Foundation Engineering
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Module – 02
Lecture - 18
Well Foundations - 2

Hello viewers, in the last lecture we saw that what exactly do we mean by well foundation that is, it is a type of deep foundation like you have already studied pile foundations, so this well foundation is another type of deep foundation. And then, we saw that, what are the various shapes which are available to be used as well foundation. And then, we discussed many aspects related to this well foundation like the various components of well foundations, what are their functions, etcetera.

So, today we will be studying that, how you can determine allowable bearing pressure of well foundation then, what all the various forces which acts on well foundation and then we will see that, how we can analyze this type of well foundation. So, first let us try to see that, how we can get the allowable bearing pressure in case of well foundation.

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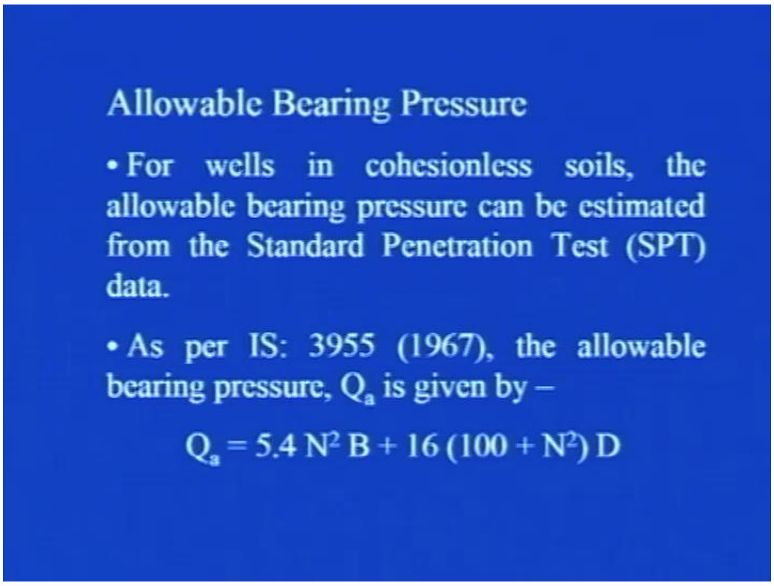

For wells in cohesionless soils, the allowable bearing pressure can be estimated from a standard penetration test data. As you have already studied in the very beginning of this particular course, what are the various field test and how the data of those field test can be used in the analysis and design of various foundations. So, the standard penetration test is such insitu test, whose data is used quite frequently in the analysis and design of foundations.

So, you know that from this particular data, you get a standard penetration number which is N and which is used in the analysis and design. So, IS 3955 1967 has given an expression for the allowable bearing pressure, which is represented by Q a, and it is given by 5.4 N square B plus 16 times 100 plus N square into D.

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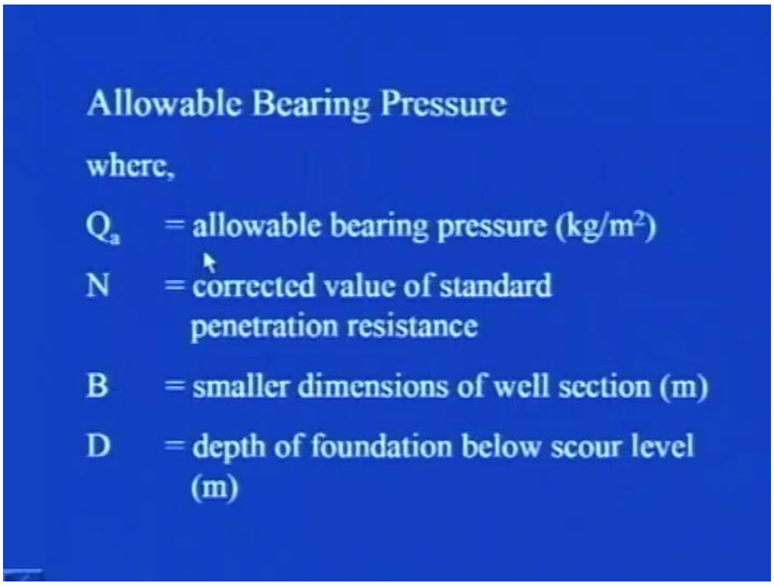

Where Q a, is allowable bearing pressure in kg per square meter, N is corrected value of a standard penetration resistance and this you will get from directly from standard penetration test data. Then B is smaller dimensions of well section, say if it is a rectangular section then, the smaller dimension of that particular rectangle if it is oblong, then the smaller dimensions, so whatever is the smaller dimension that is B. D is depth of foundation below scour level in meter, so using this particular expression, you can get the allowable bearing pressure as per this IS 3955 1967.

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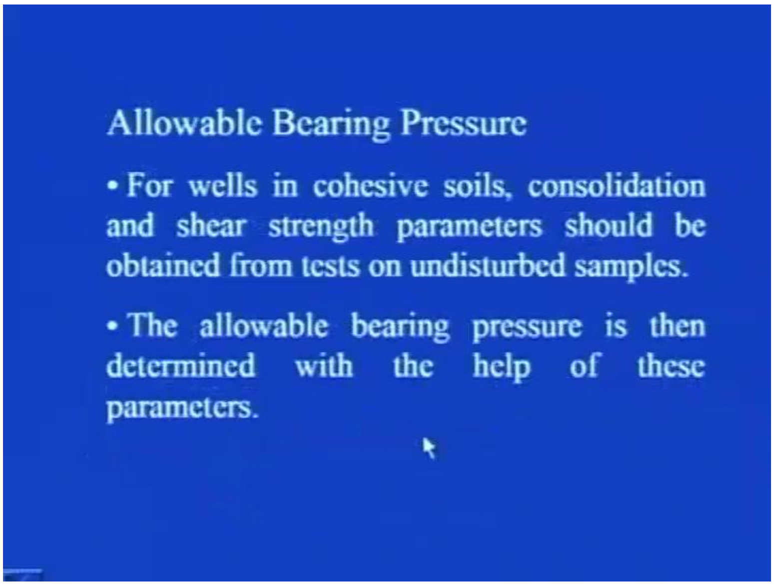

For wells in cohesive soils, consolidation and shear strength parameters should be obtained from the test on undisturbed samples. When you know that, where the foundation has to be laid, you can definitely collect the undisturbed sample and carry it to the laboratory and then conduct the test, to determine this shear strength parameters; that means, cohesion an angle of internal friction and then we use consolidation characteristic like coefficient of consolidation etcetera.

And in case of cohesive soil, you know that the settlement is consolidation settlement mainly, so that is why this consolidation characteristic becomes quite important. The allowable bearing pressure is then, determined with the help of these parameters like consolidation characteristic and shear strength parameters which are c and phi.

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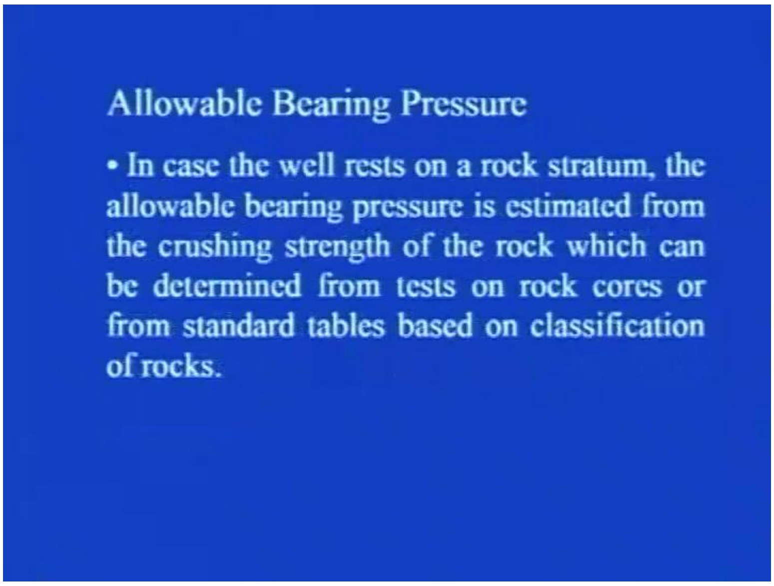

In case, the well rest on a rock stratum, the allowable bearing pressure is estimated from the crushing strength of the rock, which can be determined from test on rock cores or from standard tables based on, classification of rocks. See, if you take up some advanced study then, you will be studying more about this rock mechanics, but for the scope of this particular course, you must know that, the strength of the rock can be found out either insitu or in laboratory.

And, to conduct the test in laboratory is quite cumbersome, as well as to conduct the test in field is also quite cumbersome, but then, there are methods from which you can obtain this crushing strength of the rock. So, it can be determined either from insitu test or you can conduct the test on rock course in the laboratory and this rock course can be prepared from the chunk of rock, which can be collected from the field.

Now, there are various forces which act on well foundation, as I told you in the last class also, that mainly this well foundation are being provided in case of bridge foundations, where there is a presence of water all around and then, the bridge can be constructed for various types, various purposes to serve, so different type of loads they come to the foundation, what are they.

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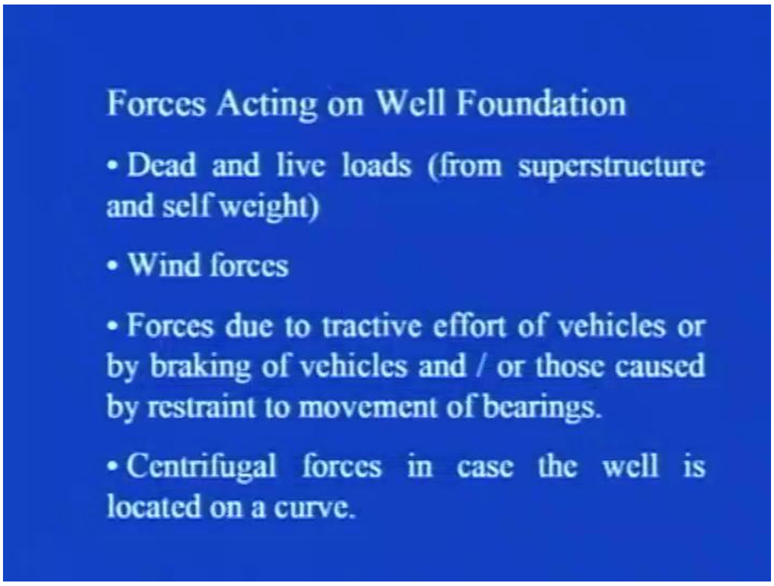

These are dead and live loads, which comes from superstructure and self weight of the bridge. Then wind forces because, it is exposed to the nature and wherever this wind forces are quite prominent, dominant there, this wind forces comes into picture, then forces due to tractive effort of vehicles or braking of vehicles and or those caused by restraint to movement of bearings.

The bridge, for which it has been constructed, let us say that you are using it for the transport purpose mainly. So, there, these forces due to tractive effort of different vehicles will be coming into picture. Now, in case the well is located on a curve, there this centrifugal force will come into picture.

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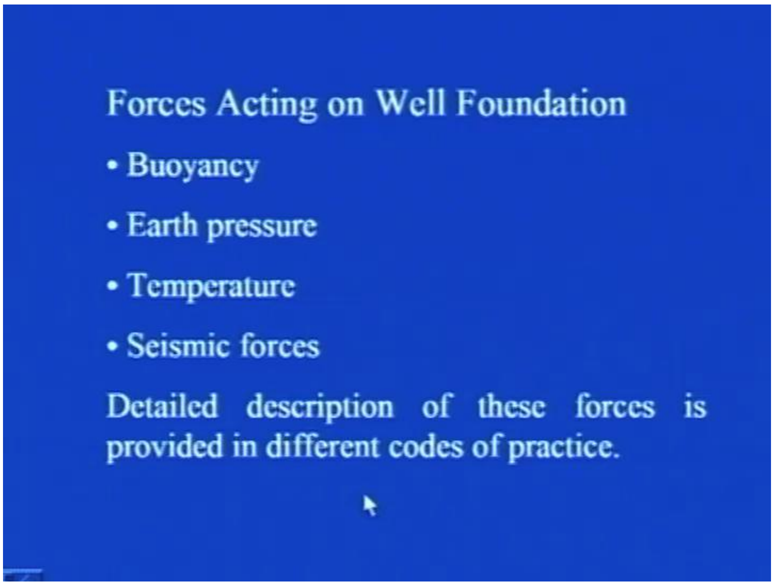

Further, due to the presence of water buoyancy force will be coming; further, earth pressure will be coming on the well foundation then, the force due to temperature and very well known seismic forces because, wherever it is earthquake prone area seismic forces will come into picture. Then detailed description of all these forces are available in the relevant IS codes or IRC recommendations.

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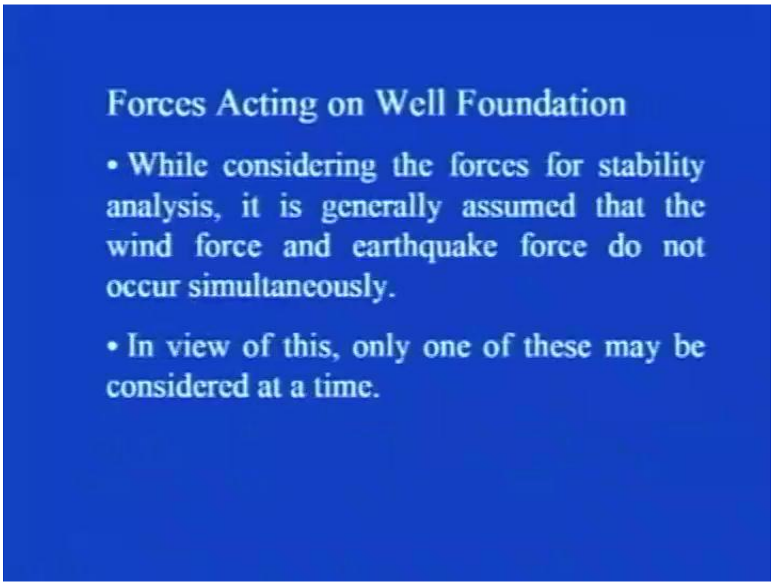

Now, there are few guidelines and the group of these forces which have been formed and some of the salient features of these, we will be discussing here. That while considering the forces for a stability analysis, it is generally assumed that wind force and earthquake force, they do not occur simultaneously. So, since they do not occur simultaneously, so only one of these may be considered at a time, so whenever you, if you are considering, let us say wind force then, you may not consider earthquake forces and vice versa.

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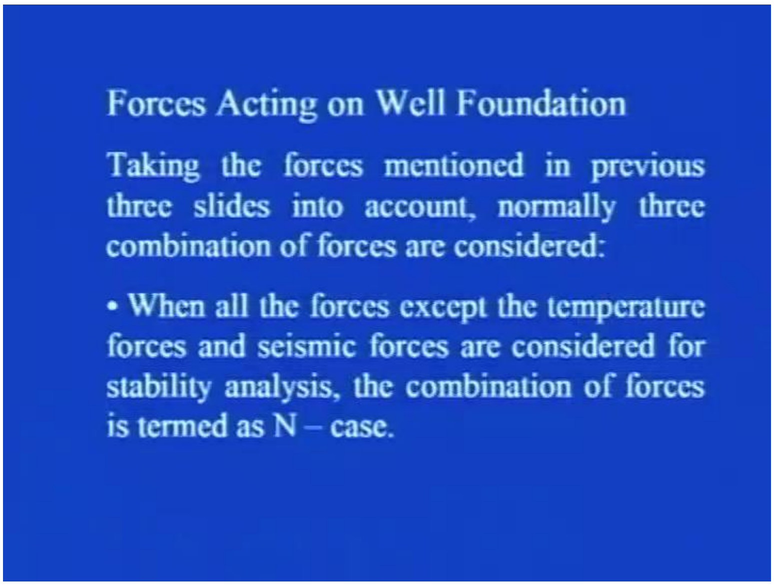

Then, taking the forces mentioned in the previous three slides as I told you, various forces dead load, live load and then, forces due to the tractive effort of vehicles, buoyancy force, earth pressure, etcetera. Normally, three combinations of these forces are considered, see we have to make sure because, these all these forces they will be acting simultaneously. So, we have to group them, so mainly three groups have been recommended and we determine the forces, the combination of forces from all these three cases and the worst one that, we considered for the analysis purpose.

So, what are these three groups, when all the forces, except the temperature forces and seismic forces are considered for the stability analysis, this combination of forces is termed as N case. So, all those forces which I have already told you, if you ignore temperature force and seismic force and consider all other forces, while you analyse for the stability of well foundation then, this particular combination of force is termed as N case.

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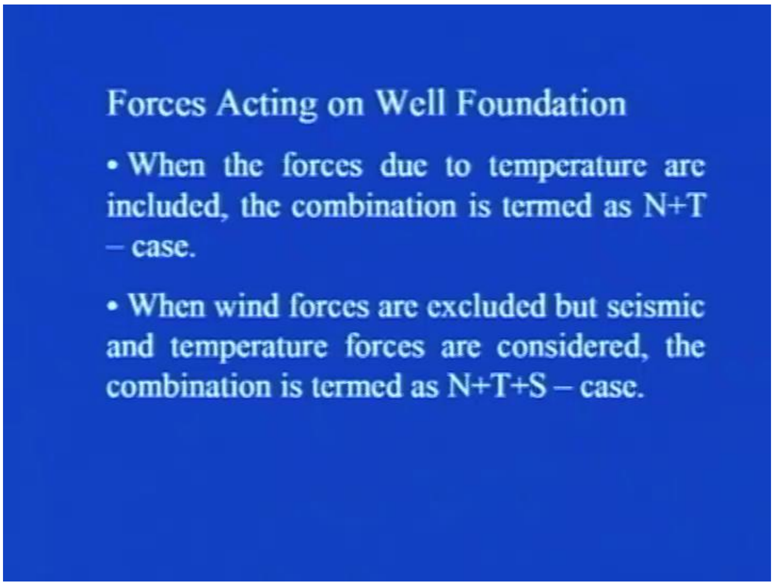

When, the forces due to temperature are included then, the combination is termed as N plus T case; that means, only seismic force that you have neglected and rest all forces that you have taken into account. So, this particular combination is known as N plus T case. When wind forces are excluded, but seismic and temperature forces are considered, the combination is termed as N plus T plus S case.

So, you have to be clear about these three cases, N case means, that you have considered all the forces except for temperature and seismic forces. N plus T case means, you have considered all those forces which are falling under N case plus the temperature forces. Then N plus T plus S case, in this case you have to exclude this wind force and include seismic as well as temperature forces, so that is N plus T plus S case.

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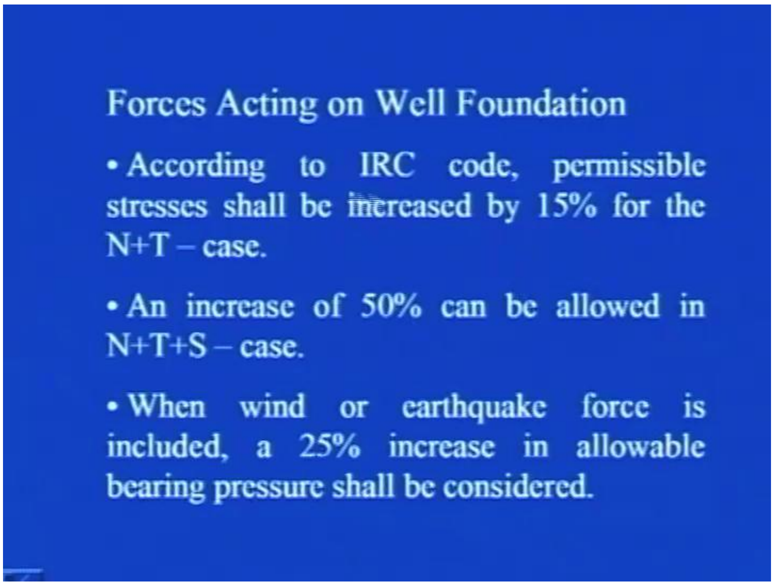

Now, according to IRC code, permissible stress shall be increased by 15 percent for the N plus T case then, an increase of 50 percent can be allowed in N plus T plus S case. When wind or earthquake force is included a 25 percent increase in allowable bearing pressure shall be considered. So, these are IRC recommendation which you have to follow.

Now, how to decide upon that, which case will be playing important role or which case will be the most dominant one or which case, you have to use for this stability analysis. For that, you have to consider all these three cases and then you have to carry, find out the worst possible combination of these forces, whichever is the worst case that you have to consider.

So, once you decide that which case that you are going to take for the stability analysis of well foundation, then correspondingly based on these IRC recommendation whatever is the case, whether it is N plus T case N plus T plus S case or if you are considering wind or earthquake force then, correspondingly you have to increase, that allowable bearing pressure or permissible stresses by these particular percentage which has been recommended by IRC codes.

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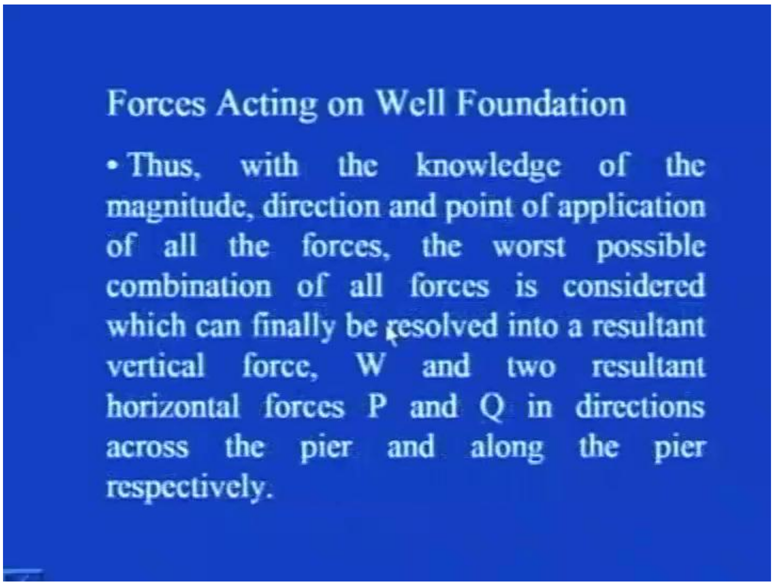

Thus, with the knowledge of the magnitude, direction and point of application of all the forces, the worst possible combination of all forces is considered, which can finally be resolved into a resultant vertical force W and two resultant horizontal forces P and Q in directions across the pier and along the pier respectively; that means, that the force P that is horizontal force P is across the pier and horizontal force Q is along the pier.

So, whatever is the combination that is the most general one be it N case, be it N plus T case, be it N plus T plus S case, but finally, you can resolve all these forces into the three component, the first one is your vertical force, which we are representing here as W and then two horizontal forces P and Q across N along the pier respectively.

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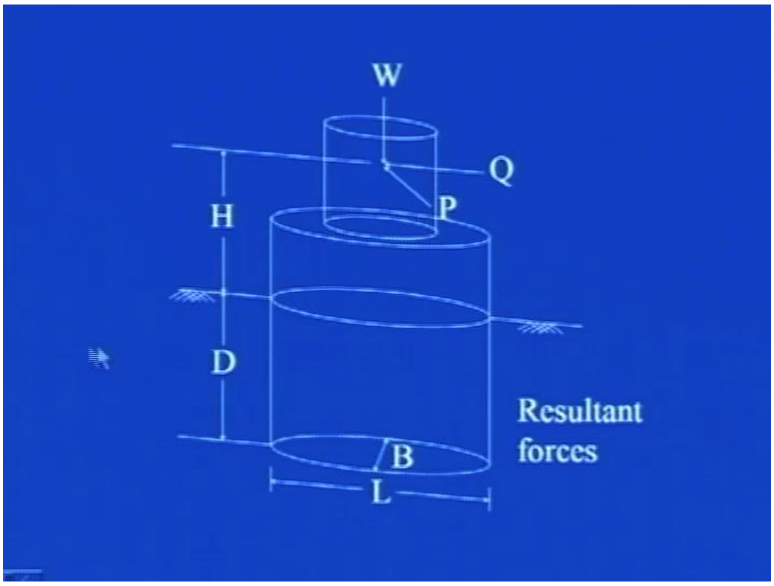

Here this figure shows that, how these forces they will be acting, you can see here, that this is the ground level and it has a, this well I am showing here the 3 D picture. So, this is the vertical, whatever is the combination of worst possible force that is whether it is N case N plus T case or N plus T plus S case all these finally, that you can resolve into these three forces which are W in the vertical direction then, this is the force P and the force Q, which is along the pier and force P is across the pier, L and B are the longer and shorter dimension of the well foundation.

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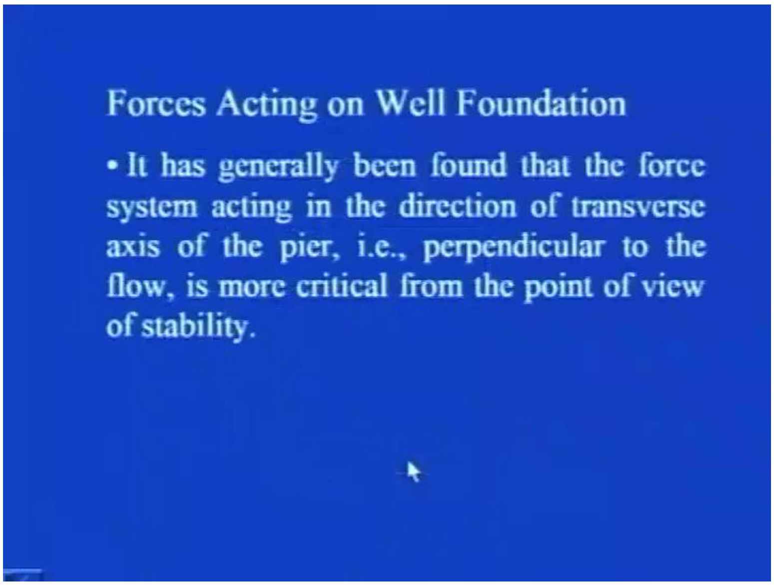

It has generally been found, that a force system acting in the direction of transverse axis of the pier, that is perpendicular to the flow is more critical from the point of view of stability because, two horizontal forces are there, that is P and Q, so which one to consider. So, usually it has been seen, that the force system which is acting in the direction of transverse axis of pier, that is opposite to the flow is more critical, so it is considered in the stability analysis.

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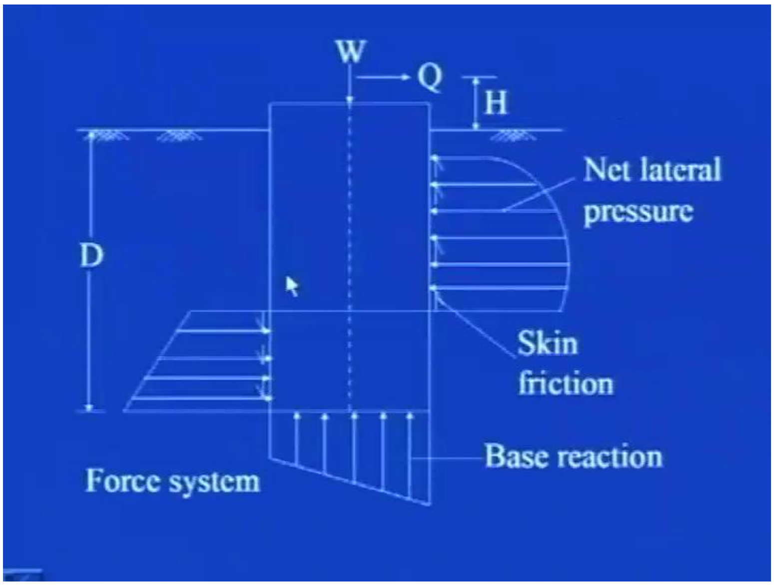

You can see here, that these are the various force systems, which will be acting on the well foundation. This is the vertical force W, then the horizontal force Q which is acting at a height of H from the existing ground surface and then, it is the lateral earth pressure and then along the surface of this well foundation, skin friction will be developed and at the base, this base reaction will be developed and here you are seeing that it is the lateral force in this particular direction, along with the skin friction. So, this is, what is the force system that is, the schematic diagram of the various forces which are acting on the well foundation.

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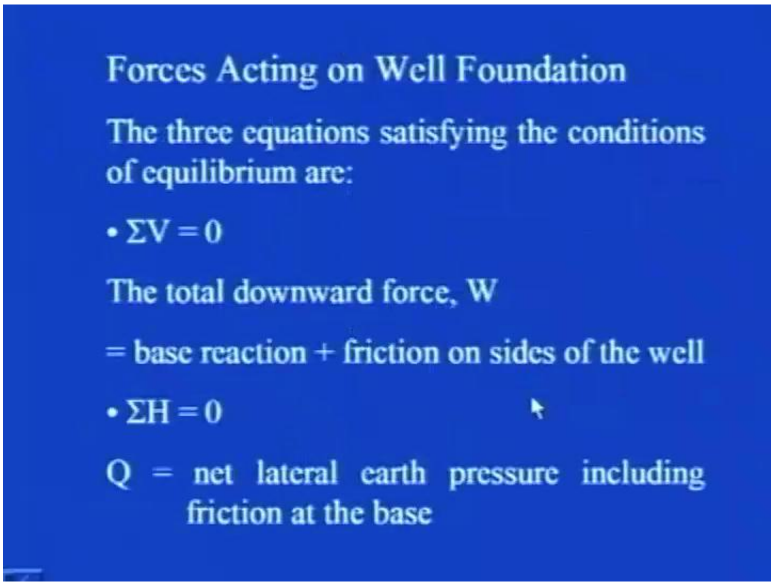

Then, for the stability analysis, you know from the mechanics point of view that, we usually require to satisfy equations of equilibrium. So, exactly the same thing we are going to do here in the case of well foundation also, so the three equations which satisfy the equation of equilibrium they are, first one is summation of all the forces in vertical direction is equal to 0.

So, here I am representing it as summation of V that is, all vertical forces are equal to 0, which will result into this particular expression, that is the total downward force W will be equal to base reaction plus friction on sides of the well. You can see here in this figure, that it is the weight W which is acting in vertical direction and then it has to be resisted by this vertical base reaction, as well as the skin friction which is being developed on these sides of well, here as well as here.

So, this result into this particular equation that is, the total downward force W is equal to base reaction plus friction on sides of the well. Then the second equation is summation of all horizontal forces to be equal to zero, so summation H is equal to 0, you can see here in this figure, that it is the horizontal force Q and then the lateral earth pressure, this side as well as this side.

So, this results into, Q is equal to net lateral earth pressure including friction at the base, that is here some friction if it is developed. So, that will also be acting in horizontal direction, so that has to be taken into account while you consider this summation H is equal to 0.

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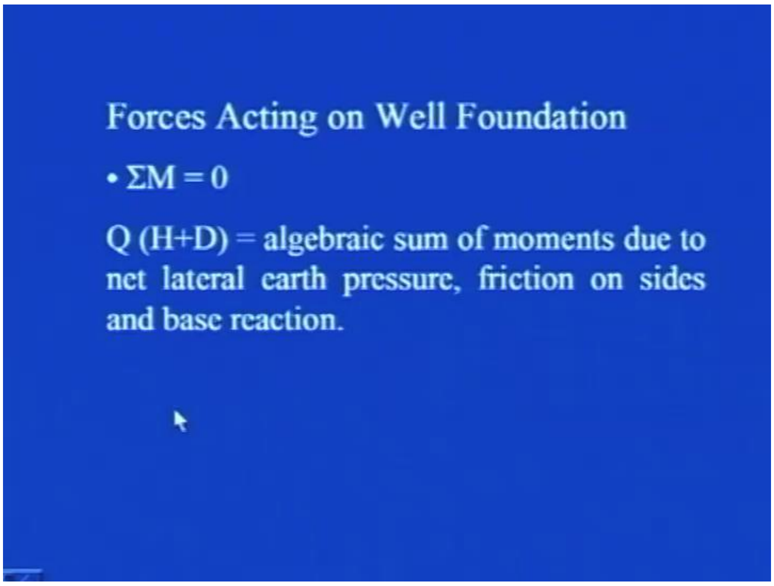

And then, the third one is that summation of moment about any point has to be equal to 0. So, that will result into Q H plus D is equal to algebraic sum of moments due to net lateral earth pressure friction on sides and base reaction. So, you have to pick a point from where that, at which you want to take the equilibrium of moment and then whatever are the forces that are acting on the well foundation, you have to consider the moment generated about that point, due to all these forces and then you will be able to get this resulting equation.

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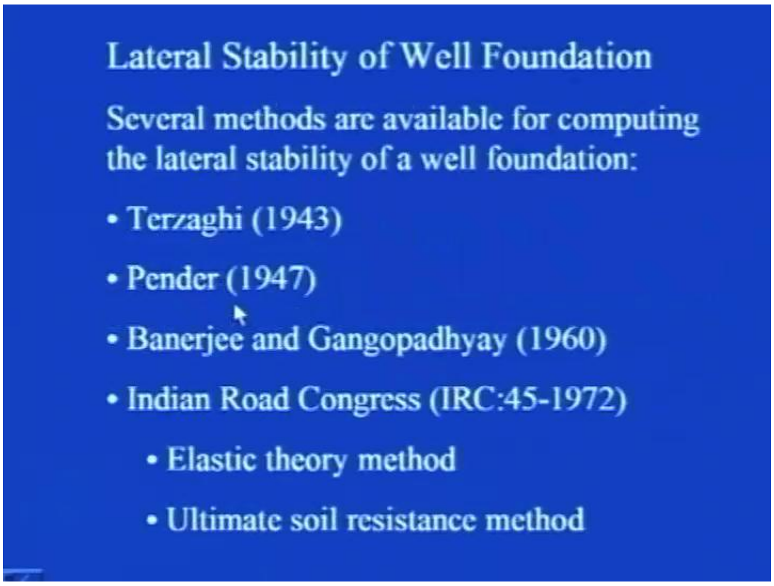

Now, coming to once we have the idea, about these forces and then how we can go for the stability analysis of this well foundation. Now, we have to see that, what all are the various methods which are available for the lateral stability of well foundation because, you know that it is a monolithic and a very rigid structure and its longer dimension is in the vertical direction and that is, why the lateral stability becomes quite important.

So, various methods are available for computing the lateral stability of a well foundation, they are Terzaghi, which he proposed in 1943. Then Pender proposed an analysis in 1947, further in 1960, Banerjee and Gangopadhyay proposed an analysis procedure. Then IRC that is, Indian Road Congress 45-1972, they recommended two methods that is, elastic theory method and ultimate soil resistance method to know the lateral stability of well foundation.

So, using this IRC method we have to employ, these two methods that is elastic theory method as well as ultimate soil resistance method to know or to get the lateral stability of well foundation. Here in this scope of this particular course, I will be discussing with you this Terzaghi theory and then, IRC elastic theory method along with an example to make you or to give you a feel that, when it comes to the, when it comes to the analysis of well foundation, then of a real problem then, how you can go ahead using these theories. So, first we will be discussing this Terzaghi's analysis.

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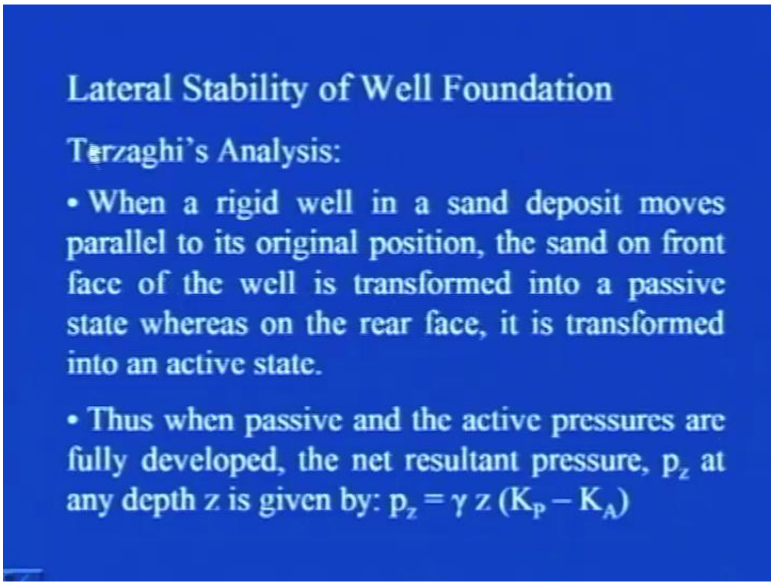

So, in this one, it has been considered that the, when a rigid well in a sand deposit moves parallel to its original position, the sand on front face of the well is transformed into a passive state whereas, the sand on the rear face is transformed into an active state. You must be recalling that, when we discussed about the lateral earth pressure theories there, we have already studied the concept of active earth pressure and passive earth pressure.

So, in that one, we saw that, when wall moves away from the backfill soil then, it is an active state and when it moves towards the backfill soil, then it is passive state. So, in case if the rigid well is having any moment then, the sand on the front face of the well because, if it is the well, there is a sand here and here both ways. So, if it is moving towards this side, so the sand which is on the front of the, front of the well it will get transformed into the passive state because, here the movement of the well is towards the soil.

So, that is why the passive state will be generated and on the other side, since it is moving away from the sand, sand stratum, so that will be active state. Thus, when passive and the active pressures are fully developed, the net resultant pressure if I represented by p z at any depth z will be given by p z is equal to gamma z K P minus K A. So, this is the one, when this is both the pressures, that is active and passive pressure they are fully developed and you know that the well has to displace, sufficiently to the, for the development of this active and passive pressure fully.

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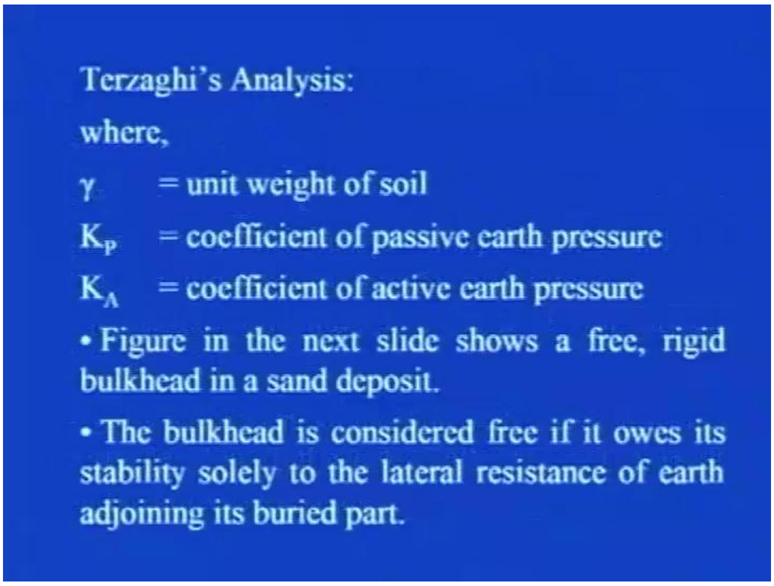

Where, this gamma is the unit weight of soil, K P is coefficient of passive earth pressure K A is coefficient of active earth pressure. Then I am showing you a figure in the next slide, which is giving you the schematic diagram of the bulk head in sand deposit.

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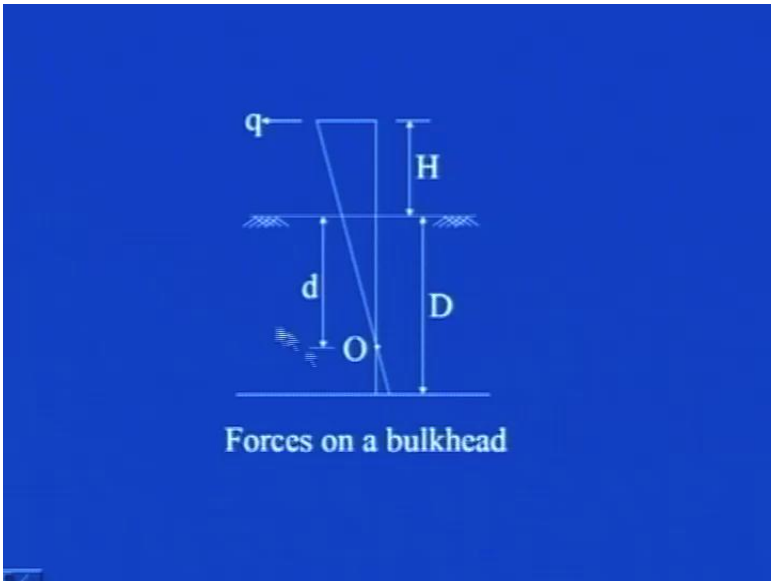

So, you can see here, that it is a kind of bulk head which is in the sand deposit, the bulk head is considered free, if it owes its stability solely to the lateral resistance of earth adjoining its buried part. So, here I am assuming that, the lateral stability is only due to the soil which is present in the neighborhood. So, it has a tendency under the application of this load q that is, horizontal load q it has a tendency to rotate about the point O from the base of the well that is, above the base of the well there will be a point O, about which the well will be rotating under the action of this horizontal force q.

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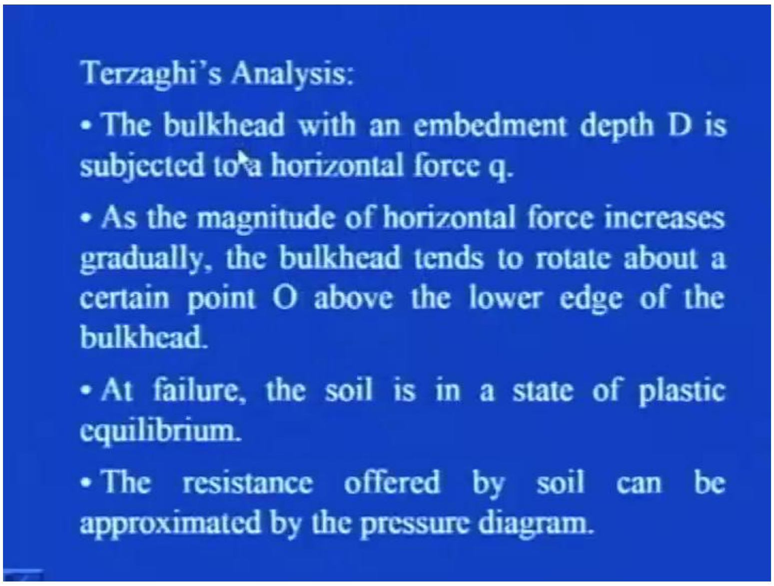

The bulk head with an embedment depth D is subjected to a horizontal force, here you can see that, it is the embedment depth D and this is subjected to a horizontal force q. As the magnitude of horizontal force increases gradually, the bulkhead tends to rotate about a certain point O above the lower edge of bulkhead you can see if this is the lower edge of bulkhead. So, as this value of q is increasing it will have a tendency to rotate about a particular point which is O here, in this particular figure and it is above this base of the bulkhead.

Now, what will happen at failure, at failure the soil will be in plastic equilibrium or it will be in the state of plastic equilibrium the resistance offered by the soil, and this case it can be approximated by the pressure diagram which is shown here.

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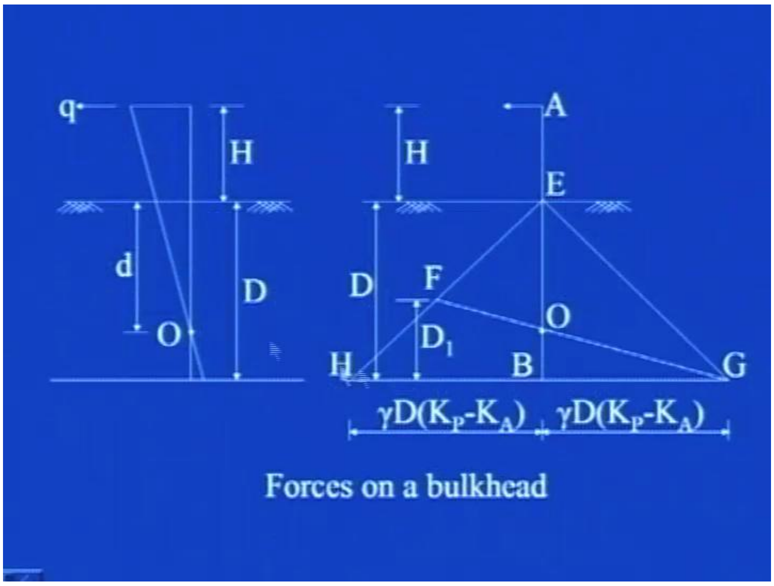

So, you can see as the q is being increased, the wall is having, well is having the tendency to rotate about this point O and then, the resultant pressure diagram due to this moment can be drawn here. In this case, here this B H and B G is approximately equal to gamma D K P minus K A, where D is the depth of embedment, H is the height where this q is acting and small d is the location of this point O, where this rotation of well is taking place.

So, all these, these are the pressure diagrams, it is having this ordinate and if I join from this ordinate G to this point O, it cuts this particular pressure line which is showing this pressure diagram at F and let us say that, that particular distance is D 1 which is unknown right at this particular point of time, but in the process of the analysis for stability, we will be determining this depth D.

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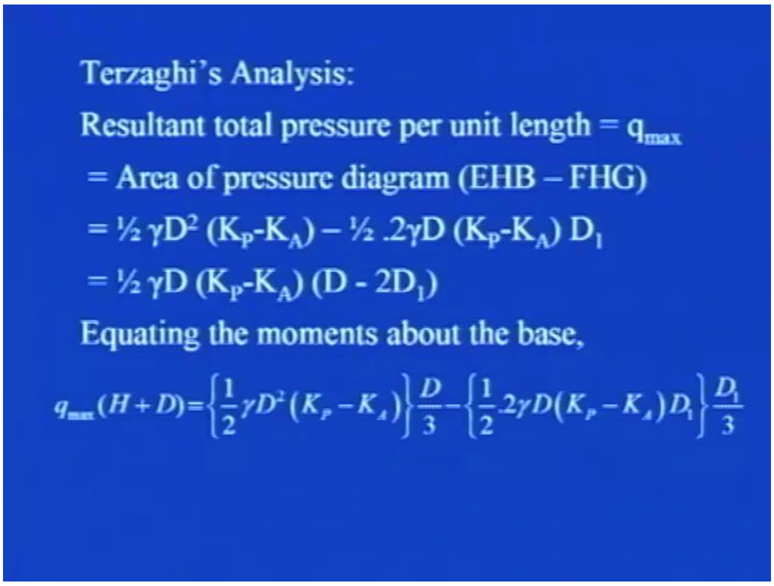

So, here resultant total force per unit length, which if I represent by q max it becomes equal to the area of pressure diagram, which is E H B minus F H G. So, you can see E H B minus F H G. So, this is the area of the pressure diagram from which you have to subtract, this particular area and this will give you resultant total pressure per unit length of well. So, from this pressure diagram, you can find out the area of this E H B and F H G.

So, what is the area of E H B it is this triangular region which is half of this base H B in to B E that is B E, so half D into gamma D K P minus K A while this area of F H G is half of this is the base; that means, 2 gamma D K P minus K because, this is also gamma D K P minus K this is also gamma D K P minus K A. So, this H G will become 2 gamma D K P minus K A and the height of this triangle is D 1.

So, accordingly you can write this expression as half gamma D square K P minus K A, which is the area of pressure diagram under E H B. Then half of 2 gamma D K P minus K A into D 1 which is the area of pressure diagram F H G and this will result into, that this particular expression which is half gamma D K P minus K A D minus 2 D 1, mind you that all these things, they all are known except for D 1.

So, to know this resultant total pressure per unit length that is, q max we need to first know that, what is the value of this D 1. Now, if we equate the moment about the base, what we will get is that q max H plus D is equal to, you can see here that this area and its moment will be at one third that is, D by 3 here it will be acting and for this one, the moment the lever arm will be, from the base will be one third of D 1.

So, this is what that it has been taken, the area and at a distance D by 3 from the base minus this particular area that is, the area of this pressure diagram F H G and it will be acting at a distance of D 1 by 3 from the base and this will be equal to q max H plus D. Now, the expression for q max you have already obtained as, half gamma D K P minus K A D minus 2 D 1, so if you substitute it here.

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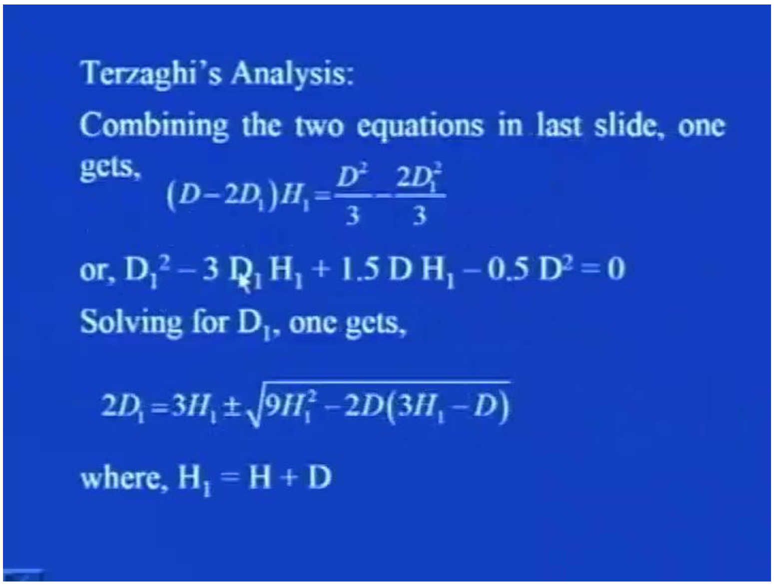

And then, try to simplify the expression, you will be getting this simple or simpler expression which is D minus 2 D 1 into H 1 is equal to D square by 3 minus 2 D 1 square over 3. If you further solve it, you will be getting this particular expression which is a second order equation, quadratic equation in D 1 and you know that, if you have an equation in X that is A X square plus B X plus C is equal to 0, you can solve very easily that equation for X.

So, using that particular expression, one can solve for D 1 and gets this particular expression which is equal to 2 D 1 is equal to 3 H 1 plus minus square root of 9 H 1 square minus 2 D into 3 H 1 minus D. Where this H 1 is known to us, I mean for the simplification purpose we have written it like this, in the form of H 1, where this H 1 is H plus D.

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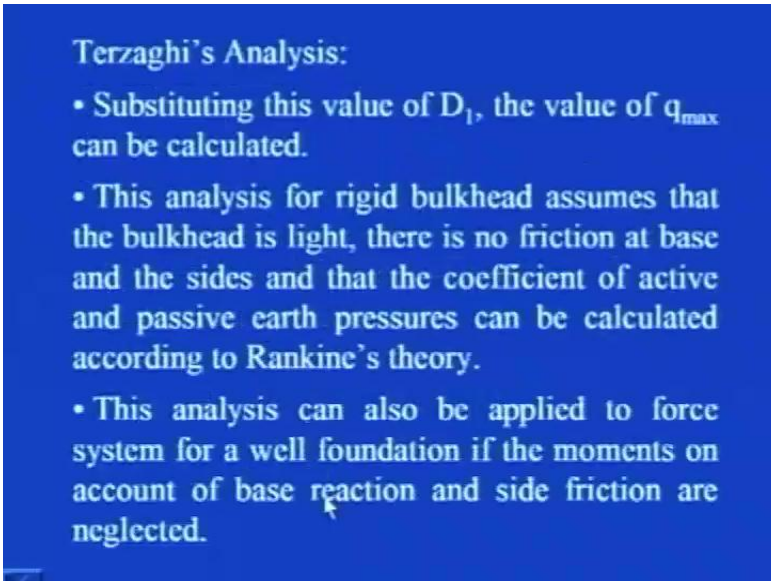

Now, substituting this value of D 1 the value of q max can be calculated, so you have seen that in the expression of q max, only unknown was D 1. So, by using the equation of equilibrium with respect to moment, we can obtain that unknown D 1 and if we substitute it in the expression for q max, we can get the value of q max. This analysis for rigid bulkhead assumes that the bulk head is light and then, there is no friction at base and the sides and that, the coefficient of active and passive earth pressures can be calculated, according to Rankine's theory.

You know that, there were two theories, Rankine's theory and Coulombs theory, so in this one, this is an assumption in Terzaghi's analysis that K P and K A that is, coefficient of lateral earth pressure in passive and active condition have to be obtained using Rankine's theory. Further this analysis can also be applied to a force system for a well foundation, if the moments on account of base reaction and side friction are neglected.

Here we had considered the forces due to base reaction and side friction both, but in case if you, if they are very less or negligible. So, that there is nothing to lose as far as the stability of well foundation is concerned, we you can neglect and in case you neglect then, Terzaghi analysis can also be used for the same.

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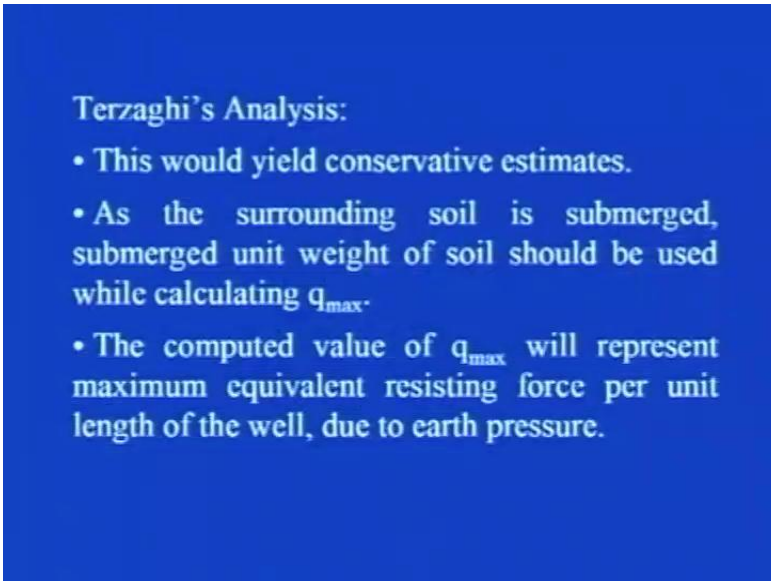

Further, that by ignoring these two things, you will yield the conservative estimates that is, we will be towards the, that the q max will be less and then we will be towards the conservative values. As the surrounding soil is submerged, submerged unit weight of soil should be used while calculating q max due to the presence of water, the soil which is surrounding the well foundation is in submerged condition and so, gamma submerged should be taken in the analysis. The computed value of q max will represent maximum equivalent resistance force per unit length of the well, due to the earth pressure.

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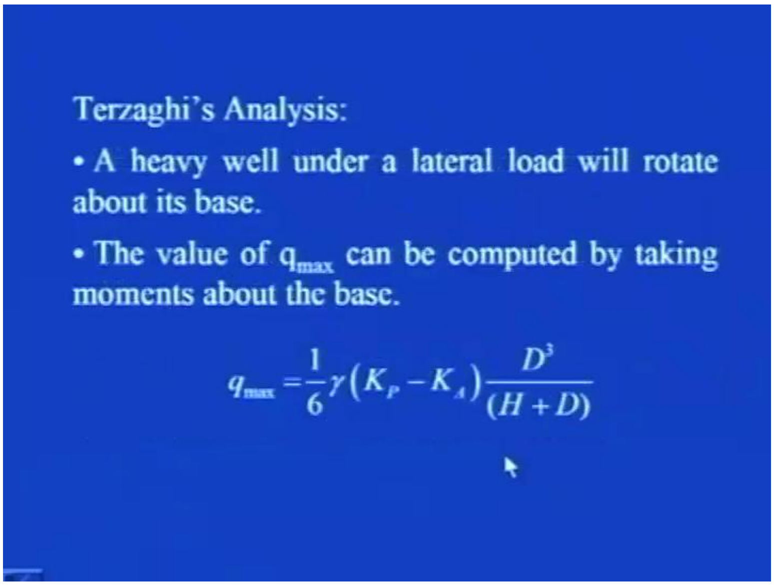

Then, in case if it is not light then, what for what, how you will get that value of q max. So, for a heavy well under a lateral load that, well will have the tendency to rotate about its base because, in case of light well it was rotating about a point O which was above the base of that bulkhead little above the base, but in case of it is a heavy well. So, under any lateral load, this will rotate about its base, so that point O will shift to the base of the bulkhead.

So, in that case the value of q max can be computed by taking moments about the base directly, there you, you do not require because, that D 1 thing which was unknown in the earlier case, in this case it will be known. So, you will be getting, if you take that moment equilibrium equation about the base, you will be obtaining this particular expression for q max and which is 1 by 6 gamma K P minus K A D cube upon H plus D.

Here, you can see that all the things are known to you, K P and K A you can obtain from the Rankine's theory, gamma which you have to take as gamma submerged, D is depth of embedment and H is the height, where the height above the ground level where this lateral force will be acting on the well foundation.

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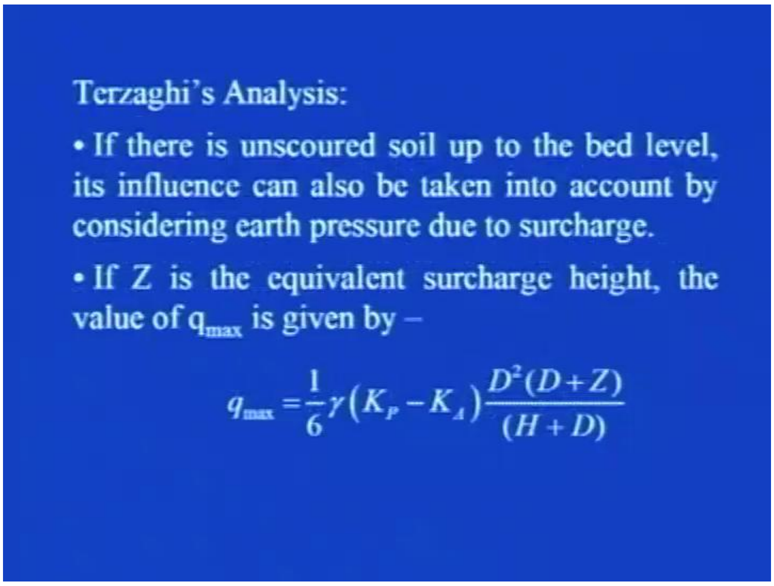

Now, if there is unscoured soil up to the bed level, its influence can also be taken into account by considering earth pressure due to the surcharge. So, in the previous cases, we did not consider any surcharge that is, we were considering that there is no unscoured soil up to the bed level, but in case if it is present, it can also be taken into account. So, if Z is the equivalent surcharge height the value of q max is given by, this particular expression again this is coming from the fundamental equation that is you have to, have that equilibrium of moment and then you can get the expression for this q max.

This is equal to 1 by 6 gamma K P minus K A D square into D plus Z H plus D. So, this Z term comes additional over here, which is the equivalent surcharge height. So, whatever is the surcharge, you can always convert into the equivalent surcharge height and can, it can be considered in this particular form using this Terzaghi's analysis.

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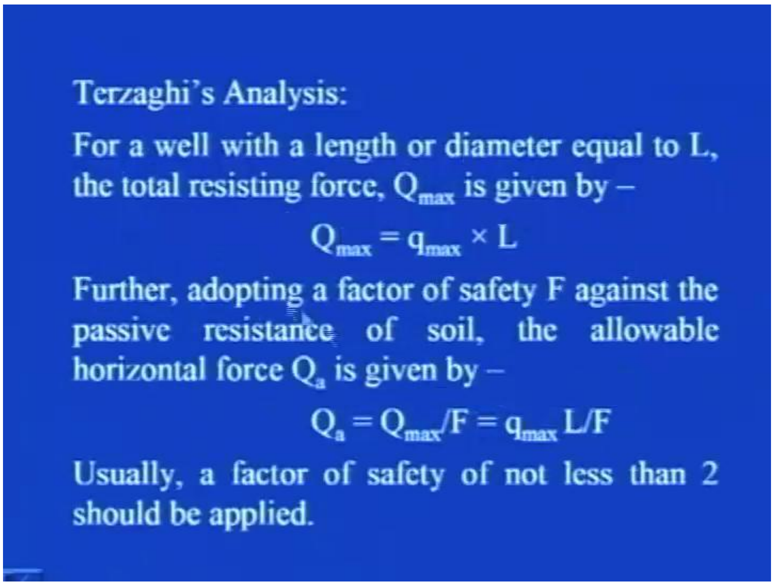

Now, for the well with a length or diameter equal to L, the total resistance force Q max is given by Q max that is, capital Q max it is the total resistance force while this Q max was the lateral resistance force per unit length. So, if you multiply it by length or diameter of the well, you will be getting this total resistance force.

So, further adopting a factor of safety F against the passive resistance of soil, the allowable horizontal force Q a will be given by this Q max divided by this factor of safety, where this will result into that small q max into L by F, this usually this factor of safety is adopted not less than two. So, minimum factor of safety of 2, you should adopt.

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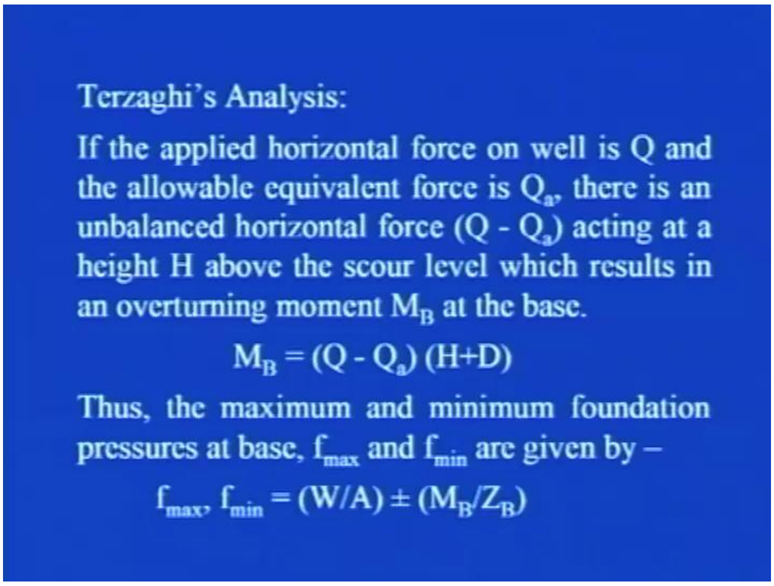

If the applied horizontal force on well is Q and the allowable equivalent force is Q a, there is an unbalanced horizontal force which is Q minus Q a and it will be acting at a height of H above the scour level which results in an overturning moment M B at the base, which will be equal to Q minus Q a H plus D. So, thus the maximum and minimum foundation pressures at base, if I represent them by f max and f minimum, they are given by f max or f minimum is equal to W by A plus minus M B upon Z B.

So, in case if this condition is there that is, a applied horizontal force on well is Q and the allowable equivalent force is Q a then, the resultant force that is Q minus Q a will be acting and because of that an overturning moment at the base will be acting and this will also contribute to the maximum and minimum foundation pressures at base. So, as in the last class I told you that, these pressures should be within the permissible limit, so that is why it is essential to know that, what is the value of or the what is the magnitude of these stresses that is, the maximum and minimum 1.

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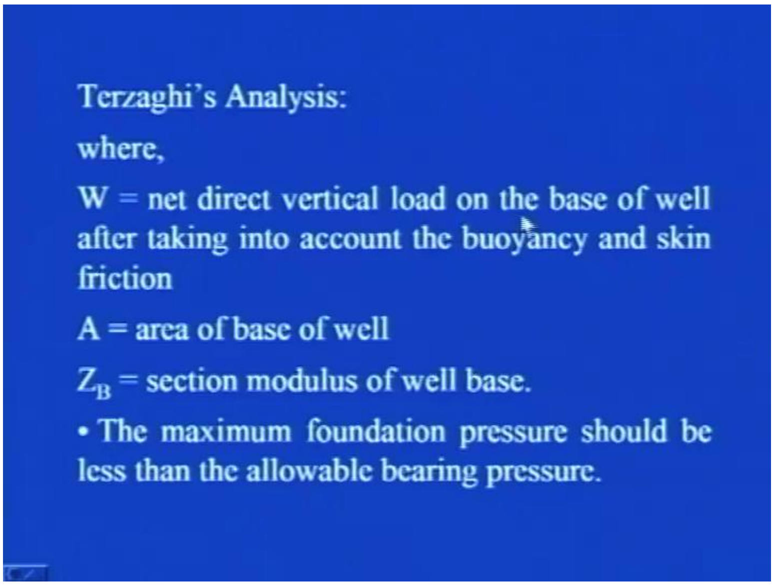

So, where this, your W is net direct vertical load on the base of well, after taking into account, the buoyancy and skin friction. A is area of base of well, if it is circular in section it will be simply phi by 4 into diameter square, if it is having some other shape and size then, accordingly you have to find out that area, which is the base of the well. Then Z B is the section modulus of well base.

The maximum foundation pressure should be less than the allowable bearing pressure, so we know that, how you can get this allowable bearing pressure using the speedy test data. So, an in this one, you have seen that, how you can find out the maximum and minimum base pressure. So, the maximum foundation pressure, it should always be less than the allowable bearing pressure.

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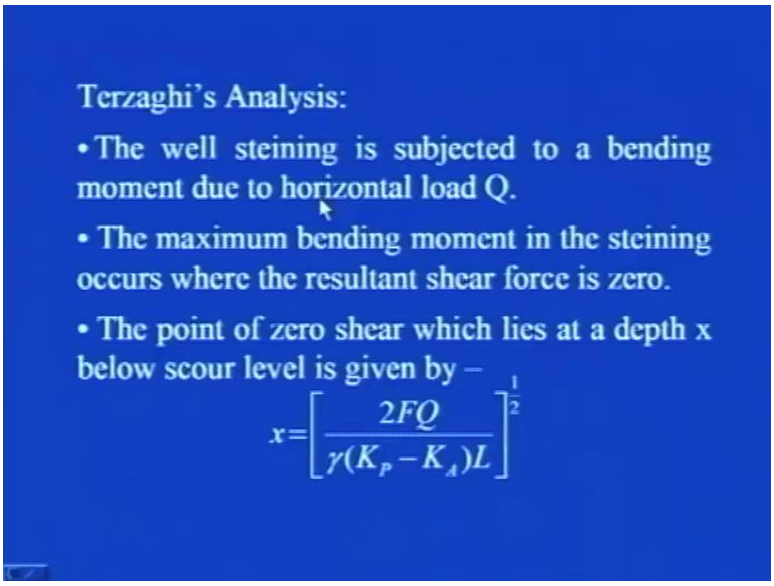

The well is steining, is subjected to a bending moment due to horizontal load Q, right now, we were discussing from the point of view of the base reaction that is, whatever is the maximum and minimum foundation pressure. Now, the well is steining is a vertical component of the well foundation and which is subjected to a bending, due to this horizontal load Q. So, the maximum bending moment will be occurring and where this bending moment will be occurring is the point, where the shear force will be zero.

So, where the resultant shear force is zero, the maximum bending moment will occur at that particular location in the steining. So, the point of zero shear which lies as a depth x below scour level is given by, so these you can obtain from the fundamental basic three equations of equilibrium. And that, you can obtain as 2 F Q divided by gamma K P minus K into L to the power half that is, the square root of this total expression.

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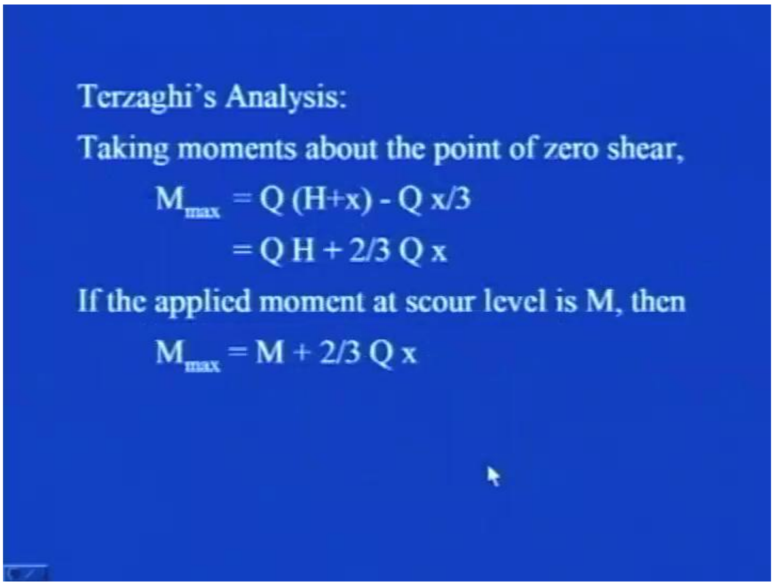

Then, taking moments about the point of zero shear because, that will be the point about which the maximum moment will be occurring and you know that, in the analysis and design procedure we always go for the maximum force and the maximum bending moment. So, M maximum you can obtain as Q H plus x minus Q x by 3, which will result into this particular expression as Q H plus 2 by 3 Q into x.

So, if the applied moment at scour level is M then, this M max will be M plus 2 by 3 into Q x. That is, this particular expression is getting reduced to this expression, only the change here is Q into H we are replacing by M, where this M is the applied moment because, in case the applied load is Q which is acting at a height of H above the scour level then, Q into H will be the moment and if I know directly that applied moment at scour level. So, directly if I substitute it in this particular expression, I can get the value of maximum bending moment.

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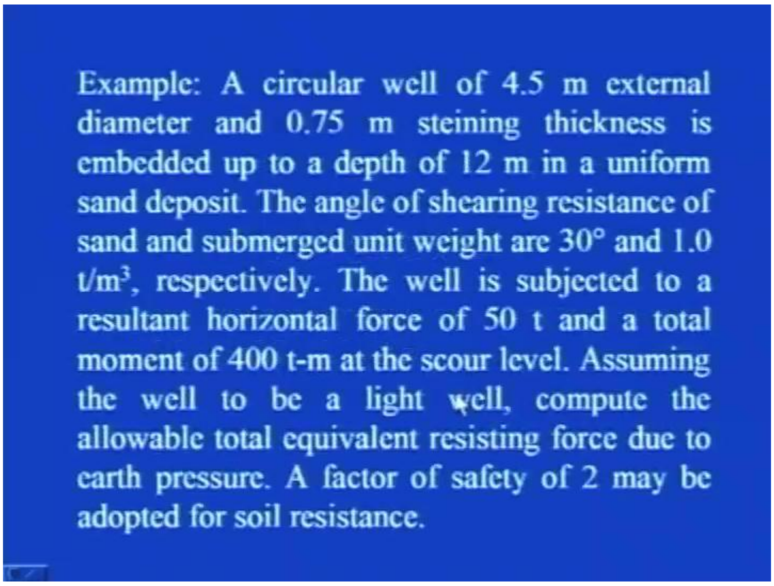

Now, let us try to take an example to develop the understanding of a real problem, that right now we discussed, so many expressions and mathematical things that, how we can analyze or get the lateral stability of well foundation using Terzaghi’s analysis. Now, let us take one example based on this Terzaghi’s analysis that, whether the well is safe or not for all these values which are given in this particular example.

So, it says that a circular well of 4.5 meter external diameter and 0.75 meter steining thickness is embedded up to a depth of 12 meter in a uniform sand deposit. So, what is the value of D is 12 meter, external diameter of the well is 4.5 meter and steining thickness is 0.75. So, internal diameter of well will be 4.5 minus 2 times 0.75 that is, 1.5, so internal diameter will be 4.5 minus 1.5 that is 3.

Further, it says that the angle of shearing resistance of sand and submerged unit weight are 30 degree and 1 tonne per meter cube respectively. The well is subjected to a resultant horizontal force of 50 tonnes and a total moment of 40 tonne meter at the scour level. So, here the horizontal force as well as the additional moment, they are both are acting on the well. Assuming the well to be a light well, compute the allowable total equivalent resistance force due to earth pressure and for this one, it has been given that a factor of safety of 2 may be adopted for soil resistance.

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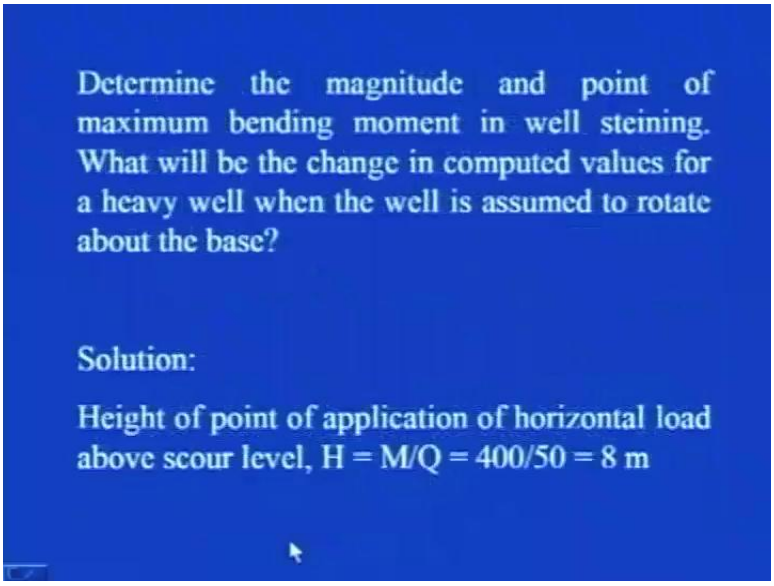

Further it says, that determine the magnitude and point of maximum bending moment in well steining, what will be the change in computed values for a heavy well, when the well is assumed to rotate about the base. So, two cases that we need to consider, once is, one is when the well is considered as light well then, as I discussed with you that, the point of rotation will be above the little, above the base of the well.

However, if you consider the well to be heavy well then, the point of rotation will be at base. So, what exactly will be the difference in these two cases that, we will be able to see while solving this particular example. So, let us now, have a look on the solution procedure that, how height of point of application of horizontal load above scour level, which I can obtain as M by Q.

Because, the horizontal load is given and the moment is also given, so you can get this height H which you can divide as M by Q, which will be working out to be 8 meter in this particular case because, M is given to be 400 tonne meter and Q is given to be 50 tonne.

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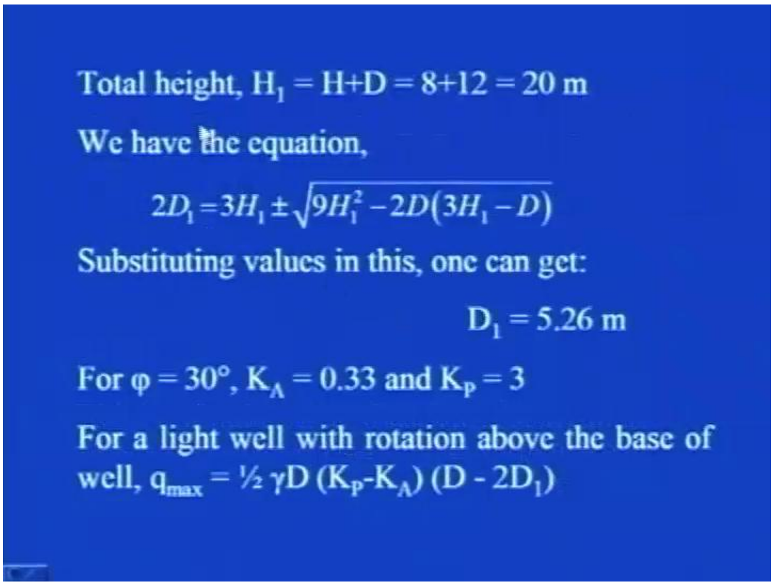

Then, the total height which is H 1 will be equal to H plus D and D is given as 12 meter, so that will result as H 1 to be equal to 20 meter. Then, you have the equation because, in calculating that Q max, I told you that D 1 is the only unknown, so first we need to calculate or evaluate this D 1. So, we have this expression as 2 D 1 is equal to 3 H 1 plus minus square root 9 H 1 square minus 2 D into 3 H 1 minus D.

So, if I substitute appropriate values like H 1 to be equal to 20 meter then, D to be equal to 12 meter, one can get this expression for putting all these values in expression for D 1, one can get D 1 to be equal to 5.26 for the numerical value of H 1 to be equal to 20 meter and D to be equal to 12 meter. Now, this Terzaghi's analysis has the assumption that K P and K A, they are to be determined using Rankine's theory.

So, if you go back to the concepts of lateral earth pressure theories, so phi given that is angle of shearing resistance is given a to be 30 degree and correspondingly K A and K P will be .33 and 3. So, in case of light well with rotation above the base of well that is, q max will be equal to half gamma D K P minus K A D minus 2 D 1 which we have just now, saw that how we can obtain this expression for q max.

So, now I know each and every thing in this particular expression gamma is submerged unit weight of the sand which is given out to be 1 tonne per meter cube. D we know is 12 meter K P and K A we have obtained corresponding to the angle of shearing resistance which is given to be 30 degree. Then, D we already know it is 12 meter and D 1 we have obtained from this particular expression as 5.26 meter.

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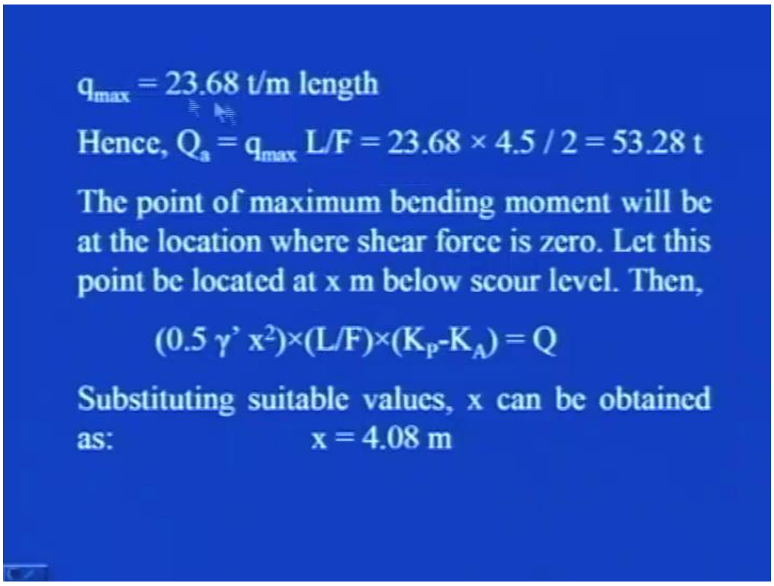

So, substituting all these values, I will be getting this q max to be equal to 23.68 tonne per meter length of well. Then, I told you that, how you can find out the total allowable force which is Q a and is equal to q max into L by F. Q max we have obtained as 23.68 here and then, length of the, this well is given out to be 4.5 meter because, it is an external diameter, which you have to take into account divided by the factor of safety which is 2 which is given in the statement of the example.

And this will result into the value of 53.28 tonne, further this was one part of the solution, further it was asked that, we need to find out the location of occurrence of maximum bending moment in well is steining. So, this will be you know that, where the shear force is zero, the point of maximum bending moment will be that particular point.

So, let this point be located at x meter below a scour level, then in that case if you take the equilibrium forces, so that way you will be getting .5 gamma prime x square into L by F into K P minus K A to be equal to Q. This Q value you know it is 50 tonnes then, gamma prime you know it is 1 tonne per meter, cube L you know as 4.5 meter factor of safety is 2 K P and K A you have obtained as 3 and .33 respectively. So, you substitute all these values and then, you can obtain this value of X as 4.08 meter for all these numerical values.

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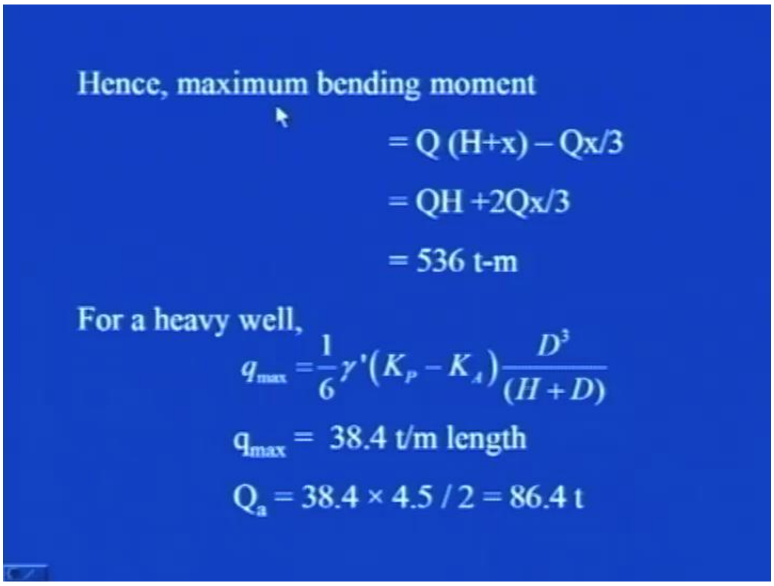

So, the maximum bending moment, you can obtain using this particular expression that is, Q H plus 2 Q x upon 3 and this will result into 536 tonne meter. So, this was the case when you have assumed the well to be light well, in case it is a heavy well then, I gave you the expression for that. So, you simply substitute all these values in this expression of q max which is 1 by 6 gamma prime K P minus K A D cube upon H plus D, you know all these values.

So, substitute it here and then, you will get this value of q max to be equal to 38.4 tonne per meter length, so in case of light well, it was 23.68 tonne per meter length. However, in this case you are getting it to be 38.4 tonne per meter length and correspondingly that Q a, that is the total allowable force that will be 38.4 into the external diameter of the well divided by the factor of safety which is 2 and this will result into 86.4 tonne. So, with the help of this example, I hope that you got the idea that, how you can analyse a real field problem related to the well foundation by considering Terzaghi's analysis.

Now, when we were discussing many methods that is, Terzaghi then Pender and then, some of the methods given by IRC method, so we already discussed about the Terzaghi's analysis, now let us try to have a look on one of the method of IRC recommendation. So, first I will be discussing some of the general aspects and then, we will see that, what is the recommendation by IRC as far as elastic theory method is concerned.

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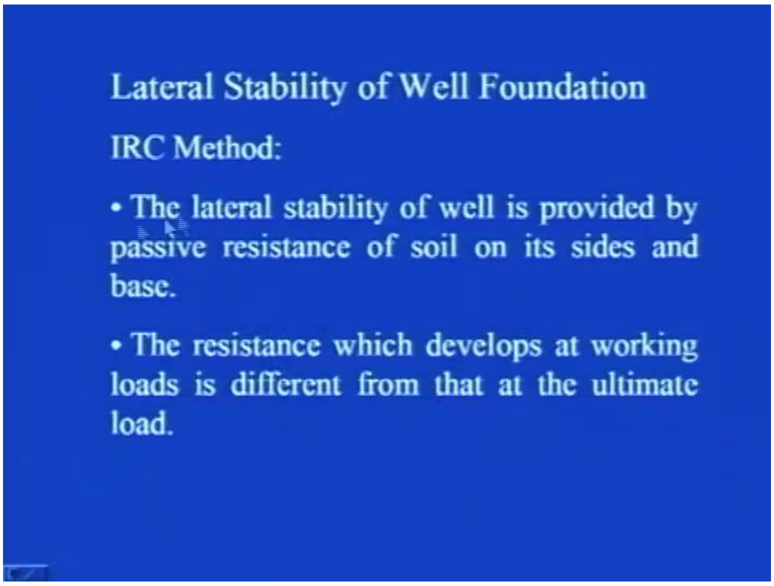

So, in IRC it says that, the lateral stability of well is provided by passive resistance of soil on its sides and base. The resistance which develops at working loads is different from that at the ultimate load that is, so obvious and it has been associated in recommendation by IRC also.

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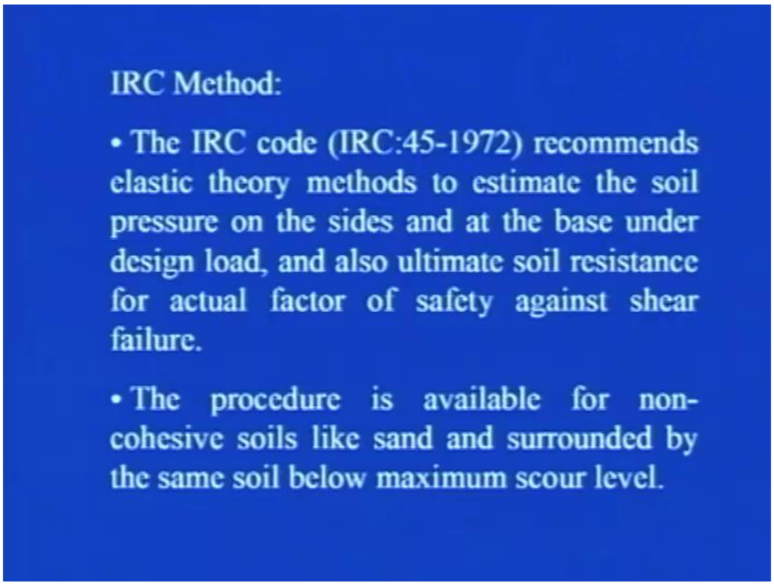

The IRC code that is, number is IRC 45 1972 recommends elastic theory methods to estimate the soil pressures on the sides and at the base under design load and also ultimate soil resistance for actual factor of safety against shear failure. So, two things are there, one is that you, it estimates the soil pressure on the sides and the base, under design load and the another one is due to the ultimate soil resistance. The procedure is available for non-cohesive soils like sand and surrounded by the same soil below maximum scour level.

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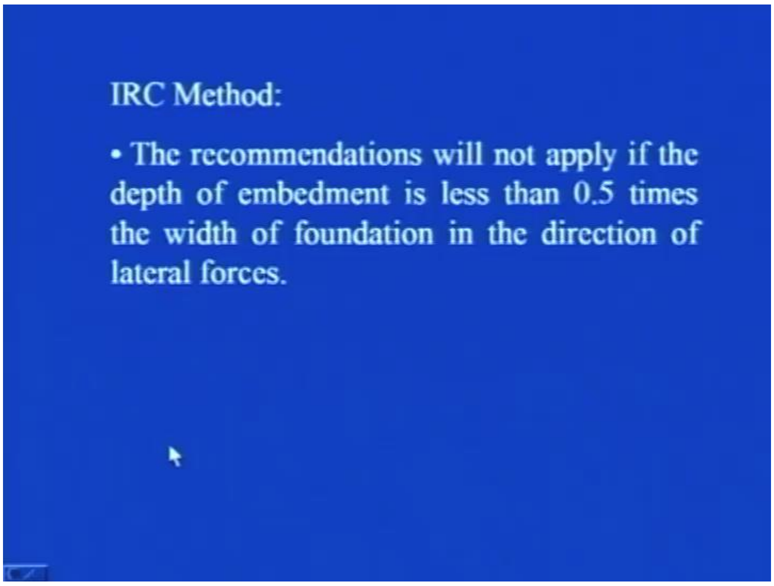

Then the recommendations will not apply, if the depth of embedment is less than .5 times the width of foundation in the direction of lateral forces. So, this is the limitation of this IRC method that, the depth of embedment if it is less than 0 point.5 times the width of the foundation in the direction of lateral forces then, these recommendations by IRC will not hold.

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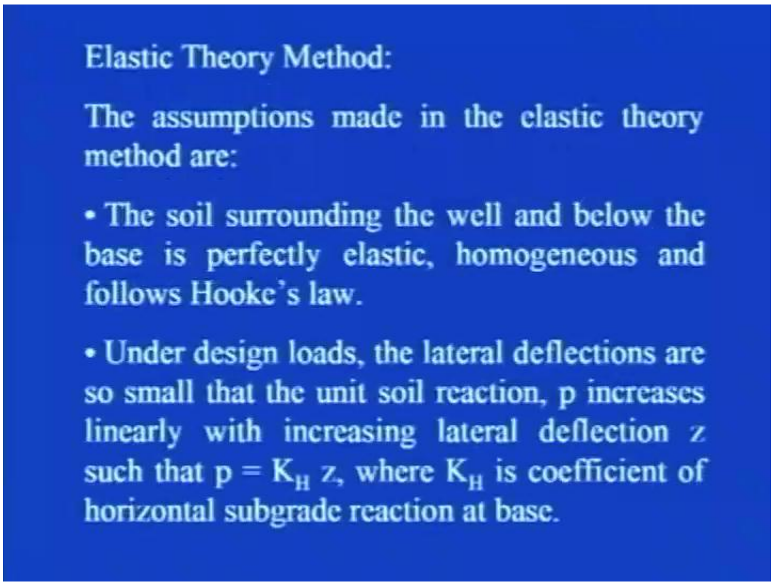

Now, let us try to discuss the 1 method which is given by IRC that is, it is elastic theory method. So, first we will see that, what are the assumptions associated with it and then we will see that, what are the various steps involved in this elastic theory method for the analysis of lateral stability of well foundation. So, first assumption is the soil surrounding the well and below the base is perfectly elastic homogeneous and it follows Hooke's law.

Under design loads, the lateral deflections are so small that the unit soil reaction which is p, it increases linearly with increasing lateral deflection which is z such that p is equal to K H into z, where K H is coefficient of horizontal sub grade reaction at base. So, this is an important assumption that p increases linearly with increase in the lateral deflection z and that coefficient of proportionality is represented by this coefficient of horizontal sub grade reaction at base, which is represented by K H.

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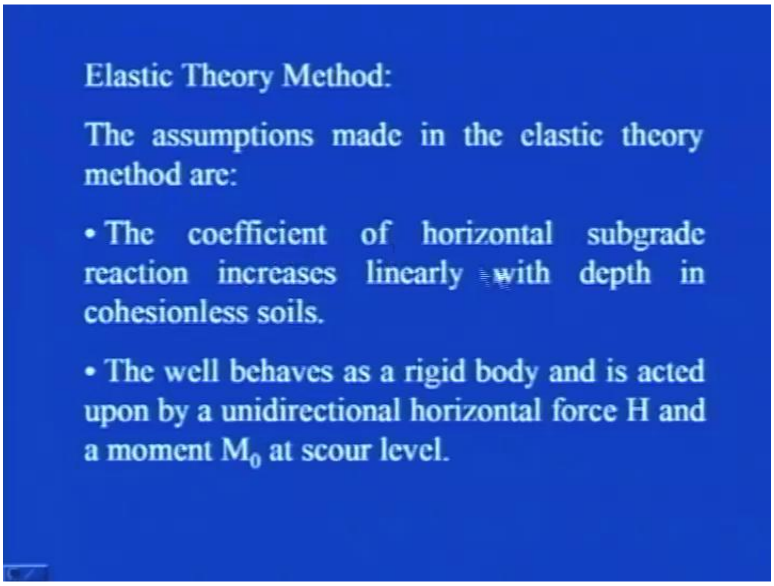

The coefficient of horizontal sub grade reaction increases linearly with depth in cohesionless soils. So, this is again another assumption, it may not be true in the practical cases, but this is, what is the assumption associated with the elastic theory given by IRC. The well behaves as a rigid body and is acted upon by a unidirectional horizontal force H and a moment M 0 at a scour level. So, this is again horizontal force H is acting only in one direction and a moment is also present at a scour level, which is represented by M 0.

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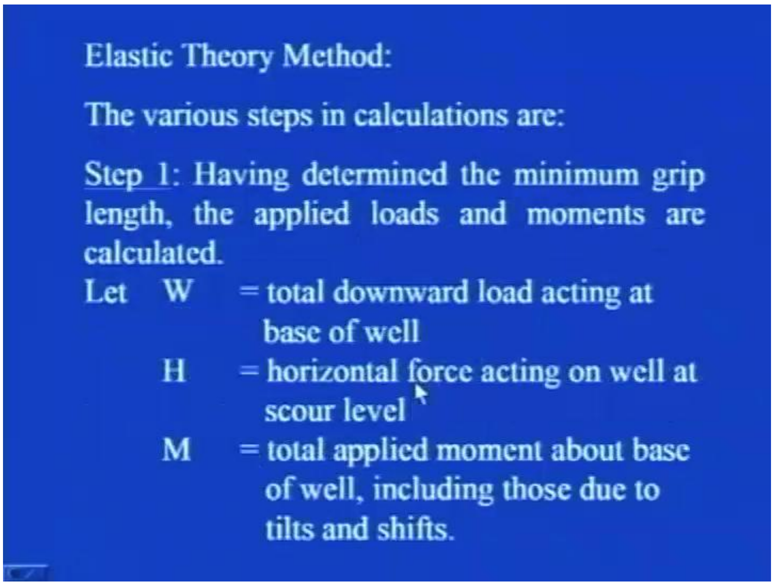

Now, after knowing all these assumptions of elastic theory method, various steps to be followed in this particular method, they are. Step 1 is that, first having determined the minimum grip length, the applied loads and the moments are calculated. So, if you assume that, let the W be the total downward load acting at base of well. Let H be the horizontal force acting on the well at scour level, M is the total applied moment about base of well, including those due to tilts and shifts because, in the last class I was telling you that these tilts and shifts should be should not be present or if even though, if they are present, they should be within a permissible limit.

Because, they cause this additional moment which can be if you do not take care of this, these additional moments during your analysis procedure then, it can be hazardous to the safety of that well foundation therefore, these tilts and shifts should be within the permissible limits.

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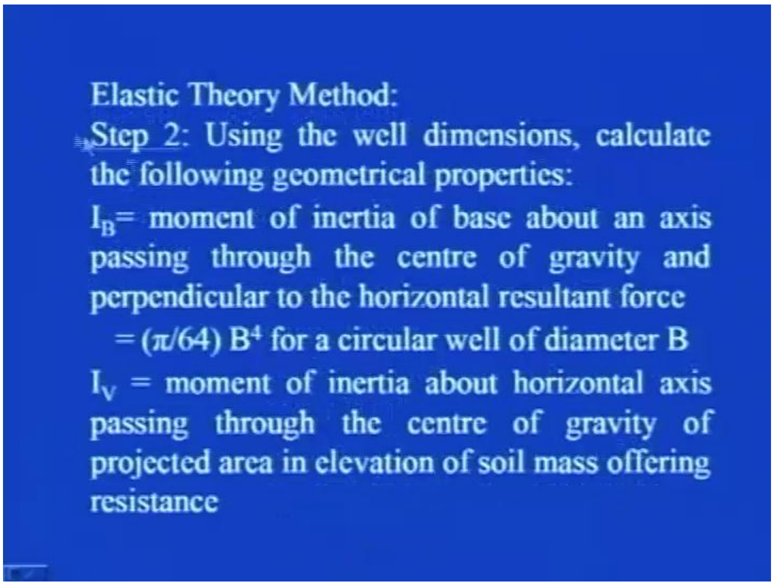

Then, step 2 using the well dimensions, calculate the following geometrical properties, these geometrical properties are the, properties of section of well foundation. IB is moment of inertia of base about an axis, passing through the centre of gravity and perpendicular to the horizontal resultant force and this is equal to pi by 64 B to the power 4 for a circular well of diameter B. Then IV is the moment of inertia about horizontal axis passing through the centre of gravity of projected area in elevation of soil mass offering the resistance.

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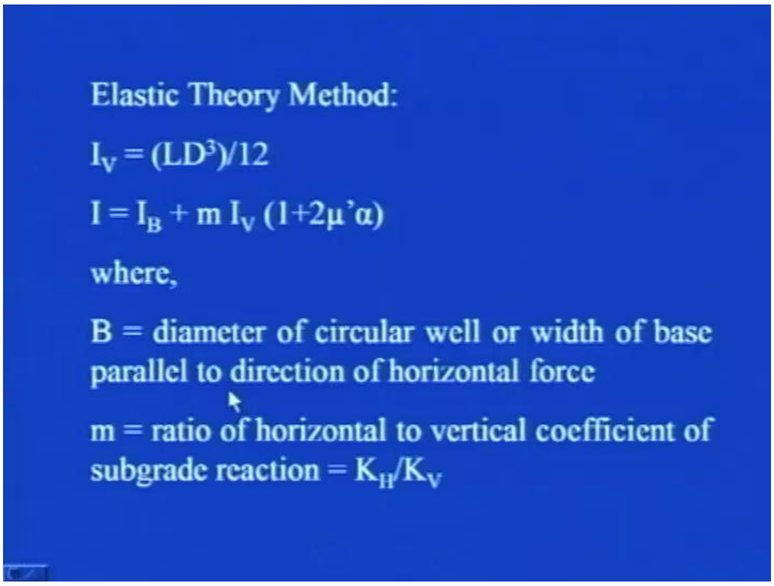

So, once you know these two properties you have to get this IV that is, LD cube by 12 and then, you can obtain this expression for I as IB plus m IV 1 plus 2 mu prime into alpha. Where your, this B is diameter of circular well or width of base parallel to the direction of horizontal force, m is the ratio of horizontal to vertical coefficient of sub grade reaction that is, KH upon KV.

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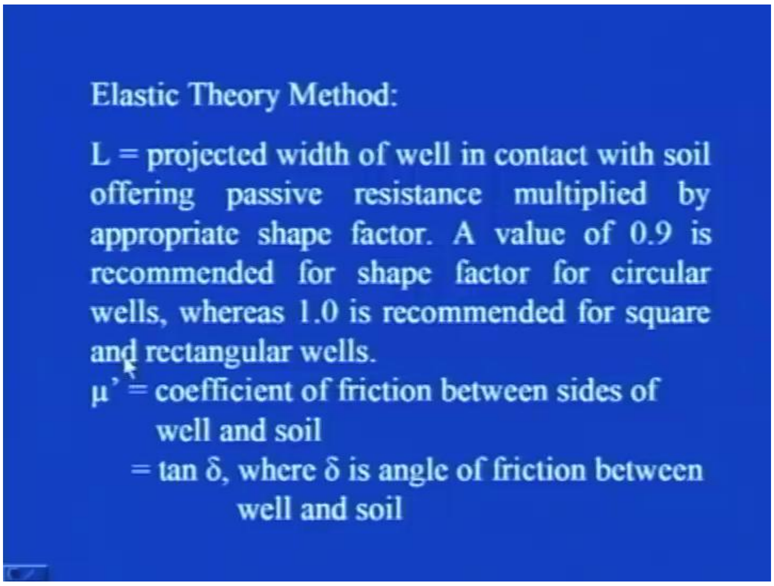

L is the projected width of well in contact with soil offering passive resistance multiplied by an appropriate shape factor and the value of .9 has been recommended by IRC as the shape factor for circular well. However, for square or rectangular well, this can be taken as 1. Mu prime is the coefficient of friction between sides of well and soil which is equal to tan delta, where delta is the angle of friction between the well and soil.

So, these are the various three steps, you have few more steps that, we will be discussing in the next class and then, we will take up one example to, just to give you the feel that, in case if a practical problem is available in front of you, how you can analyse the well foundation. So, today we have seen that, what all are the various forces which are acting on the well foundation. Then we have seen that, how you can determine allowable bearing pressure.

Further, we also saw that, which combination of forces we need to consider while doing the stability analysis of well foundation. Then we discussed that, how the lateral stability well foundation can be checked, we discussed along with one example, the Terzaghi's analysis and then, some of the steps related to the elastic theory method which has been recommended by IRC. So, rest all things we will proceeds in the next class.

Thank you.