Soil Dynamics
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Lecture No. 45
Analysis of Machine Foundations (For Impact Type Machine) - 1

Welcome friends in the course Soil Dynamics. So, last few classes, we have discussed the procedure to analyze the machine foundation for the reciprocating type machine. So, today we will start discussion how to do the analysis of machine foundations for impact type machines.

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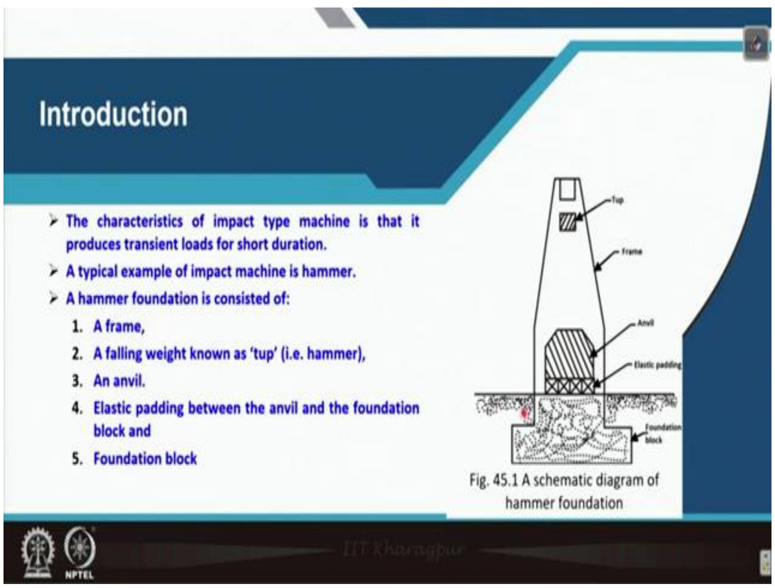

A good example of impact type machine is hammer and here in the figure 45.1 you can see a schematic diagram of one hammer foundation. So, the characteristics of impact type machine is that it produces transient loads for a short period of time and as I said, a typical example is hammer. Now, you can see that in the figure 1 that what are the different components of hammer foundation. Of course, we need to construct a foundation block for the hammer type machine. However, it has some other components also.

So, in this figure first you can see the tup which strikes on the anvil, here you can see the anvil. Also, there is the frame to which this tup is attached and it allowed us to it is allowed to fall freely from the tup and then it strikes this anvil. Sometime, this frame which you see here is attached or resting on the foundation itself, some time it rests on the anvil also.

So, when it rests on the anvil, we consider the total weight of the anvil is equal to the actual weight of the anvil and plus the weight of the frame. Likewise, when the frame is attached to the foundation, that time, when we calculate the total weight of the foundation that time, we consider that total weight of foundation is equal to the actual weight of the foundation block plus the weight of the frame.

Fourth component is elastic padding, which is provided between the anvil and the foundation block. So, here this is the elastic padding. What is the function of elastic padding? It absorbs the shock. So, it reduces the shocks which transmitted from the anvil to the foundation block and the final, but essential component is the foundation block which is made of concrete.

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Now, let us see the features of the foundation for impact load or I can call it as the machine foundation for impact type machine. Generally, depending upon the capacity of the hammers, we classified hammers into three different categories; small hammers or small capacity hammer, medium capacity hammer and large capacity hammer.

So, generally for small hammers that anvil is directly mounted on the foundation block. So, if you see in such type of system, how we can model? Such type of system we can model as a single degree of freedom system, I can show you the figure.

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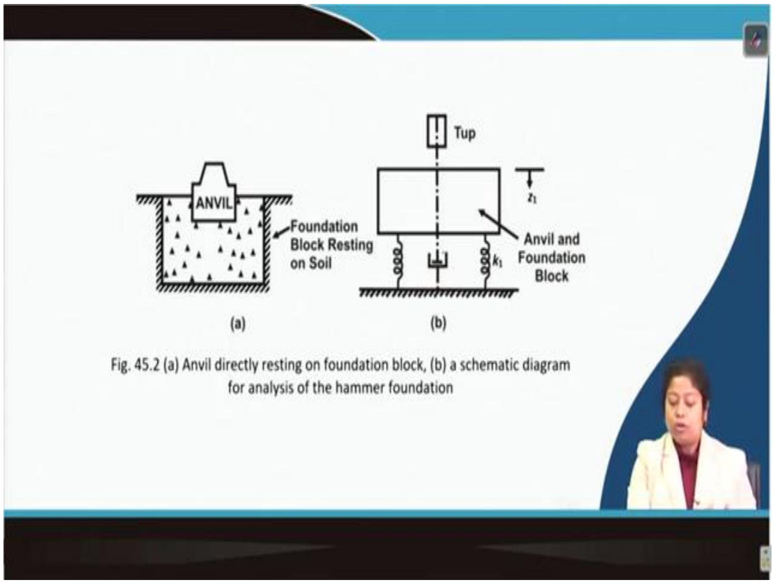

So, here you can see that the anvil is resting on the foundation block itself, there is no elastic padding between the anvil and the foundation block in this case and this is when we allow when the capacity of the hammer is small. And if we represent these foundations soil system by mass spring system, then how do we represent it? There is a mass which actually is the total mass of the anvil plus the mass of the foundation block and that is attached to spring which represents the soil here in this figure the anvil of the soil is also shown.

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Now, for the hammer of medium capacity and elastic padding, which acts as a vibration isolation is provided between the anvil and the foundation block as shown in figure 45.3. So, let us see.

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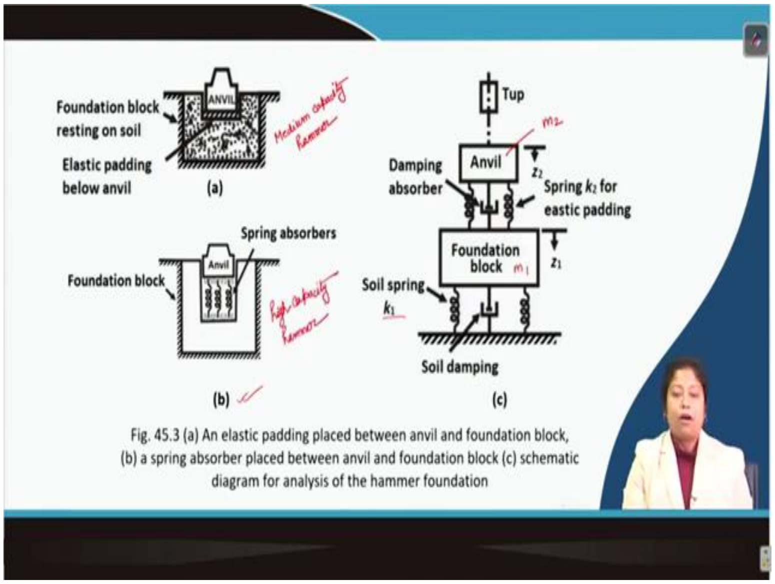

So, here you can see one elastic pad is provided in this finger, this is the anvil and anvil is resting on this elastic pad and below the elastic pad, you can see that foundation block which is made of concrete. Sometime, in place of elastic padding, spring absorbers are also provided. So, how we will represent figure a or figure b we this type of foundation soil system can be represented by two degree of freedom system you can see here and will itself represent one mass it may be you can take it as m2. So, if I will, I can show it clearly.

So, mass of the anvil let us take m2 and it is attached to the spring which actually acts as observers or maybe the stiffness of the elastic padding. And that spring below that spring or that spring itself connected to the foundation block as well at the bottom. So, we can take mass of the foundation block m1 and this foundation block is resting on the soil. So, the soil is represented by the spring k1 that means, k1 is the stiffness coefficient for the spring which represents the underlying soil.

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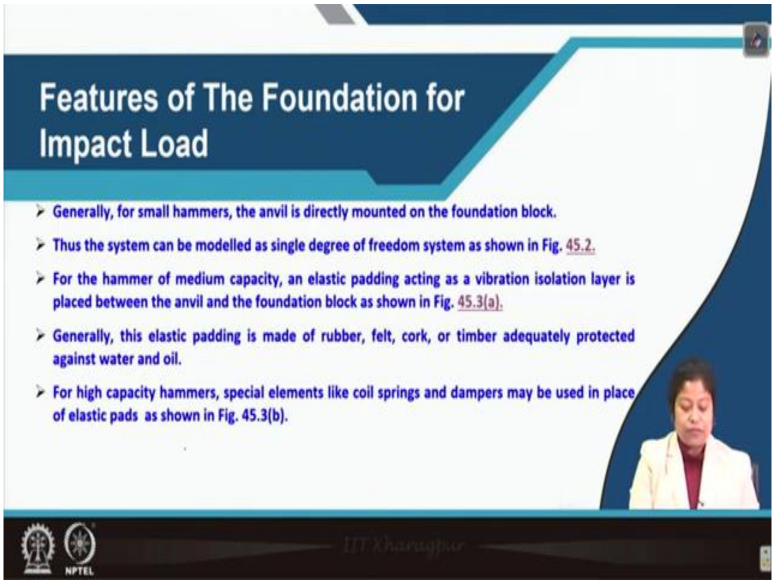

So, this elastic padding is made of rubber, felt, cork or timber which is adequately protected against water and oil. Now, let us see what is happening for the high capacity hammers. So, for high capacity hammer like coils, springs and dampers may be used in place of elastic pads already that I have shown in figure 43 b.

So, here you have already seen. So, this is for the medium capacity hammer. For this type of case, we use elastic padding below in between the anvil and the foundation block. Whereas we provide spring absorbers below the anvil or in between anvil and the foundation block for high capacity hammer.

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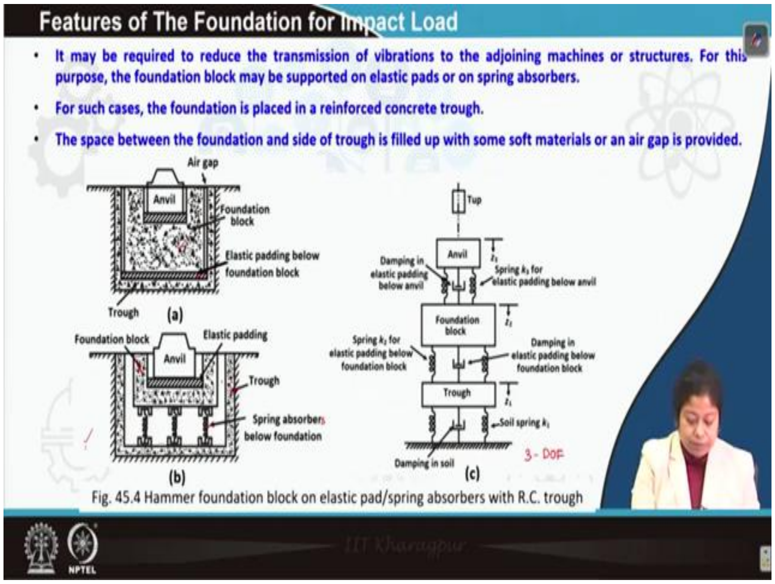

Now, in this figure you can see, hammer foundation block on resting on elastic pad and also spring absorbers are provided with RC trough. So, why this kind of arrangement? It is required to reduce the transmission of vibrations to the adjoining structures or machines and for this purpose the foundation block may be supported on elastic pad or spring absorbers. So, in figure a, you can see this is the foundation block and that is resting on the elastic padding. So, here it is your elastic padding.

In figure b, what we can see foundation block this is the foundation block so, it is resting on the spring absorbers. So, this is our spring absorber, and here you can see the trough also. Now, how we will represent this type of system that is shown in figures c. This type of foundation soil system where spring absorber are provided a below the foundation and then the trough is provided this type of system can be represented by a three-degree of freedom system. So, this is your three-degree of freedom system which represents this type of situation which shown in figure a and b.

Also, in this type of foundation, what is generally done the foundation is placed as I already mentioned in a reinforced concrete trough. So, you can see here and these the space, this space is generally filled by soft material or an air gap.

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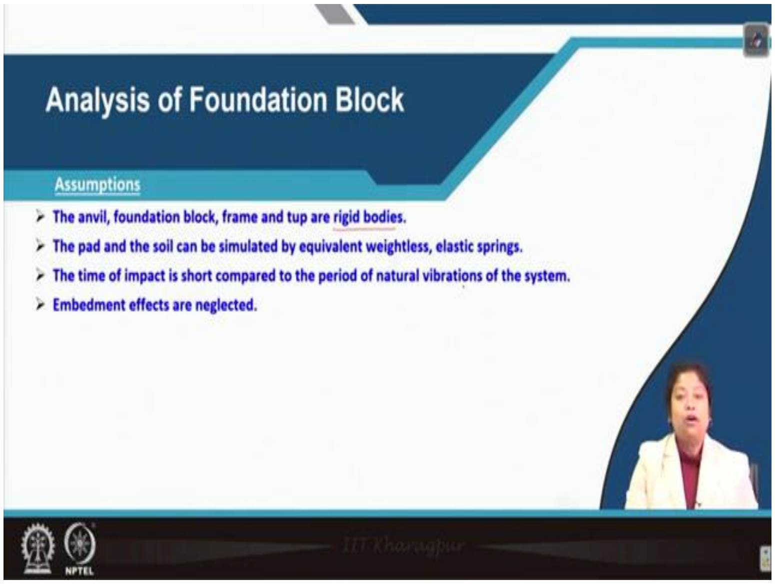

Now, what we have seen, we have seen that depending upon the capacity and depending upon the what type of absorber we will provide and where it will be provided, we can model foundation soil system in three different ways. We can model it as single degree of freedom system, we can model it as two-degree of freedom system and we can also model it as three-degree of freedom system when we need to reduce the shock which is generated from the machine to the and protect the adjacent machine or structures from that shock.

Now, for the analysis of foundation block of the impact type machines first we need to see first we will assume a few things, what are those things? First one is that the anvil foundation block frame and tup are rigid bodies that means, we will consider no deformation of the anvil foundation block frame and tup.

Second assumption is that the pad and the soil can be simulated by equivalent weightless elastic springs that we have already seen that springs are used in place I mean springs are used when we are we do the analysis in place of elastic padding, in place of soil to represent the stiffness of the elastic padding and the underlying soil respectively. Now, those springs should be considered as weightless and of course, elastic. The third assumption is that the time of impact is short compared to the period of natural vibrations of the system. And in this case, we will not consider the effect of embedment.

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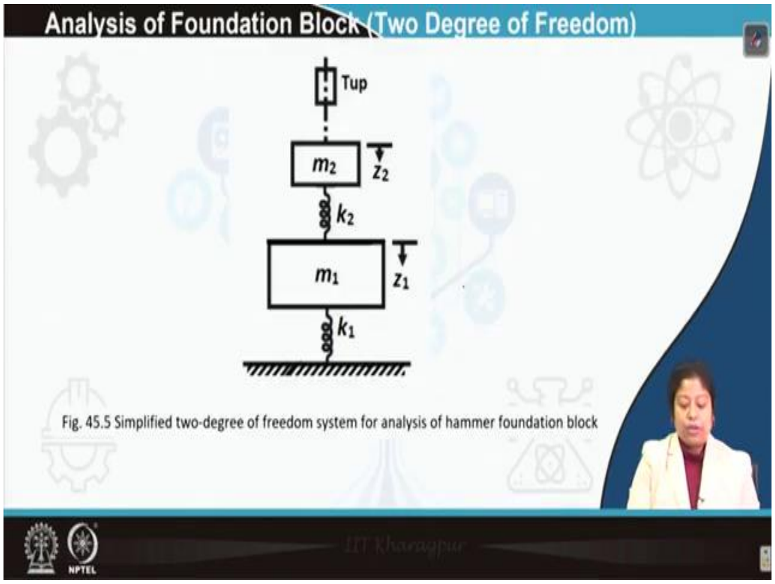

So, here you can see the simplified two-degree of freedom system. So, before discussing it first let me discuss the single degree of freedom system.

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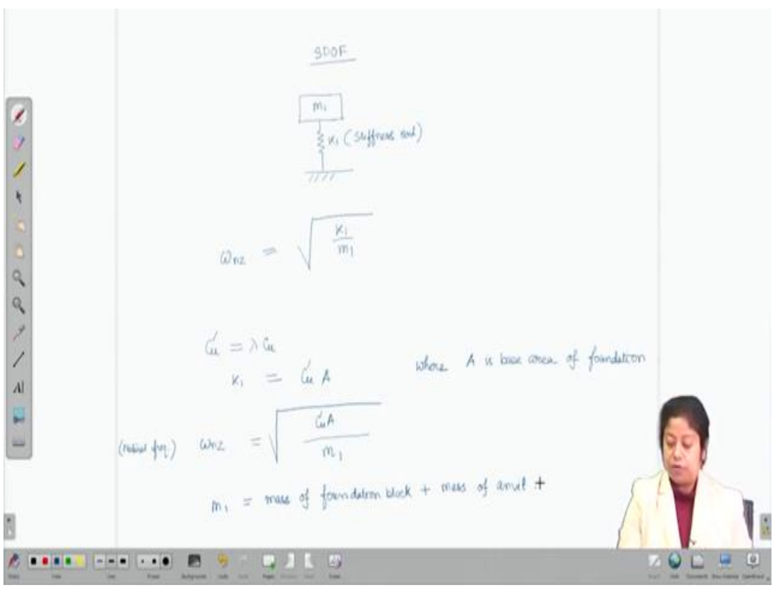

So, let us come to the whiteboard. So, if I am representing the machine foundation system that means foundation and the underlying soil together will be considered as a single mass, then how it will be represented, a mass m we can write it as m1 also which is resting on the underlying soil and these k1 represents the stiffness of soil. Now, in these case, if we know the stiffness of soil, then we can find out the natural frequency of the system.

So, natural frequency of this single degree of freedom system is square root of k1 divided by m1 now, if we know the coefficient of elastic uniform compression of soil which is Cu, then we can correct it for the from these we can find out Cu dashed by multiplying a factors lambda. After knowing these corrected coefficient of elastic uniform compression, we can find out k1 which is equal to Cu dashed times A where A is the contact area or base area of foundation.

So, from this finally, I can write omega nz which is the natural frequency I can write here also natural frequency omega n z is equal to Cu dash times c divided by m1 what is m1 here m1 is mass of foundation or foundation block plus mass of anvil. So, in this way we can solve the single degree of freedom system and we can get the natural frequency of machine foundation soil system.

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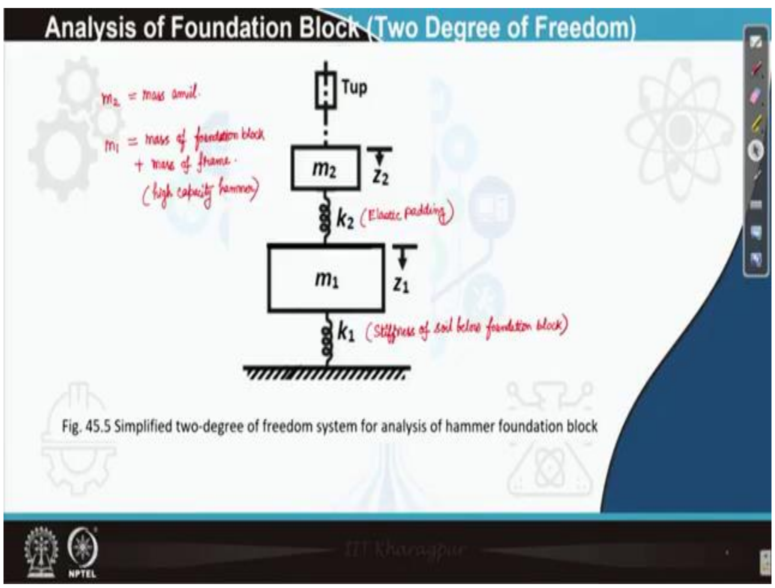

Now, when it is two-degree of freedom system, how we will solve the problem. So, before analyzing the problem, first let me to explain what is m2 m1 k2 k1 and then how we can draw the free body diagram for this type of problem. So, that from the free body diagram we can get the equations of motions and then we can discuss the procedure to solve this type of problem.

So, here m2, m2 is mass of anvil. In this case, if the frame is attached to the anvil then we need to consider also the mass of the frame. However, if the frame is attached to the foundation, which is generally have been for medium size or high (capa) sorry medium capacity and high capacity hammer, then we do not need to consider mass of the frame in when calculating m2, but in m1 we need to consider the mass mass of the frame. m1 is the mass of foundation block plus mass of frame this is for as I say high capacity hammer.

What is k2, k2 is stiffness of elastic padding. So, it represents the elastic padding which is provided between the anvil and the foundation block. What is k1 here? k1 represent the stiffness of soil below foundation. Now, if we will draw the free body diagram for this system, what it will be, let us see the free body diagram for this case.

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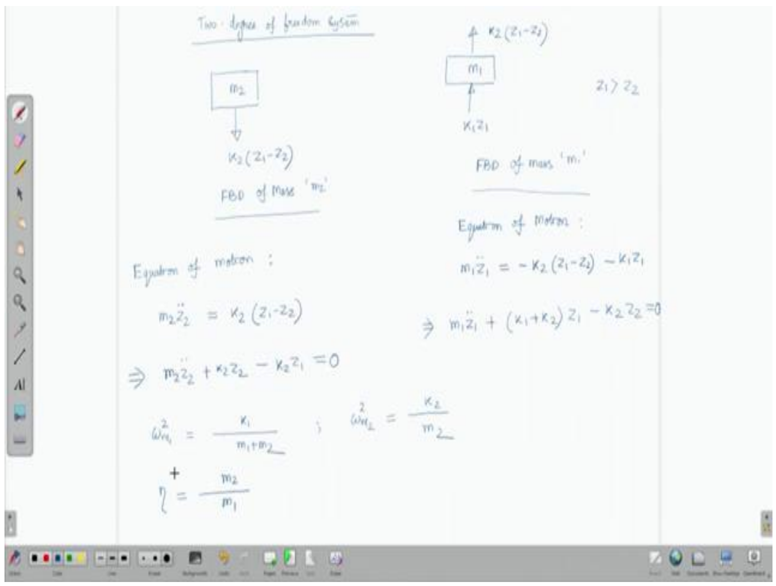

So, let us see here the free body diagram. So, for first mass m2 I am writing here we have two-degree of freedom system so, this is the mass m2. Now, if I consider here z1 is greater than z2, then what will be happened if z1 is greater than z2, then the free body diagram will look like this mass. Now, spring exerts force to the mass m2 and that force is k2 times z1 minus z2, then what will be happening to the mass m1. Here, for mass m1, if you see it is attached to the spring k2 and k1.

So, for spring k2 it will experience tensile force which is equal to k2 times z1 minus z2 and for the spring k1 what will be happening, if it will push the spring k1, then spring k1 will also push the mass m1. So, k1 will exert a force k1 times z1 in this case and what I have consider is that z1 is greater than z2. Then from these 2 free body diagram, this is free body diagram of mass m2, this is free body diagram of mass m1.

So, from these free body diagram, what we can write for m1 we can write the equation of motion that is inertia force m2 z2 dot z2 double dot that means mass times acceleration it is equal to K2 times z1 minus z2 which is the unbalanced force in this case, then our equation of motion is m2 times z2 double dot plus or yes plus k2 times z2 minus k2 times z1 is equal to 0.

Now, if you see the free body diagram of mass m1 from that, we can write equation of motion for mass m1 as inertia force m1 z1 two double dot that means mass times acceleration, this is equal to the unbalanced force, which is here minus k2 times z1 minus z2 minus k1 times z1 that means, unbalanced force because of the spring k2 and because of the spring k1. So, from these what we can write m1 z1 double dot plus k1 plus k2 z1 minus k2 z2 is equal to 0.

So, if we now do the 2 equations of potions from this what we can do, we already have studied how to get the natural frequency for the two-degree of freedom system or multiple degree of freedom system. So, we will we can follow the same exercise here and finally, we will get that equation if we consider some trial solution and finally, we will get this equation which is omega n to the power 4 minus 1 plus eta times omega n l 1 square, what is omega n l 1 first better I should write the assumptions.

In, first, let us assume that omega n l 1 is a new term, which is omega n l 1 squared is equal to k1 divided by m1 plus m2 likewise, we can consider another new term omega n l 2 and omega n l 2 is equal to k2 divided by m2 also we can consider a factor eta which is equal to m2 divided by m1. So, m2 is the mass of anvil and m1 is the mass of the foundation, it may even include the mass of the frame as well.

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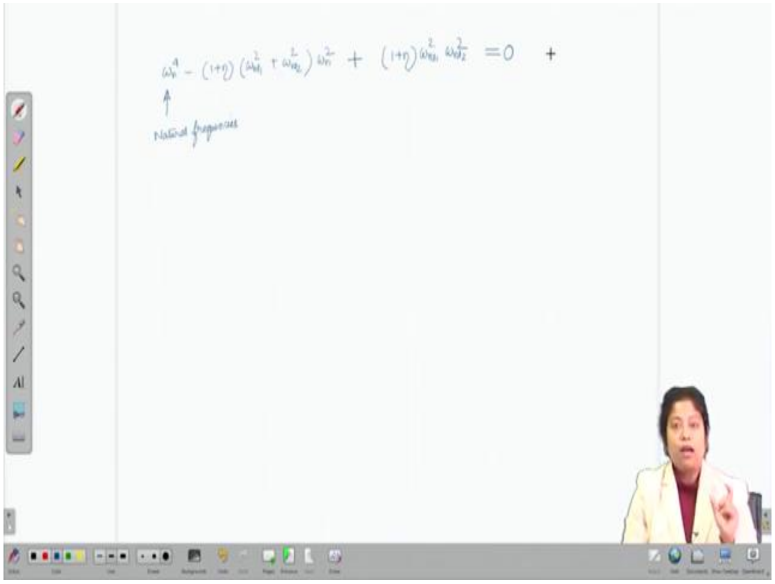

So, if we assume omega n l 1 omega n l 2 and eta as I have written here, then I can write a new X equation omega n to the power 4 minus 1 plus eta times omega n l 1 square plus omega n l 2 squared times omega n square plus 1 plus eta times omega n l 1 squared times omega n l 2 square this is equal to 0 where omega n is the natural frequency this is a two-degree of freedom system.

So, there are 2 natural frequencies omega n1 and omega n2 which we will get from this equation. Now, in this equation, which I would like to mention is that it is a fourth order equation. So, obviously, we should get 4 roots. Among the 4 roots, 2 roots are on the positive and we are interested only the positive values of omega n. So, in this way we can get the natural frequency for the system, which is shown here.

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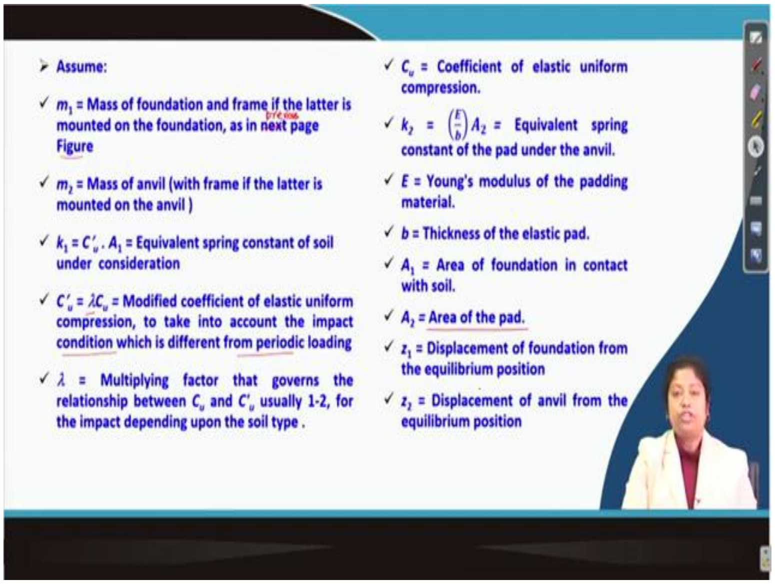

Now, a few thing which are useful when we solve the this type of problem is given here. So, already we have discussed what is m1, actually not next page previous page. So, m1 is given. m2 is already discussed, how to get k1 that is also mentioned. You can see Cu dash that also I have told that that is the corrected or modified coefficient of elastic uniform compression and why this modification or a factor lambda is multiplied here reason is there to consider the impact condition which is different from the periodic loading.

And what is the value of lambda generally 1 to 2 the value of lambda varies. In this course, when we will solve numerical problems related to the foundations of for impact type machines, we will consider lambda is equal to 2. Cu is already known to you. k2 is equivalent spring constant of the elastic padding which is provided in between anvil and the foundation block.

Then E is young's modulus of the paddy material. If we know E value and if we know that the thickness of the padding material which is b here, then we can find out the k2 which is E divided by b times A2, A2 is the or the contact area of the padding material. Now, z1 and z2 are the displacements of the foundation and the anvil respectively, displacement from the equilibrium position.

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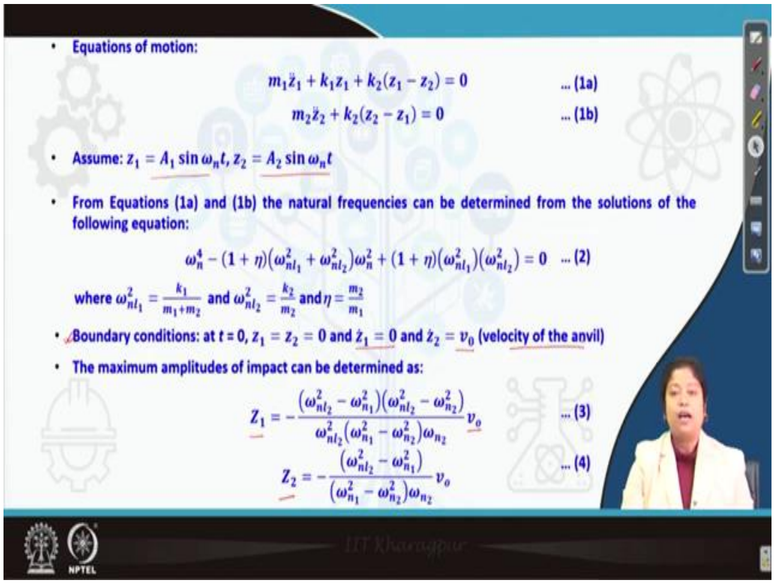

So, already I have shown how to derive the equations of motion. If you see here, already we have discussed how to get the equation of motion. So, the same thing only difference is that here I when I have written these, I have taken the coefficient of z1 together and coefficient of z2 together whereas, in this case first preliminary equation as it is are written.

So, as I already mentioned, if we consider a trial solution for z1 and z2 like this z1 is equal to A1 time sine omega n t and z2 is equal to A2 times sine of omega n t, then from that we can get the equation 2 where omega n is representing the natural frequency of the system. Now, if I will impose the boundary condition, what is the boundary condition here, at t is equal to 0, both z1 and z2 are 0. And what about the velocity, z1 dot which is the velocity of the foundation block that is 0 however the velocity of the anvil is v0 because it is now 0.

From this boundary condition, we can find out the (max) expression for the maximum amplitudes z1 which z1 is the amplitude of the displacement for the foundation block and we can also determine z2 which is the amplitude of displacement for the anvil. So, what is v0 here? v0 is the velocity of the anvil in this case.

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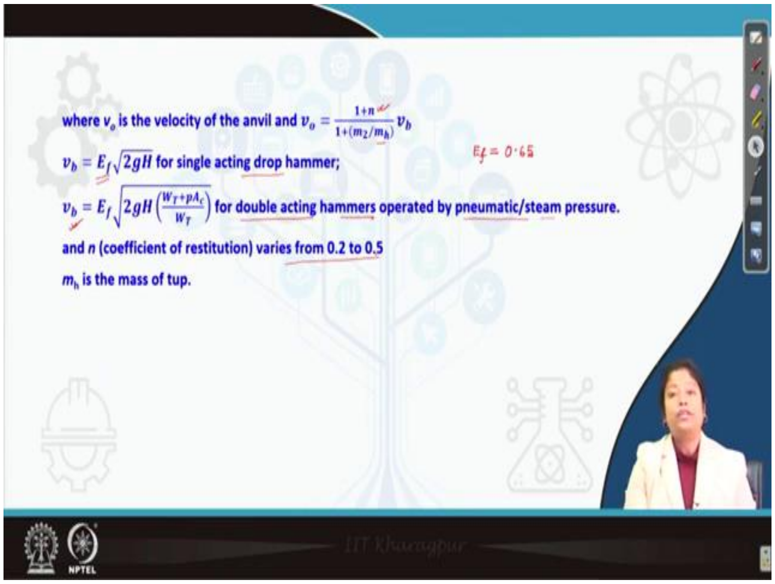

Now, here you can see how we can get the velocity of the anvil v0. So, if we know the mass of the anvil, which is m2, if we know the mass of the hammer or tup m h, then (vel) velocity of the anvil, what is vb here, vb is the velocity of the tup before impact. Tup is striking the anvil so, just before striking, what is its velocity that can be represented by vb. And we can calculate vb also if we know about the hammer. So, how we can calculate? From physics, we know that this vb is equal to square root of 2gH.

Now, in this case, you can see 1 factor which is E f is multiplied, the reason is that the energy may not transfer fully from the tup to the anvil. So, depending upon the efficiency of the tup, one efficiency factor is introduced here, generally we take 65 percent efficiency of the hammer. So, generally, we take if no information is provided, then we can take E f is equal to 0.65. Now, this is for single acting drop hammer.

Now, what about double acting hammers? In that case, we use the second equation where how you will get WT and rest of the t. WT is very simple, it is the weight of the tup AC is the contact area and P is the pneumatic or steam pressure. One more thing, what is n in the equation which we use to calculate V0, n is called as the coefficient of restitution. So, it generally varies from 0.2 to 0.5. Generally, we take 0.4 or 0.5 for our analysis.

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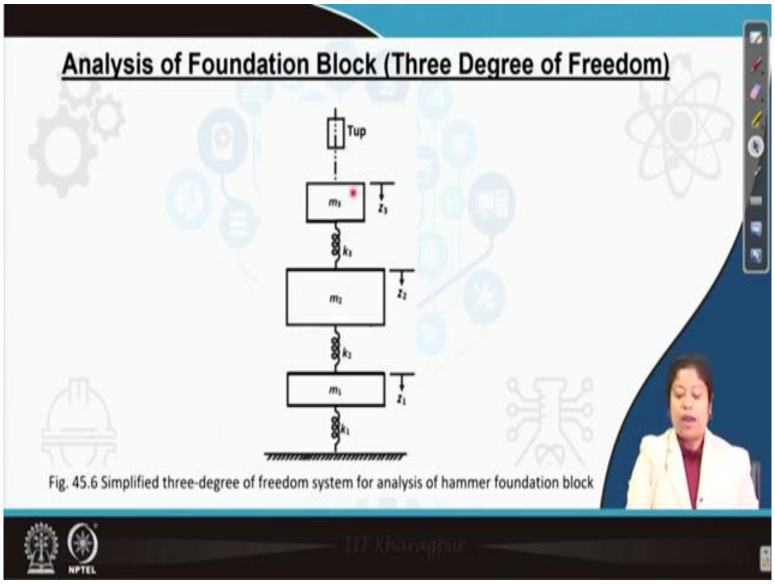

In this figure, you can see that machine foundations soil system is represented by a three-degree of freedom system, where m3 is the mass of the anvil, m2 is the mass of the (foun) foundation block and m1 is the mass of the trough reinforced concrete trough.

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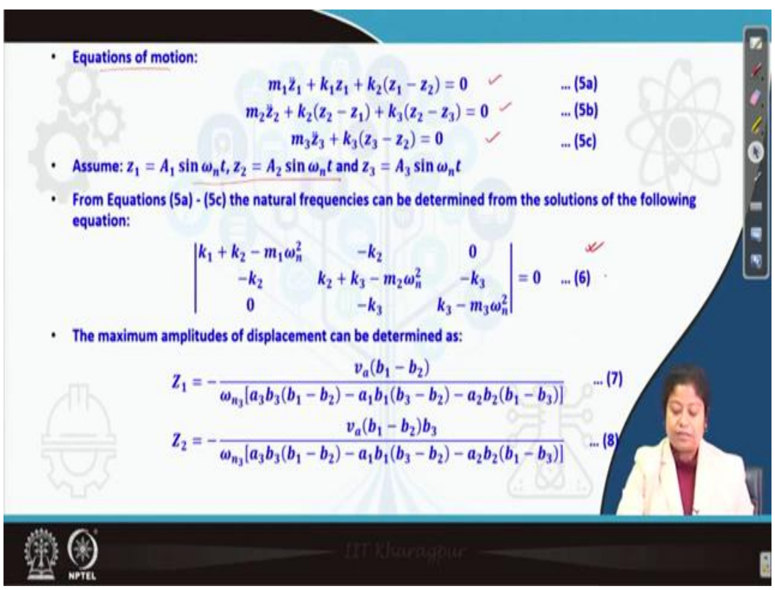

From the equations of motion for mass m1 for mass m2 and for mass m3 from, then we will assume the trial solutions as stated here, and we will from that, we will get these equation. Solving these equation, we can get natural frequencies for 3 different modes of vibrations. So, what are the 3 natural frequencies here omega n1 omega n2 and omega n3. Eventually, omega n3 is the smallest one and omega n1 is the largest one here. And if we calculate if we can calculate the natural frequencies from equation 6, then using equation 7 and 8, we can also calculate z1, z2 and z3.

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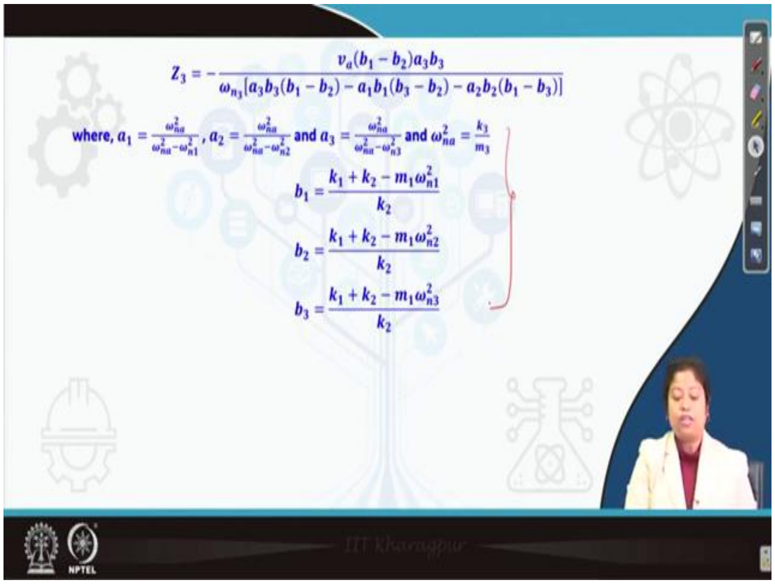

What are z1 is so, z1 is the displacement of the mass m 3. So, mass m 3 here is the mass of the anvil. So, z3 basically represent the this amplitude of the displacement of anvil, what is z2 here they to represent the displacement amplitude of the displacement of foundation in this case. So, generally, we are interested main for z1 and z sorry, z2 and z3. And here you have seen new factors n1, a1, a2 and a3. So, how you will calculate a1, a2, a3 and b1, b2, b3 that are given here so, using these equations, you can get z1, z2 and z3.

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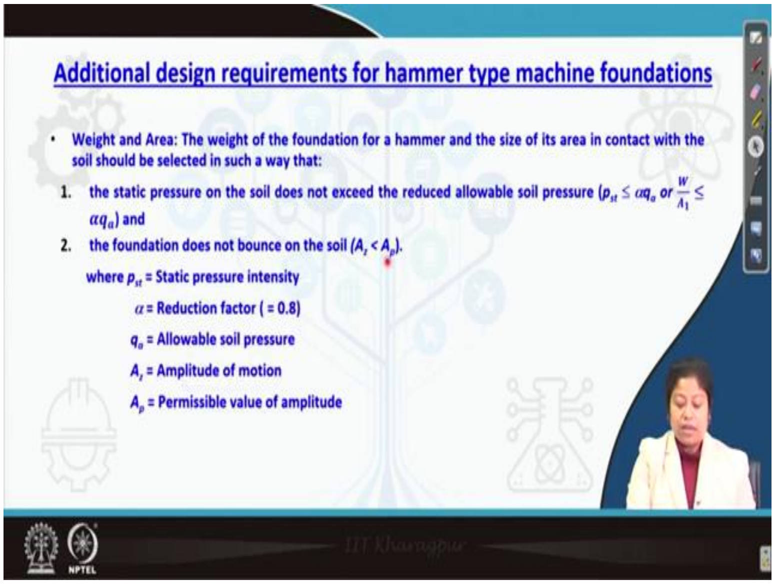

Now, we need to know a few additional design requirements for hammer type machine foundations, what are those first is weight and area, the weight of the foundation for a hammer and the size of its area in contact with the soil should be selected in such a way that it the static pressure on the soil does not exceed the reduced allowable soil pressure.

So, P st which is the static pressure should not exceed the allowable, reduced allowable soil pressure. Here, qa is the allowable soil pressure and alpha times qa is called as the reduced allowable soil pressure. And the second criteria is that the foundation does not bounce on the soil or that we need to ensure that Az is less than Ap, Az it is amplitude of motion, whereas Ap is the permissible amplitude.

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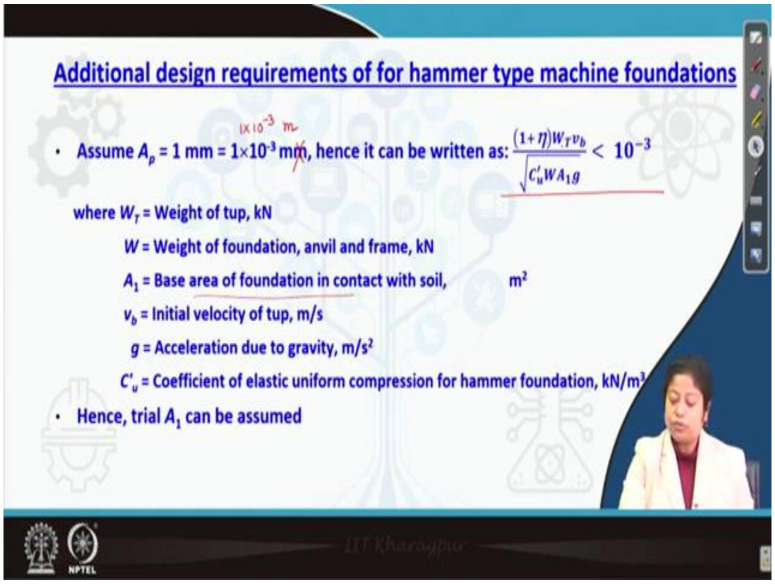

What else so, we when we know the two additional requirements, from this, we can assume or consulting to code we can get Ap value. So, let us take it is 1 millimeter, here I made a mistake. So, it is not millimeter 1 millimeter means 10 to the power minus 3 meter. So, I can write it as 1 into 10 to the power minus 3 meter. Hence, what we can write we can write this equation and what are the different terms used here Wt is the weight of the tup, vb is the weight sorry velocity of the tup before impact.

Now, Cu dashed already discussed, W is the weight of the foundation anvil and frame together, A1 is the base area of foundation, which is in contact to the soil and g is acceleration due to gravity. So, if we know all these things, then from these we can calculate actually A1, because eta is known, Wt is known, Vb is known, Cu dashed from the soil testing we can calculate capital W is also known only unknown is A1. So, A1 can be calculated from this equation.

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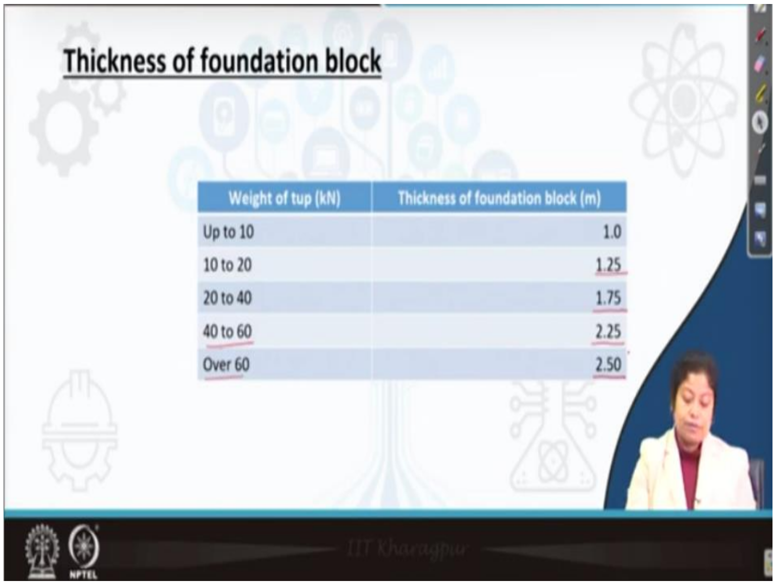

Then, we need to know what is the thickness of the foundation that depends upon the weight of the tup. So, up to 10 kilo Newton weight of tup, we can provide we can assume 1 meter thickness of foundation block. For 20, up to 20 that means 10 to 20 kilo Newton weight of the tup, we can consider the thickness as 1.25 millimeter. For 20 to 40 kilo Newton weight of the tup, we can consider thickness of the foundation block 1.75 millimeter. For 40 to 60, it is 2.25 meter, all are in meter there is no millimeter. Over 60, we consider 2.50 meter.

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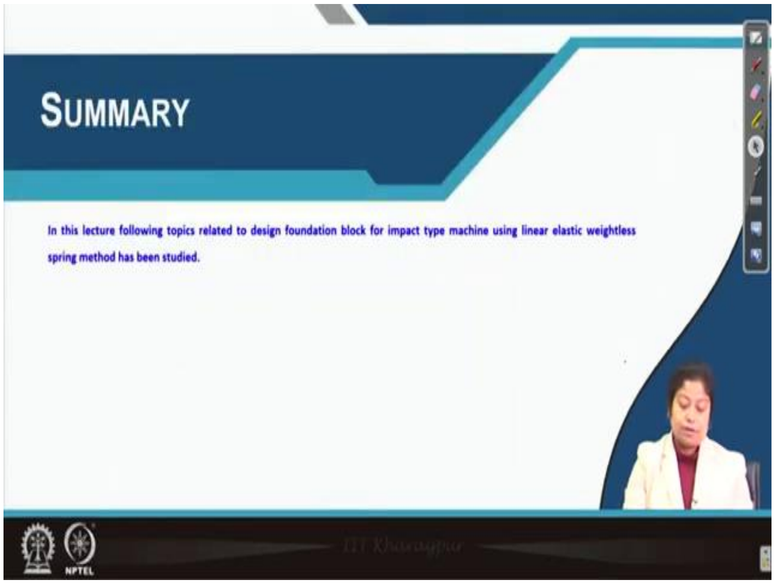

So, now, come to the summary of today's class. Today, we have discussed how to analyze the foundation for impact type machines, where we have seen that we can for small capacity hammer, we represent the system as single degree of freedom system. For medium capacity hammer, we represent the system as two-degree of freedom system. For high capacity hammer, where we need we need to control the effect of the vibration so, that it should not create trouble to the adjacent machines and structures, in such case, we represent we do the analysis considering three-degree of freedom system and also how to consider the additional requirements to get some rough idea about the contact area of the foundation that also we have studied in today's class.

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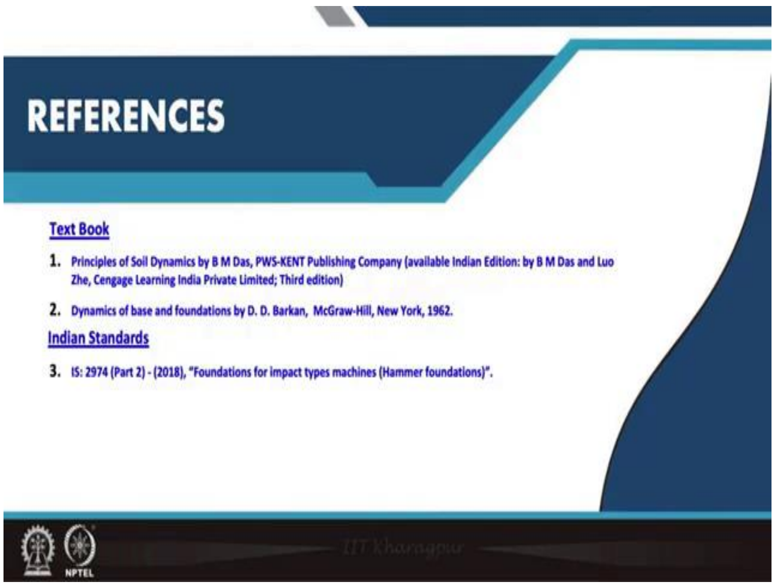

These are the references that we have used. So, thank you.