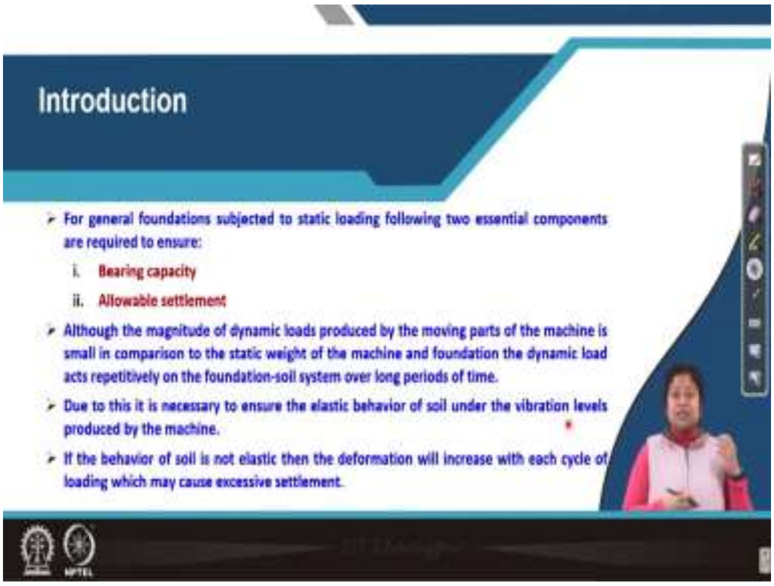
Soil Dynamics
Professor Paramita Bhattacharya
Department of Civil Engineering
Indian Institute of Technology Kharagpur
Lecture 36
Machine Foundations (Design Criteria)

Hello friends. So far in the course Soil Dynamics, we have studied the theory of vibrations, how to analyze the single degree of freedom system, multiple degree of freedom system, then how to determine the dynamic properties of soils by conducting different laboratory tests and the field tests. And then, last week we have discussed on soil liquefaction.

(Refer Slide Time: 01:11)

Now, from this week onwards, we will start to discuss on application of the knowledge which we have gained in last few weeks. So, where is the application? First application is machine foundations, analysis and design of machine foundation. So, today we will see that different design criteria which is required to meet when we are analyzing machine foundation or when we are designing the machine foundations alright.

(Refer Slide Time: 1:53)

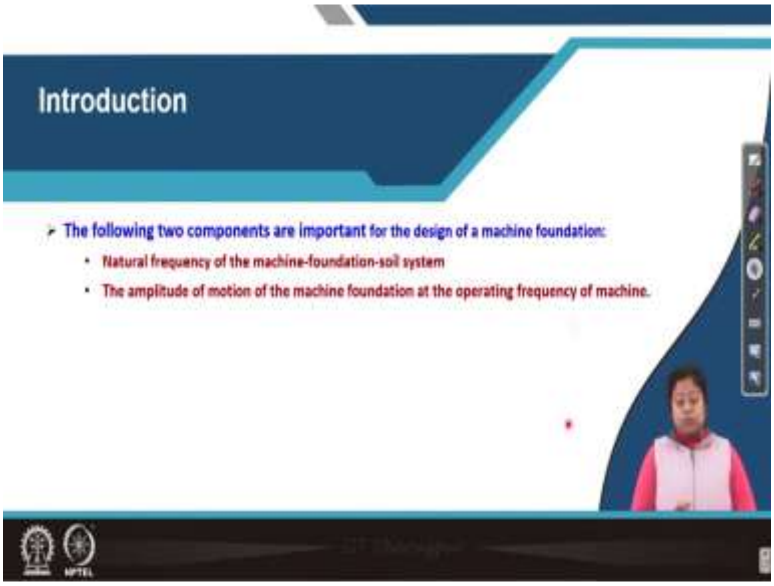


So, first we need to understand what is the difference? Where is the difference? Or what is the difference when a foundation is subjected to static loading and when it is subjected to dynamic loading. So, for general foundation, when it is subjected to static loading, we need to ensure 2 essential components what are those components first are bearing capacity and another important component is allowable settlement.

So, when we are designing foundation subjected to static loading, we need to ensure that it should not fail for bearing capacity and it should not exceed the allowable settlement. Although the magnitude of the dynamic loading is very small in comparison to the static weight of machine and the foundation, but the dynamic load acts repeatedly on the foundation soil system over a long period of time.

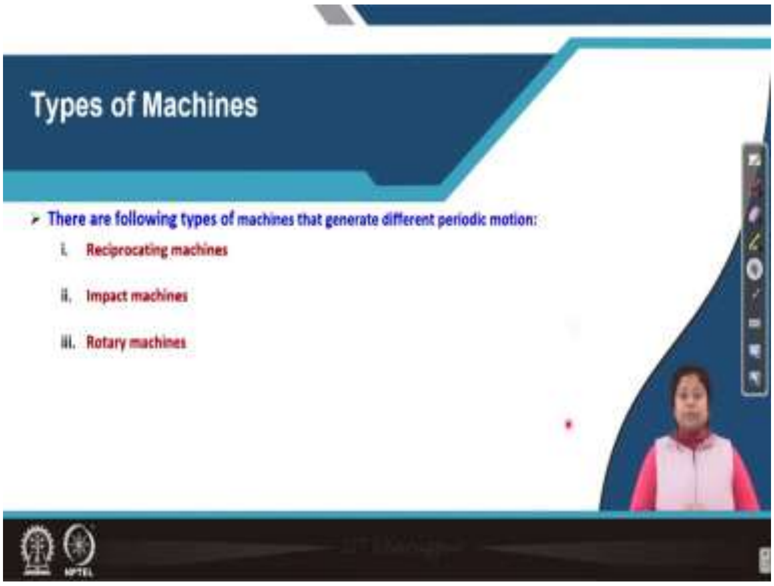
Therefore, what has happened due to these long event it is necessary to ensure the elastic behavior of soil under the vibration levels produced by the machine if we will not do so, then what will be happening then excessive settlement will be encountered why so? Because then deformation will increase with each cycle of loading and finally, it results and excessive settlement.

(Refer Slide Time: 3:55)



So, now, then what are the components for the machine foundations are required to check that there are 2 components which are important when we are designing machine foundation these are natural frequency of the machine foundation soil system. So, we will consider together the machine foundation and the soil and its natural frequency is a subject of our concern. Second important component is the amplitude of motion at the operating frequency of machine.

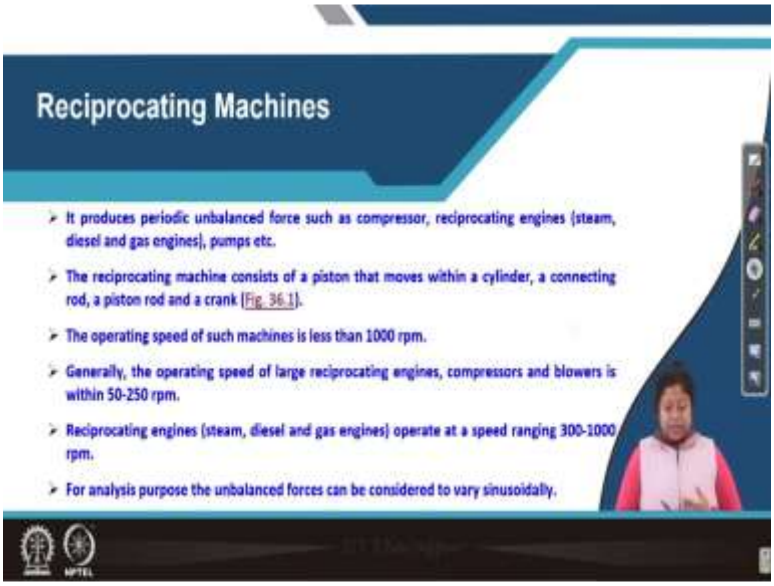
(Refer Slide Time: 04:43)

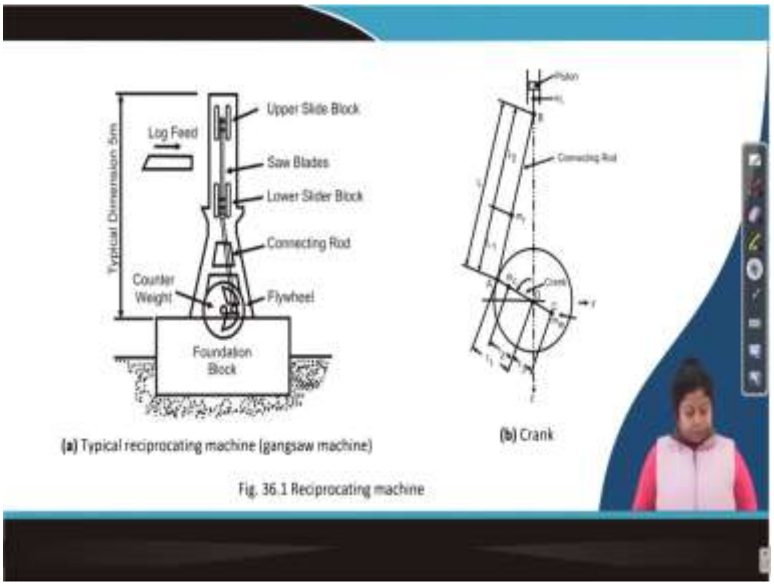


So, before seeing different types of machine foundations, it is important to know also what are the different types of machines that we encounter when we are designing the foundation for those machines.

So, there are following types of machines that generate different periodic motion, what are those one is reciprocating machines, impact machines and rotary machines. So, let us see the reciprocating machine.

(Refer Slide Time: 5:28)

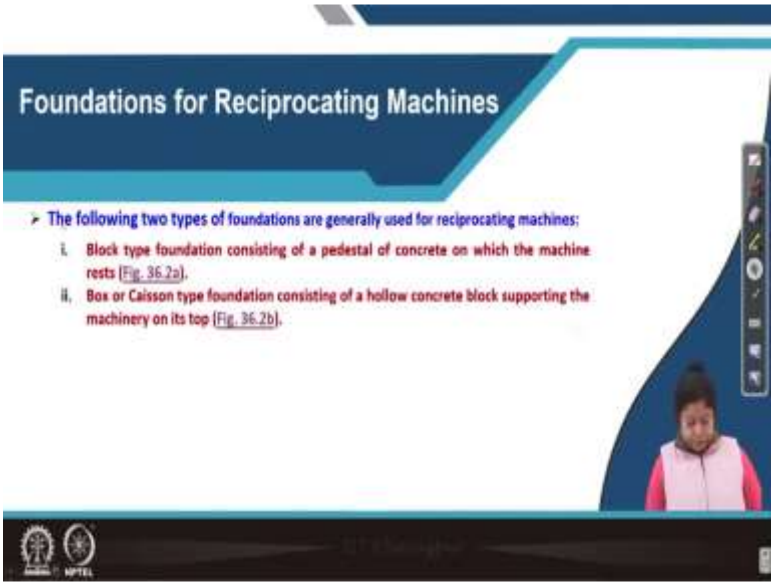


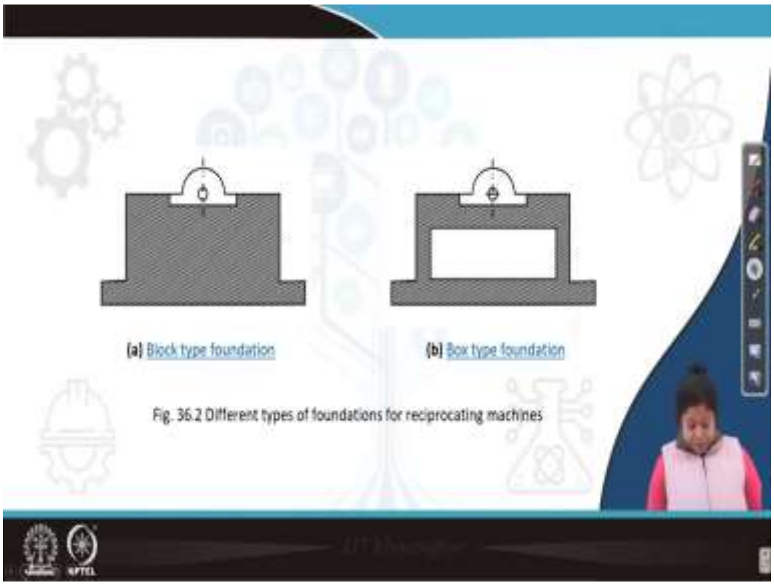


So, what is happening in reciprocating machines it produces periodic unbalanced force such as compressor reciprocating engines like steam, diesel and gas engines, pumps etc. Now, the reciprocating machine consists of a piston which moves within a cylinder and a connecting rod and a piston rod and a crank. So, let us see a typical reciprocating machine here. So, in this figure, you can see a typical reciprocating machine. And these machine you can see resting on the foundation block here in the figure B you can see the crank mechanism we will discuss it later also.

So, that what is the operating speed for this type of reciprocating machine? Generally the operating speed of reciprocating machines is less than 1000 RPM generally the operating speed of large reciprocating engines like compressors, etc. is within 50 to 250 RPM rotation per minute. Reciprocating engines like steam, diesel and gas engines operate at a speed ranging 300 to 1,000 RPM. So, for the analysis purpose, we need to check the unbalanced force. Now, in case of reciprocating machines for the analysis purpose the unbalanced force can be considered to vary sinusoidally.

(Refer Slide Time: 7:52)

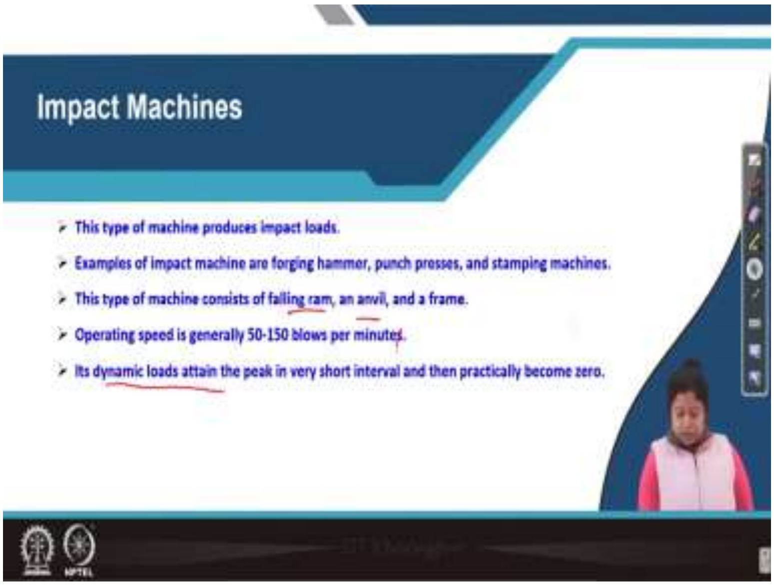




Now, let us see what type of foundations can be provided for reciprocating machines. There are 2 types of foundations that are generally used for reciprocating machines one is you can see blocked type foundation consisting of a pedestal of concrete on which the machine will rest so, let us see the figure. So, you can see here this is typical block type foundation over which a machine is resting.

Second type is box or caisson type foundation consisting of a hollow concrete block supporting the machinery on its top. So, here you can see this portion is hollow and this portion is solid. So, on the top of this box type foundation machine is resting.

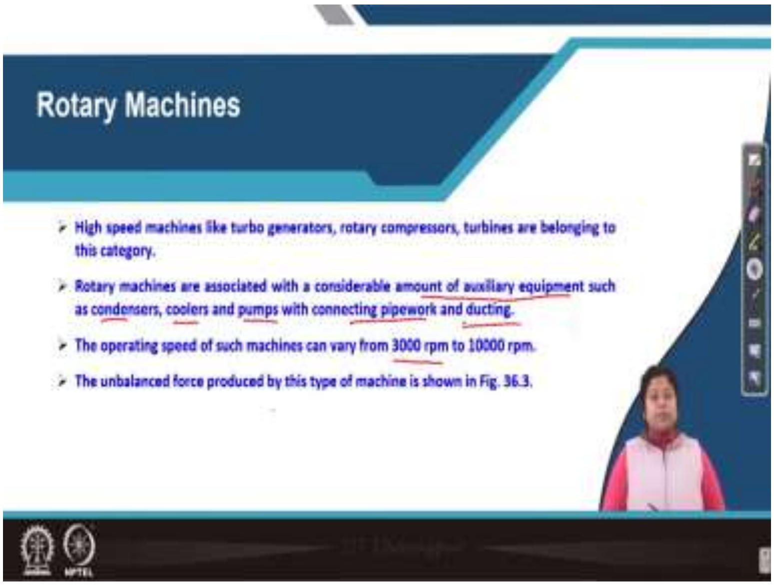
(Refer Slide Time: 9:18)

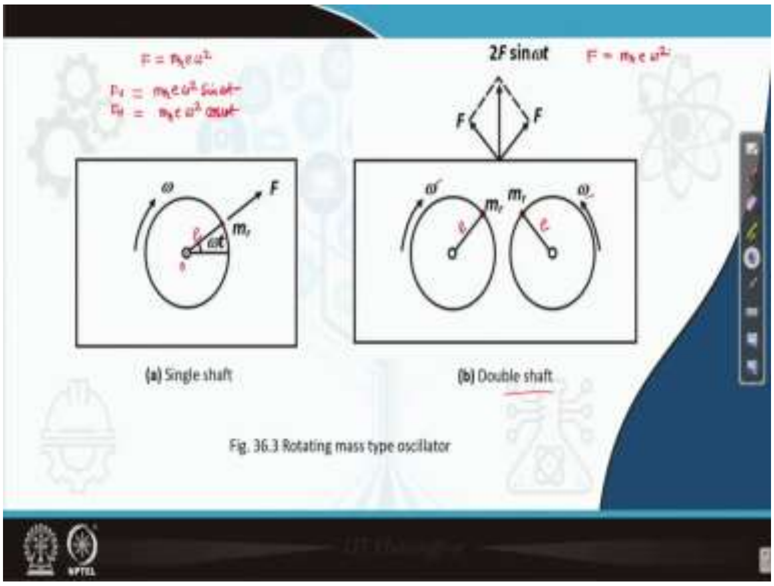


Now, the second type of machines which we encounter is impact machines, this type of machine produces impact loads, what is the characteristics of impact loads? These type of let us see the characteristic first basically these dynamic loads attain the peak in very short time interval and then practically becomes zero.

So, this is the typical characteristics of the impact load. Now, the examples of impact machines are forging hammer, punch presses, stamping machines etc. This type of machine generally consists of falling RAM and anvil and a frame. What is the operating speed? You can see here the operating speed of impact machine is generally 50 to 150 blows per minute, there is no s here.

(Refer Slide Time: 10:32)



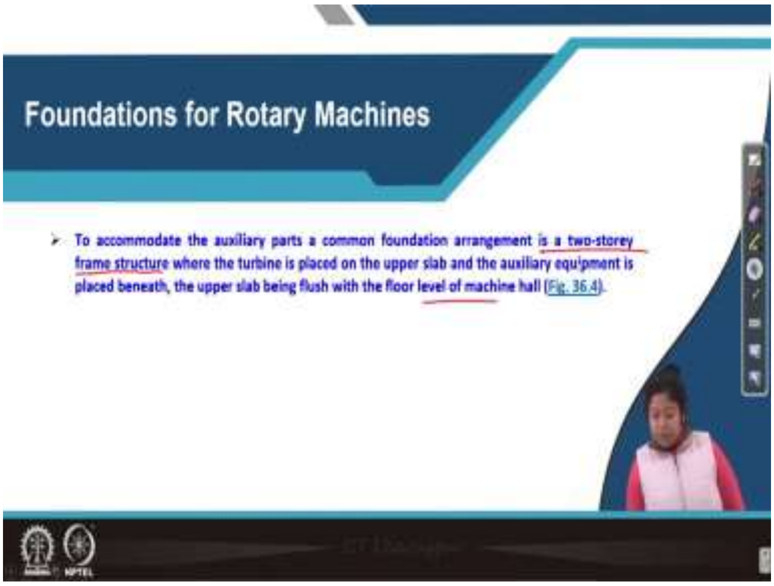


Now, let us see the rotary machines which also is encountered frequently when we design the machine foundation. So, this is high speed machines like your turbo generators, rotary compressors, turbines, etc. which are belonging to this category. Now rotary machines are associated with a considerable amount of auxiliary equipment and we need to keep space for that. What are those auxiliary equipment? One is condenser, then cooler, then pump, etcetera and those are connecting pipework and ducting.

So, entire things are required to rest on the foundation. So, for these types of machines generally we prefer frame type of foundation. So, what is the speed of rotary machines you can see it varies from 3000 RPM to 10,000 RPM, the unbalanced force produced by this type of machine is shown in next figure you can see here can be represented by F v for vertical component and F h for horizontal component now, what will be a F v then, F v is equal to a bar times e times omega squared times sine omega t whereas, F h is equal to m r times e times omega squared times cosine omega t.

Now, let us see the double shaft in this case, what we can see in this case, 2 equal masses m r you can see here mounted on 2 parallel shafts at the same eccentricity e and rotating these 2 shafts rotating in opposite direction with the same angular velocity omega then what is F here in this case F is equal to m r times e times omega square.

(Refer Slide Time: 13:37)



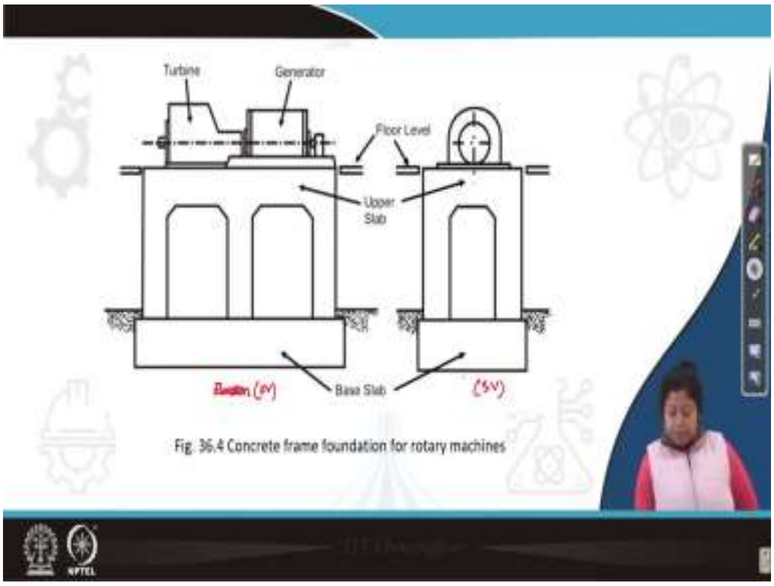


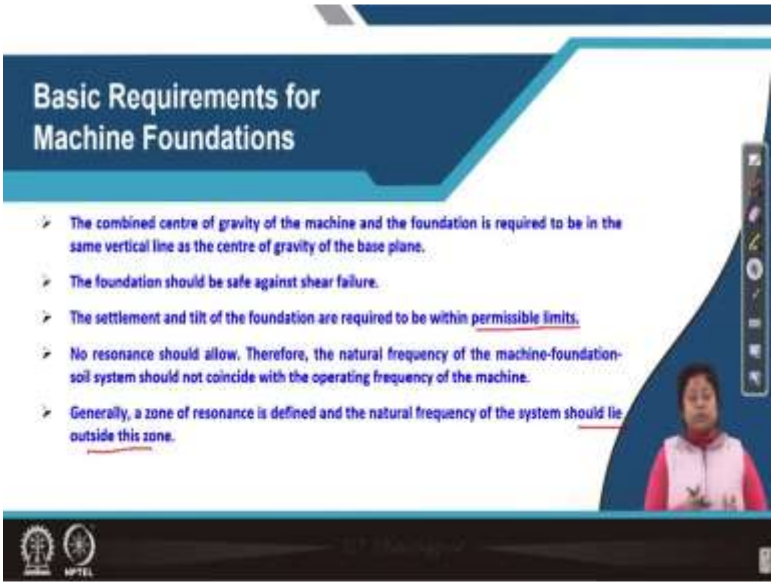
Fig. 36.4 Concrete frame foundation for rotary machines

Now, what is total unbalanced force in vertical direction that is, so, what type of foundations we will choose for these types of rotary machines. To accommodate the auxiliary parts which I have presented in previous slide what we used to do a common foundation arrangement is a

2 storey frame structure, where the turbine is placed on the upper slab and the auxiliary equipment is placed beneath, the upper slab being flush with the floor level of the machine hall.

So, let us see the configuration of this type of machine foundation. So, here we can see the machine is resting on the upper slab and upper slab is flush to the floor level and it is a frame structure. Now, what is the left hand figure and what is the right hand side figure? Basically, this is the elevation of the foundation. That means, I can say front view and this is the side view. So, here you can see this frame is resting on a base slab.

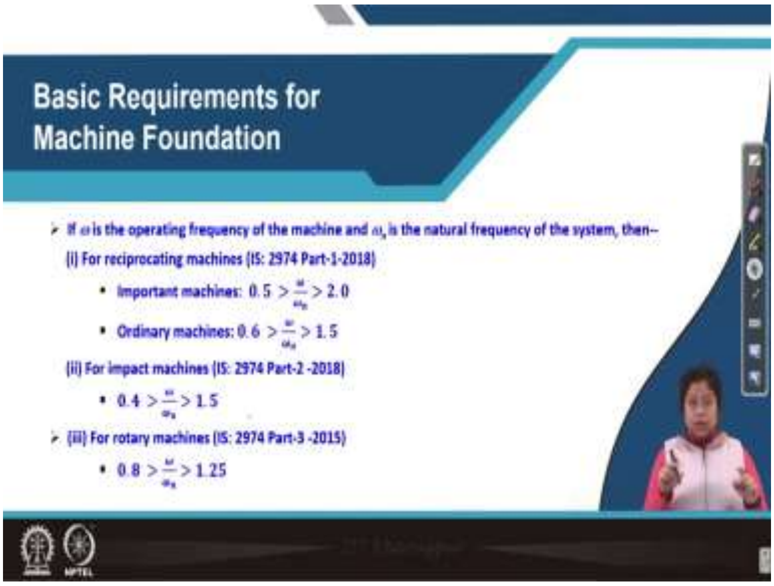
(Refer Slide Time: 15:07)



So, now, let us see what are the basic requirements of machine foundations. The first requirement is the combined center of gravity of the machine and the foundation is required to be in the same vertical line as the cg of the base plane. So, both the CG should be in the same vertical line. Second criteria is requirement is the foundation should be safe against shear failure the settlement and tilt of the foundation are required to be within permissible limits.

So, tilting and settlement may be allowed, but that should not exceed the permissible limits. The most important thing no resonance should allow therefore, the natural frequency of the machine foundation soil system should not coincide with the operating system of the machine for these generally a zone of resonance is defined and the natural frequency of the machine foundation soil system should not be reading that zone of resonance or in other words should lie outside this zone.

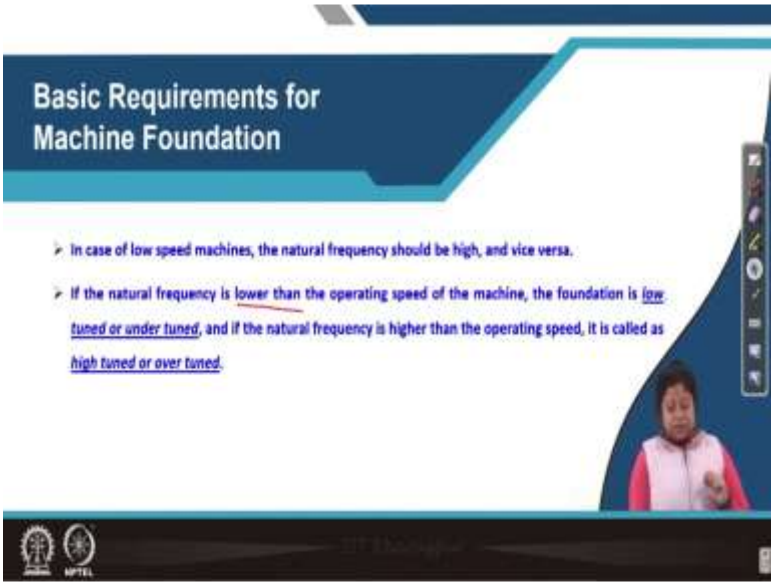
(Refer Slide Time: 16:55)



So, let us see what is the zone of resonance for different types of machine foundations. So, if omega is the operating frequency of the machine and omega m is the natural frequency of the machine foundation soil system then for reciprocating machine what is the resonance zone? If it is important machine then resonance zone is 0.5 to 2 that means, the ratio of omega by omega n either should be less than 0.5 or should be more than 2.

Now, if the machine is less important, then this zone of resonance is reduced in that case zone of resonance is within 0.6 to 1.5. What does it mean, it means that the frequency ratio which is omega by omega in either should be lower than 0.6 or higher than 1.5. For impact machine, what is the zone of resonance? For impact machine the zone of resonance lying in 0.4 to 1.5 that means, operating frequency to natural frequency or we can call it as the frequency ratio either should be lower than 0.4 or higher than 1.5. For rotary machine these frequency ratio either should lower than 0.8 or higher than 1.25. So, 0.8 to 1.25 is the zone of resonance for rotary machines for foundation.

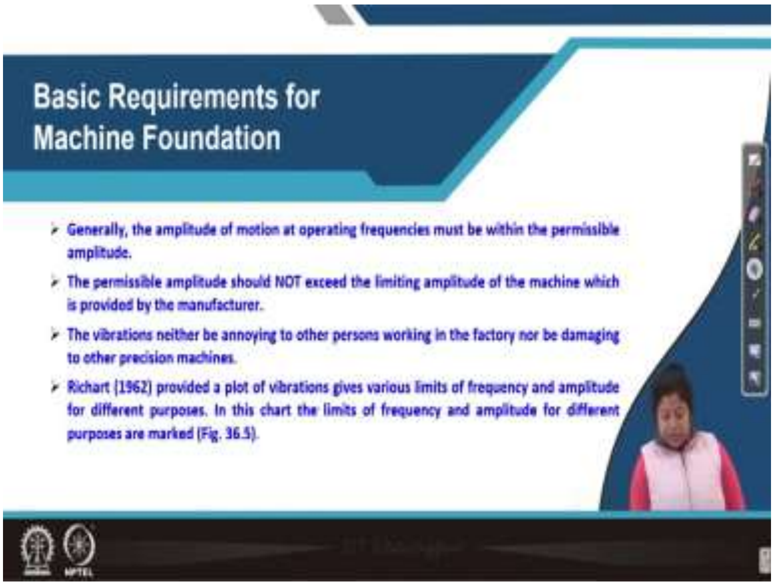
(Refer Slide Time: 19:18)

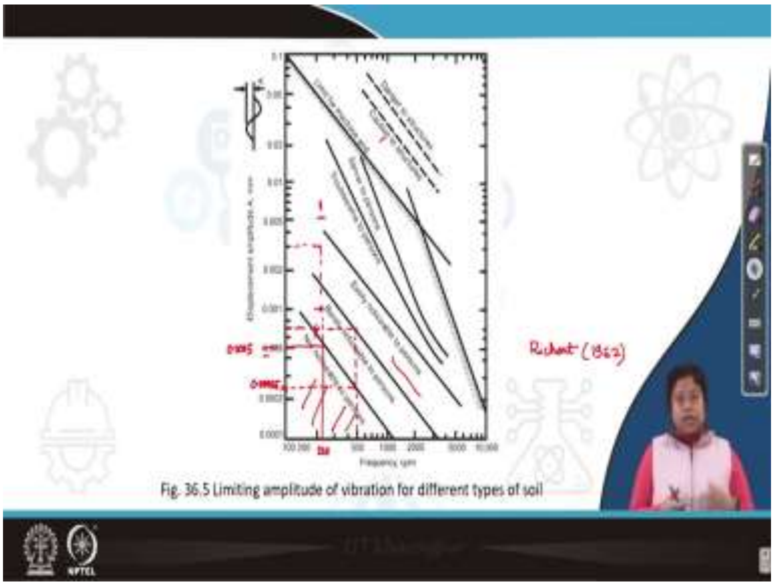


Now, in case of low speed machines the natural frequency should be high and for high speed machine the natural frequency should be low. This is a simple guideline when we are designing and analyzing the machine foundation. Now, when the natural frequency of the machine foundation soil system is lower than the operating frequency of the machine we call the foundation is low tuned or under tuned.

Now, if the natural frequency of the machine foundation soil system is lower than the operating speed of the machine the foundation is set to be low tuned or under tuned. Similarly, if that natural frequency of the machine foundation soil system is higher than the operating speed of the machine, then the foundation is said as high tuned or over tuned.

(Refer Slide Time: 20:58)





Generally, the amplitude of motion at operating frequencies must be within the permissible limit. So, the permissible amplitude should not exceed the limiting amplitude of the machine which is generally provided by the manufacturer. The vibrations neither be annoying to other persons working in the factory nor be damaging to other precision machines. Now, we can see a chart which is provided by Richard to give various limits of frequency and amplitude for different purposes.

In this chart the limits of frequency and amplitude for different purposes are marked. So, here is the chart which is provided by Richard in 1962. So, let us see this now, if we are expecting that the function of the machine is not noticeable to any persons then its frequency and amplitude should fall within this zone. So, this is the upper limit for this condition that means, suppose if the vibration… if the amplitude of displacement let us take it is 0.005 in millimeter that means, if I will draw this line and then from here I will drop a perpendicular on horizontal axis.

So, we will get the frequency and in this figure what is the frequency approximately I can see 220 CPM cycles per minute. So, for operating frequency to 20 CPM what is the maximum displacement that is 0.005 in millimeter which says that if operating frequency is this much and if it satisfy the amplitude up to 0.005 or below that then the system machine soil foundation system or I can say machine foundation soil system should not create any problem to any persons it is not at all noticeable.

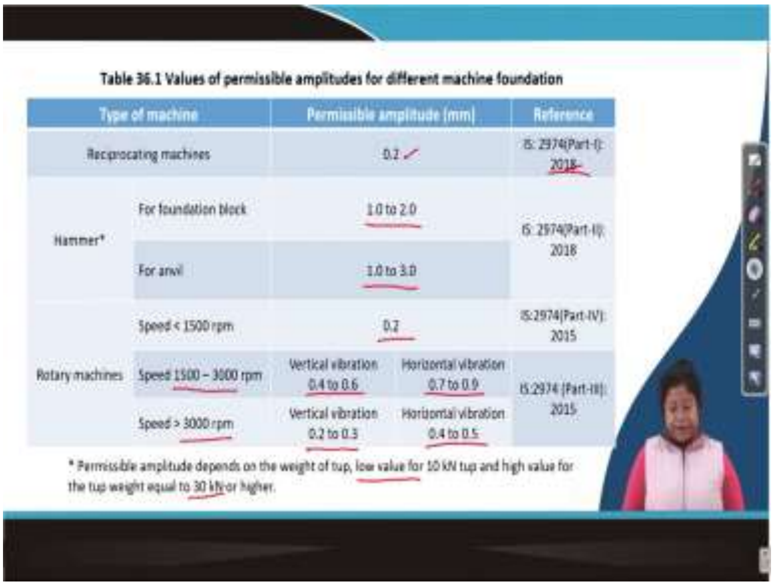
Now, if at the same operating frequency if the amplitude is different for example, we can take it as I think there is a mistake here let me correct it, it is not 0.005 but 305 please correct this figure so, I am repeating. So, for a machine operating at a speed 220 CPM, if the amplitude is reading 0.0005 in millimeter, then what will happen? Then it will not be noticeable to any person, but if the amplitude exceeds this value then for an example, if the amplitude reaches to 0.001 millimeter, then what will happen then it is no more not noticeable, but it will come under barely noticeable to a person that means, now, we are reaching to this zone.

Now at the same operating frequency if the displacement amplitude increases up to let us take 0.003 that means, here this is 0.003 then what will happen it is we can see this is easily noticeable to persons. So, in this way using Richart's chart we can see whether the thing is workable or not workable, whether it is alright or it is giving trouble to the society. For an example, we can take another case you can see here at the same operating frequency 220 if the amplitude exceeds 0.005 millimeter that means somewhere here higher than 0.005 millimeter, then what will happen it should be treated as troublesome to persons.

Now, in this chart you can see the limit of machine also provided the limit for danger to structures and caution to structures are also provided. So, first you can see here caution to structure that limit and then the limit for danger to structures. Another interesting thing for this chart is that if operating frequency increases then what happens, then the displacement amplitude should be low to make it all right to the persons or to the society. For an example, instead of 220 if the operating frequency is 500 CPM, then what is the permissible displacement amplitude.

So, that it should not be noticeable to persons you can see here in that case, we can drop a perpendicular on vertical axis, so, this value, so, this value is approximately 0.00025. So, in this way if it is barely noticeable that time also you can see this value is increasing now, it is somewhere 7 or 8. So, in this way, what we can see if operating frequency increases, then the permissible limits for the displacement amplitude or limiting amplitude of vibration reduces.

(Refer Slide Time: 29:34)



Now, in this table you can see the permissible amplitude for different machine foundation. So, if we are using reciprocating machine for that permissible amplitude is 0.2 in millimeter as per IS 2974 part one, which is published in 2018. Now, for hammer, we need to check 2 components for foundation block and for anvil. So, for foundation block permissible amplitude is 1 to 2 millimeter whereas for anvil the permissible amplitude is 1 to 3 millimeter, what is the speed sorry not speed, next is rotary machines.

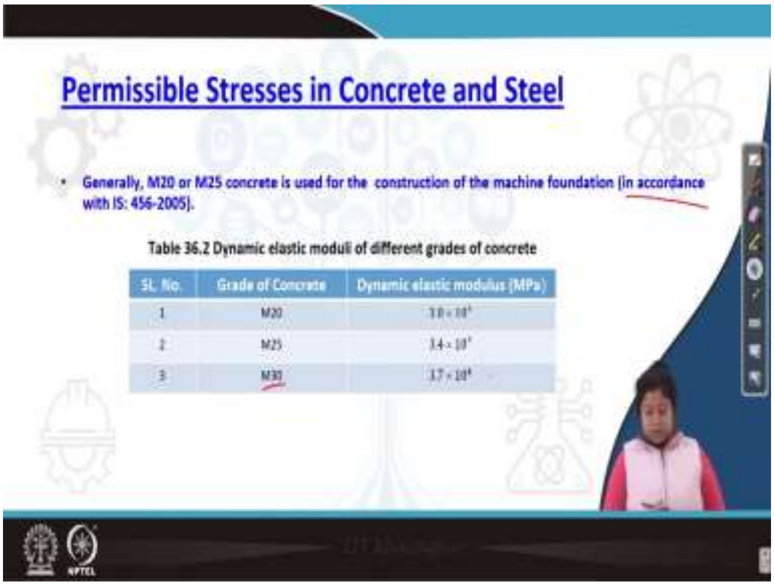
Now, Rotary machines are divided into 3 categories depending upon its operating speed. So, if the operating speed is less than 1500 RPM that means 1500 RPM, then the permissible amplitude is 0.2 millimeter, if the operating speed varies within 1500 to 3000 RPM, then vertical vibration should be within 0.4 to 0.6 millimeter, whereas, the horizontal vibration, permissible amplitude for horizontal vibration should be within 0.7 to 0.9 millimeter, that means, vertical vibration should not be more, but horizontal vibration may be slightly higher than the vertical vibration.

Now, if the speed of the rotary machine is higher than 3000 RPM rotation per minute, then that permissible amplitude for the vertical vibration is 0.2 to 0.3 millimeter and permissible amplitude for the horizontal vibration varies from 0.4 to 0.5 millimeter. Now, you can see here for hammer permissible amplitude depends on the weight of the tup also, if for low value 10 kilo Newton tup and high value we can see for the tup weight equal to 30 kilo Newton or more than that.

(Refer Slide Time: 32:34)

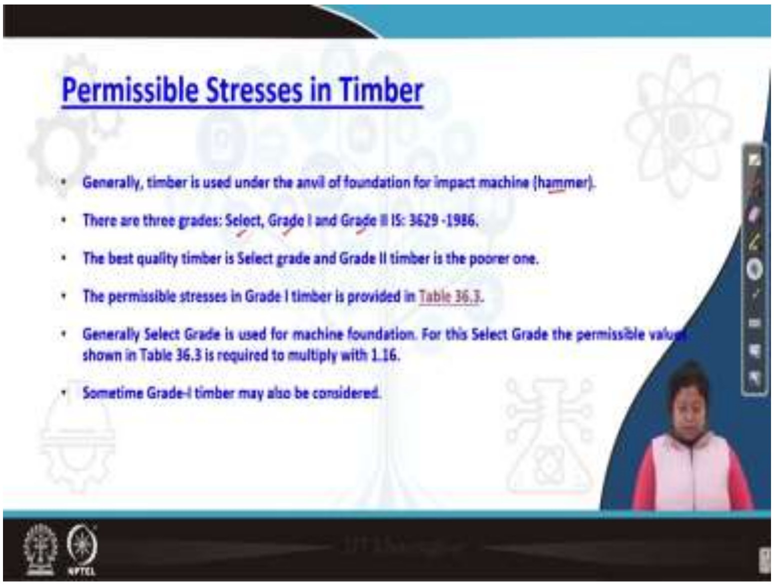
Now, the next important parameter is soil pressure or allowable soil pressure. The subsoil exploration and testing generally is essential in accordance with IAS 1904 published in 1986 to determine the allowable soil pressure, the stress in soil located below the foundation should not exceed 80 percent of the allowable soil pressure. Now, while considering the seismic forces the allowable soil pressure may be increased as specified in IS 1893 published in 2016.

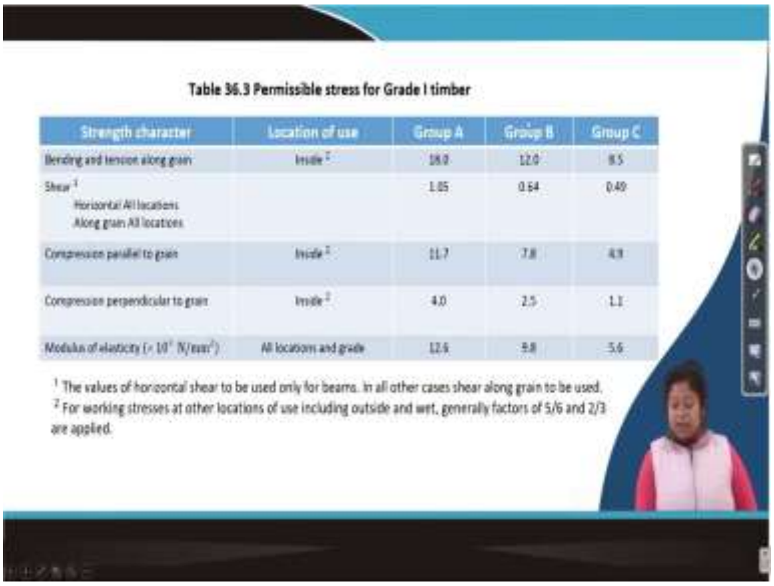
(Refer Slide Time: 33:32)



What is the permissible stresses in concrete and steel? Generally for machine foundation we use M 20 or M 25 concrete for the construction in accordance with IS 456 2005. Here you can see the dynamic elastic modulus of different grades of concrete for M 20 the dynamic elastic modulus is 3 into 10 to the power 4 in MPA for M 25 the concrete this dynamic elastic modulus is 3.4 into 10 to the power 4 MPA for M 30 grade of concrete the dynamic lasting modulus is 3.7 times 10 to the power into 10 to the power 4 MPA.

(Refer Slide Time: 34:35)





Now, sometimes we use timber below the anvil for impact machine for the foundation of impact machine like hammer. So, what type of timber we will use. Generally, 3 different grades of timber are available first grade is select which is the best quality there is no damage grade one which has some damage, but it is also very good quality, grade 2 which is poor quality. So, we should not go with the grade 2 at any reason.

Now, the permissible stresses in grade 1 timber you can see in table 36.3. So, let us see here. So, for grade 1 timber depending upon its group, group A group B or group C you can see the permissible stresses and here you can see the working stresses at… so, permissible stresses at the different locations basically are provided in this table.

Now, generally select grid as I said already is used for machine foundation and for that how do we get the permissible stresses whatever shown in table 36.3 if we multiply those value by 1.16 then we will get the permissible stresses for the select grade timber. Sometimes we may also use grade 1 timber.

(Refer Slide Time: 36:58)

So, now come to the summary of today's lecture. So, in this lecture, we have discussed different things which are related to the design of machine foundation, what are those things? First is types of foundation. And for that first we have studied what are the different types of machines and then what are the suitable foundations for those types of machines that we have studied?

Then we studied the basic requirements of the machine foundations. Then we have seen what are the values of permissible amplitudes under for different types of machines under different operating speed? We have also discussed the permissible stresses for these.

(Refer Slide Time: 38:00)

Here these textbooks and different IS codes are the references, 2 references I have list here. Because those references I have not cited here because those are not directly related to the material. So, thanks you next class we will discuss the different way to find out the natural frequency and amplitude of the machine foundation system by following different methods like elastic half space method and elastic weightless spring method. Thank you.