Foundation Engineering
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Module - 02
Lecture - 16
Machine Foundations - 4

Hello viewers, in the last class we saw that, how we can get a response of the block foundation, when it is subjected to the translation, in vertical direction and then rotation, in wide direction. So, in that sequence, let us start the another few mode of vibration, because they are necessary, the analysis of these vibration modes are necessary to know the equivalent soil spring constants. Such that, we can go ahead in the analysis of the block foundation.

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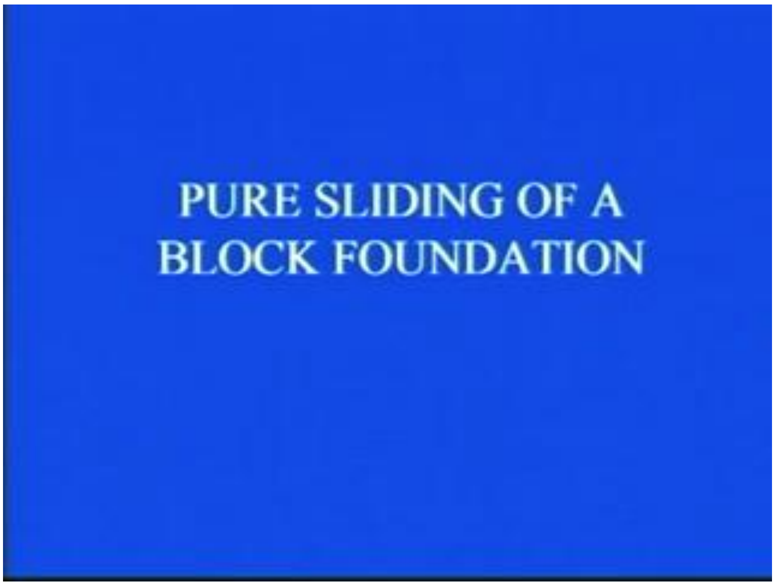

So, in that sequence, let us start that, how the block foundation is analyzed, when it is subjected to pure sliding.

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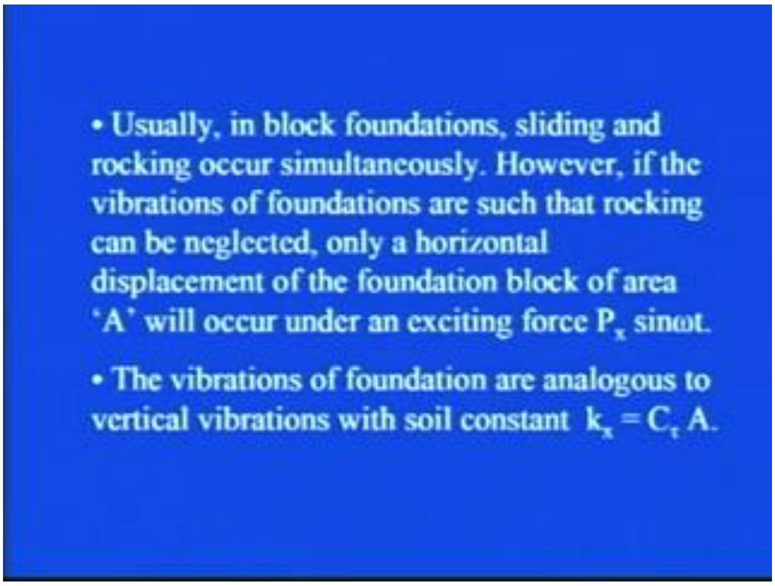

Usually, in block foundation, sliding and rocking occur simultaneously, however if vibrations of foundations are such that, that rocking can be neglected, only a horizontal displacement of the foundation block of area, A will occur, under an exciting force p x sine omega t. So, when we are talking of that sliding, so usually, sliding does not occur independently, sliding and rocking they occur simultaneously, but if we can assume that the rocking is quite less as compared to the sliding mode of vibration.

Then, in that case, the only the sliding can be considered under the exiting force, which is P x sine omega t. So, in this case, pure sliding means that, we are applying of translation force in x direction or along x direction and that force is P x sine omega t. So, the vibrations of foundation are analogous to vertical vibrations with soil constant k x is equal to C tau into A. When we were discussing that pure vibration in vertical direction of a block foundation, there we saw that, k z was equal to C u times A.

However, equivalent to that or analogous to that, in this particular case, when it is subjected to pure sliding, this soil constant k x will be C tau into A.

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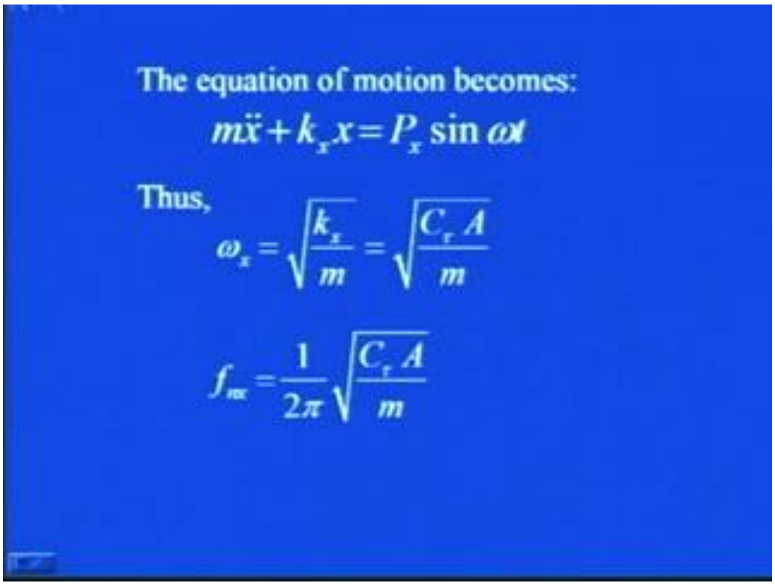

And then, exactly on the similar lines, the equation of motion will become, m x double dot plus k x into x is equal to P x sin omega t, where omega x is equal to square root of k x by m and k x. Just now, we saw that, we can represent it by C tau into A and then, this natural frequency can become, that is 1 by 2 phi into omega x, omega x you can substitute from this particular expression. So, your f n x, that is natural frequency in pure sliding of a block foundation will become, 1 by 2 phi square root of C tau A by m

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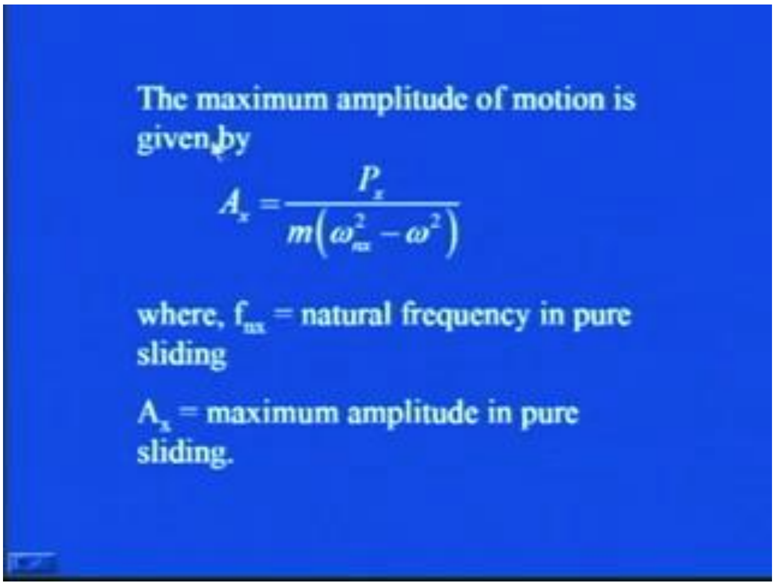

And, the maximum amplitude of motion will be given by, A x is equal to P x divided by m omega n x square minus omega square, where from omega n x, you can get f n x, that is f n x, which is natural frequency in pure sliding, A x is the maximum amplitude in pure sliding. So, exactly as we did for the case of pure vertical vibration, likewise here also we can get the corresponding values, then coming to yawing of a block foundation, as I explained to, explained you, that what exactly do we mean by the yawing.

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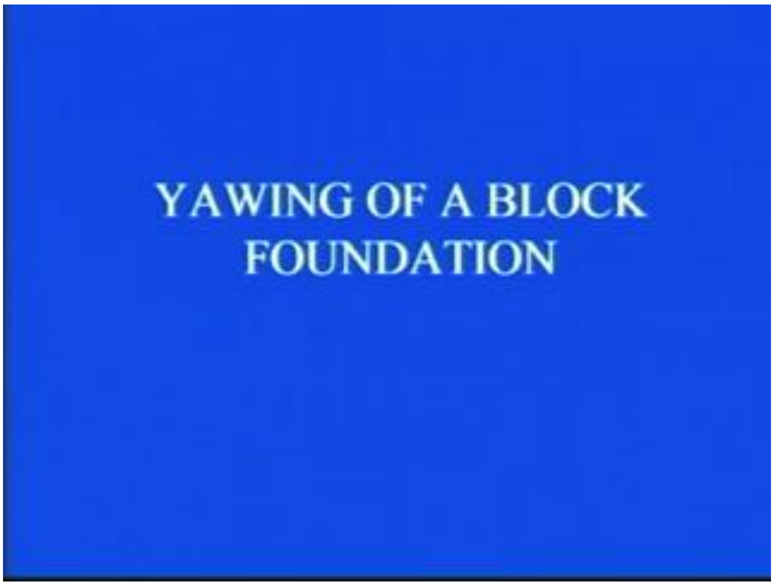

Yawing is the rotation along the vertical direction that is the Z direction.

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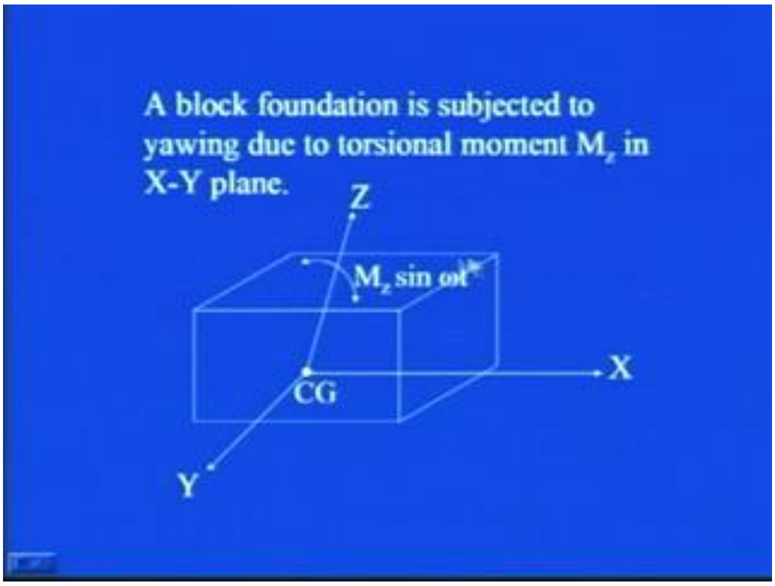

So, you can see here, that this has been shown, this block has been shown here and then, this is X axis, Y axis and Z axis and along Z axis, the rotation has been given, that is a moment has been given, that is of the magnitude of M z sin omega t. So, a block foundation is subjected to yawing, due to torsional moment M z in X Y plane, along Z axis.

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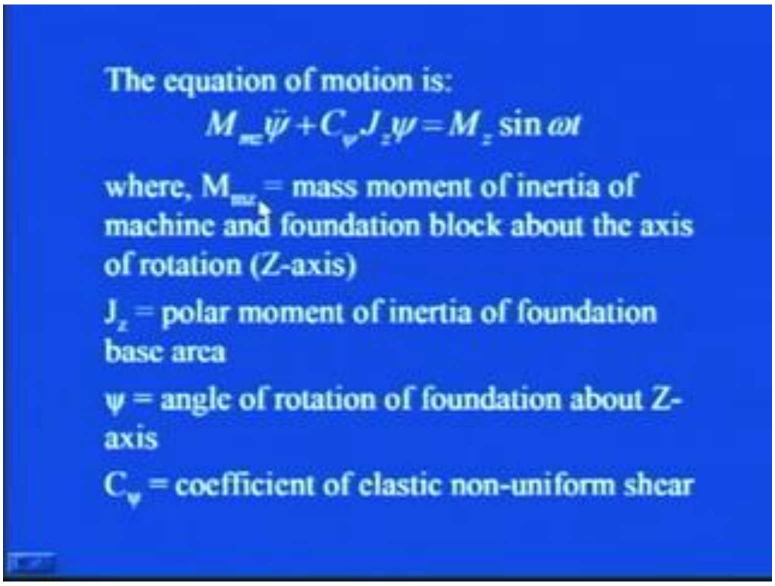

So, in that case, if it is rotating by an angle of psi, then it will become that M, the equation of the motion, as we did in case of pure rocking of the block foundation, exactly on those similar lines, this is for yawing. So, only the difference is that, it is now the moment has been applied along vertical axis. So the, when you take the moment equilibrium equation.

So, that will result into M m z psi double dot plus C psi J z psi, is equal to M z sin omega t, where M m z is mass moment of inertia of machine and foundation block about the axis of rotation, which is Z axis in this case. J z is polar moment of inertia of foundation base area, psi is angle of rotation of foundation about Z axis and C psi, you know, that, it is coefficient of elastic non-uniform shear. So, this equation becomes the equation of motion.

Now, we have to solve this equation to get the natural frequency, when the sub system is subjected to the yawing.

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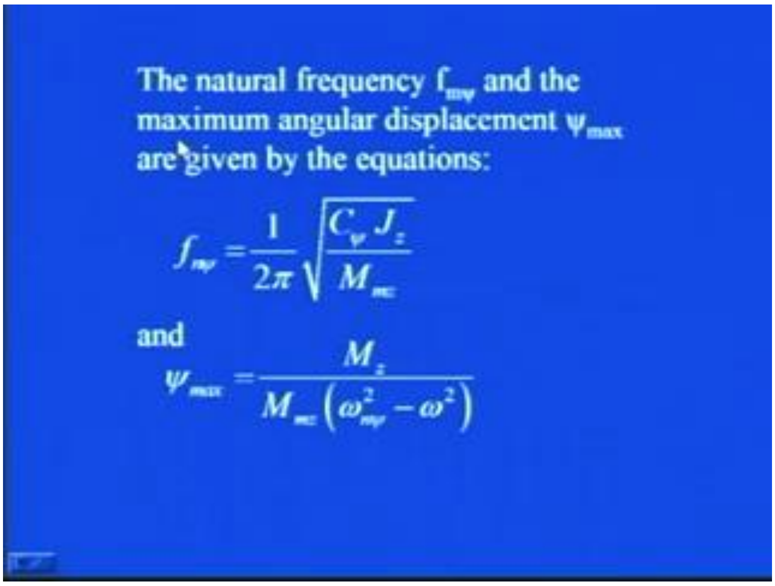

So, the natural frequency, f m psi and the maximum angular displacement, that is psi max, they are given these equations, that is f n psi is equal to 1 by 2 pi c psi J z by M m z, where J z and M m z, I have already told you, that what exactly do they mean and psi max is equal to M z divided by M m z into bracket omega n psi square minus omega square. So, this is how, you can get the response or the natural frequency and the maximum amplitude, under the block foundation, which is undergoing only yawing.

That is, the rotation about the vertical axis.

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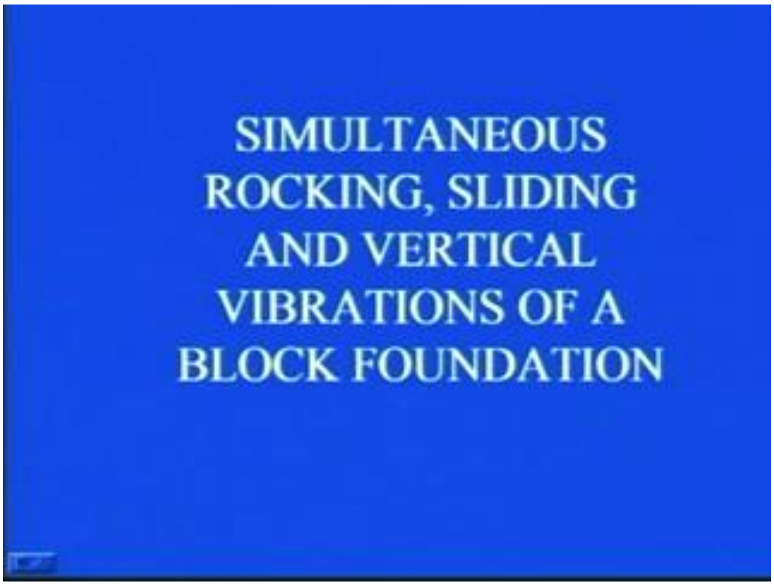

Then, as I told you that, there are coupled motion, right now we discussed that, pure vertical vibration, pure rocking, then pure sliding and then, we discussed pure yawing, now, what happens, when they act simultaneously. So, let us try to see, that how you can go for the analysis of simultaneous rocking, sliding and vertical vibrations of a block foundation. See, this, since it is the simultaneous three type of motion, that is rocking, sliding and vertical.

The analysis becomes quite complicated, which is beyond the scope of this particular course, however, I will just tell you, that how you can, what exactly is the procedure or how you can step ahead, while you analyze such type of situation that you must know. However, we will not be going into much detail of the mathematical formulation of equation of motion and their solution.

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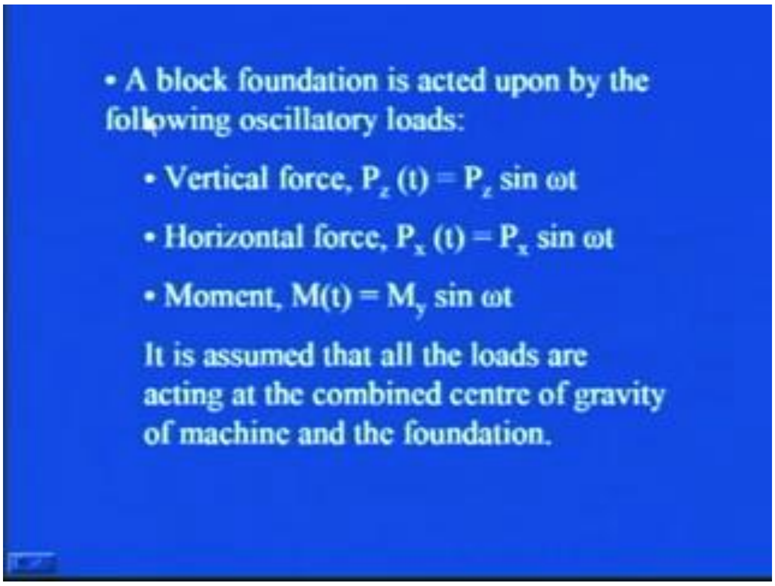

So, in this case, a block foundation is acted upon by following oscillatory loads, that is, vertical force, which is P z, that is a function of time, as P z sin omega t. Then, horizontal force P x is, which is a function of time is equal to P x sin omega t and then, a moment, that is M y sin omega t. So, you see, this vertical force will cause the vertical translation, this horizontal force will cause the sliding and this moment, which is about Y axis will cause the rocking.

So, these three forces, when they act simultaneously, the simultaneous process of vertical translation, sliding and rocking will take place. It is assumed that, all the loads are acting at the combined center of gravity of the machine and the foundation. So, the line of action of all these three forces, they are coinciding with the combined c g of machine and the foundation.

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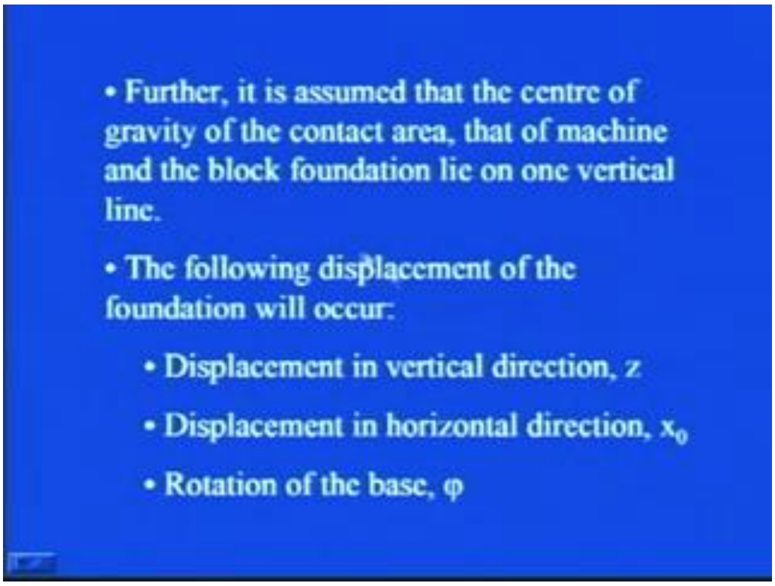

Further, it is assumed that, center of gravity of the contact area and that of machine and block foundation lie on one particular vertical line, because, if there is some eccentricity, then the situation will all together be different, the mode of vibration will be changing. So, we see to it, that there is no eccentricity present in the system as far as loading is concerned and that is why, the line of action of the load and c g of the machine and the foundation, we try to see to it, that they lie on the same vertical line.

Then, the following displacement of the foundation will occur, that is the displacement in vertical direction, because the system has been subjected to a force in the vertical direction, which was P z sine omega t. Then, displacement in horizontal direction, which we are calling as x naught and that is, due to the horizontal force, that is P x sin omega t and then, rotation of the base due to the moment which has been applied along Y axis, which is M y sin omega t.

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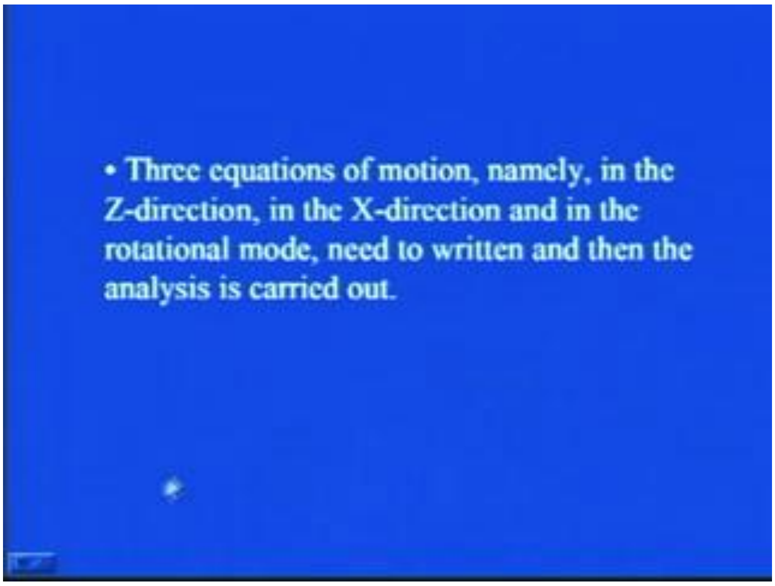

Then, these three equations of motion, namely, in Z direction and in X direction and in rotational mode, need to be written and then the analysis is carried out. See, earlier when we are talking of purely one type of vibration mode, you get only one type of equation of motion, only one equation of motion, solution of which is quite easy. However, when you have the system of equation, like three equations in this particular case, the analysis become little complicated and that is why, we are not discussing it, right now here.

But, then, you must know that, how you, what exactly are the forces, what are the mode of vibration and how you can write the equation of motion separately and then, how you can combine them.

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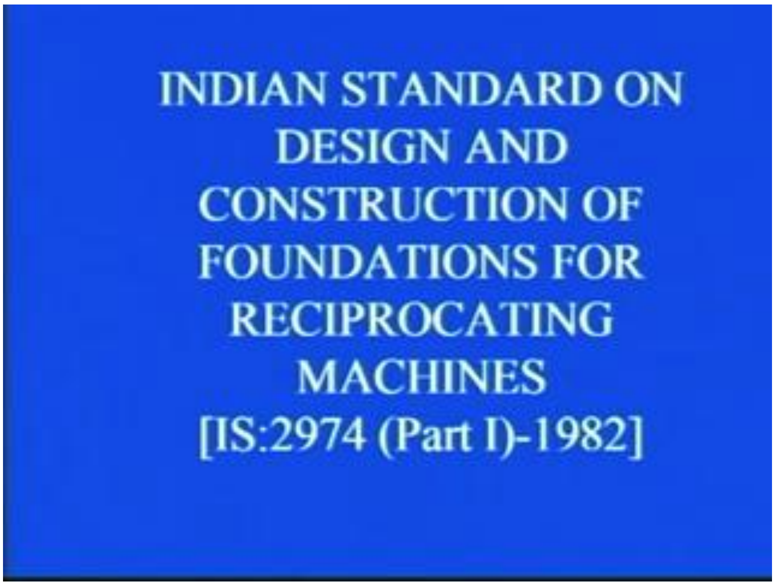

Now, let us try to have a look, on the Indian standard of code of practice, what exactly it says about the design and construction of foundation for reciprocating machine. The code which deals with this is, that IS2974 part 1 1982.

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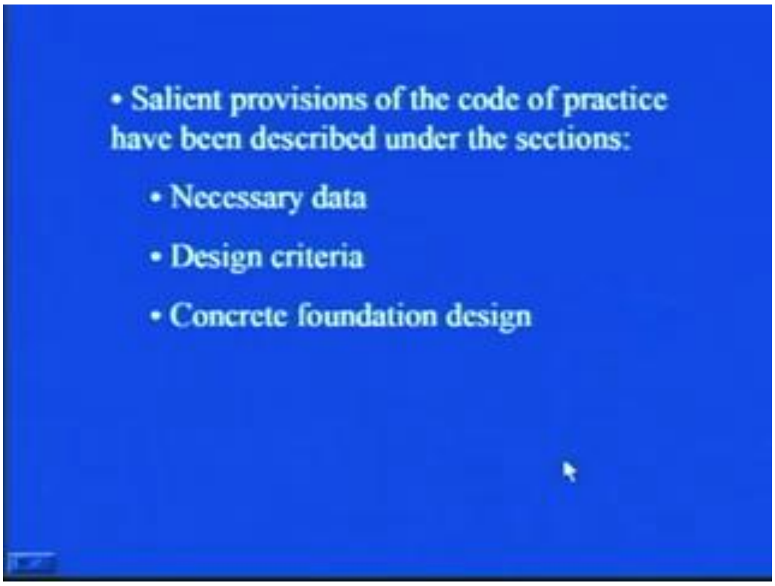

The salient provisions of the code of practice, have been described under these particular sections, they are necessary data and then design criteria and after that, concrete foundation design. So, we will try to see that, what exactly is the necessary data which we require for the design and construction of the machine foundation, what is the design criteria, that we need to keep in mind while going for the design of machine foundation and when we go for this concrete foundation.

Then, what are the method that, we have to choose for the design of concrete foundation. So, we will see, one by one all these three sections.

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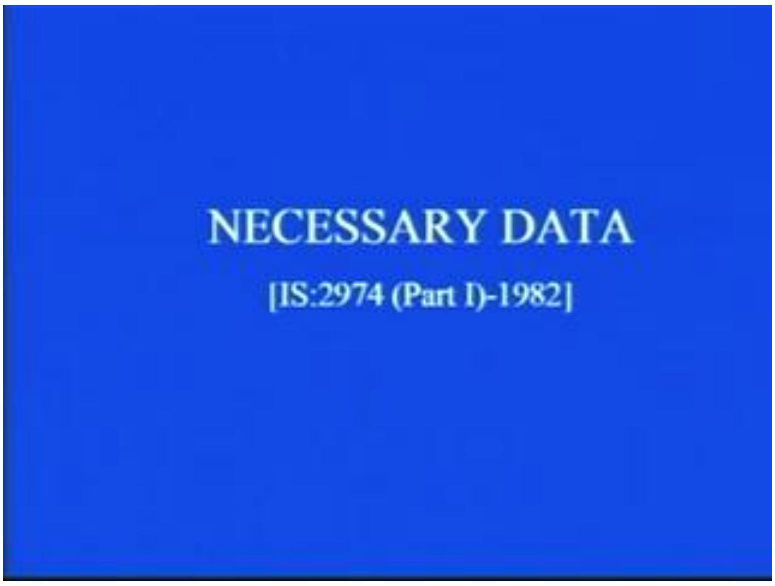

First, let us try to start with necessary data and the, all the source is that IS 2974 part 1 is 1982.

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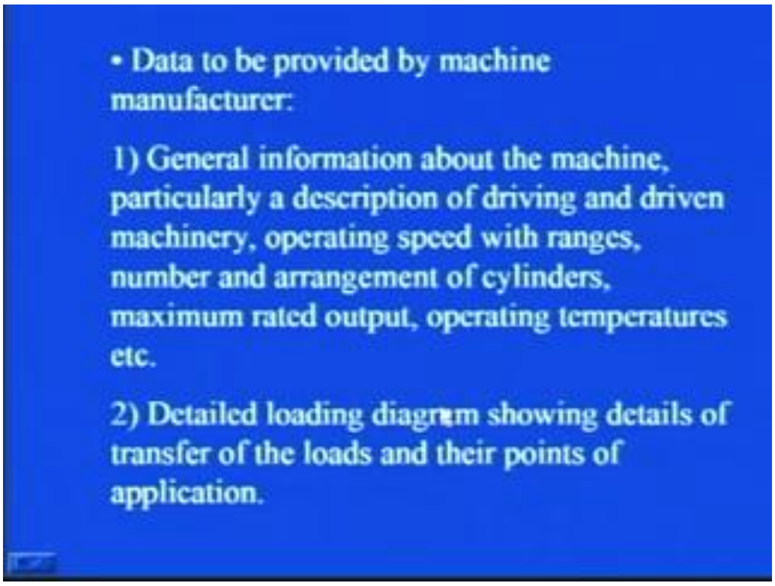

Now, what are the necessary data, so, see the thing is that, some of the data which the manufacturer of the machine has to provide us, so what are those data. So, data to be provided by machine manufacturer, is the first one is, general information about the machine, particularly a description of driving and driven machinery, operating speed with ranges, number and arrangement of cylinders, maximum rated output, operating temperatures etc.

So, these are the data, which when the machine is being constructed, that the, that particular manufacture keeps in mind and these data, to be provided by the manufacture of the machine. Then, detailed loading diagram showing details of transfer of loads and their point of application.

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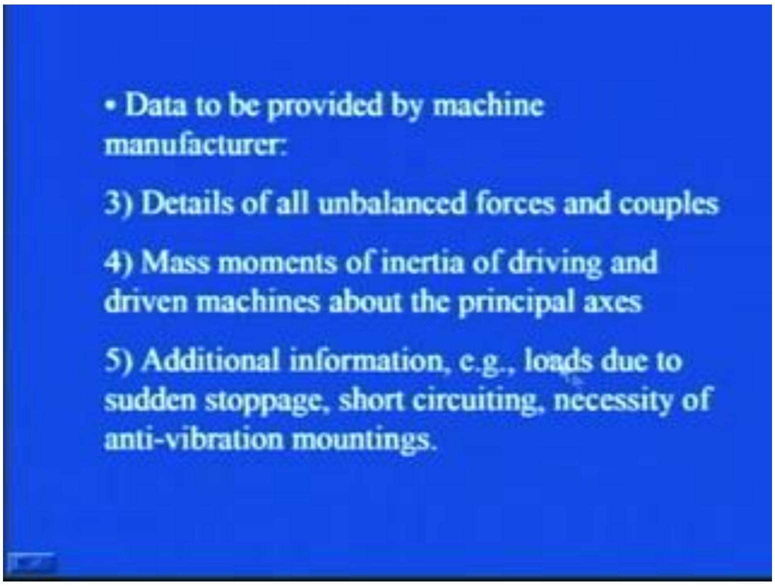

Then, the details of all unbalanced forces and couples, so when you are designing the foundation, then all the forces which are present there, that needs to be known. In the absence of this particular data, let us say that, when you were analyzing or designing the foundation, this data was not known and there is the presence of some unbalanced forces and couples and once the machine is operating, then all these unbalanced forces, if they are coming to the foundation, then they may cause and or they may make the foundation unstable.

So, these data is very important, that we should get from thus manufacturer of machine. then, mass moment of inertia of driving and driven machines about the principal axes.

Further, additional information for example, loads due to sudden stoppage, short circuiting and necessity of anti-vibration mountings, if any. So, all these data that machine manufacturer should provide to us.

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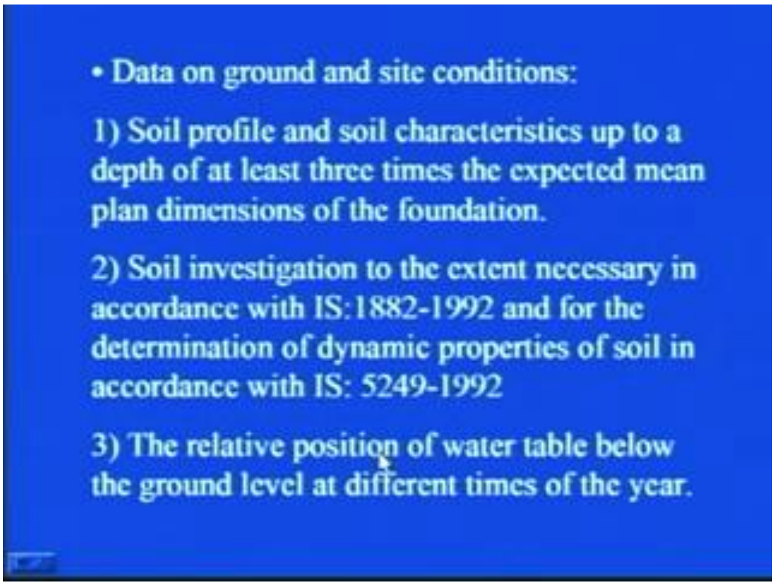

Now, some of the necessary data, which we should have on ground and site conditions, what are they, let us try to see. Soil profile and soil characteristic up to a depth, of at least three times the expected mean plan dimension of the foundation. So, let us say, that the foundation area or the dimension of the foundation in plan is say, two meter by two meter, so it says that, we must know the soil profile and soil characteristic, up to a depth of three times the foundation dimension.

So, if it is two by two, that means that, below that, wherever we will be placing the foundation, below that, that is six meter soil strata and it is characteristic should be known to us. Then, soil investigation to the extent necessary, in accordance with IS 1882-1992 and for the determination of dynamic properties of soil, in accordance with IS 5249-1992. So, whatever is the extent, that we need to go for like, if we take two by two size foundation, then we need the foundation six meter strata.

So, for that particular strata, we must know that, what exactly is the type of soil and what are the various soil investigation, that needs to be carried out as per the IS code 1882 1992 and then, when we were discussing about this soil spring constant, so all those constant also, we must have before, we go for the analysis and design of this block foundation as per IS 5249 -1992. Then, the relative position of water table below the ground level at different times of year.

So, as you know that, water table really affects the performance of the foundation, so it is position, if there is any variation in the position throughout the year, that also should be known to us.

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Then, this was the necessary criteria, which we required from manufacturer side as well as, from on ground and site characteristic. Now, we will see, some of the design criteria, as per IS 2974 part 1 1982, as far as, the design of block foundation for reciprocating machines are concerned.

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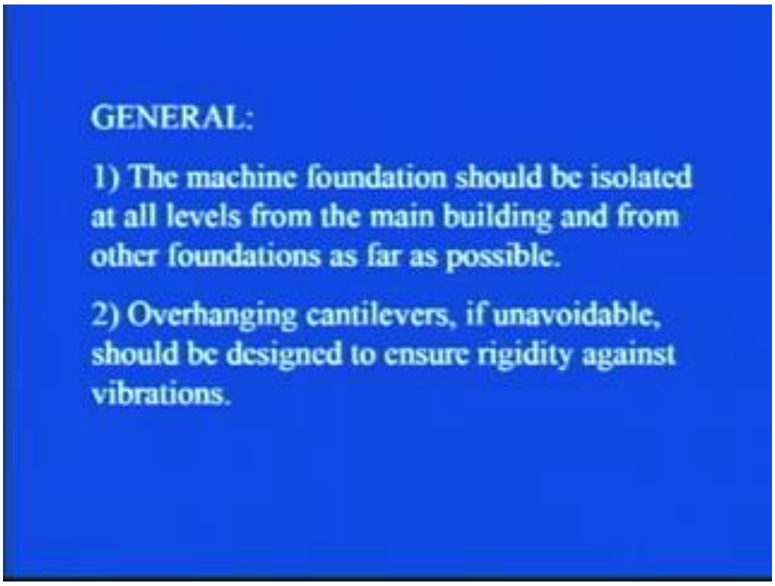

So, this also has been further divided into few category, so first, let us try to see, that what exactly are the, some of the general guidelines for this design thing. The machine foundation should be isolated at all the levels, from the main building and from other foundations as far as possible, because machine foundation is subjected to static as well as dynamic loads and it may happen that, it is subjected to lot of vibration. So, that is why, it has to be separated out or the isolated, at all the levels from the main building and the foundation of other structures.

Then, second one is overhanging cantilevers, if unavoidable, should be designed to ensure rigidity against vibration. So, first of all, this overhanging cantilever should be avoided and, but, if the condition is such that, that they are unavoidable, then the rigidity should be like that, that it should be, it should not, it should not be quite flexible against the vibration. So, whatever is the rigidity is required, that should be provided to these overhanging cantilevers.

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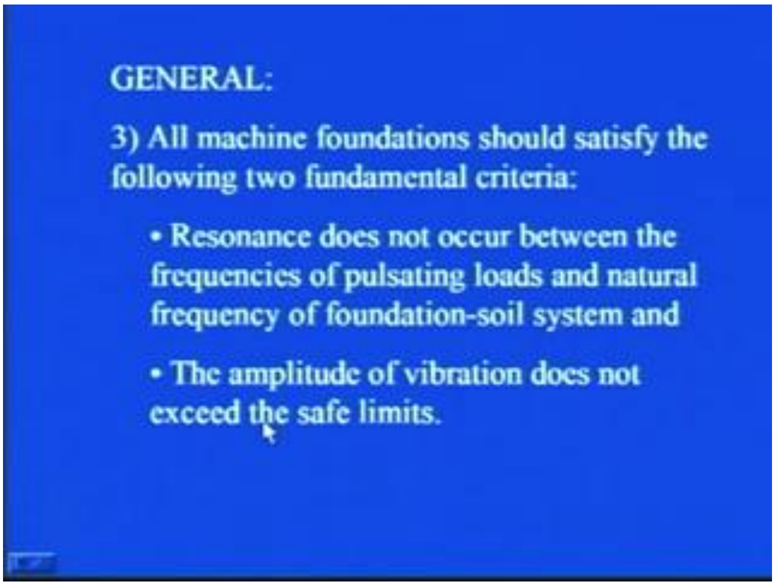

Then, the third one is, all machine foundations should satisfy the following two fundamental criteria, one is resonance does not occur between the frequencies of pulsating loads and natural frequency of foundation soil system, because you know, that at resonance, the amplitude is almost infinite. So, usually, we avoid this resonance, so this resonance should not at all occur between these frequencies of loads and the natural frequency of foundation soil system.

And the second one is, the amplitude of vibration does not exceed the safe limits, you know that, as the two conditions were there, for a static loads also, that, it should be safe against shear failure and the settlement should be within permissible limit. So, likewise, in this machine foundation, since they are subjected to dynamic loads, so the condition become little different, that is, the resonance should not occur and the second one is the amplitude of vibration should not exceed the safe limits.

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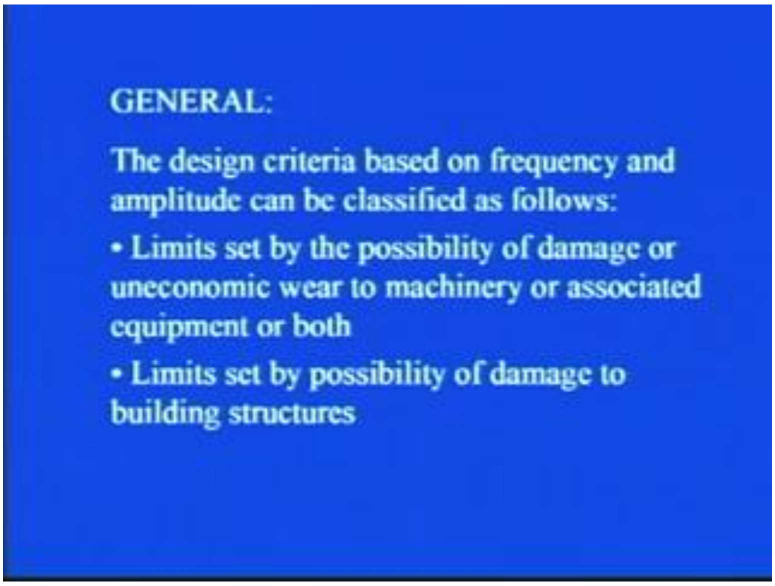

Then, the design criteria based on frequency and amplitude can be classified as follows, that limits set by the possibility of damage or uneconomic wear to machinery or associated equipment or both. So, there should be some limitation, that should be set for the possibility of damage of machine or uneconomic wear to machinery or the combination of both. Then, limits set by possibility of damage to building structures.

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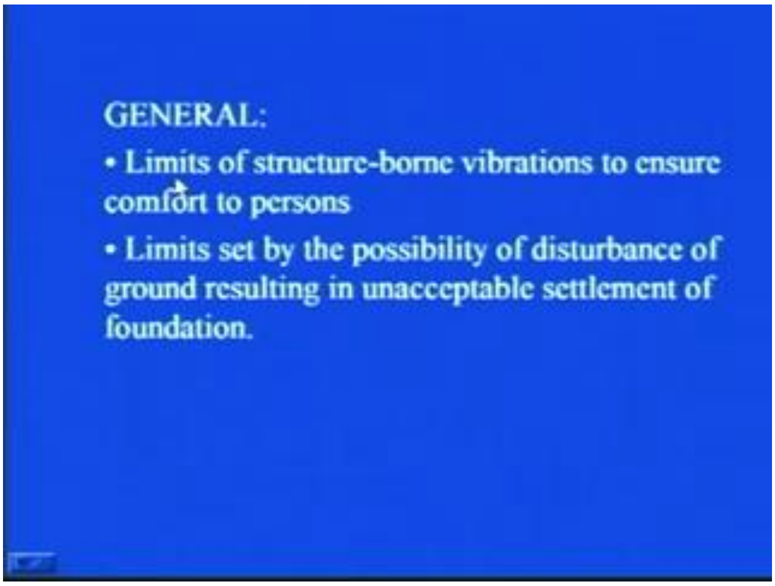

Third is, limits of structure-borne vibration to ensure comfort to persons, because, whatever is the vibration, it should not cause discomfort to the persons who are working around there or who are living over there, so that limit should be set. Then, limits set by the possibility of disturbance of ground resulting in unacceptable settlement of foundation. As I told you, that the settlement, be it under static load or dynamic load should be within permissible limit.

So, there should be some limit for this particular settlement and the settlement which is being caused by the foundation under the load, that is the static as well as dynamic load, must not exceed this permissible limit. Then, some of the guideline related to frequency ratio.

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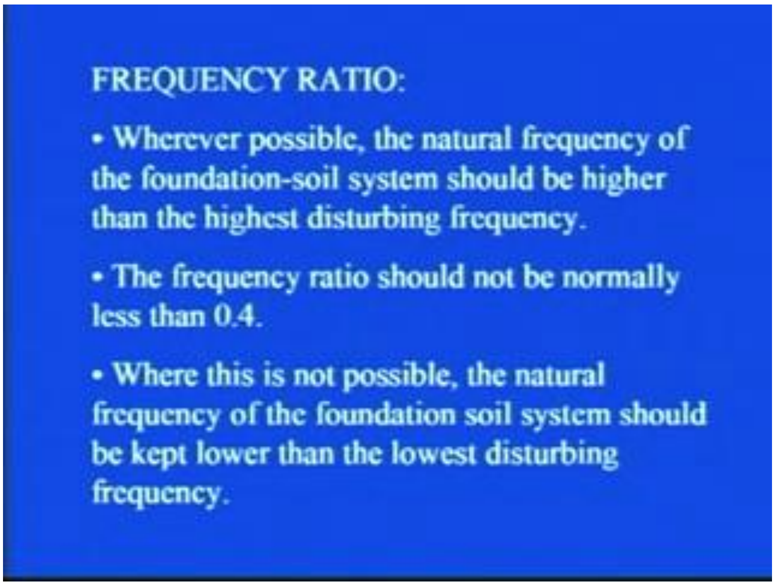

Wherever possible, the natural frequency of the foundation-soil system should be higher than the highest disturbing frequency. As you know that, to avoid the resonance, the natural frequency or the frequency of the soil operating frequency should not be equal to the natural frequency of the soil foundation system. So, here, the natural frequency of the soil foundation system should be kept always higher to the highest disturbing frequency. Because, if the natural frequency of the soil foundation system is more than the highest disturbing frequency, obviously, the resonance condition will never be reached.

The frequency ratio, should not be normally less than 0.4, where this is not possible, the natural frequency of the foundation soil system should be kept lower than the lowest disturbing frequency. So, it should be either, higher to the highest possible disturbing frequency or it should be, lower to the lowest possible disturbing frequency, so these two things we must keep in mind.

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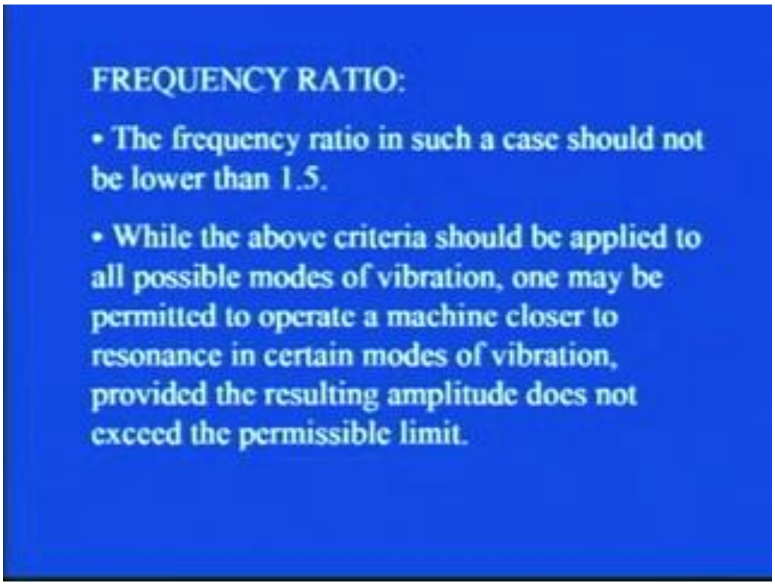

The frequency ratio in such a case, should be lower than 1.5, so in case, ((Refer Time: 22:50)) this frequency, natural frequency of the foundation system is higher than the highest disturbing frequency. In that case, frequency ratio should normally be less than 0.4 and in another case, the frequency ratio should be lower than 1.5, while the above criteria should be applied to all possible modes of vibration.

That is, whether it is, translation or the rotation about either of the axis, one may be permitted to operate a machine closer to resonance in certain modes of vibration, provided the resulting amplitude does not exceed the permissible limit. You see that, since there are four independent type of vibration of mode, so it may happen, that in one particular mode of vibration, the you may achieve a condition which is near the resonance.

You can allow that, except for the fact that, in that particular case, the settlement or the deformation should never exceed the permissible limit. If it is not crossing, you can go till that particular frequency, which is near the resonance condition.

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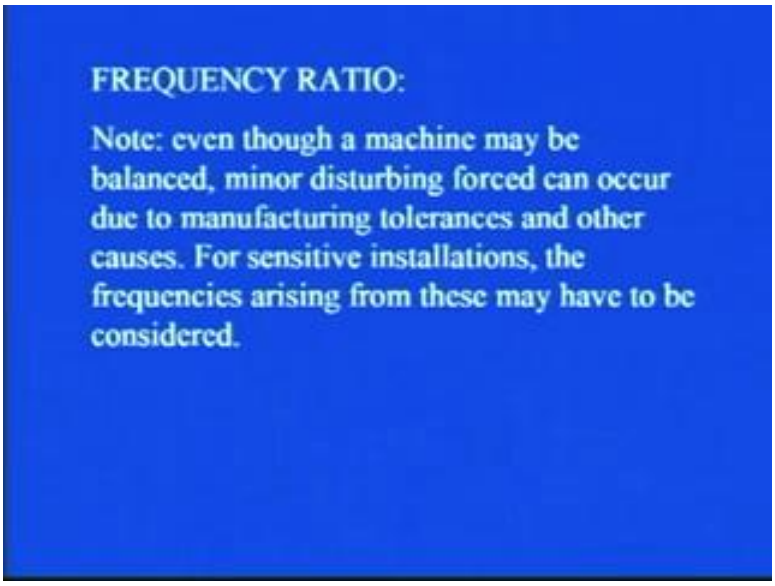

One thing we must keep in mind, that even though a machine may be balanced, minor disturbing forces can occur due to manufacturing tolerances and other causes. For sensitive installations, the frequencies arising from these, may have to be considered. So, all these things we really have to take into account, when the machine is operating, so we have to use our engineering judgment to come over with such type of situation where minor disturbing forces can be there.

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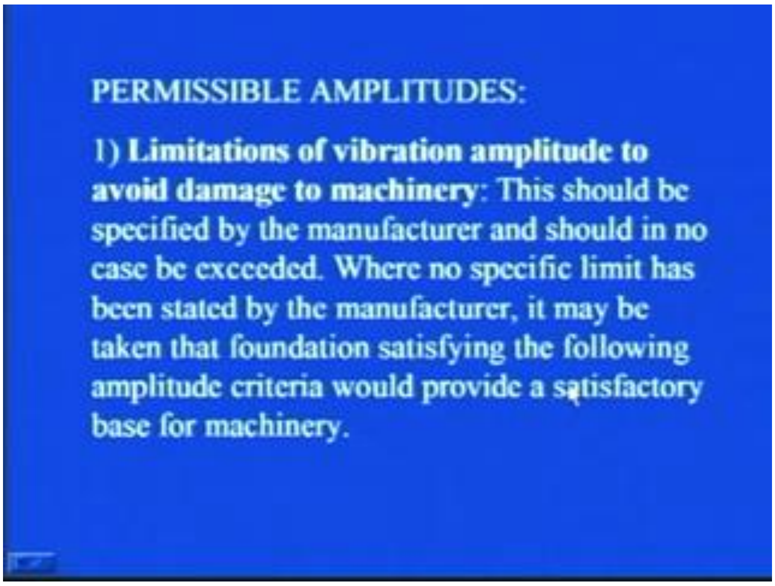

Then, what are the permissible amplitudes, how we can get that, because every time when we talk that, the resonance condition should not be reached and then, second condition was that, the amplitude should be within permissible limit. So, what exactly are the guidelines as per the IS code as far as this permissible amplitudes are concerned. So, the first one deals with, the limitations of vibration, amplitude to avoid damage to machinery.

So, to avoid any damage to the machinery, the amplitude should be limited to some value, what are they, we will see, right now, that, this should be specified by the manufacturer and should in no case be exceeded. Where, no specific limit has been stated by the manufacture, manufacturer, it may be taken that foundation satisfying the following amplitude criteria would provide a satisfactory base for machinery. Although, this data, to be provided by the manufacturer of machine.

But, let us say, in the absence of this data, from the manufacturer side, it is that, that we have to always keep in mind that, it should not be exceeded. So, for that, what will we do, in case, we do not have any data from manufacturer side, so in that case, you have to satisfy the subsequent condition, we will see that, what exactly is that.

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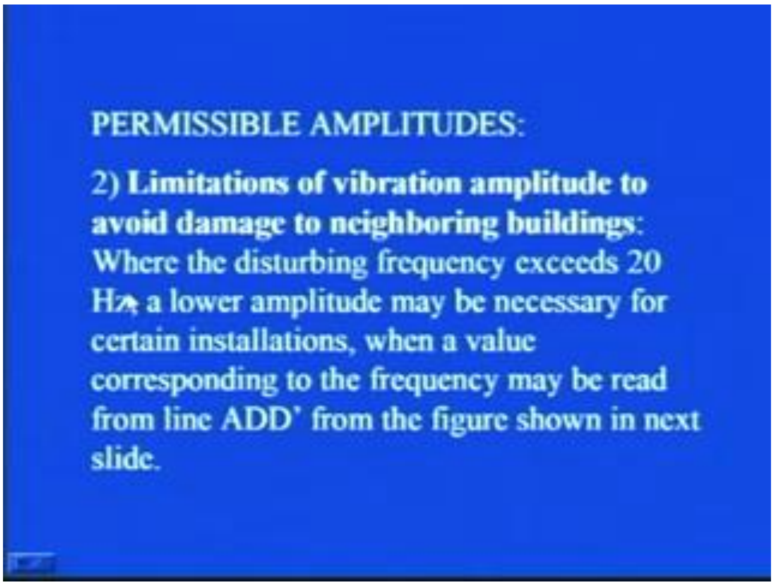

So, the second condition, that is, in the absence of any data to be provided from that manufacturer of machine, this condition should be fulfilled, that limitations of vibration amplitude to avoid damage to neighboring buildings. The damage to neighboring buildings due to resonance will be negligible, if amplitude and vibration of foundation is less than 200 microns, at frequencies below 20 hertz. So, these are the two things, amplitude is 200 microns at frequencies below 20 hertz.

If you are satisfying this particular condition, then even though, you go till the frequency, which is near the resonance condition, there will not be any damage to the neighboring structure. Then, where the disturbing frequency exceeds 20 hertz, see, earlier it was below 20 hertz, the amplitude should not be more than 200 micron. However, if the disturbing frequency exceeds 20 hertz, a lower amplitude may be necessary for certain installation, when a value corresponding to the frequency may be read from the line A D D prime from the figure.

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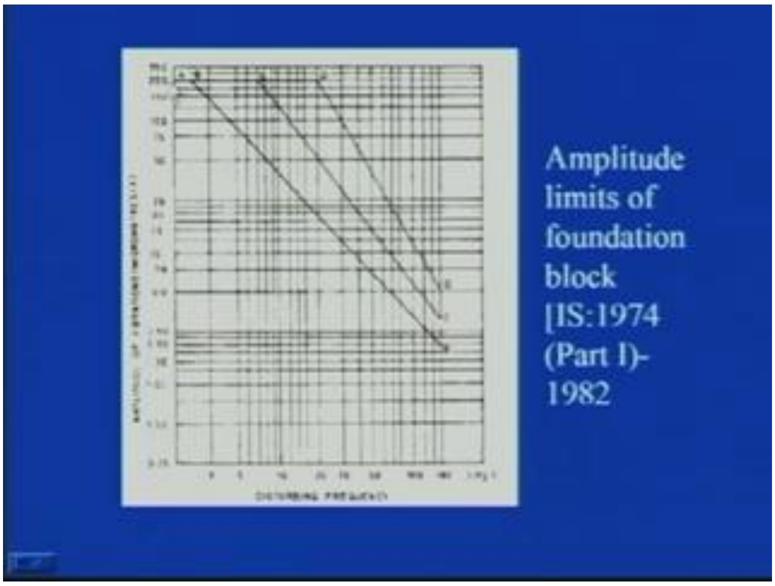

You can see here, that this is point A, this is D and prime, this figure has been taken from IS 1974 part 1 1982. So, this line, you can see here, that A D D prime, here on the X axis, you have disturbing frequency, on Y axis, it is amplitude of vibrations in micrometers. So, if you have ((Refer Time: 28:03)) that lower amplitude is required, that is for the, of disturbing frequency exceeding 20 hertz, then the value correspondingly, can be picked up from this particular line.

That is corresponding to disturbing frequency, let us say, if it is less than 20, then, you go here, pick the corresponding value from this particular line, that is A D D prime.

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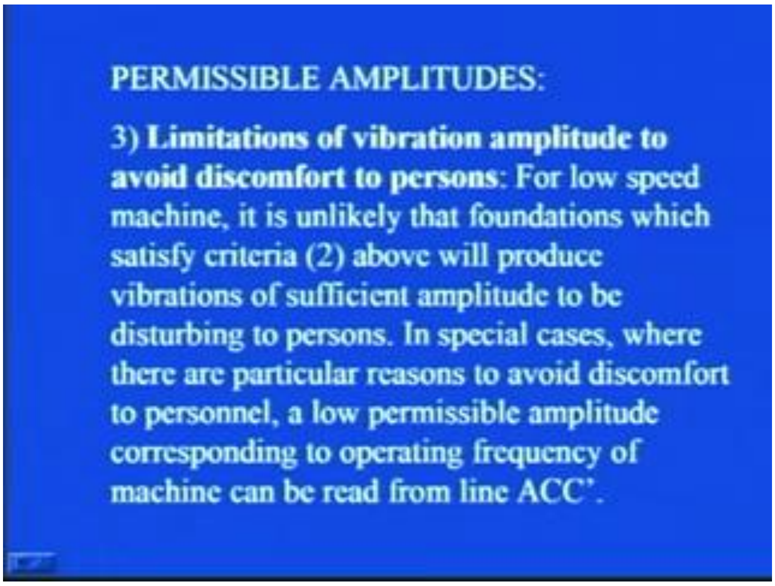

Then, the third part is, that limitations of vibration amplitude to avoid discomfort to persons. For low speed machine, it is unlikely that foundations which satisfy criteria number 2, that we have right now discussed, above will produce vibrations of sufficient amplitude to be disturbing to persons. In special cases, where there are particular reasons to avoid discomfort to personal, a low permissible amplitude corresponding to operating frequency of machine, can be read from the line A C C prime.

((Refer Time: 29:11)) So, you can see here, we get, it is the same figure from that IS code, but this time that two have the limitation, such that, the vibration are not annoying to the persons or they should not cause discomfort to the person, the line which you have to follow is A C C prime, which is this A, C and C prime. So, for the criteria number 2, it was A D D prime, however, for criteria number 3, it is A C C prime, so, whenever you require the amplitude of vibration to be lesser.

So, simply what you can do, whatever is the required amplitude of vibration, you pick that particular value. Let us say, if I want to have that 50 micrometer, so I will simply pick this value, projected on this particular curve, whatever is the corresponding frequency, you can assign to that. So, you can see here, that for, corresponding to this 50 micrometer amplitude, the corresponding disturbing frequency is 20 hertz.

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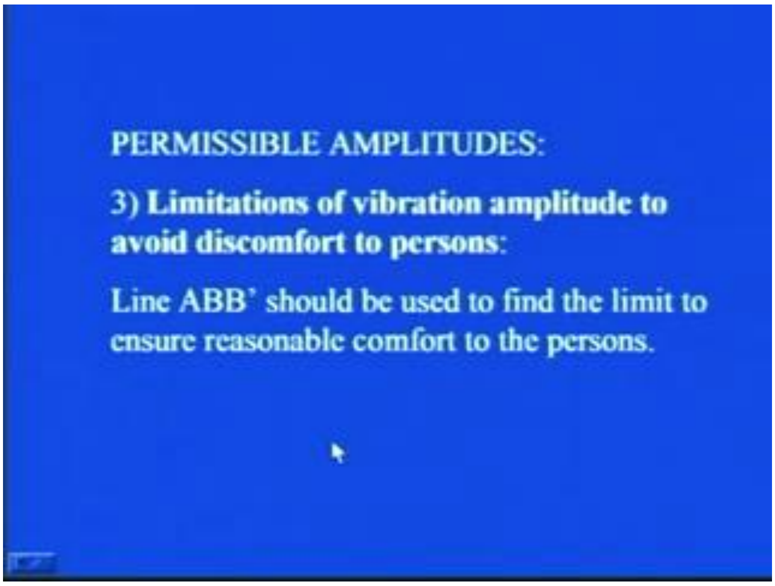

Then, line A B B prime should be used to find the limit to ensure reasonable comfort to the persons. ((Refer Time: 30:30)) Here, you see, this is, what is the line A B B prime, so in case, the discomfort to the person is unavoidable, then in that case, the limit can be defined by line A C C prime and in case, where you have to conform that, there is, there should not be any discomfort, the person should be comfortable. Then, you have to follow this line A B B prime to set the limits.

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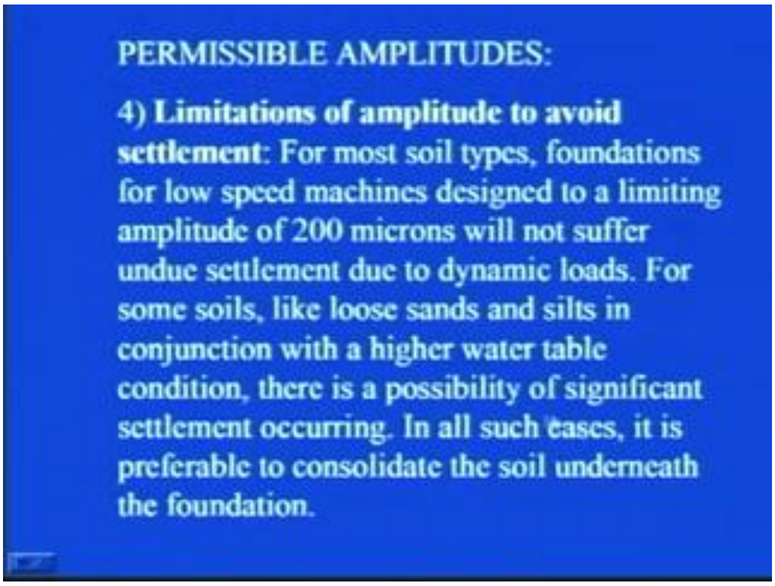

Then, this is the fourth one, that is limitations to amplitude of, to avoid settlement, so the first one was, that to avoid the vibration and then the, then we came to that, it should not be annoying to the persons, then this is that, to avoid settlement. For most soil types, foundations for low speed machines, designed to a limiting amplitude of 200 microns will not suffer undue settlement, due to dynamic loads, so usually this 200 microns below.

If you are designing the machine of the frequency, corresponding to the amplitude, which is lesser than this 200 microns, they will be safe for the settlement. For some soils, like loose sands and silts, in conjunction with the higher water table condition, there is a possibility of significant settlement occurring. Obviously, if the soil strata is loose or if the water table is present much near the ground surface, the settlements are going to be high.

So, in all such cases, it is preferable to consolidate the soil underneath the foundation, such that, the limiting amplitude, which you get is work out to be 200 microns.

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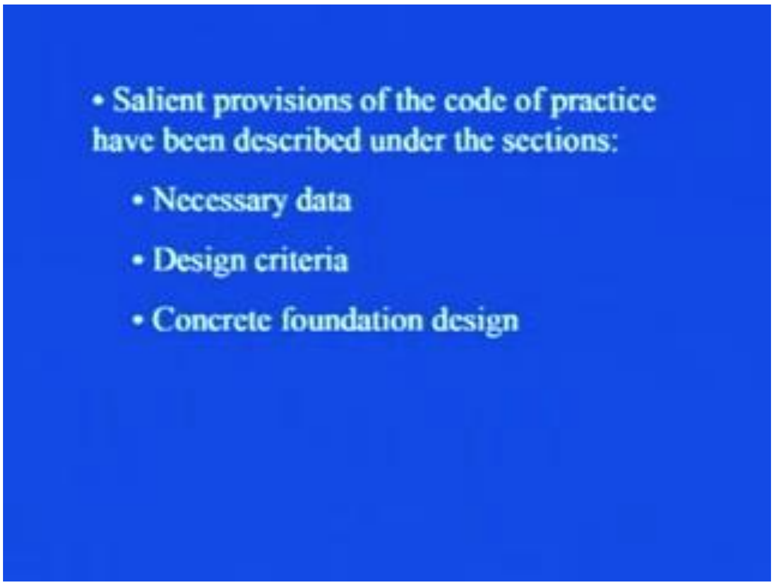

So, we were discussing about this, necessary data and design criteria and in that one, we saw that, some of the data which is necessary, that the machine manufacturer should provide to us and the, then the some of the data which we should gather, regarding ground and site characteristic. Then, there were some design criteria like, that resonance should not be reached and the, whatever is the amplitude it should be within permissible limit.

And then, there were some limitations set on vibration amplitude to avoid damage of machinery, to avoid damage of neighboring buildings, then to avoid comfort to the persons and to avoid excessive settlement. Now, let us try to start this concrete foundation design, that what exactly our IS code says about this.

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So, concrete foundation design, the contents has been taken from IS 2974 part 1 1982.

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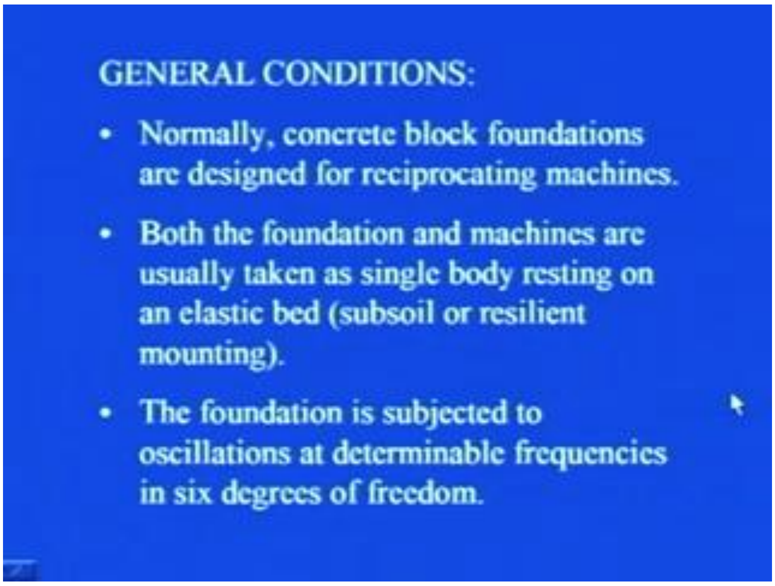

General conditions, normally concrete block foundations are designed for reciprocating machine, since, we are talking of a block foundation on reciprocating machine. So, usually concrete block foundations are designed. Both the foundation and machines are usually taken as single body resting on elastic bed that is elastic bed means, subsoil or resilient mounting. So, you see what happens is, first you cast the foundation and then on top of that, you mount the machine.

But both of them, they do not work as two different units, they work as one integral unit, so that is what is the general, one of the general condition, that both the foundation and machines are taken as one single unit, when the machine is operating. The foundation is subjected to oscillations at determinable frequencies in six degrees of freedom. We have already seen that, there are six degrees of freedom, that is, the translation along X axis, Y axis and Z axis.

And then, the rotation along X axis, which we call as pitching, then rotation about Y axis, which we call as rocking and then, the rotation about Z axis, which was called as yawing. So, the foundation which is subjected to the oscillation is at determinable frequencies, so the, all the frequencies in these six degree of freedom should be determinable. That is, we should be able to analyze, that what all are the modes of vibration and what are the corresponding frequency.

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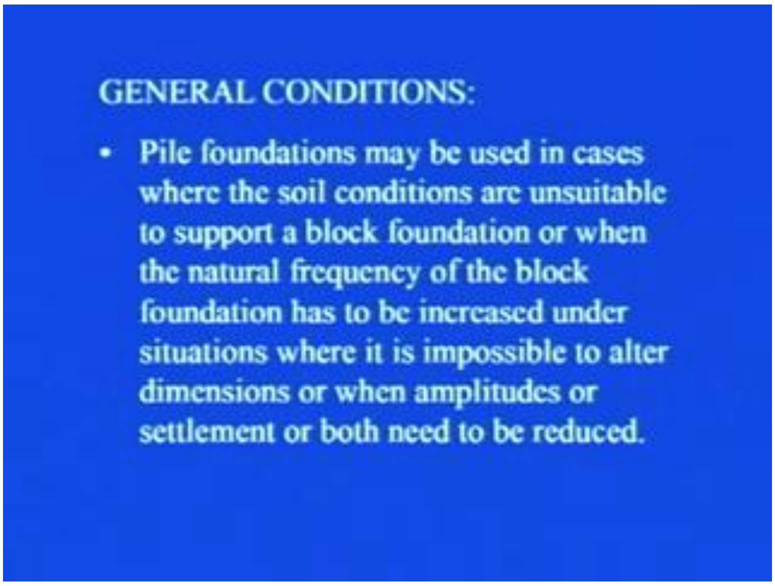

Pile foundations may be used in cases, where the soil conditions are unsuitable to support a block foundation or when the natural frequency of the block foundation has to be increased under situations, where it is impossible to alter the dimension or when amplitudes of settlement or both needed to be reduced. See, as you know that, why the pile foundation is a type of defoundation, so wherever the soil strata is not that much good that, it can take soil strata at the shallower depth.

Then, we need to transfer the load at relatively deeper level, where the soil strata is relatively good enough. So, in the, in this case also, that is, in the case of machine foundation, if the soil conditions are not suitable, that they can support the block foundation, you can go for pile foundation. Further, the option for pile foundation can also be used, when, the natural frequency of the block foundation has to be increased, under situation, where see, the increase of the natural frequency can be done by different means.

That is, you can either alter the dimension of the foundation or you can alter the amplitude or settlement or both. You have to reduce them, to increase the natural frequency. When all these conditions are not possible and still you have to go for higher frequency, higher natural frequency of the block foundation, in that case, the option of pile foundation can be used.

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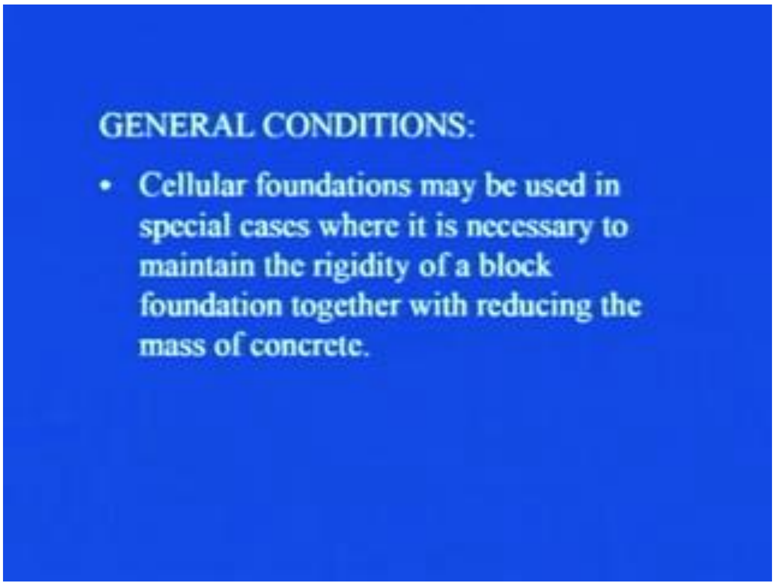

Then, cellular foundations may be used in special cases, where in, where it is necessary to maintain the rigidity of a block foundation together with reducing the mass of concrete. So, the cellular type of foundation, they like, it is also one type of defoundation, which has some of the very typical features, so wherever the block foundation cannot be put or because you know that the, weight of the block foundation is quite high.

So, wherever that, that much weight of the block foundation or the mass of the concrete which has been used in the construction of that foundation is not permissible or when the conditions are not favorable. As, far as the block foundation construction is concerned there, you can go for the cellular foundation.

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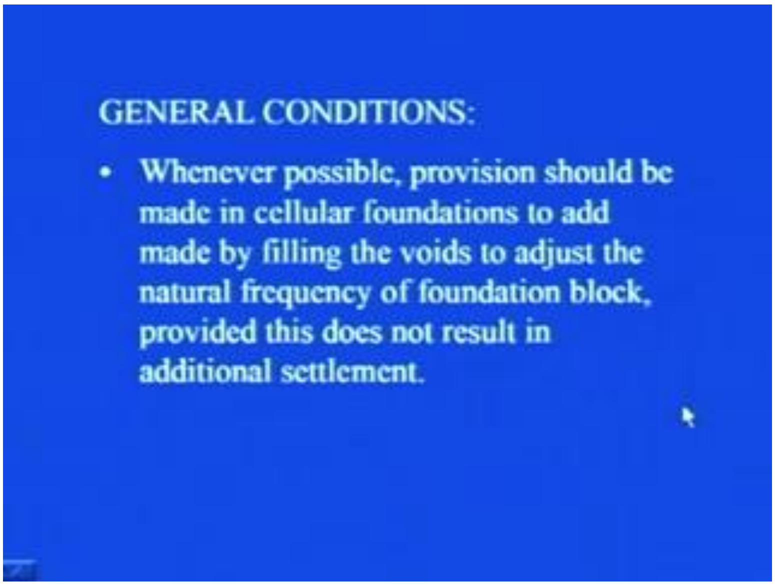

Then, wherever possible, provision should be made in cellular foundation to add, made by filling the voids to adjust the natural frequency of foundation block, provided this does not result in additional settlement. In cellular foundation, you have the flexibility of adding the mass to it, so that flexibility should be there, such that, you can adjust the natural frequency of the foundation block. However, when you put the extra load or extra filling or you fill that particular void which is there in the cellular foundation.

That should not cause additional settlement, because in any case, the settlement should not cross it is permissible limit. So, in case, the settlement is within the permissible limit, this option can be used as for as cellular foundations are concerned. Then, how we can decide upon the dimensions of concrete foundation blocks.

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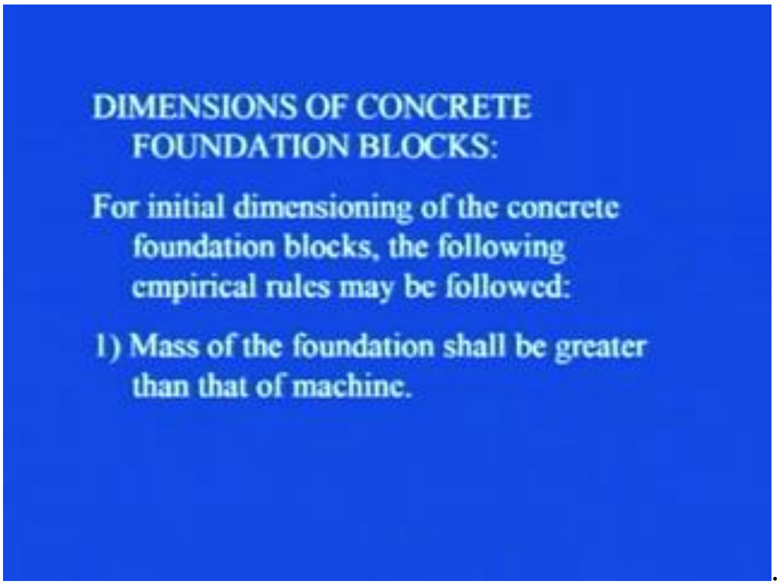

So, for initial dimensioning of the concrete foundation blocks, the following empirical rules may be used or they can be followed. See, these are not the hard and fast rules, these, the IS code of practice has been carried out or has been constructed in such a manner, that it comprises of the experience of different research works, which has been carried out in that particular area, plus the experience of various practitioners, engineers and then their engineering judgment.

So, they just give a rough outline of the, of any particular aspect, which has been dealt in that particular code. So, one should not see that, if it is to be said like this, so there cannot be any alteration to that, they just give an overall picture to give us little idea about that, so that, let us say, that the code, whatever, for some value the, code is giving me the value, let us say for some variable as 20. So, I can make the variation between, say 18 to 24, I mean around 20, because 20 is an average value, that we get from the code.

So, this we give, we get the rough idea from that codal provision, that is, if the code is giving us 20 value, then we really cannot take the value as 50, but we can take the value between 18 to 24, right. So, whatever is the case, that is not very hard and fast rule, as for as, IS code provisions are there, however, they give us overall idea, so in this case also, that mass of the foundation shall be greater than that of machine.

So, we should keep in mind, that whenever we go for this form of a concrete foundation design, then the, whatever is that mass of the machine, it should be less than the mass of foundation.

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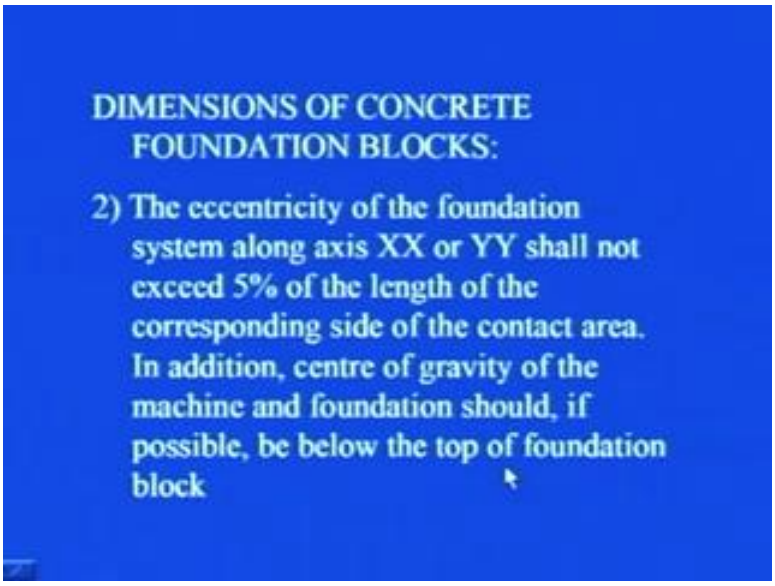

Then, eccentricity of the foundation system along the axis X X or Y Y, shall not exceed 5 percent of the length of corresponding site of the contact area. Let us say, that, if you are taking the particular side along X direction, then the eccentricity of the foundation system, along that, it should not exceed 5 percent of the dimension in that particular direction. Likewise, if you are considering, say Y Y axis, so in that one, you have to consider the dimension in that Y Y direction.

And then, you have to take the 5 percent of that and then you have to provide the check on the eccentricity. So, in any case, the eccentricity shall not exceed 5 percent of the length of the corresponding side, in addition, centre of gravity of the machine and foundation should, if possible, be below the top of foundation block. That is, when you find out, see machine is having 1 c g and the foundation is also having 1 c g.

So, you can get, when you mount the machine on the foundation, you can get the combined center of gravity of the machine foundation system. So, this particular location of the center of gravity of this combined machine and foundation system, it should be possible, possibly or preferably, it should be below the top of the foundation block.

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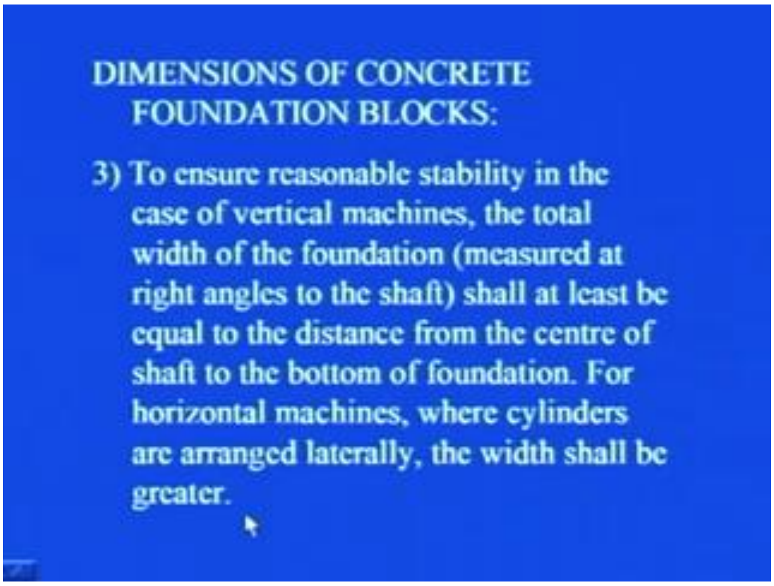

Then, to ensure, reasonable stability in the case of vertical machines, the total width of the foundation shall be, shall at least be equal to the distance from the center of shaft to the bottom of foundation. So, this thing, you must keep in mind, when you go for deciding upon the dimension of concrete foundation blocks, so and in case of horizontal machines, where cylinders are arranged laterally, the width shall be greater.

So, this thing you, we should keep in mind that, in case of vertical machine, this should be at least equal to the distance from the center of shaft to the bottom of foundation and in case of the horizontal machines, this width should be greater.

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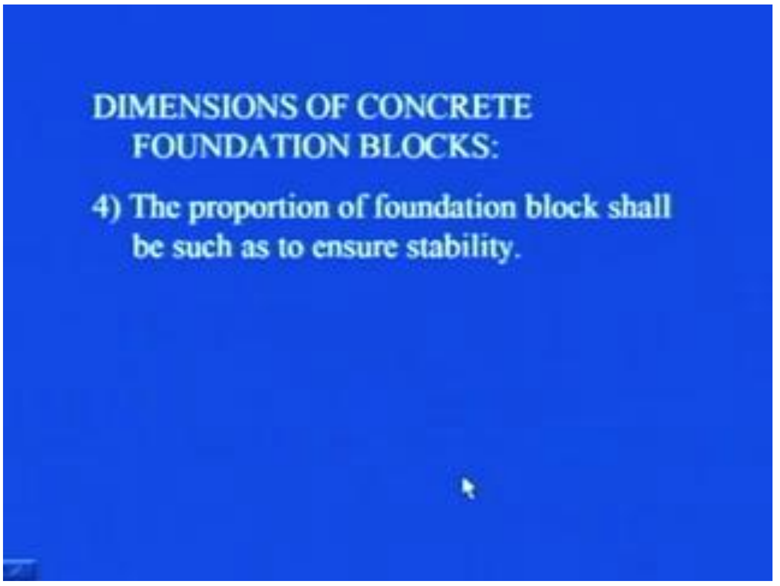

Then, the proportion of foundation block shall be such that to ensure stability, if let us say some, first time you proportion this foundation block and then you worked out the stability, if that is not coming out to be safe, then you have to reproportion the foundation block and then, check the stability provisions all together again. So that, we must keep in mind, that whatever is the provision for the dimension of the concrete foundation block, it has to ensure the stability.

Now, we will see that, what exactly are the stresses, type of the stresses which are being developed in this case and how we can take care as for as IS codal provisions are there.

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Full value of permissible stresses for steel and concrete, as specified in IS 456-2000 can be allowed, if dynamic loads are considered in detailed design by applying suitable dynamic and fatigue factors. You see, this IS 456-2000 deals with the stresses, which generate there in the concrete block. So, in case, if you have taken the dynamic loads and it is fatigue behavior into the consideration, then, you can use the full value of permissible stress for steel and concrete, as it is specified in IS 456.

So, you have to keep in mind, that you have to, have a detailed design, in which you have the proper measure or suitable measure for dynamic and fatigue behaviors.

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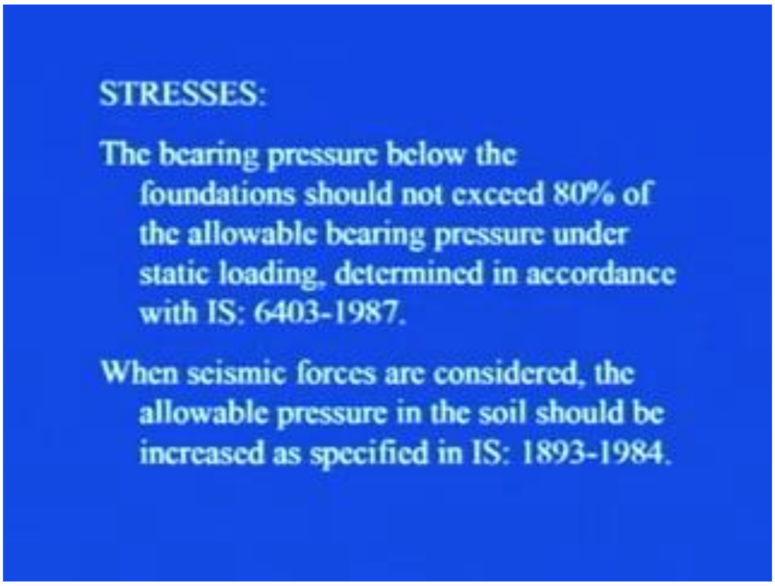

Then, the bearing pressure below the foundation, should not exceed 80 percent of the allowable bearing pressure under static loading, determined in accordance with IS 6403-1987. So, this one, this gives the, this gives us the guideline that how we can determine this allowable bearing pressure under static loading and in the case of machine foundation, see, once you can find out this IS from IS 6403-1987, this allowable bearing pressure.

And in case of, this is under static loading and in case of machine foundation, the bearing pressure, you should reduce it by 80 percent, by 20 percent. That is, this bearing pressure below the foundation, it should not exceed the 80 percent, which you get for static loading as per this IS code, that is IS 6403-1987. When seismic forces are considered, the allowable pressure in the soil should be increased, as specified in IS 1893-1984.

So, you know that, these days, since the, scarcity of the land, there are various sites, which are quite seismic prone. So, there we need to keep into account these forces also and we have to follow the IS code provisions. So, in this one, in this particular lecture we discussed that, what exactly will be the behavior of a block foundation under pure sliding and then pure yawing, of the pure yawing vibration mode of the block foundation, we found out that, how we can get the natural frequency and the maximum amplitude in all the three cases.

And then, we tried to study the simultaneous behavior, that is when the block foundation is simultaneously subjected to a translation force in Z direction, that is in vertical direction, in X direction, that is in a sliding mode and moment about the Y axis, that is the rocking one. There, we saw that, it became very complicated mathematical exercise, but we must know that, what exactly are the forces which are acting on a block foundation and what are the corresponding mode of deforming.

However, that can be done and which can become the scope for further study, then we started with that, what exactly is the, are the IS code provisions, as for as the design of foundation for reciprocating machines are concerned. In that one, we saw that what exactly are the general criteria. Then, we saw that, what exactly is the necessary data which we require from manufacturer of machine or, and the data which we require, as for as soil and the ground characteristic is concerned.

Then, we saw that, what are the design criteria for the design of this block foundation for reciprocating machine. There we saw that, how we can set the permissible limits for vibration amplitude to avoid any damage to machinery, to avoid any damage to neighboring structures, then to avoid discomfort to the persons and the fourth one was, to avoid the excessive settlement.

Then, we saw that the machine foundation should have the condition, that the resonance condition is not approached, while operating the machine and the settlement or the amplitude, under the vibration condition, should not exceed the permissible value of the settlement and after that, we saw that, what are the various features, as far as the concrete reinforced, concrete foundation design is concerned. So, you are now well conversant with the different IS codes, which deal with the design criteria, as far as the block foundation for reciprocating machines are concerned.

So, this is. what is all about the machine foundations, if you feel interested about this particular subject, you can, you, there are standard text books which are available, you can go through them, but as far as your scope of foundation engineering course is concerned, we restrict to this particular point.

Thank you.