Foundation Engineering
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Module - 01
Lecture - 01
Shallow Foundation

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Good morning. I am Dr. N.K. Samadhiya, Associate Professor in the Department of Civil Engineering, IIT Roorkee. And I am going to deliver a lecture on shallow foundations today. As you know that all the engineering structures are supported by soil and rock and those not they either fly float or fall over.

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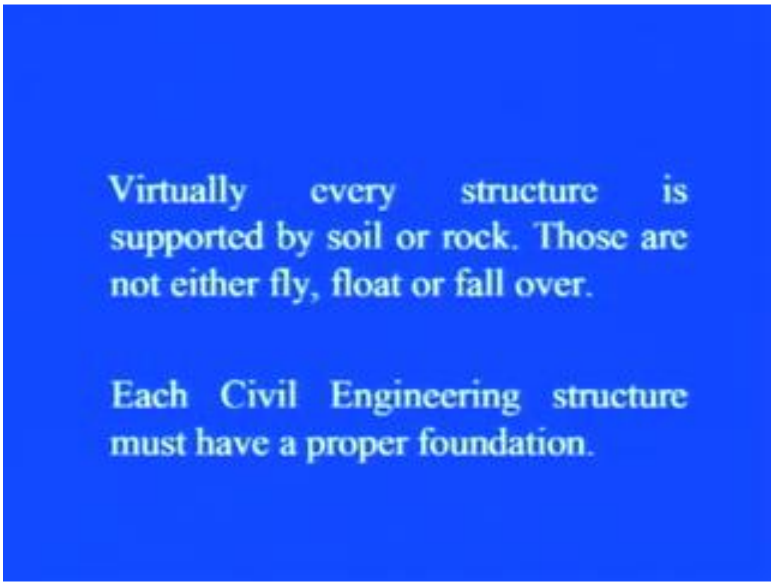

So, you will find that in all the cases of all the civil engineering structures like dams, buildings and multi-story buildings, literally, and all type of civil engineering structures whatever it may be, it may be road or railway embankment or any other thing, they are supported by a proper foundation.

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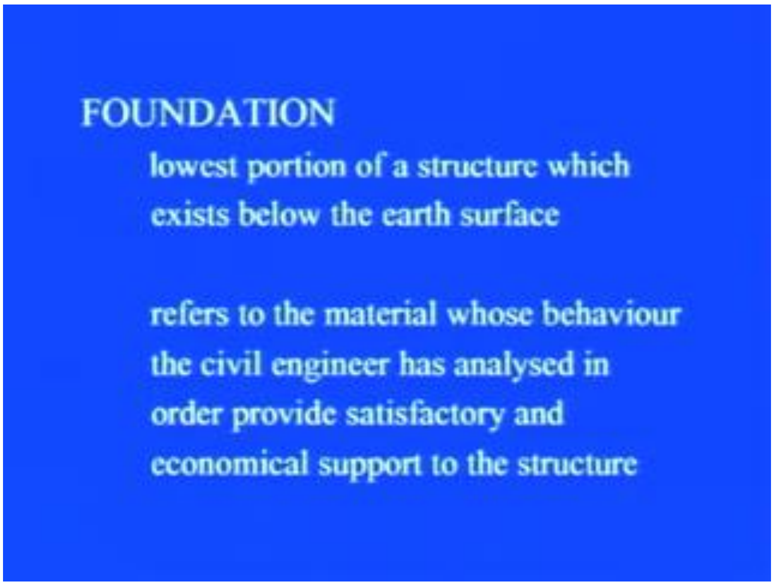

Now, when we say proper foundation - foundation means it is the lowest part of a super structure and which normally exists below the earth surface. Now, it refers to the material whose behavior the civil engineer has analysed in order to provide satisfactory and economical support to the structure.

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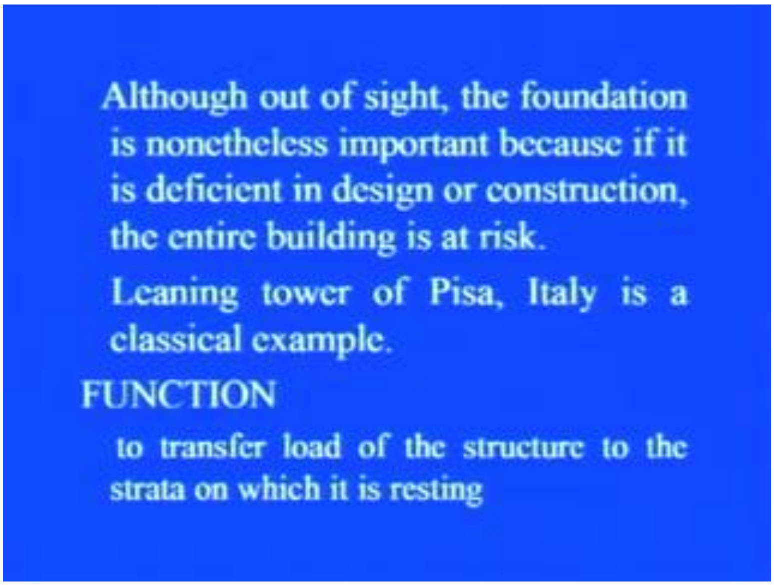

Now, these foundations may be classified a different type of foundations. And these foundations as we know that they are below the earth surface then they are out of sight. So, although out of sight, the foundation is nonetheless important, because if it is deficient in design or construction, the entire building or the super structure is at risk. And you can take that Leaning tower of Pisa, Italy as of classical example for this. You must have heard that this Leaning tower of Pisa was leaning towards one side. Now, it has been replaced or erected to its vertical position very recently in 2001. Now, the function of the foundation is to transfer the load of this structure to these strata on which it is resting. And mostly it is the geological strata that consist of either soil or rock. Now, in order to design there are certain important considerations.

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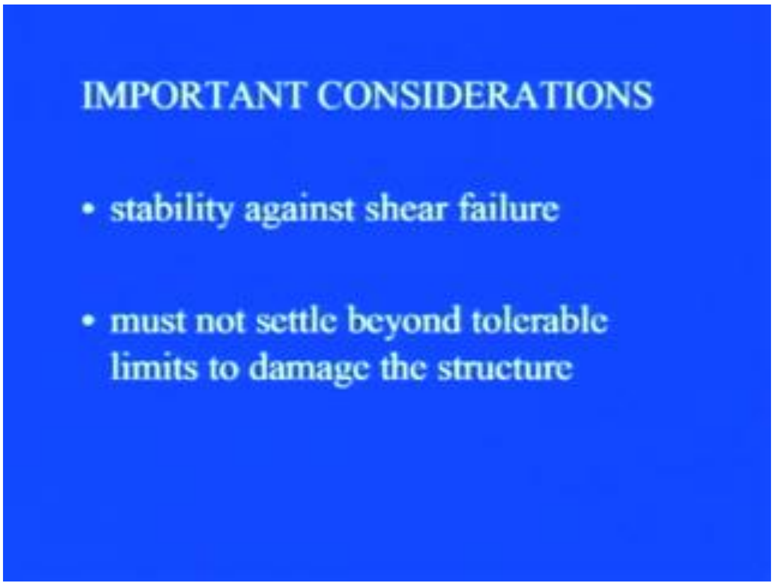

Now, one of the important considerations is the stability against shear failure. Now, when we say shear failure we mean that the shear stress which is there in soil below the foundation they are within permissible limits. So, they are related to the shear strength of the soil. And another important criterion is that the foundation must not settle beyond tolerable limits to damage the structure. Now, for different type of structure and for different type of soils they are various permissible limits suggested by Indian standard code and these limits are based on the performance of this structure.

Let us say, if a structure is satisfy more than a permissible value than it may impart with the functioning of the structure like in the case of let us say buildings. It supposes that building foundation is resting on clay and if the settlement of this structure is more than 75 millimeter or may be 100 millimeter, which is prescribed by different highest cote. And if due to that settlement there may be possibility of a cracking of the cracks appearing in the super structure. And likewise there may be other inconveniences to the structures. So, this must not settle beyond or tolerable limit and all this limits are given in different high course.

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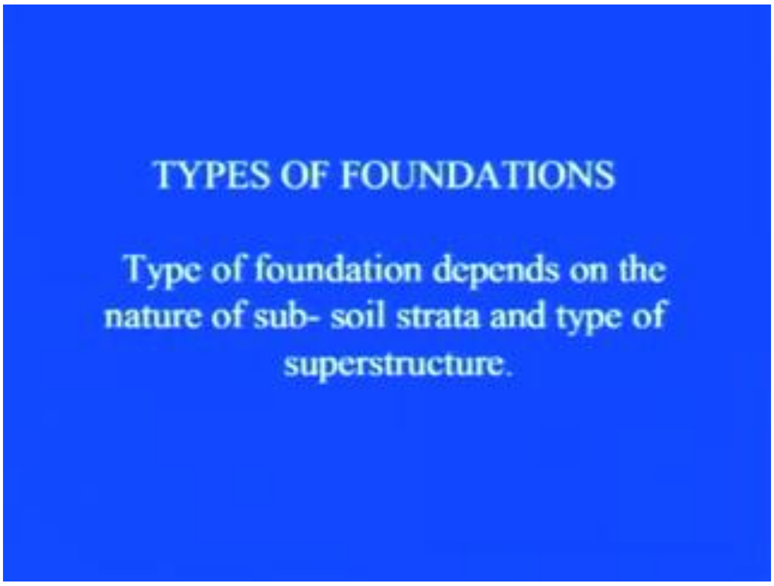

Now, there are different types of foundations, foundations may be considered as rigid foundation or fled gable foundation. Foundations may be considered depending upon the depth of the foundation. So, here type of foundations that depend on the nature of sub soil strata and the type of superstructure.

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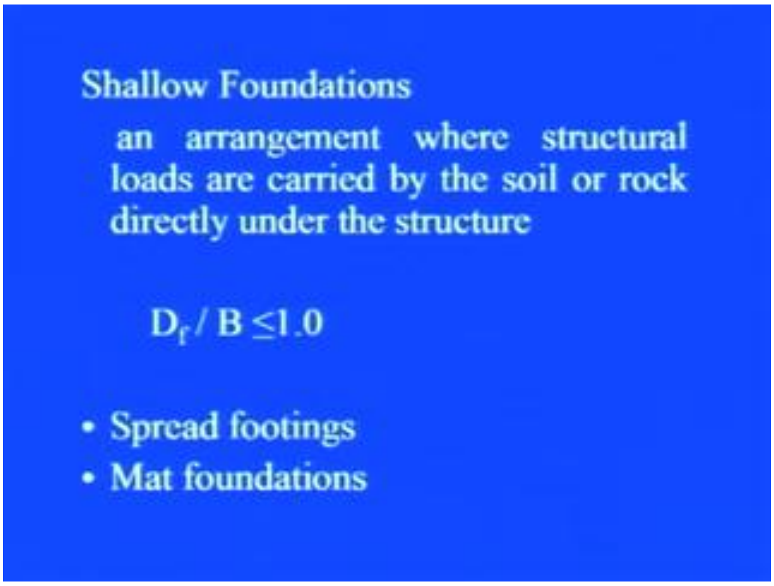

Broadly we classify these foundations either as the shallow foundations or as the D foundations. Now, in the shallow foundations is it is an arrangement where structural loads are carried by soil or rock directly under the structure. Now, in most of the cases it has been found that the depth to width ratio is kept less than 1. And this is defined by various other researches and especially Terzaghi has given this criteria, that if depth of the foundation to the width of the foundation is less than or equal to 1. It will be treated as the shallow foundation. Now, in case of shallow foundations there are many other types and some of them are like spread footings or mat foundation or the rock foundation. Now, is spread footings, strict footings, continues footings, rectangular footings, combined footings. All these come in the category of the shallow foundations as long as this depth to width ratio is less than 1.

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Now, in this figure if you see that this is foundation now, there is a column this is column foundation which is a spread foundation. This load is taken up by a larger area of the soil and this foundation is in direct contact with the soil. Now, this total load imposed by this particular column foundation or of the one of the column of the superstructure is it taken up by the soil which is below this it may be soil or rock. Now, it is this when we say depth, this is the depth of the foundation below the ground surface this is the ground surface.

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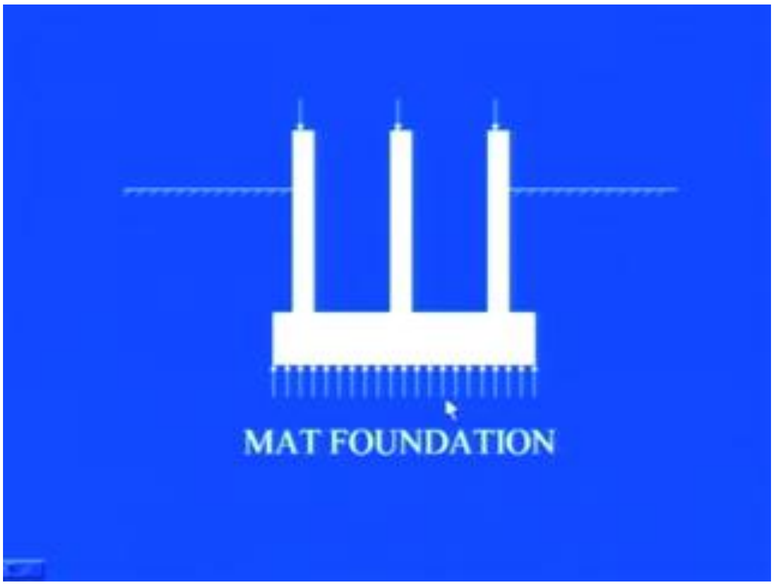

In the case of mat foundation or rock foundation, when the area of the column footing or the spread footing is more than or equal to the loaded area than in that case we go for the mat foundation or the rock foundation. Now, this is a combined foundation for many such columns and the load acted by this column is taken up by the soil which is below the mat foundation.

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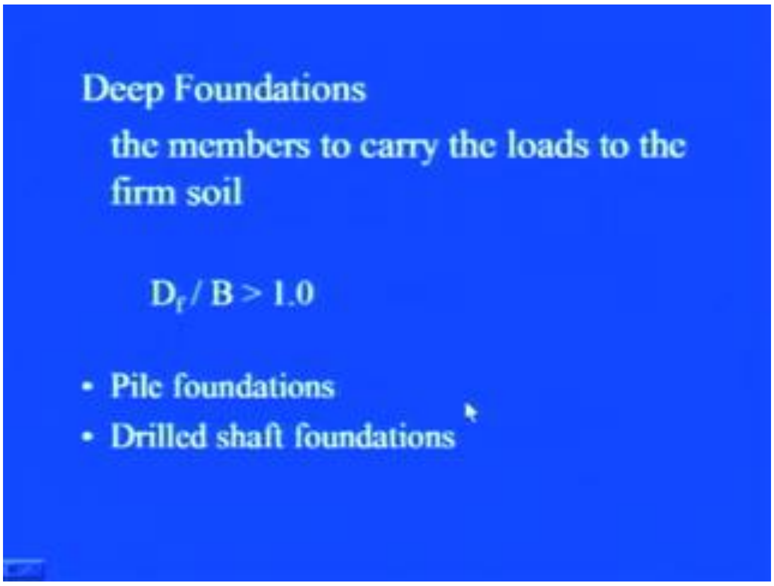

Another category is the deep foundations. Now, in the deep foundations we define the deep foundations as the members which carry the loads to the firm soil. Now, in this case the depth of the foundation to the width of foundation is greater than 1. Normally pile foundation and the drilled shaft foundations, well foundations and foundations for bridge pilers etcetera, we call we in the category of the deep foundations.

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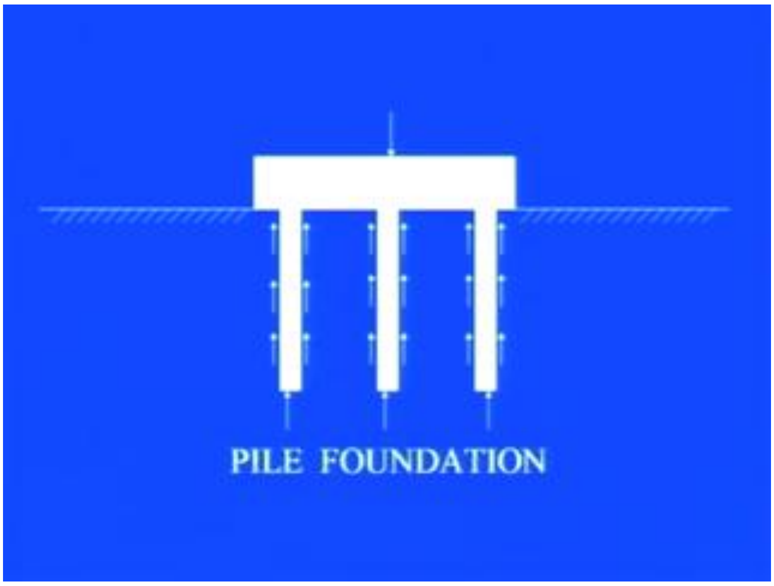

Now, this is one of the deep foundations in which we have different piles and or pile raft. Now, here pile raft although it is shown the ground surface, but in most of the cases that this pile raft also is below the ground surface. Now, in this particular case if you can see that these are the structural members which are called piles. Piles of may be of different material. So, these materials are the material which is transferring the load from the super structural to the sub soil that is actually the member and this member is that foundation. Now, the resistances offered by the skin friction between the member and the soil and the hand bearing of the pile tape. So, in the case of shallow foundations like in this case the complete load is resisted by this particular in the bearing. Whereas, in the case of pile foundation it is resisted by the hand bearing as well as the friction would been the soil and the member.

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Another example in this cases the drilled shaft foundations form it is use may be bridge pear and for other structures.

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Now, the important criteria which we have seen that the foundation must not fail in shear and that criteria is for these foundation which is this stability of shear failure.

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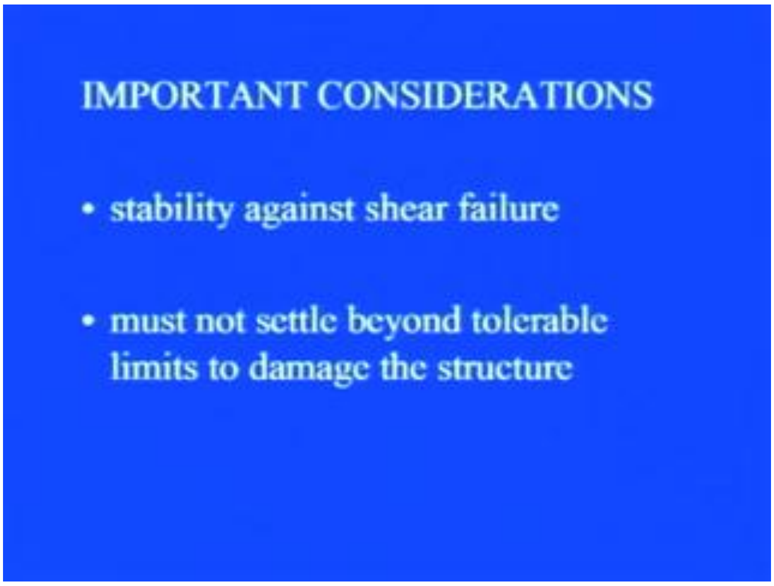

Now, it has been found that the factor of safety in this case of shallow foundation is always kept in such a way that the foundation does not fail in shear. Now, mostly the failure takes place or when we say failure we mean the failure due to the excessive settlement and especially the differential settlement. We will have to keep this differential settlement within permissible limits, because this differential settlement is more dangerous to the stability of the structure. Now, in order to find out the bearing capacity of the load carrying, capacity of the foundation from shear failure criteria, which we call it as the ultimate bearing capacity of foundation.

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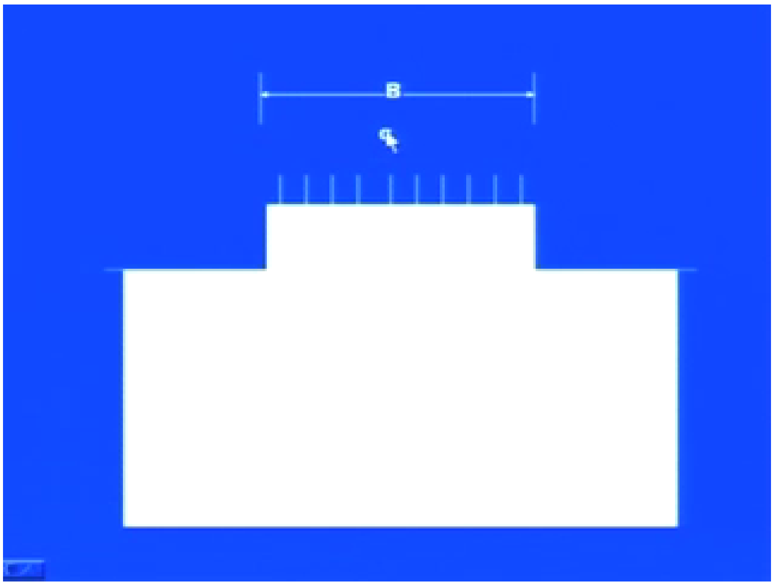

There are many theories which we are given by various researches. For that let us take an example of a foundation which is resting on soil. So, this is the foundation which is resting on soil and here the load acting on the foundation is this load intensity q and the width of the foundation is B. Now, when we apply the load when we keep on increasing the load there is settlement of this particular foundation settlement of the foundation due to the compression of the soil which is this soil stratum.

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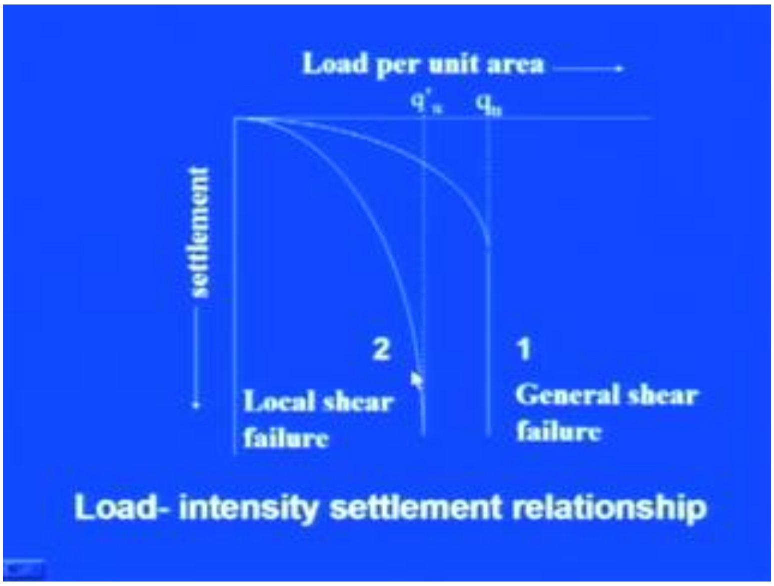

Now, when you increase the load; the load per unity area, that is the pressure which is exerted by the foundation. Now, you will get the response load intensity settlement response like this. In this on this axis this load per unit area is plotted and here this settlement of the foundation is plotted. Now, you will find that with the increase in load there is increase in settlement and a condition reaches beyond which there is no increase in the load. But there is sudden drop of the stress taken this type of failure we call it as the general shear type of failure. Now, in another case where the, you will find that there is no clear cut failure, but the stress keeps on increasing and there is no clear cut failure. And the settlement and corresponding strains are very excessive strain. Now, we classify these 2 as the general shear failure and the local shear failure cases.

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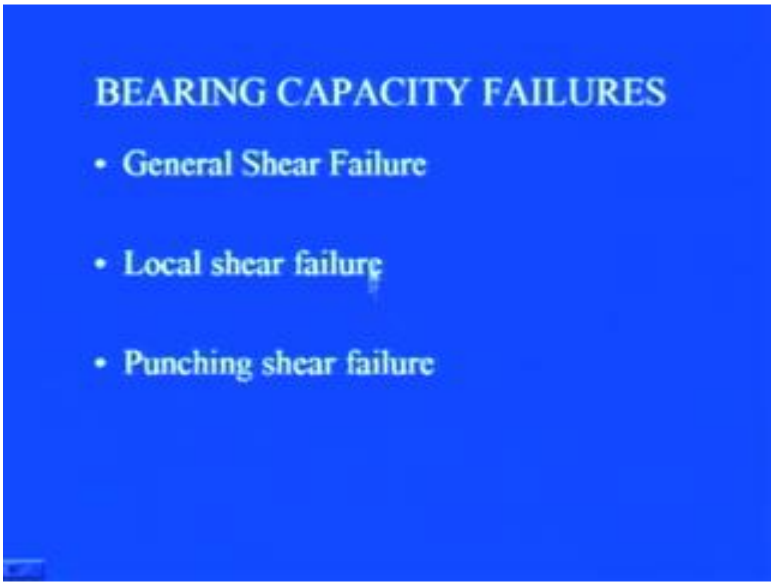

Now, so, the failures one is general shear failure, another one is local shear failure. And the third category which is intermediate would be the local shear failure and the general shear failure is the punching shear failure.

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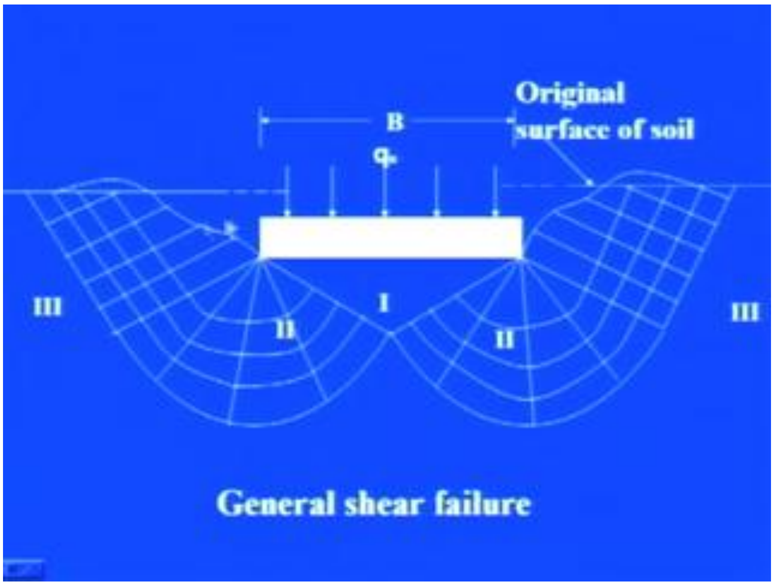

Now, in the case of general shear failure the situation is like this. You have this soil mass and on this soil mass is resting of foundation of width B. And this is the load ultimate load or the bearing capacity of the soil that is q u original ground surface shown here. Now, with the increase a load there is settlement of the structure and you will find there are 3 clear cut zones which are formed below the foundation. This zone we call it as the elastic zone and zone 2 zone 3 these are called as the plastic zone. Now, there is development of the clear cut development of these plastic zones and you will find that there is up evil type of bulging type of as surface which is on the ground surface. This is the case of the general shear failure.

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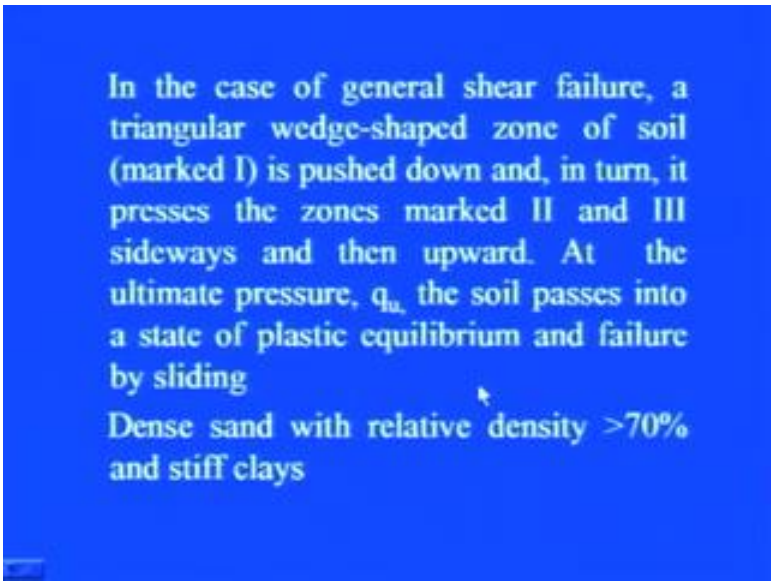

So, in the case of general shear failure, a triangular wedge-shaped zone of soil marked 1 is pushed into the soil and which in turn it presses the zones marked 2 and 3 sideways and then upward. At the ultimate pressure which we call it has the bearing capacity. The ultimate bearing capacity of the soil the soil passes into a state of plastic equilibrium and failure is taken by sliding. Now, such type of failure occurs in the case of sands and clays with the in the case of dense sand with relative density greater than 70 and in the case of stiff clays.

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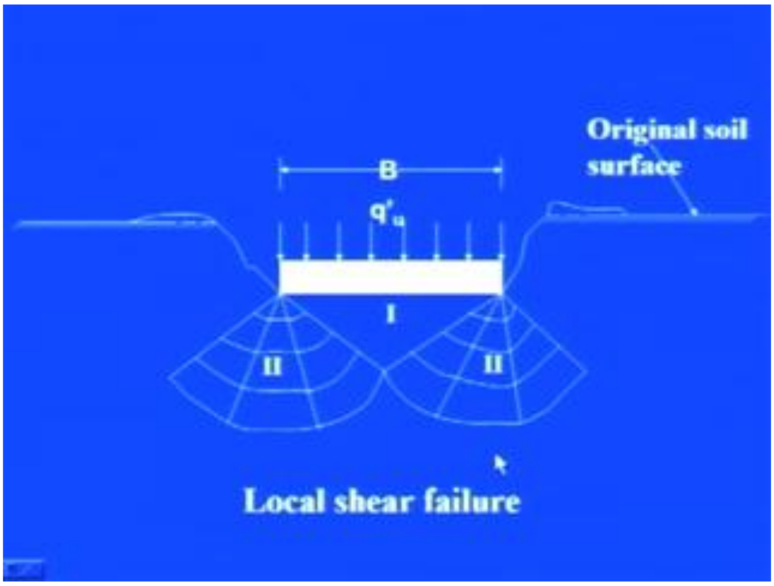

Another type of failure which is the local shear failure you will find that the zones plastic zones are not clearly clear cut defined. But they are subdued and you will find that the bulging is varies as small as compare to the general shear failure. In the third type of failure which is punching shear failure you find that there is no development of bulging and the zones are not clearly defined.

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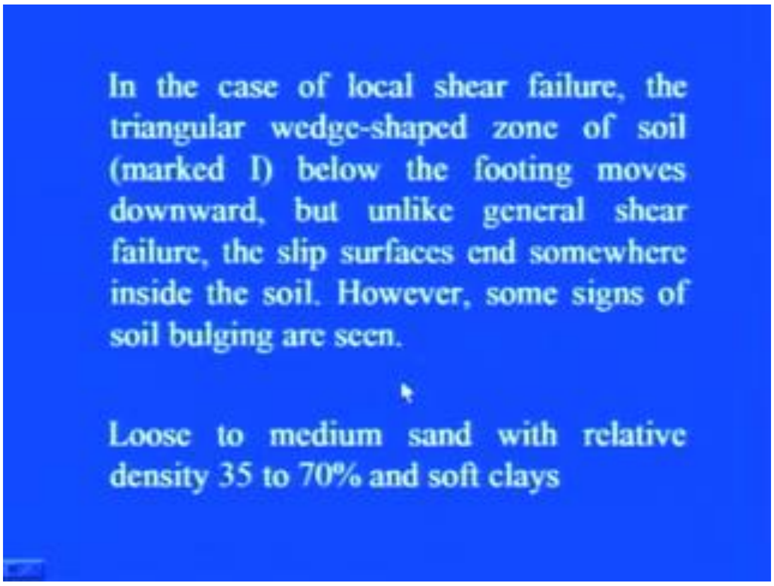

Now, in the case of local shear failure the triangular wedge shaped zone of soil marked 1 below the footing moves downward. But unlike general shear failure, the slip surface ends somewhere inside the soil these ends; however, some signs of soil bulging are seen. But are not has not pronounced as in the case of general shear failure such types of failure occurs in the loose to median sand with relative density 35 to 70 percent and in the case of soft clays.

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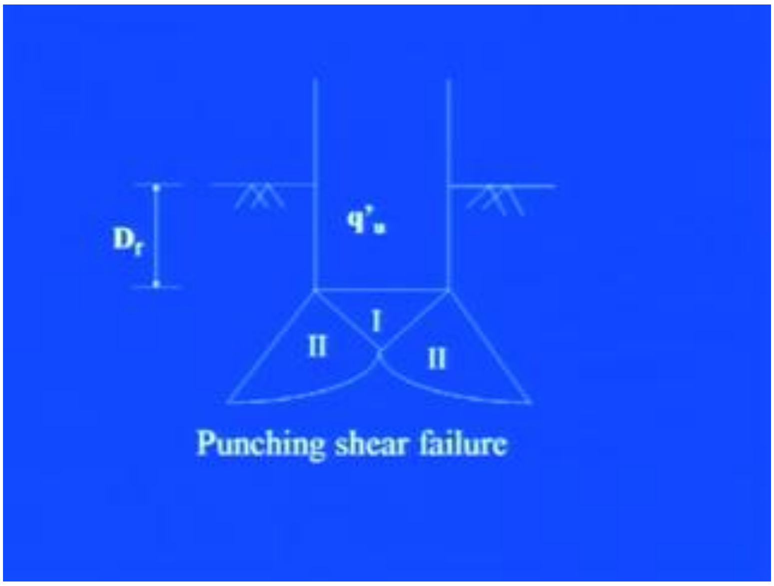

The third type of failure which we call it has the punching shear failure. In the punching shear failure.

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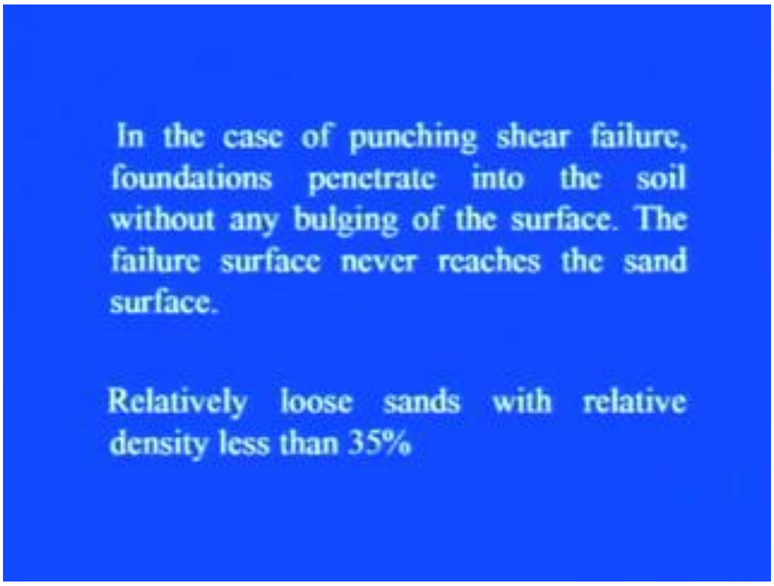

The foundations penetrate into the soil without any bulging on the surface. The failure surface never reaches the top surface or the sand surface. Now, this occurs in the case of relatively loose sands with relative density less than 35 percent

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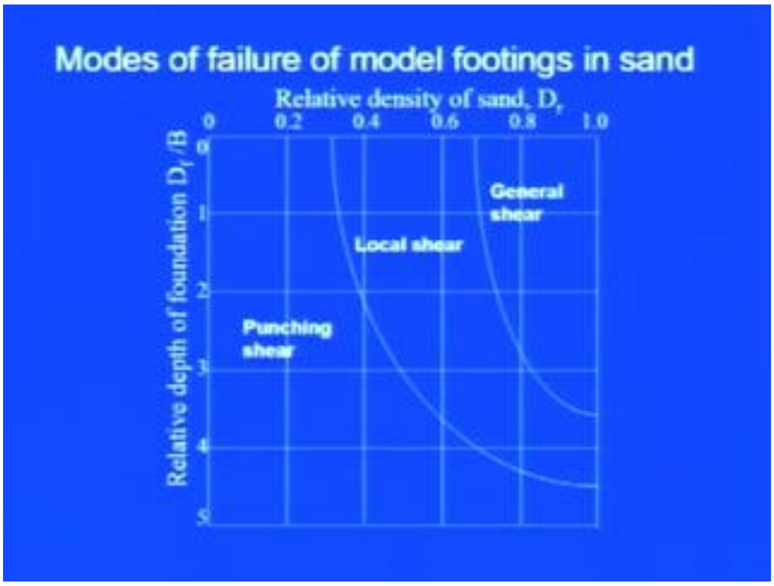

On the basis of the model study this is a relationship shown here would be relative density of this end and the relative depth of the foundation in terms of Dr by B ratio. Now, you will find that for this case there are different zones in which you will find general shear failure, local shear failure and punching shear failure. For example, let us say your depth 2 width ratio is equal to 1 and corresponding to that, this is the point below. This will be local shear failure and other this general shear failure that will depend on what is relative density of the sand.

How is stiff or how dense the stratum is? Now in nutshell we can say that in the case of a stiff clays and den sand. Normally we get general shear failure and in the case of loose sand and dense clay dense sand and loose or soft clay we get the local shear failure. So, on the basis of that in between we can get the intermediate. Now, these values are also defined as, if when we say den sand if angel of shearing resistance of this sand is greater than 36 degrees. You will get general shear failure and if the angle of shearing resistance of sand is less than 28 degree is then we call it as local shear failure and it between in between it is the intermediate failure.

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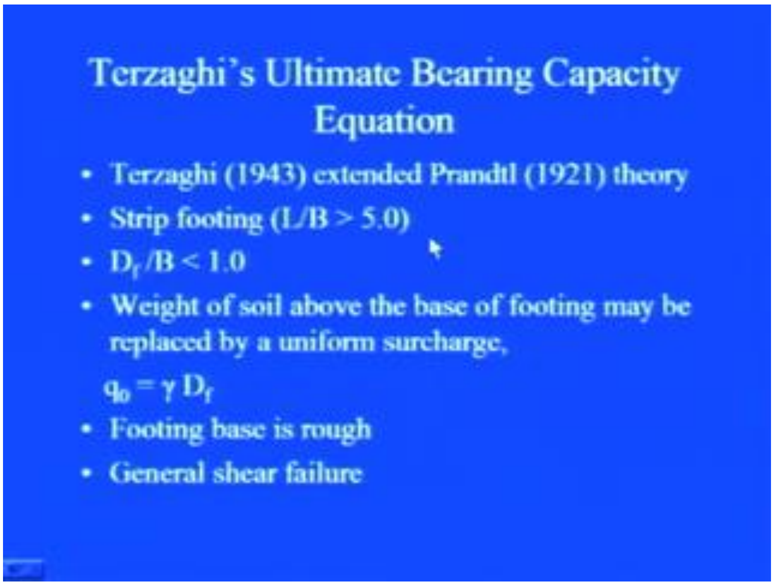

Now, there is there are many equations or the theories develop for to determine the ultimate bearing capacity of the soil. Now here we say ultimate bearing capacity as that pressure at which the soil the soil can take up before failure. Now, here the rest of the terms ready to ultimate bearing capacity I will discussing the next lecture, but as far as the Terzaghi's ultimate bearing capacity equation is concerned. This Terzaghi equation is based on the Prandtl theory which was postulated for the soft metals. Now, there are some assumptions which are made in the case of ultimate bearing capacity given by Terzaghi very first assumption is that here considered the case of a strip footing.

Now when we strip footing into strip footing the length dimension is far greater than the width of the footing and we say when L by V ratio is greater than 5 we call it as a strip footing. Now, this particular equation has been postulated or this theory has been postulated only for the shallow foundations. And we say that when depth to width ratio is less than or equal to 1 that is the shallow foundation. The third assumption which is taken into account is the weight of the soil of the base of the footing may be replaced by a uniform surcharge. Now, all the foundations you will find that they are placed at depth below the ground surface. But here that depth the effect of that depth taken into account only by surcharge given by q equal to gamma into Df. Now, this gamma is the unit weight of the soil.

Now it means the resistance offered by the soil which is above this depth D is not taken into account. And that is that is why it is the shallow foundation. Another assumption is that footing base is rough. So, when footing base is rough there is a formation of an elastic wedge below the ((refer time: 18:00)) below the foundation and that wedge also penetrates into the soil along with the foundation. So, the case of only the general shear failure is considered in which all the zones failure zones are clear cut developed and there is bulging of this soil on the surface of the footing at the level of.

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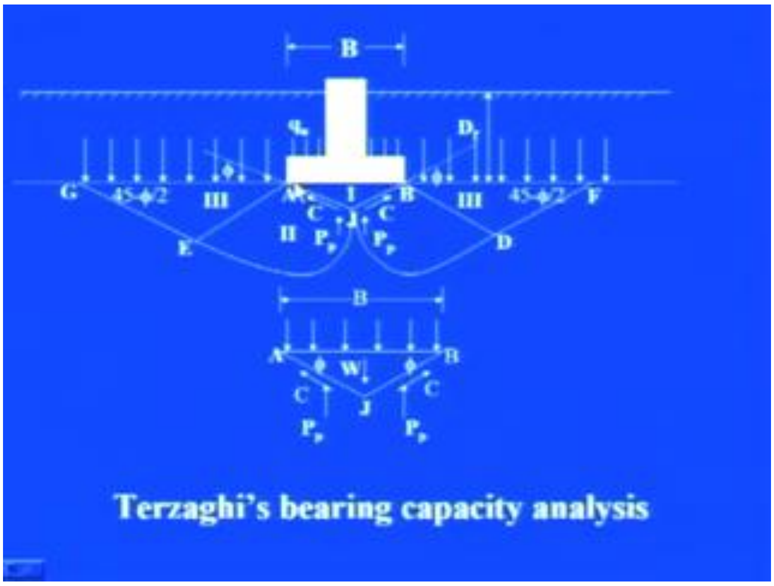

Now, this is are definition is sketch you will find there is footing column this strip footing of width B and it is resting at it depth D f below the ground surface. The effect of this depth is taken into account by this surcharge q 0 that is equal to gamma D f. And the level of the foundation is given shown by this line and these arrows are showing that surcharge. Now, there are formation of different wedges wedge number 1 wedge number 2 and wedge number 3 on both this sides. Now, the inclination, this footing is considered as rough. You will find that this is triangular wedge which we call it as elastic wedge which also penetrates along with the foundation and it precedes the soil. And there is formation of these plastic zones. The second zone it is the plastic zone this is the radial shear zone failure zone failure surface you can see from here is given by IDF on this side and the failure surface is IEG on this side.

Now, from here to here, it is the radial shear zone which is marked as zone 2 and you then we have another straight line EG. That is marked as a straight line which is inclining at 45 minus 582. Now, here the inclination of different boundaries are also shown, this boundary BJ is inclined at an angle 5 with the horizontal. Whereas, boundary GE and FD and BD and AE they are inclined at 45 minus 5 by 2. And this soil wedge is acted upon by the forces like C and Pp which is nothing but the passive earth pressure. In this particular case passive earth pressure conditions developed and if you see the free body diagram of this wedge itself. You will find that there is weight of the wedge is sides are inclined at 5. And you have this load intensity q which is the ultimate bearing capacity of the soil and it is acted upon this sides are acted upon by force is C and Pp like this.

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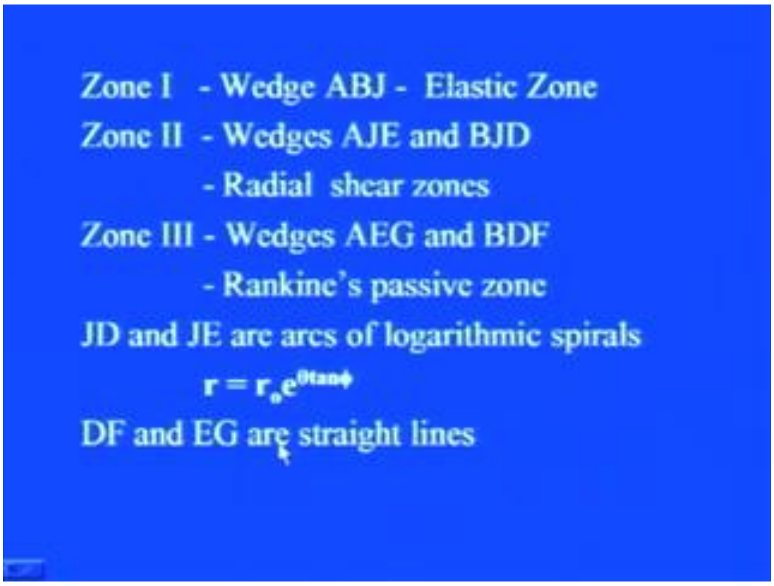

So, here zone 1 is the wedge ABJ which is the elastic zone way the sides are inclined it 5 zone 2 is wedge AG AJE and BJD. These are the radial shear zones in which all the radial lines are starts from the wedge of the footing. Zone 3 is the wedge AEG and BDF this are the Rankine's passive zone you must have learnt Rankine's earth pressure theory that is applied here. Then JD and JE are the arc of logarithm spirals which given by are it going to r 0 e to the power theta into tan phi of this spirals are also function of this strength parameter phi of the soil and DF and EG are the straight lines. So, this is the geometry of the wedge. Now, let us imagine that AJ and BJ are 2 walls that are pushing the soil wedge AD EG

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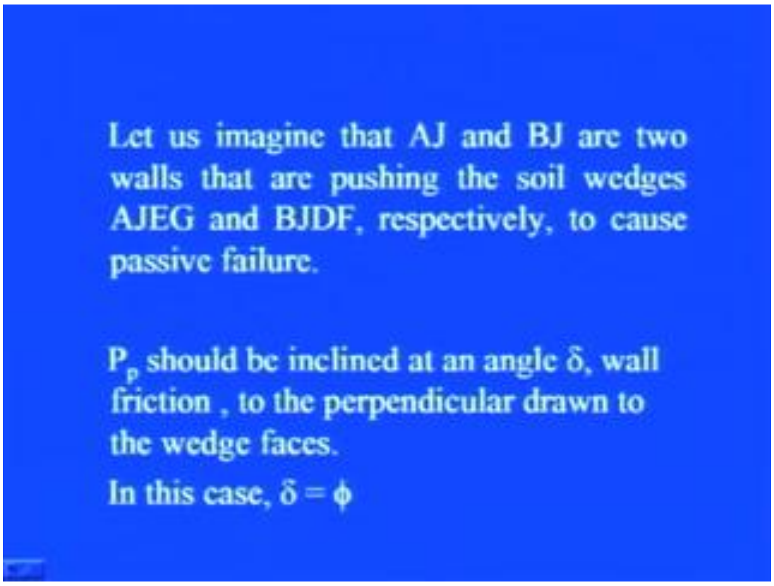

And BJ DF respectively to cause passive earth pressure condition. So, when this soil pushes is pushed by this particular wedge. Now, earth face passive earth pressure conditions are developed here and because of pushing of this these shear zones are developed. And the soil expose like this and you will get a bulging somewhere here. Because in this particular case we are considering the effect of this so, the bulging will be considered somewhere here. Then this Pp, now here this angle of this wedge is equal to 5. So, this the passive earth pressure condition passive pressure now this passive pressure will be inclined at an angle that delta that is the angle of friction between the this material. And this material in this particular case both the materials are soils.

So, this will be taken as the angle of wall friction that with delta that will be equal to 5. And hence this Pp will be perpendicular means it will be acting in a direction of the weight. So, it is acting in the vertical direction with will be inclined at delta with the normal to AJ. So, in this particular case this delta will be equal to phi where delta is the angle of wall friction here this walls are made up of soils. So, there is soil to soil contact. So, delta is equal to phi. Now, as AJ and BJ are inclined at phi to horizontal that is why Pp should be vertical. Now, what we will have to do? We will have to consider the equilibrium of ABJ wedge per unit length. Now, when we consider static equilibrium now, here you will find out we are not considering movement equilibrium although the errors involved may be very small and which can be neglected. But in this particular case it should be remember that we do not consider movement it equilibrium of the wedge.

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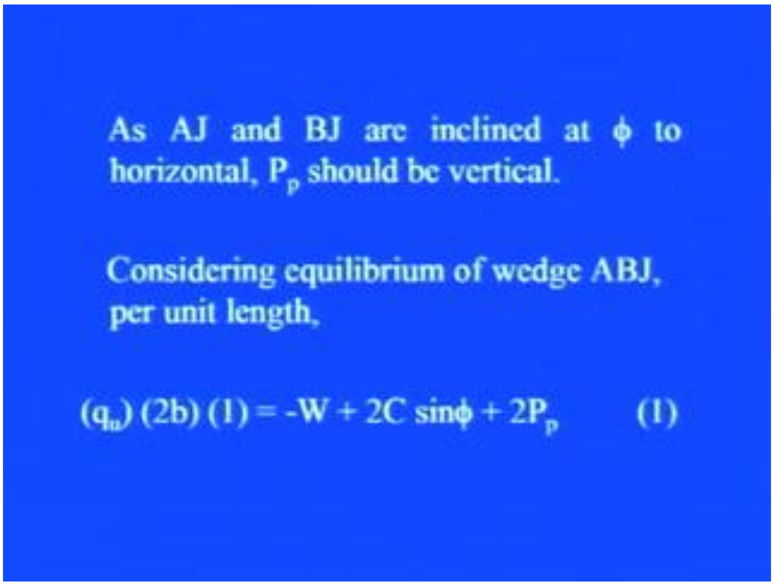

Now, the force which is acting downward will be equal to the force which is acting upward. Now, here the downward force will be due to the ultimate wearing capacity of the soil which is acting per unit length on the width of the foundation. And the weight vector which is acting downward the component of the cohesion which is acting on the side walls of the wedge its component in the vertical direction.

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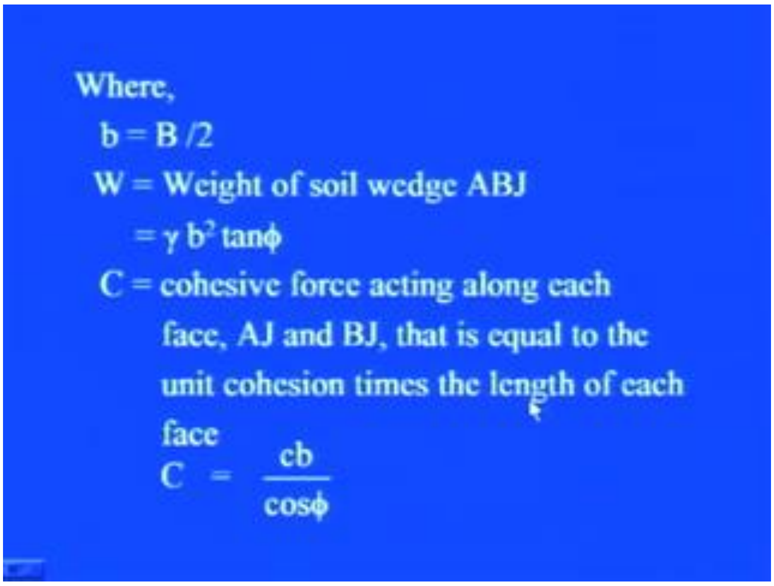

And then the pressure which is acting on the passive earth pressure is the force due to passive earth pressure which is acting in the vertical direction. Now, here this will be here I have consider this B as the half of the width is with just for the simplification. So, this is equal to qu into 2 b where b is the b is equal to 2 b acting vertical downward this per units. So, this is multiplied by unity here weight vector this is acting vertically downward the component in the vertical direction and the vertical component here. So, for static equilibrium these vertical forces are equated.

Now, here W is the weight of soil wedge ABJ which can be determined by the geometry. Now, if B is the width and B is the half of the width then the weight will be equal to the area of the triangle multiplied by 1 multiplied by unit weight. So, which comes out to be equal to gamma b square tan phi? Now, C is the cohesive force, which is acting along each phase AJ and BJ. So, we will have 2 C there are 2 phases and those will be equal to the unit cohesion times the length of each face. So, length of the so, it will be come out to be equal to C into b upon c cos of c into b upon cos of phi.

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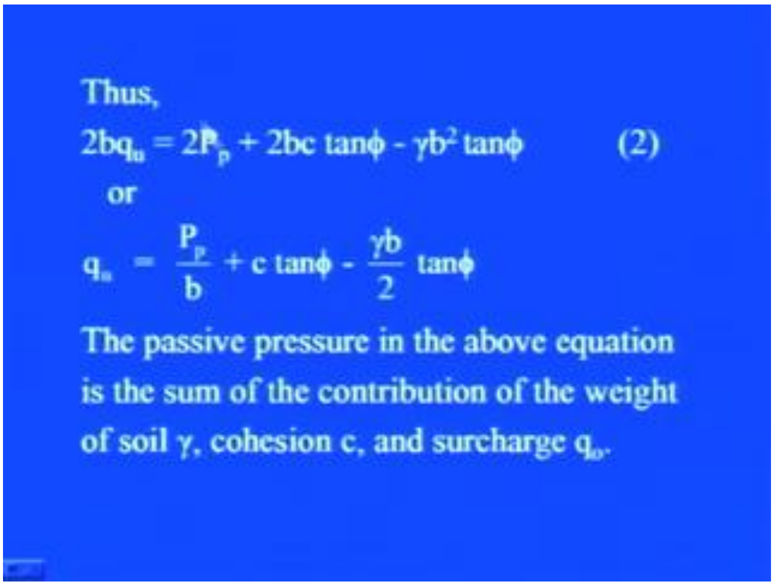

So, if you substitute these an equation 1 you will find this will become equal to 2 b into qu that will be equal to 2 P p plus 2 b c tan of phi minus gamma b squared tan of phi. Now, this can also be written as q u equal to P p upon b plus c tan of phi minus gamma b upon 2 tan of phi this is equation number 3. Now, the passive pressure in the above equation is the sum of the contribution of the weight of the soil cohesion and surcharge. Now, what we can do? We can separate all this 3 by considering only 1 and then other 2 neglect by neglecting others 2 are keeping those 2 as value 0.

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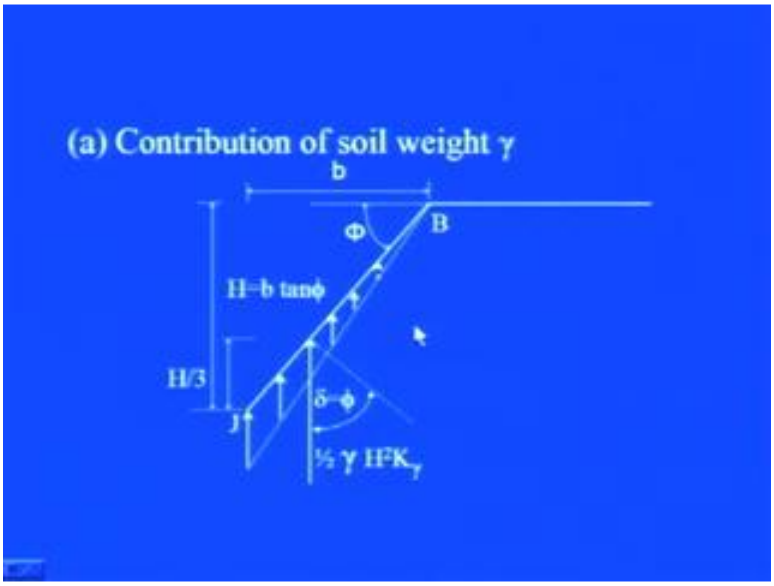

Now, here in this particular figure now, this is shown the contribution of the soil weight soil weight, because of the unit weight of the soil. Now, here this is the face of the elastic wedge now here this is acting as a wall and it is pushing here. So, there is a passive resistance which is developed here and that passive force that will be dependent on what is the depth of this particular point j below the ground surface and the pressure distribution will be triangular. So, here if H is the H will be the height of this that H will be given by b into tan of phi where b is half of the weight. And this will be acting at a height that is equal to H by 3. We have already seen that this particular force will be acting at an angle phi or delta with the normal to the this particular plane Jb. So, here this pressure distribution is triangular this inclination of wedge is phi here this will also be equal to phi. And it will be given by half gamma H square into K gamma where K gamma is the passive and pressure coefficient which can be determined by Rankine theory.

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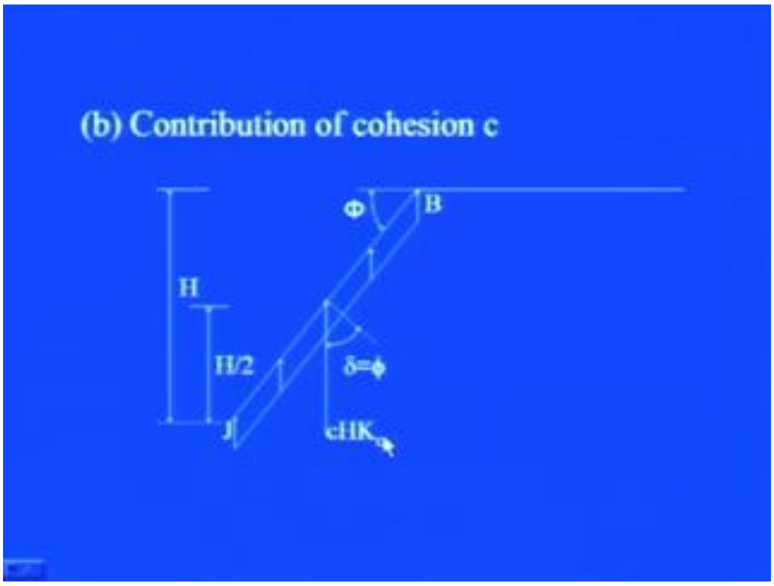

Similar to this the contribution of the cohesion now cohesion will be considered uniform all along the side that is J b. And hence the contribution will be given by C into H into Kc and the, this will be acting H a height H by 2. Whereas, in the earlier slide you must have seen it is acting as H by 3 you can find it out from the Rankine earth passive theory. Similarly, contributions of surcharge give 0 that is gamma into Df. Now, that surcharge preserve distribution is like this it will be uniform throughout the height of the, or the length of the wall. Now, here this will again we acting at height of H by 2 and the magnitude will be equal to q into H into K q where K q is the coefficient due to this surcharge.

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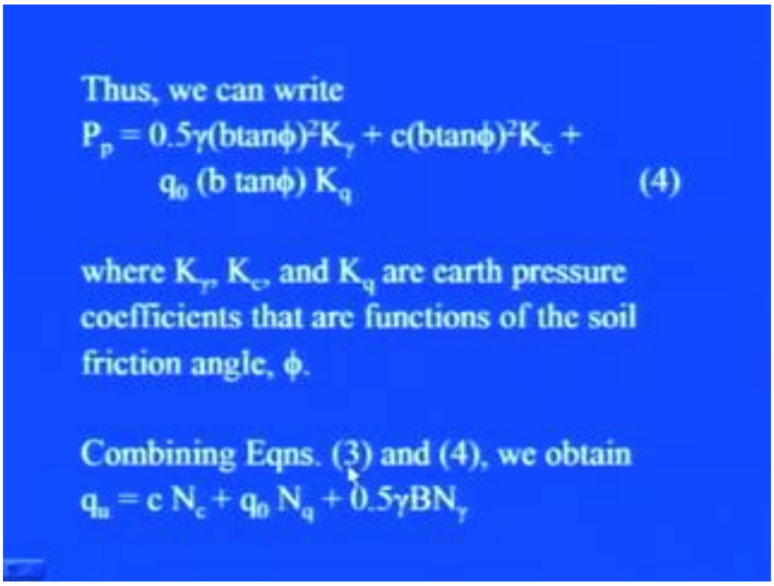

Now, thus we can write that equation number 3 as Pp equal to 0.5 gamma b tan square phi K gamma plus cb tan square Kc q 0 b tan phi Kq where gamma Kc Kq is the earth pressure coefficients. And these earth pressure coefficients is function of angle of shearing resistance beside. Now, when you combine this equation 3 and 4 we obtain this in the for qu equal to c Nc plus q 0 gamma q 0 Nq plus 0.5 gamma BN gamma. Now this Nc Nq and N gamma this are the bearing capacity factors.

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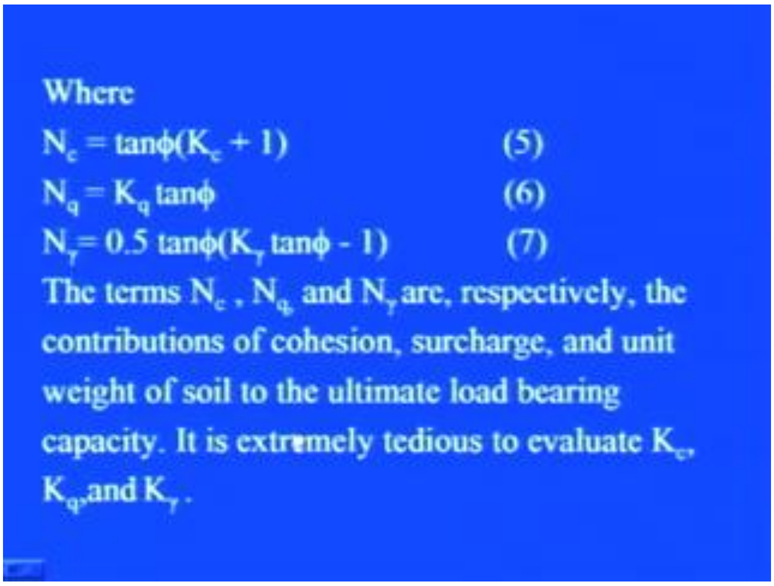

And this bearing capacity factors are function of this strength parameter phi where Nc is given by an tan phi Kc plus 1 Nq is given by Kq tan phi N gamma is given by 0.5 tan phi K gamma tan phi minus 1. The term Nc Nq N gamma are respectively the contributions of cohesion surcharge and unit weight of soil to the ultimate load bearing capacity it is extremely tedious to determine this value Ke Kq and K gamma.

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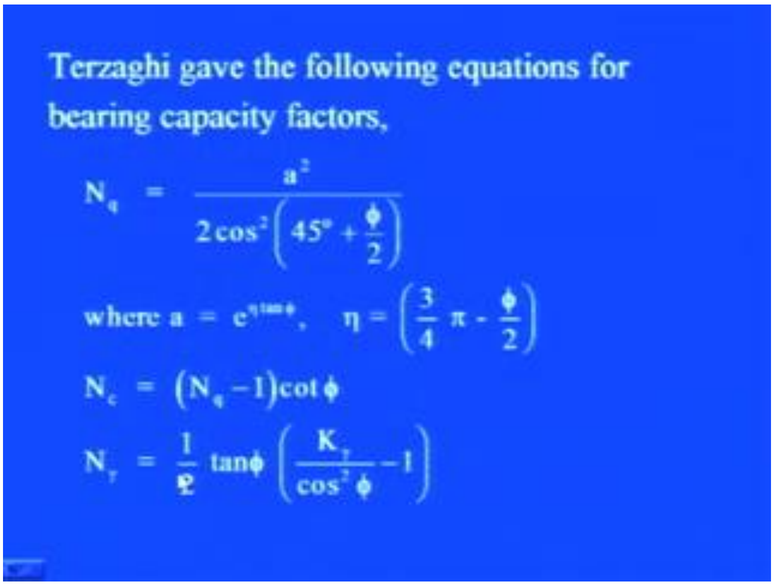

So, what Terzaghi has done? Terzaghi has given the following equation factors on the basis of the semi empirical theory is which we have developed which he has developed. And this are given by this equation like Nq equal to a square upon 2 cos square 45 plus phi by 2. Where a is equal to e eta tan of phi eta is given by 3 by 4 pi minus phi by 2 and Nc is equal to Nq minus 1 into cot of phi and N gamma equal to half tan of phi K gamma upon cos square phi minus 1.

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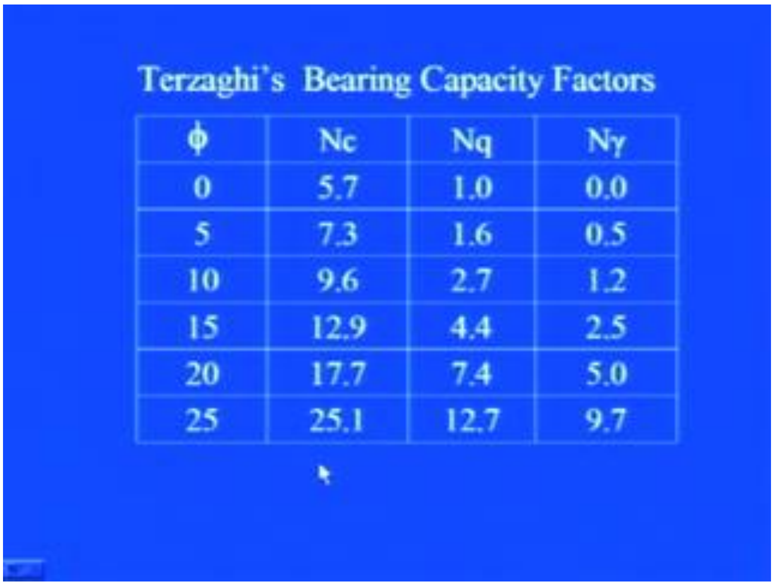

Terzaghi's Bearing Capacity Factors

ϕ	Nc	Nq	Nγ
0	5.7	1.0	0.0
5	7.3	1.6	0.5
10	9.6	2.7	1.2
15	12.9	4.4	2.5
20	17.7	7.4	5.0
25	25.1	12.7	9.7

Now, Terzaghi bearing capacity factors can be determined from these equations and these are tabulated in this chart. There are various values of phi from 0 to 50 degrees and corresponding to that we have Nc we have Nq we have N gamma. Now, this values or for example, for 5 equal to 05.7 Nq equal to 1 N gamma equal to 0.

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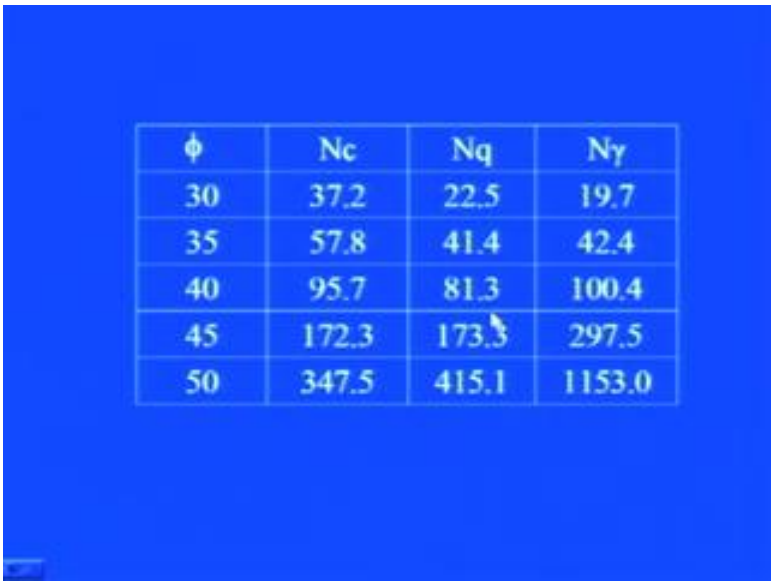

ϕ	Nc	Nq	Nγ
30	37.2	22.5	19.7
35	57.8	41.4	42.4
40	95.7	81.3	100.4
45	172.3	173.3	297.5
50	347.5	415.1	1153.0

Similarly, for 50 degree this is Nc equal to 347.5 415.1 and 1153.0. Now, depending upon the angle of shearing resistance, this angle of shearing resistance we can find out from different test. And then we can pick different values of Nc and give N gamma N substituting the Terzaghi bearing capacity equation we will find a the ultimate bearing capacity of the soil.

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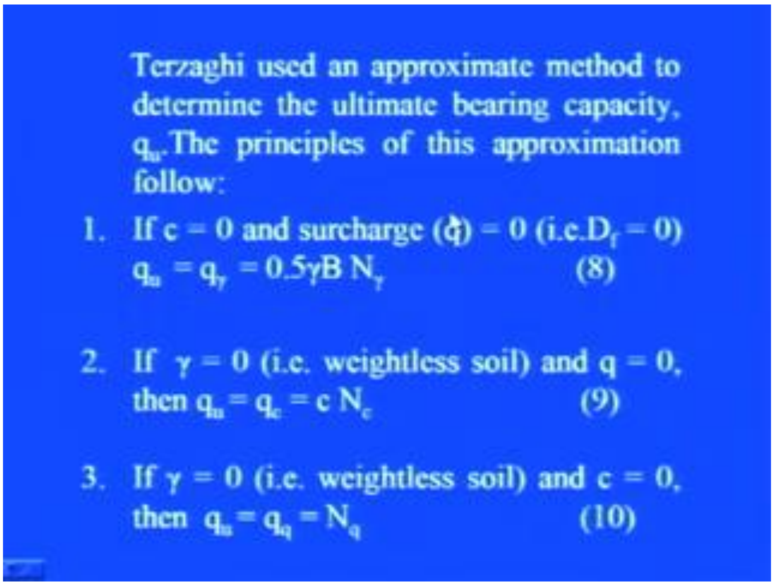

Now, Terzaghi actually has used an approximate method to determine ultimate bearing capacity q the principles of approximation follows. If c equal to 0 and surcharge equal to 0 that is depth equal to 0 we will have Qu that will be equal to q gamma the component of only the weight. Similarly, when gamma equal to 0 means we assume this soil to be weight less and q equal to 0 then Qu equal to qc that will be the component of only the cohesion. Similarly, when gamma equal to 0 and c equal to 0 we have Qu that will be given by qq that will be the component of Nq only and that is due to only the surcharge. So, I am sorry this is equal to q and q here.

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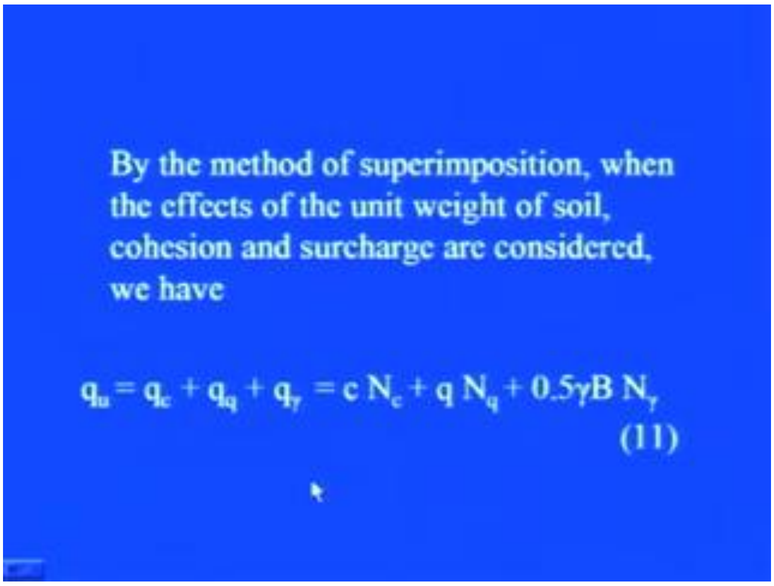

Then by the method of superimposition the effect of when the effects of unit weight soil, cohesion and surcharge are considered then we are left with this equation Qu equal to Qc plus Qq plus Q gamma. That is given by cNc plus qNq plus 0.5 gamma BN gamma the same equation which we have got here as the bearing capacity equation.

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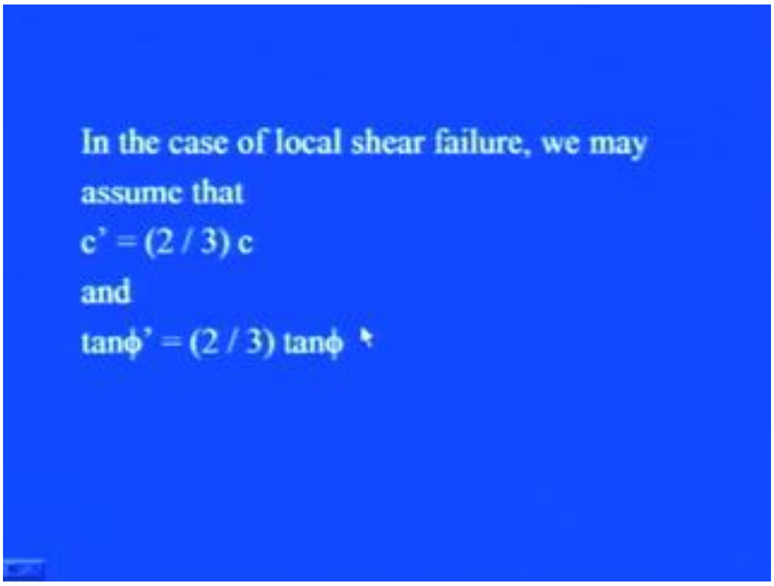

Now, in the case of the local shear failure, here local shear failure we say that when phi is equal phi is less than 28 degrees. In that case we take this parameters as c dash that is two-third of c and tan phi dash that is equal to two-third of tan phi. And c dash and phi dash, we determine and corresponding to this c dash and phi dash. We find out the corresponding bearing capacity factors and then we find out the ultimate bearing capacity theory.

Thank you.