Geotechnical Engineering II / Foundation Engineering
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Lecture – 59
Introduction to machine foundation (Contd.)

Good morning. Welcome to this course Foundation Engineering and we almost towards the end of this lecture series. And, the last topic I was discussing about machine foundation and that too introductory not much in detail and I have discussed already force vibration, free vibration, damped, undamped all those things.

Now, we have to think about the foundation design and foundation design means normally when you design for a foundation for a building or any other thing then basically our criteria will be bearing capacity and settlement. That means, the because of the building loading whatever pressure coming to the soil should be less than the bearing capacity of the soil and also because of the loading whatever the total settlement it is causing that should be within the given limit.

So, these two criteria generally used in normal regular foundation for static loading and when it is a dynamic loading as I have told already at the beginning that it is natural it is a natural frequency and the amplitude resonant amplitude. Resonant amplitude actually see amplitude mainly actually it is amplitude and that amplitude that the vibration amplitude should be within some limit and we have investigated for different types of forcing system, whether it s a constant force system or the rotating mass system and with the variation of frequency how amplitude varies that we have seen and we have shown that the amplitude is very high close to the resonance frequency at resonance.

So, because of that in the design actually basic guidelines actually that you have to design the machine foundation in such a way that it is natural frequency should be far away from the operating frequency of the machine.

So, that is one thing because if the operating frequency is much lesser or much higher than the resonant frequency and that there actually amplitude is generally is less very less whereas close to the resonance it is a very very high significantly high and so, because of that we need to restrict the amplitude by designing the foundation in such a way that it is natural frequency should be away from the operating frequency this is the things.

And, based on using the based on these guidelines if you want to design, then what are the different types of machine for foundation for different types of machine?

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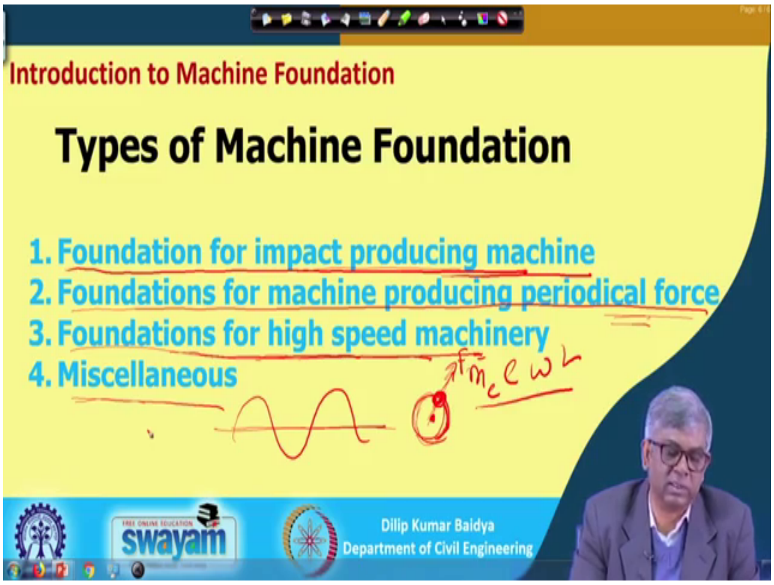

So, that actually we have some guidelines you can see there are these can be classified into three – four categories you can see one actually foundation for impact producing machine. So, that is one type of message; that means, suppose there is a hammer foundation, suddenly a weight will fall and to fabricate something and because of this heavyweight falling on the some object it will create some vibration and then for that type of foundation that type of vibrating system we have to have different foundation than other type of vibrating system.

So, that is what you have classified one that is foundation for impact producing machine that is like hammer, press and all. Similarly another is foundation for machine producing periodical forces; that means, periodical forces means; that means, you have suppose if there is machine contents eccentric rotating part that I have told number of times that if you have eccentric mass is rotating with respect to this center and because of this operational frequency this force will be here m into e into omega square. So, this is a force.

So, that means, if that type of force is there and then that will be; that means, the foundation for machine producing periodical forces; that means, this type of forces actually same force is the repeating and some interval that is actually periodic force. So, so this also will create periodic force. And, so, foundation for machine producing periodical force for that also there is a different types of foundation.

Similarly, the foundations for high speed machineries; again political force can be moderate it can be media which can be high. So, if it is a high frequency generally that a typical type of foundation we us. So, that is what another classification can be done that foundation for high speed machineries. And, then miscellaneous; that means, different other kind of any machine. So, it requires some foundations or depending upon the type of force and of frequency one can decide the, what type of foundation is required.

So, now this are the classification.

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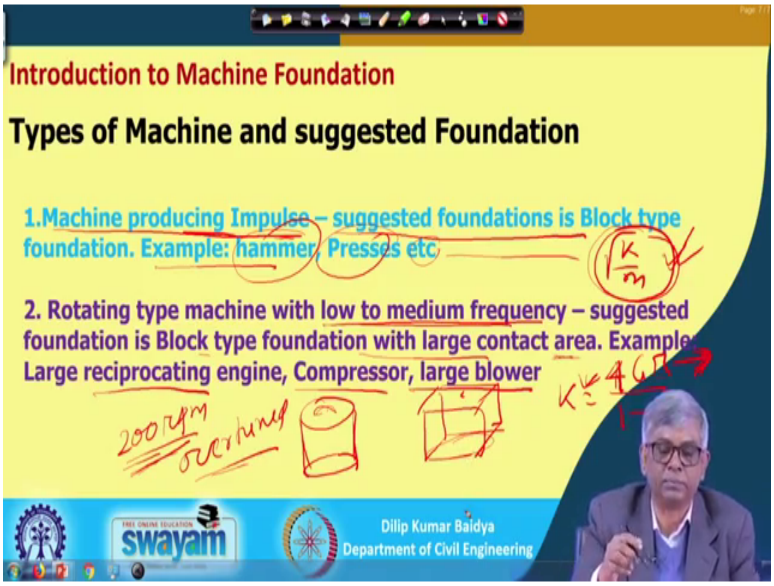

Now, what is the guideline actually? Guideline is when it is a machine producing impact or impulse; machine producing impulse generally suggested foundation block type foundation. Block means it will be a suppose something like this block like this length width and height if it is a circular it can be something like this, and in over that that impulse force will be applied over that impulse force will be there. So, machine producing impulse; that means, if there is a impact type of machine then suggested foundation generally is block type foundation and example of impulse impact producing or impulsive force will be hammer and press and similar kind of things.

Then, next is rotating time basic with low to medium frequency. This is actually low to medium assume low frequency and suggested foundation is block type foundation with large contact area,. So, why it is so? When the operating frequency is low suppose say 200 operating frequency is low 200 rpm in that case actually we originally designed over tune; over tune means natural frequency high. So, natural frequency if you want to make high then what you have to do actually natural frequency is actually under root K by m. That means, K by m to make K by m high so, it is easy you can easily increase the K by increasing the area because K equal to 4 Gr by 1 minus mu. So, this is r, so, radius.

Actually see, that means, that is why rotating type machine with low to medium frequency suggested foundation is block type with large contact area. Why large contact area? When contact area become large then K become large and when K become large then natural frequency becoming large and that is the purpose that is why because low frequency machine will generally give design for over tuned foundation and over tune means natural frequency should be higher than the operating frequency.

So, that is why this is the one type of guideline that low to medium frequency foundation machine suggested foundations of block with large contact area. What is what is the reason for giving large area because you want to increase the K; K how to K increase the K? By increasing r and if you increase K then what is increasing it is increasing natural frequency.

So, that is the way we decide that and what are the example for this low frequency machine? They are actually large reciprocating engine, compressor, large blower they are coming under this category; that means, low frequency machine and if this is the type of machine, then you have to go for block foundation with large contact area; that means, the base area will be more than the height.

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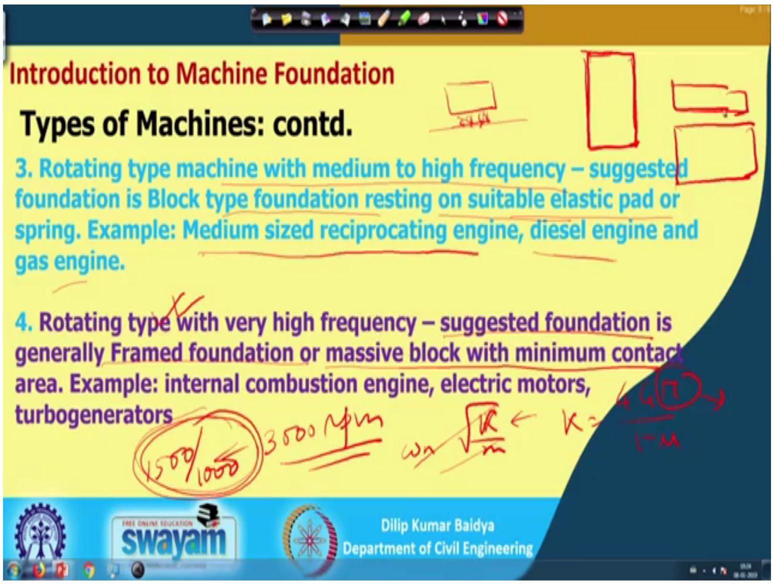

Next one the next one is again the rotating type machine with a medium to high frequency. So, in that suggested foundation block type foundation resting on suitable pad or spring; that means, if there is a high frequency machine, then there is a chance of vibration large vibration amplitude because of that one can have below the block below the block this is a block foundation one can keep some spring.

So, or some absorber and then it can be constructed. So, that will help actually to reduce the amplitude. So, if it is a rotating type machine with medium to high frequency then it will be again block with some absorber below it, ok.

And, example under this category will be medium sized reciprocating engine then diesel engine and gas engine. So, these are the kind of machines for which actually you have to go for the block foundation which suitable elastic pad or absorber ok. And, then third category actually rotating type with very high frequency, and when it is a very high frequency as I have mentioned already so, high frequency suppose 3000 rpm and then if the operative frequency is 3000 rpm, then your natural frequency will be less than that; that means, it could be this side. So, it will be may be suppose 1500 or 1000 something like that. So, this is called undertuned.

That means, when there is a high frequency machine for that when you want to find out design for foundation then you have to design for undertune. Undertune means what? Whatever natural frequency or whatever operating frequencies there you have to design in such a way that it is natural frequency falls below that; that means, it will be half or even less of that. So, this is undertune design.

And if you do that so, because of that you can see for high frequency machine the suggested foundation is actually generally frame foundation or massive block with minimum contact area. So, generally frame foundation will be there if it is a frame foundation then it will have lesser stiffness and lesser stiffness means it will have your under root K by m under root K by m, if stiffness is less than automatically omega n also will be less.

So, that is the purpose and sometime huge block can be also used in that case the contact area should be less. If you use block and contact area why should be less because you your K become for G r by 1 minus mu if you reduced the r then K will be reduced and if we reduce the K then omega n also will be reduced. That is the way actually for low frequency machine we made the large contact area to increase the K whereas, in high frequency machine we reduce the area to reduce the K and so, that you are natural frequency will become less.

So, high frequency machine generally undertune and to do undertune generally framed foundation was suitable and if you use a block foundation then the block contact area should be less; that means, it is block maybe something like this, a huge block, block actually smaller contact area, but height will be significantly high. So, it may be the like that whereas, if it is your low frequency machine block area maybe dimension maybe big, but height maybe area will be these and there may be height will be something like this, ok.

So, these are the different guidelines. If you know that type of machine then we can adopt accordingly whether it is a block with small contact area, block with large contact area or framed foundation or you can have the block foundation with some absorber. So, based on frequency range we can decide that.

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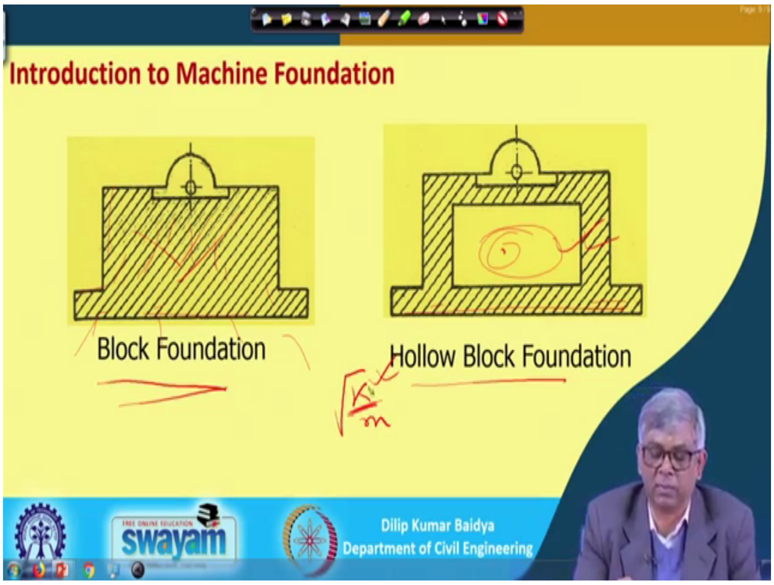

And, these are actually some examples are shown here actually a photograph of typical block foundation. If it is a block foundation this is the block actually this is the entire mass actually by concrete and block and it will be fixed this is our machine is fixed on to the block and because of this vibration caused by this machine it will be passed through these foundation to the ground and that is typical design. Some more details will be there, but we are not going much detail about the connection etcetera which is there in the code.

And, another block and suppose one can think of to reduce the mass sometime or to make it increase the area, but mass can be kept less. So, in that case actually keep can be made hollow block; that means, we can make a block with some hollow portion. So, that is also another type of block foundation can be used some time because you have to adjust natural frequency, I sometimes you have to natural frequency reduce it, sometimes increase it.

So, if by doing this what you can do under root K by m; area increase, so, K is increase and mass is reduced, of course, this has to be optimized. So, if mass is reduced then natural frequency will be increased for some adjustment has to be done by doing this process.

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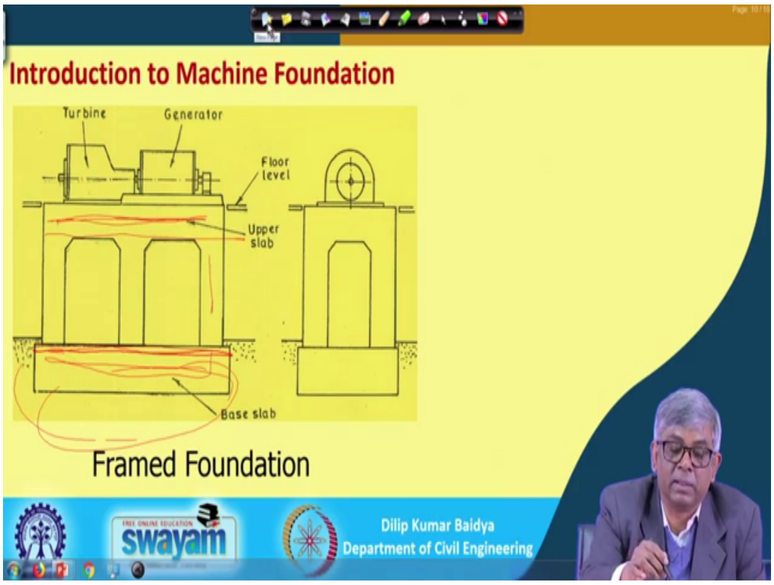

And, this is actually typical frame foundation you can see this is the front view actually and this is a cross sections suppose if you cut like this. This is the machine and this is a frame and this is the frame and there will be on this is a frame actually on the frame top of the frame there will be desk slab and at the bottom there will be bottom slab. And, bottom slab will be make a very thick generally it was so thick that while analyzing this frame foundation we assume this frame are fixed at this level. So, soil information will be ignored here.

And, then according to this position of the loading etcetera some vibration analysis has to be done, but the frame foundation analysis we are not going because it is a detailed machine foundation class only you can do it here only just introductory only I have given. So, only what type of foundation when the frequency is high that only just to show that only I am bringing this foundation type here type here, but not detail design.

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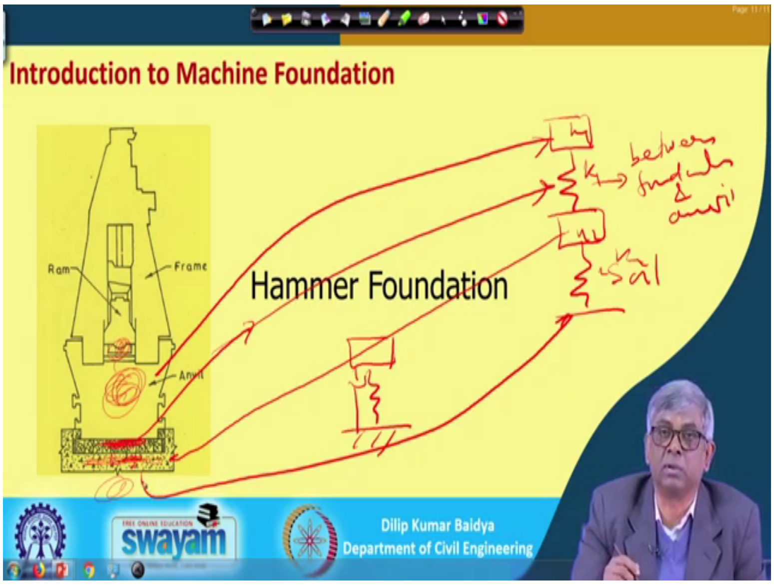

And, this is actually a typical hammer foundation. You can see here there will be arrangement and this is this is the frame and this is the anvil and then by lifting this the load will be falling on this anvil and you can see this will be main foundation, then elastic pad, then there will be anvil and then there will be this arrangement through which the load will be lifted and allowed to fall and on this impact will be producing on this anvil only.

And, when this type of foundation is there a simple way the way we have done analysis that is actually single degree of freedom; that means, we have a mass and then we have a spring and you have like this or additionally may when it is a damped then there will be dashboard you have done like this; this is a single degree of freedom. But, here actually you can see foundation here this layer will act as one spring and again soil file also will act one spring; this is one foundation that mass this will act another string and this is another mass. So, this type of foundation will be designed or analyzed like a two degrees of freedom; that means, one spring than another mass then another spring.

So, this is spring actually representing soil this actually between foundation and anvil. So, these layer. So, this is actually corresponding to this layer and this soil corresponding to this one and these mass this mass corresponding to this concrete and these mass corresponding to this anvil, ok. So, like that two degrees of freedom has to be done for this type of foundation, but we have not done two degrees of freedom we can again similar to that if I write K 1 and this is K 2 and if it is m 1 and m 2 we can write down the equation of motion and you can also solve for it.

So, that part of course, out of the scope of this class so, I am not bringing that. Only I am just mentioning that how hammer foundation looked like this is generally it will be like that there will be the job will be performed on this anvil which is a and. So, like shoemaker, they have anvil similar to that here that if the object will be here and then by some arrangement that it will give you proper shape and for that the heavy impact will be produced on this anvil; anvil to it will go to the foundation through the spring. So, that analysis of course, I am not doing here.

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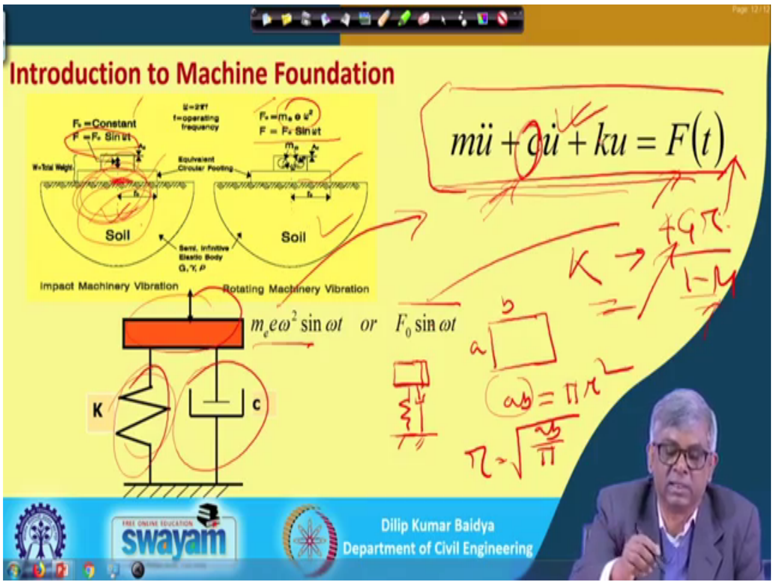

Now, typically I have discussed vibration theory and all typically a machine foundation how we have shown only like this one mass and one spring and if necessary sometimes we have given one dashboard something like that we have done, but how to be elected to the foundation resting on the soil.

So, that is should actually if you see here this is a suppose this foundation resting on ground and on the foundation this suppose machine and this machine suppose producing something F naught constant and force equal to F naught sin omega t or similar to that there will this is also machine foundation this is soil and on that there is a machine which is producing f equal to F naught sin omega t where F naught equal to m into e into omega.

So, two different types of forcing system are shown here and whether it is these or these typically I can idealize that machine and foundation together this is a mass machine and foundation and this soil will be represented by a spring in a dashboard. And, if it is done then and in this force either it can be this or it can be this and this is the model actually have taken right from beginning and from this model how to find out the equation of motion that equation of motion will be this and F t can be either this or it can F t can be this.

So, because of these F t equal to these or F t equal to these solution for this equation already have done and we have observed at with the variation of frequency what is variation of amplitude at different frequencies that we have observed. So, same thing only I am now correlating with the before that what we have done? I have assumed a mass on the resting on spring and for that I have done analysis then how it has to be connected to the machine foundation on soil?

So, that actually you can see that this, this foundation resting on the soil then that entire foundation soil will be replaced by spring, ok. So, that means, that springs; that means, to analyze machine foundation we need to find out the spring coefficient K and for that we have mentioned that if it is a vertical vibration your spring coefficient will be 4 Gr by 1 minus mu; where G is the shear modulus and how to determine shear modulus we have discussed, r is the radius of the foundation and mu is the Poisson ration.

But, here actually you can see we are mentioning only r circular; that means, radius of the circular foundation; that means, this theory cannot be applied if the foundation shape is rectangular or square, it is not sure. Actually can be applied how we can apply if the contact area of the foundation is something like this suppose this is a and this is b, then your area is actually ab and we can find out the equivalent area by equating this; that means, I can find if there is a rectangular foundation I can find out equivalent radius equal to under root ab by pi, ok.

So, this way so, if it is a circular foundation definitely directly I will take use r and use this equation to find out the K and if it is a non circular then I can find out r by equivalent method and then use that and find out the K. That is one thing we need to find; that means, when you replace the soil by spring and that spring stiffness has to be obtained and that actually is 4 Gr by 1 minus mu, it has come from the elastic theory;

that means, if I applies load here then what will be the amount of settlement then finally, load divided by settlement if I do elastic settlement if I do, then this expression comes when it is a infinitely homogeneous soil is there.

So, that is one thing to be obtained and then next thing K then the second thing is actually c, the damping coefficient and damping coefficient actually is difficult to do damping again be can be of different types of damping particularly in machine foundation vibration, there is another type of vibration is there damping is that, that is called radiation damping which will not discuss for the time being, we can think of only the material damping and that material damping actually for it depends on the material type, different material will have different material damping and it vary actually some 1 or 2 percent to 10 percent material dumping so, that I will show you the next slide.

So, that means, K to be determined and then c and of course, if you know this then of course, you need to know the mass; mass actually here mass of the foundation plus machine that to be used as a mass though there is some amount of mass will vibrate along with the foundation, but generally can it can be ignored mass means it is a mass of foundation plus machine.

So, if you know all those parameters then we can solution for this equation is given you can find out the amplitude, you can find out natural frequency and all those things without much difficulty.

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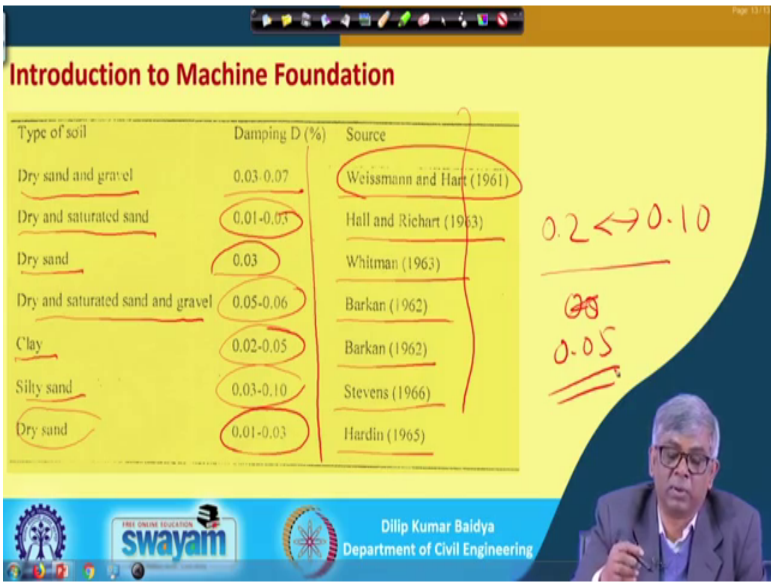

Now, as I have told you that your damping different material will have different damping and see there is a report is given here how the range of damping dry sand and gravel that material damping range between 3 to 7 percent and it is given by this person. Dry and saturated sand the material damping can vary between 1 to 3 percent that is given by him.

And, dry sand that will that you will have a material damping ranging up to maximum 0.3 percent it is given by Whitman. Dry and saturated sand and gravel the damping vary between 5 to 6 percent, it is given by Barkan, and the clay the damping vary between 2 to 5 percent, that is given by Barkan again. Silty sand damping between vary between 3 to 10 percent, it is given by Stevens. Dry sand, damping given 1 to 3 percent, that is given by Hardin.

So, that means, if I look at these. So, approximately 0.2 percent to 10 percent damping can be assumed if damping is not given for the analysis what I have told you that you need to know the mass which is equal to mass of the foundation plus machine then you need to know that stiffness; that means, which is equal to 4 G by 4 Gr by 1 minus mu that is actually for circular foundation. If it is non-circular foundation r can be obtained by equivalent circular area; that means, under root ab by pi and then you need to find out damping and damping value if it is not given, then we can find out something in the range of 2 to 5 approximately 5 percent. If you sorry approximately 05 if you assume that most of the time it will be useful.

So, and impact in machine foundation vibration another kind of damping is there which will be much more than this and which should be considered, but we are not discussing right now because that is required some more information. So, I am not going in that detail.

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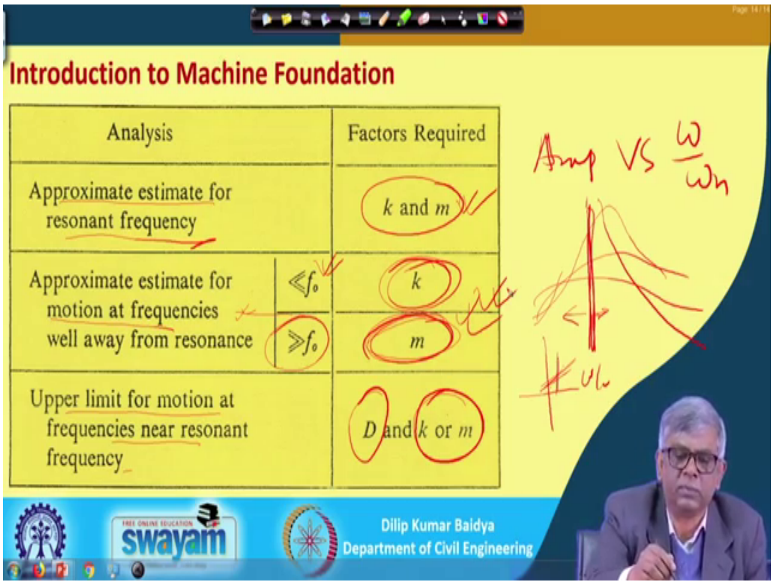

Next thing actually if you look at the response; that means, if you find out the amplitude versus omega over omega n and, you will see that when the we can approximately find out the resonance frequency, approximate estimate resonant frequency if you know the k and m though resonant frequency little bit little more or little high depending upon your forcing system, whether it s a constant force system or rotating mass system, so, we have seen that once resonance is if this is omega over omega n equal to 1, some responses are coming like this, ok. So, it is changing like this and for constant force system a resonance occurring before 1, actually frequency ratio 1.

So, that is what resonance frequency slightly away from the natural frequency sometime little more a little less, but if you want to find out approximately natural frequency, simply you know the k and m then you find out under root k by m that become the approximate natural frequency generally will get though the resonance frequency that your resonant frequency can be taken as natural frequency when damping is small. And, if it is damping is large I have given the relationship that can be used to find out correctly what is the resonance frequency.

Similarly, if you want to find out to approximate amplitude and to frequency resonance; if the operating frequency is very small then K is important because you have seen that at a very low frequency very low frequency that the amplitude whether damping is there or not almost same, all the curves are very close. So, because of that approximated estimate of motion actually when the frequency is very small K is most important and when actually frequency is very large, then actually for finding out the motion or calculate the m is important. The mass is more than a large frequency amplitude will be reduced actually, that is why it is important.

So, when large frequency machine the mass should be more; that is a guideline actually. And, if the upper limit of motion at frequency near resonant frequency actually when a resonant frequency you see that damping is the most important. If you put zero damping in theoretical infinite if you put 1 percent damping then significantly it will be reduce it will become finite value it will become 2 percent, 5 percent, 10 percent and then it will be reduced.

So, near resonance damping is most important and otherwise for some time and k and m also important because of depending upon whether it is a constant force system or rotating mass system. So, these are the observation actually from the, if you know the frequency verses amplitude that plot if you see these are the observation can be made and which can be used as a guideline for the design of machine foundation.

So, with this I will stop here.

Thank you.