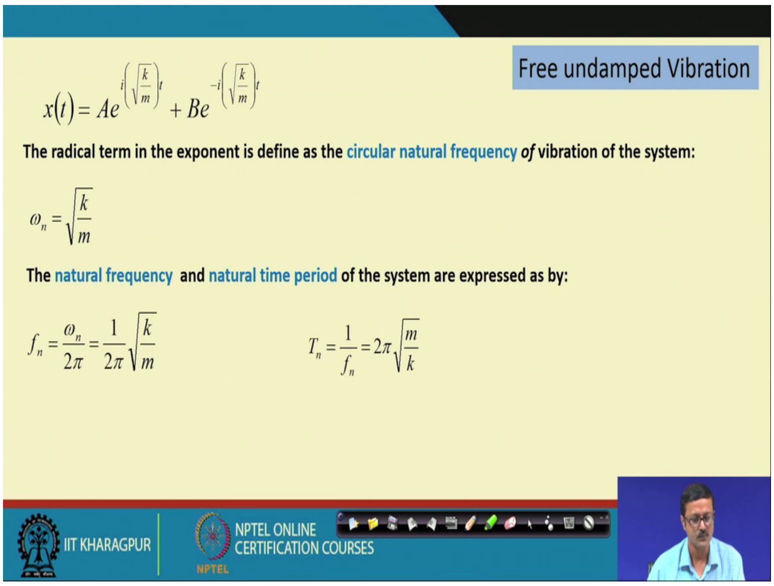

We can find out there is r radical which is under root k by m is nothing but the circular the natural frequency of this particular vibration vibrating system. And definitely it will be a circular natural frequency is there because this particular vibration motion of the vibration is the sinusoidal kind of thing or is a kind of a the simple harmonic kind of thing.

So, if I can understand that how this particular k by m comes from this radical terms and exponent, I can now write down the natural frequency of the machine that is natural frequency is denoted by f suffix n which is omega n which is the circular frequency, natural circular frequency by 2 pi and. So, finally, this f n is equal to 1 upon 2 pi under root k by m. Please remember this k has to be the stiffness of this system which can be expressed in Newton meter and m is the mass of the system express must be n k g.

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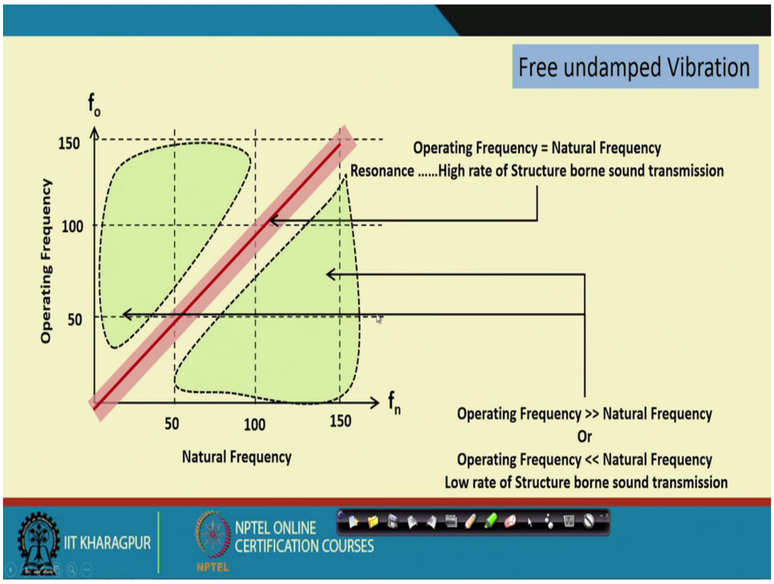

So, here I have found out a particular f n in the x axis or I have plotted they f in they x axis and the operative frequency f o in the y axis. So, what happened is that, suppose a particular machine has it is own mass and it is have it is own elasticity criteria and from that elasticity criteria is having a kind of a k. So, if is k and this m is fixed for a particular machine, it is natural frequency is fixed.

Now what is operating frequency? When you switch a electrical cable and electricity passes through and it starts the machine. So, this machine will vibrate because of the par particular operation and this operations will give you those kind of operating frequency and this if the operating frequency and the natural frequency match to matches with each other a resonance will create and what is resonance it is amplitude will be high it will am suddenly it will be the amplitude will be high and due to that this resonance affect, the vibration and the noise propagation also will be more.

So, that is why I have drawn a 45 degree line and this red zone and red line is 45 degree where the f o and f n matches together and this red zone is the zone where the operating frequency is almost likely matches to the natural frequency, resources created high rate of structure borne sound transmission will occur.

So, our idea will be we have to actually see our operating frequency and the natural frequency combination should common this green zone; either below or may be above. So, then this resonance will not going to above or not going to occur this operating operation operating frequency and the natural frequency, this is high or low will low let us structure borne sound will be transmitted.

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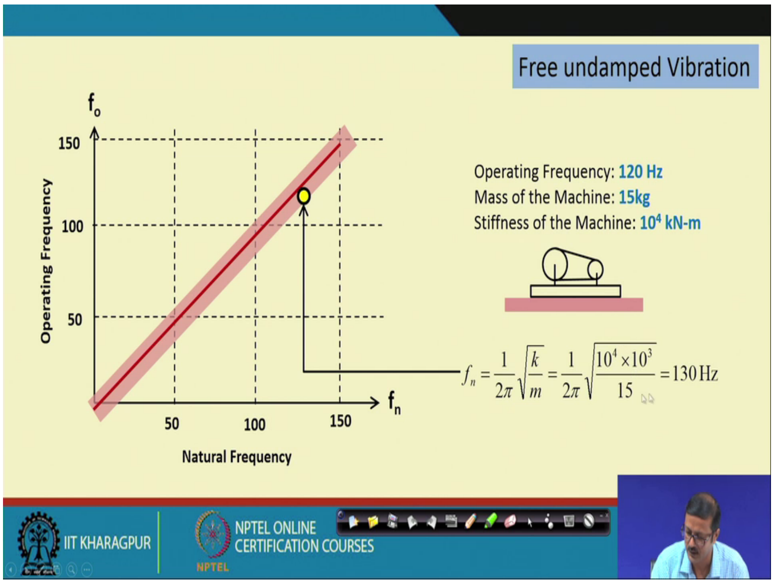

So, here what I did is that, suppose the operation frequency of a frequency is 120 Hertz and the mass of the machine is this much 15 kg and stiffness is 10 to the power 4 kilo Newton meter. So, I can use this fundamental equations for the natural frequency, 1 upon 2 pi 10 to the power 4 into 10 to the power 3, because I have to change is kilo Newton meter by 15. So, 130 Hertz is the frequency that is your natural frequency and operating frequency is 120 when it is actually going to operate. So, this is very close by this is in the red zone.

So, I need to translate or need to transfer.

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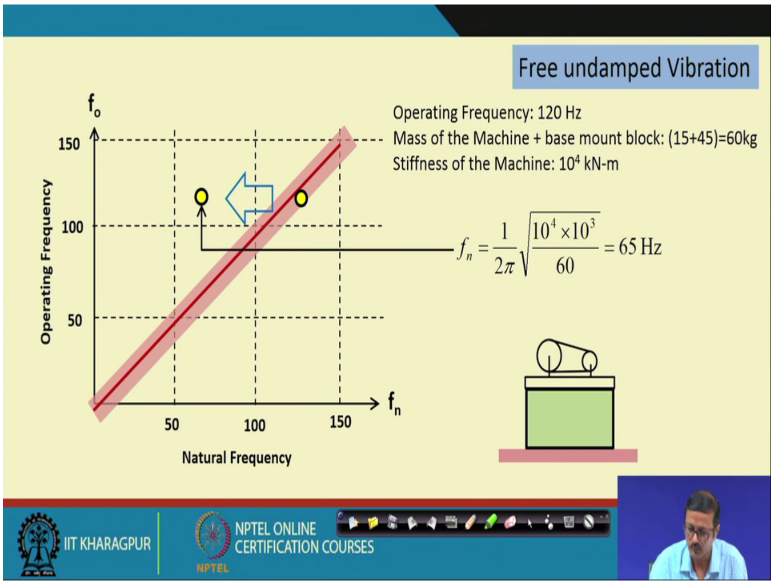

So, what I did is that I change the mass which was actually 15 here, the mass of the machine and which is rested on the slab itself. Now I put a the heavy mount system and the mass is now suppose 60 kg and if it is 60 kg and the stiffness remains unchanged this f m that is the natural frequency become 65 Hertz and now the this 130 Hertz from here, it is move to the 65 Hertz and the operating frequency remain unchanged 120 and this is your 65.

So, the point shifted over here. Why this point shifted over here because additional load of 45 k g I have attached with the particular machine by virtue of the mounting the mounting inertia block and I will reduce the reduce the natural frequency and natural frequency in operating frequency is not matching with each other.

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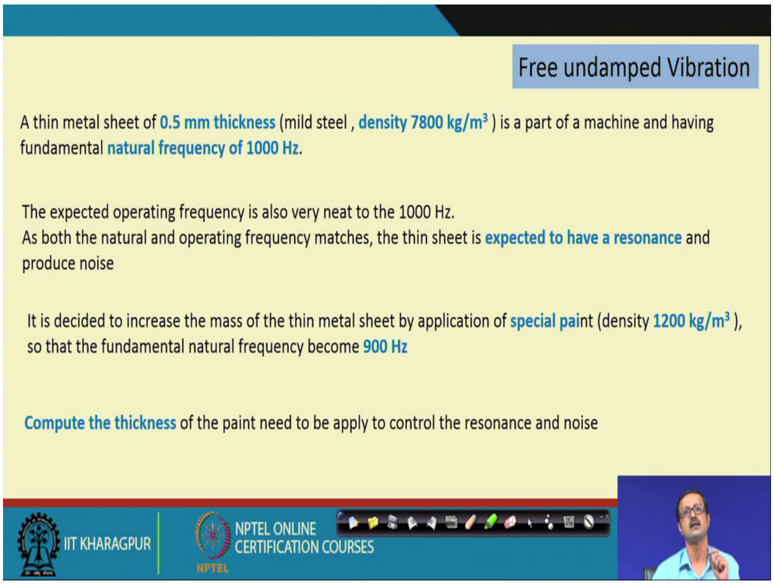

The next is what I want to do is that a thin the metal sheet of 0.5 mm thickness and the density of that is 7800 kg per meter square is a part of a machine and it is having a natural frequency of 1000 hertz ok. This is a part of the machine of a particular metal sheet which is vibrating. Now this it is expected to it is the natural frequency the operating frequency is also very near by the hund 1000 hertz or so. So, and it definitely create a noise. So, what I want to do I have to increase the mass of this metal plate by virtue of some kind of a paint over it ok.

So, I will going to apply some kind of a paint whose density is 120 zero kg per meter cube and I want to find I mean I want to change the natural frequency from 1000 kilo Hertz to 900 Hertz and operating frequency remain such 1000 Hertz. So, I will be the vibration of this particular metal sheet which is sometimes you know vibrating some fan, blade or sometimes some kind of a diffuser blade of a ac systems will be minimized, this vibration will be minimize. So, my question is compute the thickness of the paint how much thick paint I will apply to increase the mass and decrease the vibration.

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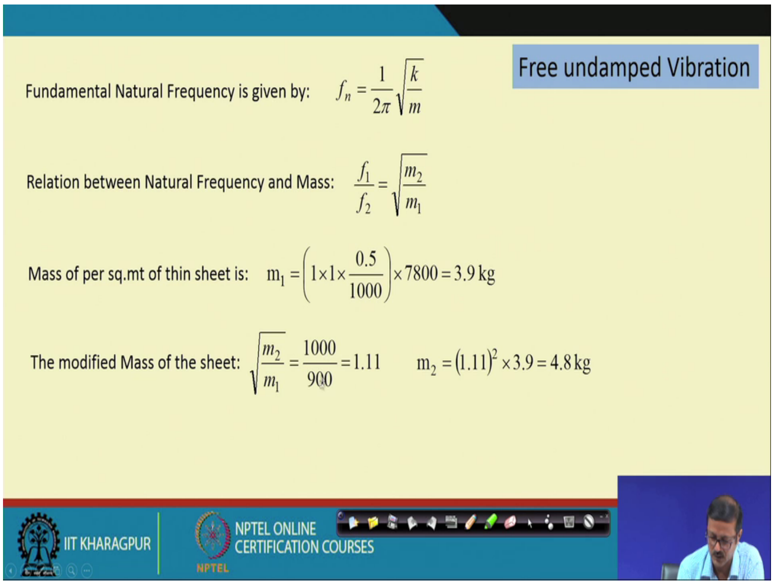

So, from this equation, I can say that the relation between the natural frequency is mass is f 1 by f 2 is equal to m 2 by m 1. Now m 1 is my per square meter mass of the thin sheet which is 1 into 1 is the area 0.5 is the thickness of this particular thin sheet millimeter, 1 by 1000 is this converting this to a meter and so, this is and multiply with the density 3.9 k g is the mass of the sheet. And then, I will use this formula and I one the f 2 as 900, because f 1 with respect to the m 1 is 1000. So, this ratio is 1.22. So, by computing this m 2 that is a new mass of this thin per should be 4.8 and if it is 4.8, it will give me a the natural frequency as 900 Hertz.

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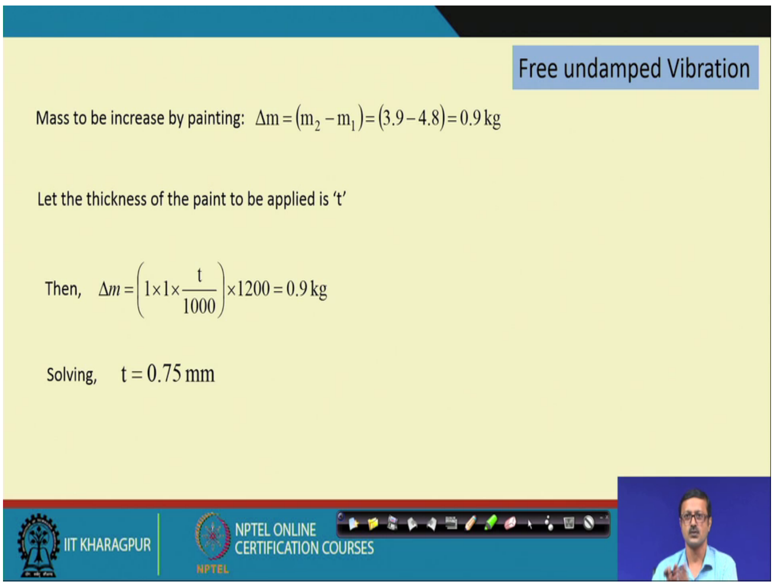

So, I have to increase the mass it mass, actually 3.9, but this has to be 4.8. So, point 9 k g or 900 gram of the mass has to be increases this particular plate. So, how can increase the 0.9 k g of the mass by virtue of some application if some kind of a thick metal paint paints?

So, let us the assume the thickness of the paint is t and the change of mass is 0.9 and again 1 meter by 1 meter and the thickness by 1000 and this is the density of the paint is equal to 900 gram on 0.9 kg. So, if you equate this and solve, you can find out the 0.75 mm thick paint has to be applied over the particular thing. So, if you have that both the sides, so it is one side is 0.75 by 2, another side is 0.75 by 2. So, that way you can apply the paint and by virtue of the application of the paint will be the mass will increase.

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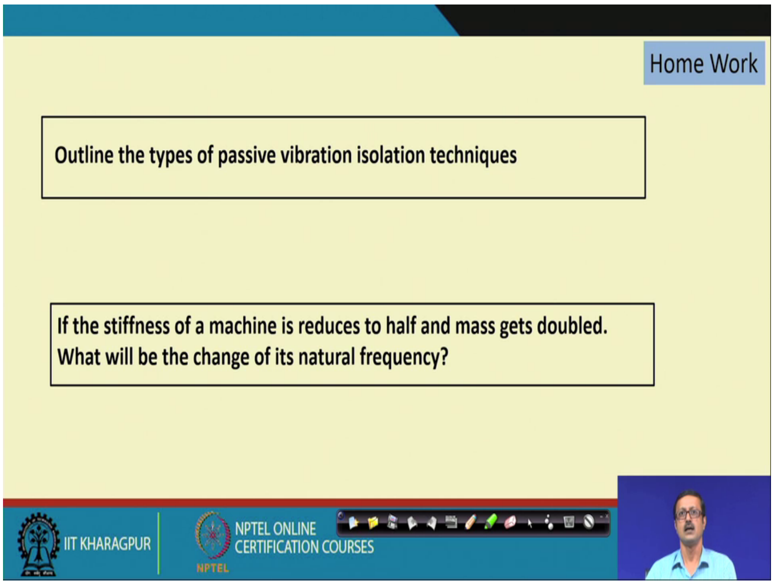

And then, your definitely your vibration will decrease and it will be separated out from the operating frequency and it will not propagate the resonance will not create.

So, this end in this lecture end of this lecture let us have take to homework for you one; first one is the outline the type of passive vibration isolation take out types of passive vibration isolation technique. So, you have discussed so many techniques. We will also going to discuss some of the techniques in the next lecture. So, let us outline this things and another question is for you as a homework is that, suppose stiffness of a machine is reduced by half and the masses get doubled then what will be the change in it is natural frequency? Is it going to be the same or it will not going to be the same? If it is not going to be the same, it will be high or low or how many times it will be high or how many times it will be low. That is I am expecting from you. So, that is all for this lecture.

(Refer Slide Time: 33:20)

And these are the some of the books I have referred for this particular lecture. And thank you very much for hearing that. And, we will go to the next lecture and that is the last lecture on the structure borne sound transmission.

Thank you.