Ground Improvement
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Lecture No. # 28

Bearing Capacity Improvement - I

Today, we would be talking about Improvement of Bearing Capacity using geosynthetics.

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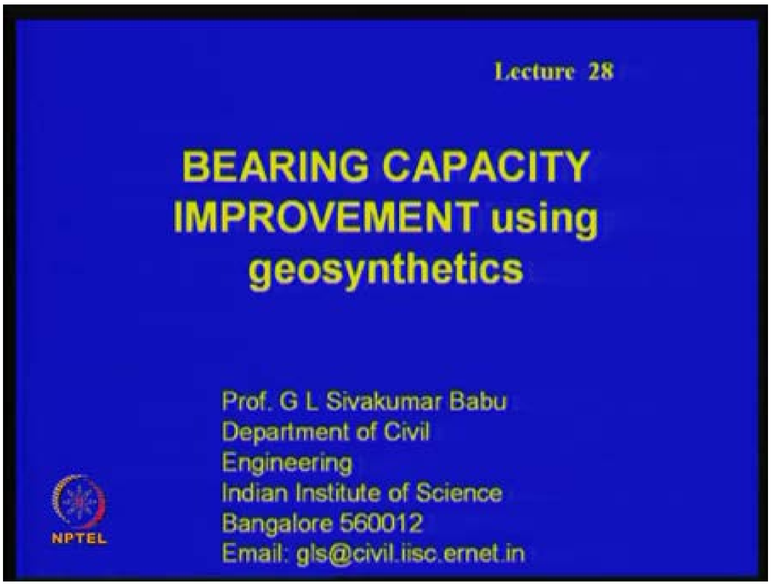

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The problem of bearing capacity is something that is very important in geotechnical engineering. When the applied loads are more than the existing resistances, we always know that the factor of safety is less than 1. But, in some cases for example, you would like to improve the bearing capacity, say you would like to increase the factor of safety; then by say for example, in a present case it could be one case, it could be 1.3, you would like to make it to 3 something like that. So, you when you want to increase the bearing capacity or reduce the settlements, you need to have some sort of improvement in bearing capacity.

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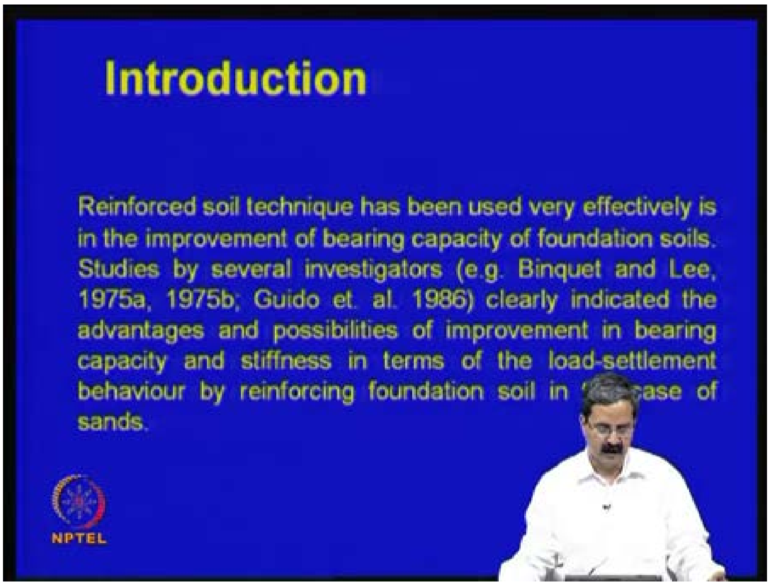

We have seen in the earlier classes that, one can use the bearing capacity improvement techniques, such as stone columns, then prefabricated vertical drains, many techniques are possible even additives are also there. So, we have seen that, these are all very useful techniques to increase the bearing capacity.

In this class of family, in this class of improvement techniques, reinforced soil technique is something that is very elegant, because it has the principles are somewhat simple and well understood; and it appears to many people, because it is more of mechanics oriented. And lot of work has been in the recent times in this area particularly, because you have so many companies producing geosynthetics.

So, this technique has been used very effectively in the improvement of bearing capacity of foundation soils. Many people have studied this work in fact, even if we can just see the latest papers also in this area in the ground improvement journal; you know there are, I just mentioned that you have number of journals in this area. One is the ground improvement journal, you have from ground engineering journals you have there are many journals geosynthetics international, geo Texas and geo membrane; you have many journals in this area.

They have many types of studies, experimental studies, numerical studies, analytical studies, field studies, there are so many. They were clearly able to bring out the advantages and possibilities of the improvement of bearing capacity and stiffness in terms of the load displacement behavior or load settlement behavior, because we tried to do a plate load test.

A simple case is that, we tried to do a plate load test on a typical soil and then put the reinforcement and again do a plate load test, how it can improve. So, in this section or in this class today would be talking about bearing capacity improvement in case of sands. As I just mentioned, a lot of work has been done in this area, lot of work both in terms of the experimental work and analytical work; even, we can think of numerical work and also think the field studies.

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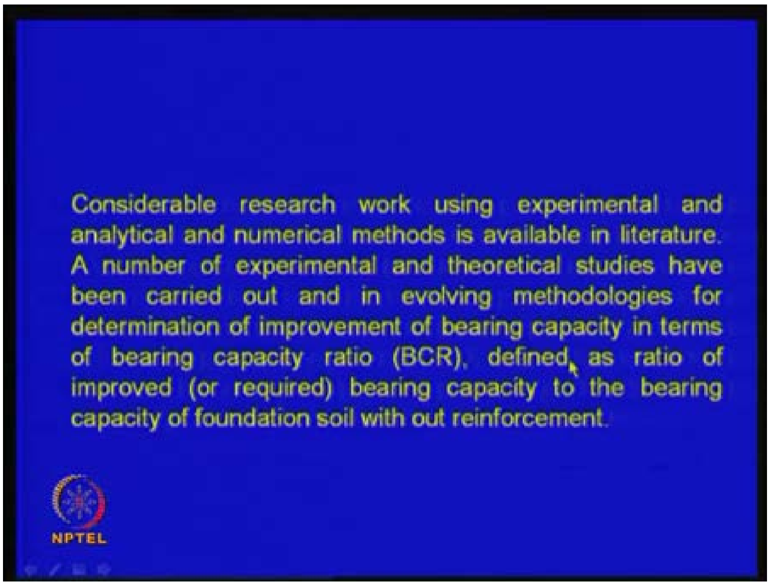

And what people try to say is that, how do you say that, there is an improvement we try to have a factor called Bearing Capacity Ratio Bearing Capacity Ratio which is called BCR; which is nothing but, the bearing capacity improved to what was existing earlier.

Say for example, if there is only a 5 ton per meter square earlier, you would like to make it to 20, 20 by 4 would be the bearing capacity ratio; this is what we look for.

A typical example could be that, you know say for example, this is the bearing capacity of an unreinforced soil (Refer Slide Time: 03:59); so, this is an unreinforced soil, this is a geo net; this is the different types of geo synthetic materials. You can clearly see that, this load displacement curve is considerably altered, because of this; you can see that, at the same settlement like say footing settlement; say for example, we are taking about 2 percent 4 4 percent you can say that, the load here is may be 150 here or 140 here, but then when you just put some sort of reinforcement, it went to as high as 250. This is in a simple plate load test like this (Refer Slide Time: 04:42), where you apply some load and you have a foundation size say for example, in a laboratory scale.

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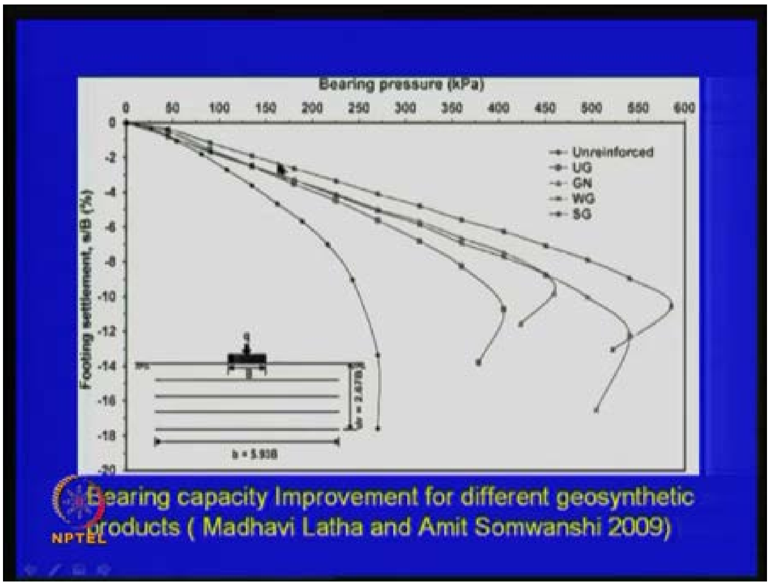

Actually, this is a laboratory result, in fact in our institute also we have done lot of work, and this is a typical result. In fact, we also published number of papers on these lines from (( )) of science, where we can clearly show that, bearing capacity improvement is possible by using some sort or reinforcement like this. Say for example, you can see clearly even the settlements also, because the movement you say that there is an improvement in bearing capacity like this, even there is a reduction in the settlements.

So, like say for example, if you just go at this level 150, you can definitely see that, at that 150 bearing pressure, there is a settlements are little higher; but whereas, in this case, it is lower. So, one can make it even very stiff like it can be like this.

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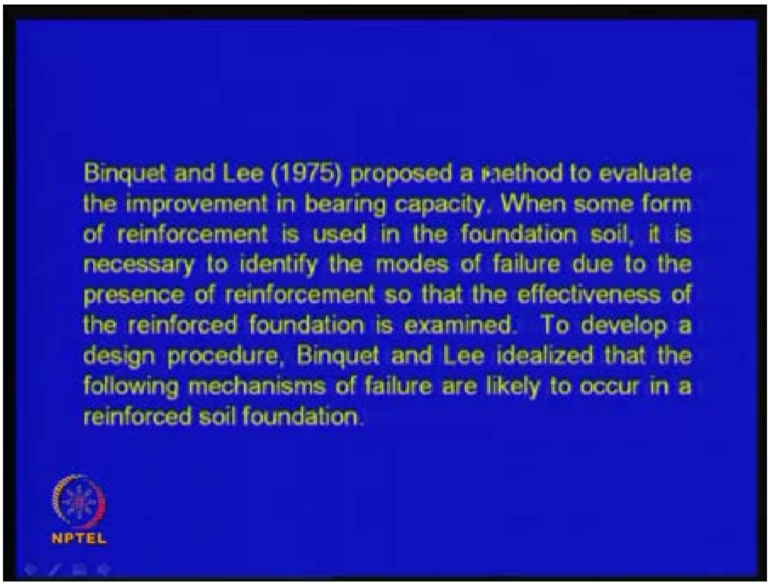

Then, the obvious question is how do you do this design? The thing is that, we know that by putting some sort of reinforcement like you have seen in the previous slide that, one can improve the bearing capacity. But, then how do you calculate is something that we should know. And In fact, Binquet and Lee in 1975 actually it is a paper of Master's thesis of the Binquet Lee. Binquet and lee was the guide, he they prepared this paper which has lot of experimental work, lot of analytical work also.

In fact, that is the first study and it has been quite useful of course, there have been many studies in this area even last year also we had some analytical work done in this line. The fact is that, it has been effective and there should be simple methods of calculating this method, we will see how it can be done. And one way is that, we know that, when you put some sort of reinforcement it has to be effective; if it is not effective, you should know why it is not effective.

So, we say that, we should be able to understand, why it can be effective or there could be some conditions under which it cannot be effective. So, to develop this design procedure we should take care of the mechanisms by which it may fail; say for example, a particular thing may fail in particular direction. So, you see that, you try to handle that particular directions see that, the failure does not occur.

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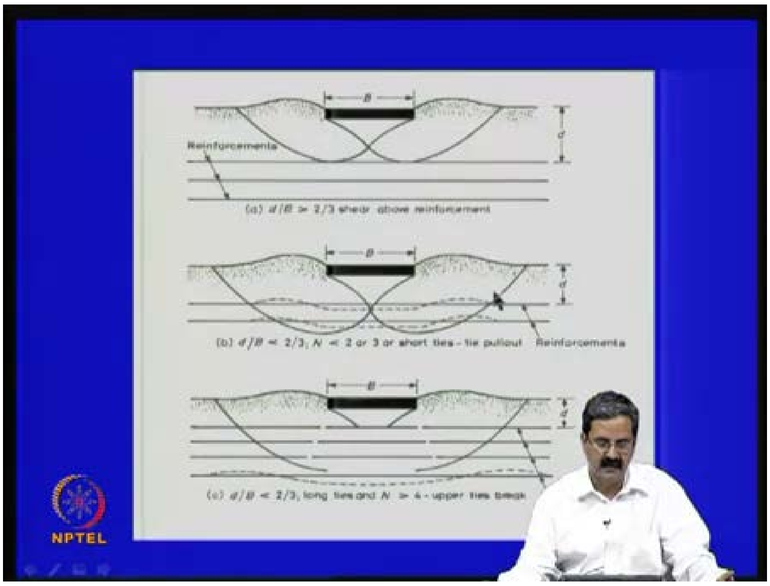

So, these researchers have identified certain mechanism that we will see. There are three types of mechanisms that they said could be possible in the case of reinforced soil; even reinforced soil may be there you may put a nice reinforcement here. But if the depth you know say for example, the depth of reinforcement is say this is breadth of the footing like footing is here.

And you have to see that, this reinforcement is somewhat close to this you know, we have to see that the failure lines that failure surfaces that we have are intersected otherwise, there is no use; like, if there is a lot of distance between this bottom of the foundation and the top of the reinforced reinforcing element here, then there is no use. So, you would like to avoid this possibility that the shear above reinforcement will not occur. So, that is like d by B should be more than two-thirds like you know it should be quite close, like you know.

So, it is normally we will see that some guidelines also; that, if d by B is more than two-thirds, the shear failure occurs. So, the obvious thing is you should see that, it should not be more than two-thirds; it should be say, for example, 0.5 it could be 0.3. If you see that, the reinforcement is somewhat close to that then it is possible. This is one important thing. So, this we call it shear above the failurement shear above the reinforcement is a failure mechanism.

Second thing is that, you provide say d by B is less than two-thirds the condition is satisfied, but the number of ties, tie is a tension member. The tie is not much like you know you put one reinforcement at two reinforcements then the possibility is that, a short tie on the length is not sufficient.

If the length is not sufficient what is going to happen? As I said, the principle of reinforced soil is that, you have to have tension also, mobilized and also the pull out resistance; if the length is not adequate, so it may not really develop frictional resistance completely. And even, if the friction developed friction is developed, it should be able to sustain that friction by pull out resistance. So, that is the reason I said the factor of safety, there is always a relationship between the pull out resistance and also the tension was developed.

So, if the short tie occurs, then short ties there is a slip. So, this is what we just tried to show you in the form of a slip. So, short ties are tie pull out reinforcement, tie pull out we call it. Then there is another possibility, like you know it is like tension failure; like, if the reinforcing element itself is not strong enough, definitely it can break; d by B is fine, but the length is also fine, but all they all are very inferior elements; so, that there is no use.

So, we should see that, the design should be such that all these three mechanisms are satisfied. If somebody can come out with another mechanism nice, like that you know you can always think of these mechanisms and see that they are all avoided.

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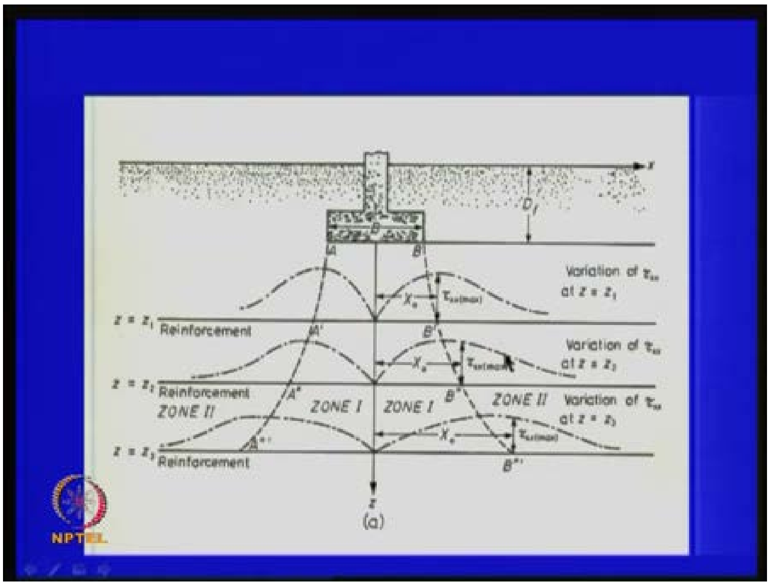

They are all simple assumptions. And what he did, you know analytically work, how did he do that, like this is B foundation of the, this is the foundation B is a foundation width and depth of the foundation is D f. So, what we assume is that, beneath the foundation, there are three zones, essentially two zones, zone 1 and zone 2; and of course, zone 3 is not here.

So, zone 1 and zone 2, what it means is that, you have a foundation system here and then, you know actually you have the reinforcements like this that is what we are trying to do. Actually, imagine that, you are trying to place some reinforcements at some depth; and what happens you take the central line of the footing and based on the elastic stress distribution, as I said reinforcement causes shear, you know shear is important in reinforced soil.

So, what we calculate is that? We calculate distribution of shear strain and shear force actually. Shear stress here, Mac shear stress shear stress distribution is calculated like; you know when there is a load applied its minimum here, because of the 0 here, because of the symmetry and it just goes like this (Refer Slide Time: 11:42).

This one can get from (( )) equation. We know that, in under grad courses, we studied how do you calculate normal stress, if a load is applied here some load is applied, and what do you calculate? If there is a say for example, if point is there at some depth z and it has some or it is away from centre line radius r.

How do you calculate the shear stress? So once you know that shear stress, you can plot like this, it it is like this only (Refer Slide Time: 12:10). So, once you plot all the shear stress distributions like you know they will be different and different depths; and what we say is that, it will have a maximum value. So, pick up that maximum value then join all this points A, A dash, A double dash and A triple dash, you know there are three reinforcement layers here.

Here also same thing B, B dash, B double dash and B triple dash. So, you call this as zone 1 in which the soil is active, in active condition; in the sense that, actives the soil is fully participating in this load bearing. And the you know you can say that, the other day I was just mentioning about the active resistance and passive resistance. And the other one is pulled out resistance; you know this is a simple way of remembering. So, this the way of distribution, that is how it will you know it is obtained from elastic stress distribution. So, you have two zones, zone 1 and zone 2.

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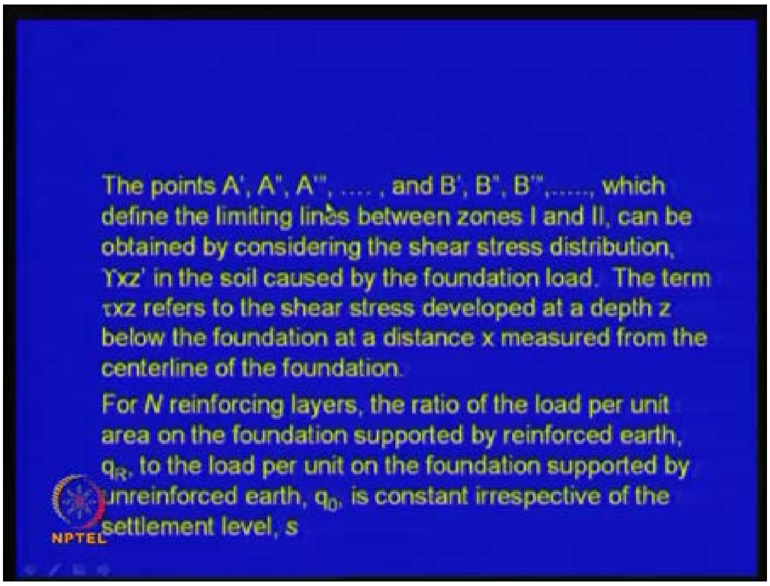

And the classification of zone 1 and zone 2 is based on this elastic shear stress distribution to exact ok. And other important thing that we would like to assume is that, this is one assumption that we will make. And the for N reinforcing layers, the ratio of load per unit area on the foundations supported by reinforced earth, to the load on the foundation at the actual old one; like see bearing capacity, you initially is q naught now you would like to improve to q R.

For example, earlier it was 10 ton per meter square you would like to make it to 30 ton per meter square. The bearing capacity is at the same settlement, we want to say that say normally, we say 25 mm is the allowable settlement in the case of footing. Some say number, 25 that corresponds to about say 10 ton per meter square; at the same settlement I would like to have not instead of 10, I would like to have 25, so 25 by 10 is called bearing capacity ratio.

So, this is an assumption that we are making irrespective of the settlement level; we have this loads q R by q naught as constant this is a simple assumption. So, these assumptions are required to make the analysis simple.

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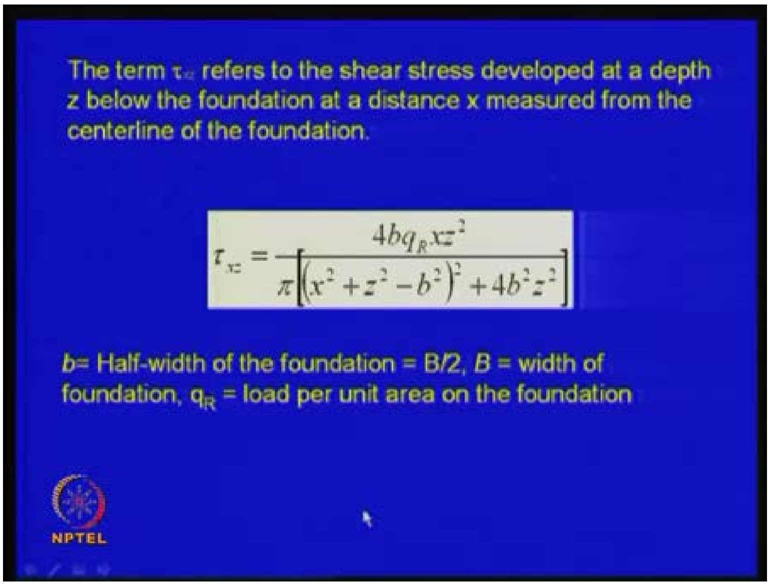

As I just mentioned, the elastic shear stress distribution is used. This is the expression that we have in theoretical soil mechanics. And if we know the x and z and b is nothing but, the half width of the foundation; q R is the load that you are expecting you know that is the reinforced soil load. Once you have this and then you can plot this, it is simple.

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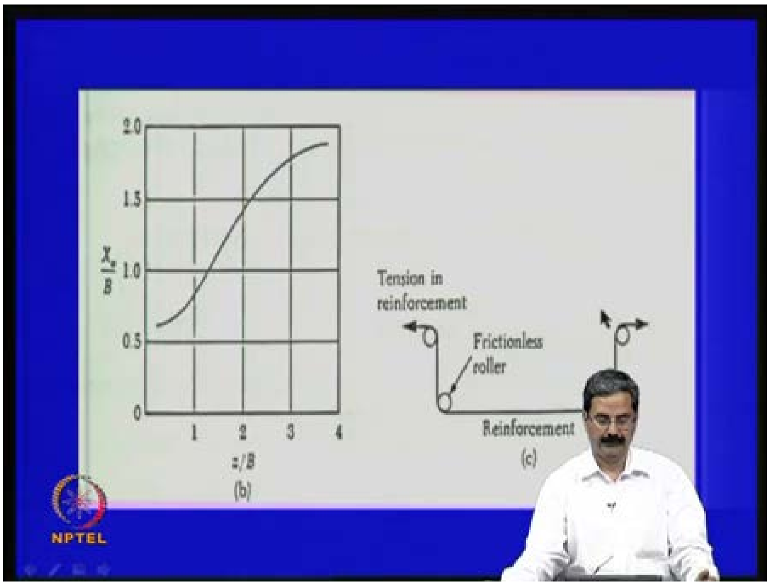

So, what they did was that, point X naught, like I just mentioned in the previous thing, this is a point called X naught, X naught is a function of B. So, he is trying to put in terms of z, z and X naught is like we have seen that it is related to z. So, to make it simpler using that elastic stress distribution, one can plot a relationship like this (Refer Slide Time: 15:49). How is that, X naught is varying with different depths, it is simple straight forward.

So, other thing that we assume is, so this plot is useful for us. Because, what exactly we are trying to do is that, you are trying to get this X naught distances; once you know the X naught distances, this is somewhat a very critical in this method of course, then we also have the other one. The we will we need to get the total, what is your objective? Objective is to get assume some sort of mechanics that they are valid, like elastics stress distribution is valid; and we try to place reinforcement at these three locations.

So, the requirement is that, I should find out the spacing of the reinforcement, length of the reinforcement, properties of the reinforcement; like, you know if I am using a geo grid one type, if I am using a steel reinforcement one thing, anything can be used any member which can take some tension is sufficient here.

So, you try to do that here and then see that, at the point X naught it behaves like a say for example, there is a kink there. So, the moment the reinforcement, we assume that at the point X naught, there is a frictionless roller; and the what it means is that? There is a load acting here t, the moment I assume that there is a roller here, tensile force will act like this; so, that is what it means.

So, that is what the assumption of that at that point X naught, we assume that there is a frictionless roller working; and to make our calculation simple. And tell that, if there is so much load, there is so much tension here and then also there is a spacing; and the tension is because of the shear stress distribution the tension is because of the shear stress distribution. So, based on these assumptions, we try to calculate some mechanism methods by which one can calculate tension force in the reinforcement.

So, once you make these assumptions, it is possible to come up with some expression, that I will show you; and also come up with some plots in which some factors A 1, A 2, A 3, and L naught by B are involved that I will show you how they are useful in the design.

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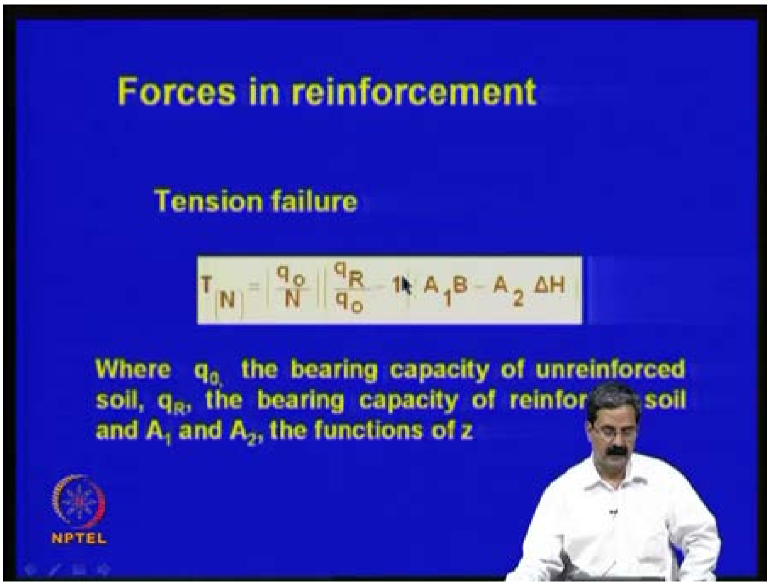

And what we say is that, you need to find out the tension force in the reinforcement. Actually, we have seen that, is in fact, a function of, if I want to say that, how much the tension is mobilized I should have proper spacing and the number. Say for example, this expression gives you the tension force in each member. There is a actually it is a theoretically derived expressions, because it involves essentially elastic stress distribution; and then you will by using you know A 1, A 2 are constants one can get from this plots.

And N is a number of layers, q R is a required bearing capacity, q naught is the original bearing capacity, B is a width of the foundation and delta H is the spacing of the reinforcement elements. Since the A 1 A 1, A 2 are the factors that I showed you here (Refer Slide Time: 19:05), A 1, A 2 I can get from here; there is an A 1, A 2 here. The A 3 factor will be also is useful in other pull out resistance.

So, once you know this, what is the required force and what the spacing is; and if I know A 1 and A 2 and I can calculate what the tension is. Essentially, the concept is that, shear stress distribution you are calculating then we are making some simplified assumptions, and put the you know put a roller there; and then calculate what is that depending on the load applied, what is the tensile force, you can you need you can calculate.

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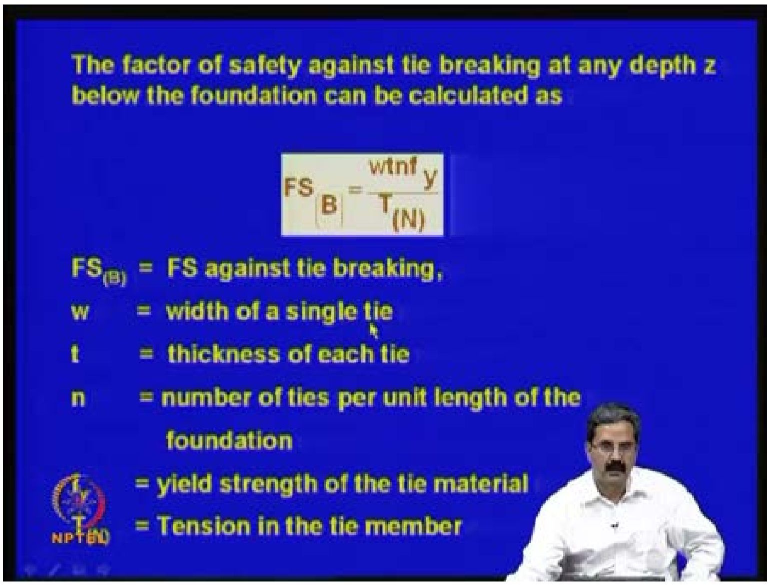

Then, now you have calculated, what is the tensile force you have that is fine. Say for example, it can be you take a meter length of geo textile or any piece of paper, you know any material that you take geo textile, geo grid or something per meter, it has a 10 kilo Newton or 20 kilo Newton or 50 kilo Newton or whatever; even steel may have higher reinforced high tensile force carrying capacity.

So, you have to have, once I calculate that, what is the factor of safety against breaking is? As I said, it should not be broken. So, what should be the factor of safety? The way that I am calculating here is that, I have n is a number to ties per unit length of the foundation. Say for example, you have you know the b width and you have number of number you know; say for example, as I said the the number of reinforcement elements is important and how do you calculate that we try to calculate, in terms of the factor of the safety.

See, we actually specify a factor of safety of 2 or 3 or whatever depending on the code. And you take a simple tie, tie means reinforcement like any steel strip, we are using an example of a steel strip here; width into thickness will be the reinforcement element, n is a number of elements; f y is a tensile yield strength of the material, time material.

So, if it is steel, you have to take that value; if it is a geo grid, you have to take that value; you want to put timber, take that value, timber reinforcement also is possible. Anything is possible here and w t all these numbers are there, and f y is the numbers are there. Then you know what is say the moment, you have placed some materials inside, you know what is the spacing and what is using that expression that I mentioned earlier, one can calculate, and if the factor of safety is satisfactory its fine.

You can take some width of the width and area cross section of the member, numbers of members you can calculate, you know; and say for example, if you are putting a thin some sheet, you say it in terms of meter length. Then, express that in term of the meter len tensile force also you calculate in terms of the meter length, it is fine.

You take some 1 meter strip, 1 meter some thickness, then you will have totally w t; and then, you test the same 1 meter strip and you put here; and then you know, it is this thing. So, you will get this space, you will get the factor of safety. Now, so sometimes what we do is that, linear density ratio is another term like; say for example, the other day I was showing you a photo, in which you have reinforcements at different places; say for 1 meter, we have some 10 or 10 or 15 numbers or something you know, it cannot like you take a wire mesh which is available you put a wire mesh, which is it also has some gaps in between, it will not be it is just a series of tension members.

And the term w n is nothing but, the linear density ratio. We use a term which is nothing but how many num number of members are present that is what is called linear density ratio. Like say for example, if I say 50 percent, 50 percent means instead of 1 meter area, there is a 50 percent tension members are present; like, if it is pulley occupied, we say linear density ratio is 100 percent or if you have tension member, you know 1 meter, there are only 2 rods, 2 or 3 rods.

So, calculate the diameter of each rod, say for example, in a 1 meter, 10 plus 10 is 20 will be the the dia area occupied by this 1 meter thing; 20 plus 20 divided by 100 will you give the LDR, Linear Density Ratio. Then, once you calculate that, that is fine you know that is what you get t f y into L D R; you know L D R into t f y you know is essentially the same thing. And its next step is, it should not get pulled out, you should not simply get pulled out that is very important.

And how do you get that again, there is a simple expression that we have, you get a term called A 3 here and you have B and all this is a gamma actually; x L naught is the length of reinforcement and depth and all that. This is another expression that we have, for break, for the pull out resistance. This is nothing but, you have two sides, you know how do you calculate as I said, higher is a normal force higher is a pull out resistance.

So, on both sides that is the term that is why you get 2 here, tan phi mu into normal force. Normal force is nothing but, any point is gamma being to height. Say z plus D f is nothing but, the normal force; so, into its gamma gives you that what is called that vertical stress; vertical stress into L naught minus X naught, L naught is the total length, X naught I am subtracting. So, L naught minus X naught will give me this and the other this other term and that comes from the stress distribution; and L D R, this all that factor that you get from distribution and 2 tan phi, phi mu actually.

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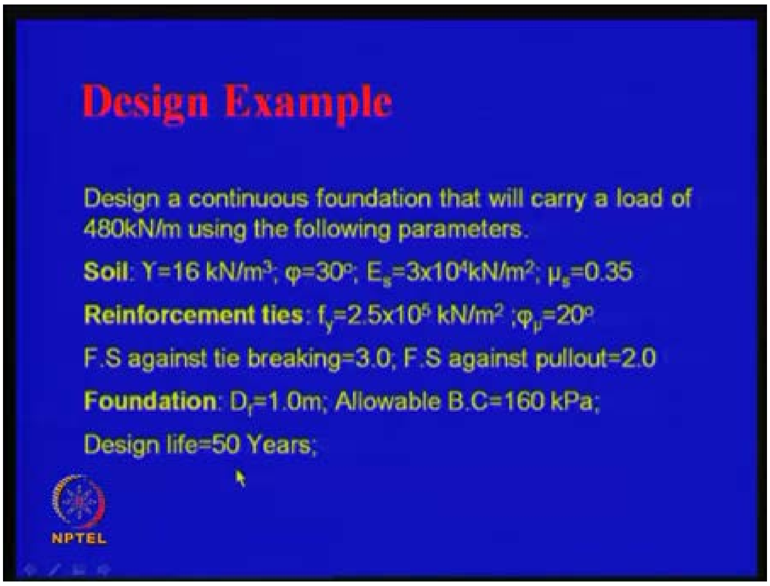

So, now you have a rough idea of how do you calculate this force in the, I mean calculate tensile force in the reinforcement and how do you check the design. So, I want to illustrate the same thing by an example; say for example, design a continuous foundation that will carry a load of 480 kilo Newton per meter. Say for example, you have a continuous foundation, may be 4 meters or 5 meters length and it carries a load of 480 kilo Newton per meter using the following parameters.

So, the density of the soil is about 16 kilo Newton per meter cube, friction angle is known, E s, E and mu of the soil are also known. Actually sometimes this information is necessary for you to calculate; say for example, in this example I have given the foundations D f equal to 1 meter and allowable bearing capacity is 160 k P a.

So, now I am using some reinforcement element, say for example, reinforced ties some tension you know I want to I have decided that some strips steel strips I am using; and this is the tensile capacity and friction angle like you know this is called additional angle, as I just mentioned we use two-thirds of the phi like you know it is like certain degrees let us use two-thirds, 20 degrees.

Now, the factor safety against breakage is we had given 3, and factor against pull out is 2, these are all some specifications that we should see. And this allowable bearing capacity is also given design life 50 years is also given. Now, based on this example we should be able to, I mean based on this sort of typical considerations; you can see that 160, like if you take a 1 meter foundation width it will be 480, 160 it is 4 almost 4 times.

So, bearing capacity improvement ratio is quite high. Why these parameters are required is that, sometimes you know 160 are not given; you can calculate using this you know. The knowing the foundation size, you can calculate the ultimate bearing capacity from shear stress, the shear strength consideration as well as settlement considerations; you take some 25 mm or 50 mm settlement and do that and get that and then calculate allowable bearing pressure.

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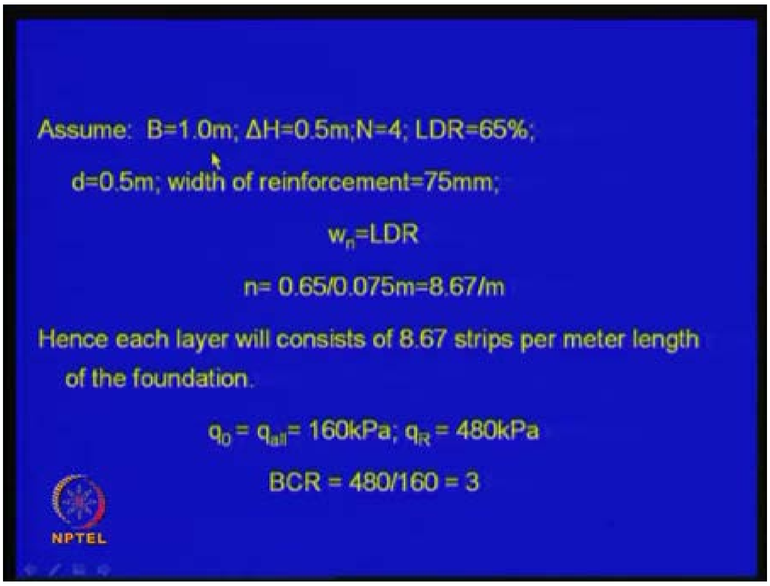

So, the same thing I assume that to precede B is 1 meter and as I just mentioned, I would like to avoid that failure like of shear failure occurring at the top. So, I have just first layer of reinforcement delta H is 0.5, and the spacing is also 0.5; you need to maintain that I had taken 1 meter footing and then 1 meter, 1 meter I am just placing this reinforcement length is still not decided.

But, at least I know that, it should be the foundation size is B equal to 1 meter. And linear density ratio I am just taking it as 65 percent; and I what which means that, in 1 meter 65 percent is a mem the you know presence of time member; like you know say 0.65 meters in a 1 meter is present or some whatever.

Then d is also like the other spacing and all that. So, both I am trying to keep d H and d as same, because it is easier to calculate. Width of the reinforcement I can just take a small strip of 75 mm, small strip 75 mm, a very small. So, number of reinforcement elements, like if I know the width, width is this much only 75. So, in 1 meter, what it means is that? If I just say that, 0.65 divided by 0.075, I will get 8.67 or 9 elements per meter length, that is what it means of having this much width, you can check.

So, we need what we are trying to say you can always change this some of this parameters, it is not an issue this is an illustrative example. And what we need is that, sorry 450 by 160 is the we need the improvement, it is about 3 factor of safety of the bearing capacity ratio required is 3. So, 16 plus 16, it is 3 times not 4 times as I just mentioned it is 3 times we need this number.

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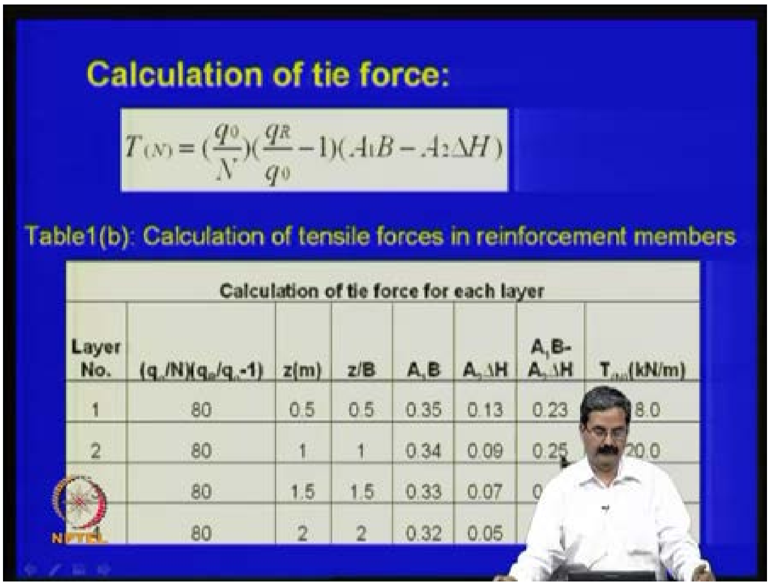

So, as I just mentioned, I we have to calculate the tie tie force. So, all these things are known their expression is known, like you know I note that q naught is 16, N is number 4 I assume that I am placing 4 numbers, you can make 3 numbers also. And A 1, A 2 that the factors B, A 1, A 2, I will get from that previous chart they are standard actually.

Once I know that, it is possible for me to calculate, what should be the tensile force in the each reinforcement; you can see that, all the quantities can be calculated. Say for example, if you want to go back to the previous charts (Refer Slide Time: 30:37), A 1 as a function of z by B, you know because I placed it z by B also you are calculating; so, z by B 0.5, 1, 1.5, 2 you can calculate. L naught is another one that we will see in the other one.

So, you will get that, so you calculate all this factors and you will get the tension in the each layer is 18, 20, 21, 26 something like that. So, you have an idea now, like if a geo grid company comes and tells you, sir what is the material you want you can say that, I want a bearing capacity improvement of factor of 3 here; and you do you have this site of this type of this grade of material that is one, not this grade; because as I just mentioned we have to correct for damage and other things and time and all that.

This but at least it gives an idea that, what should be the number of number required in terms of the tensile force required in the reinforcement as a function of bearing capacity ratio and all other factors.

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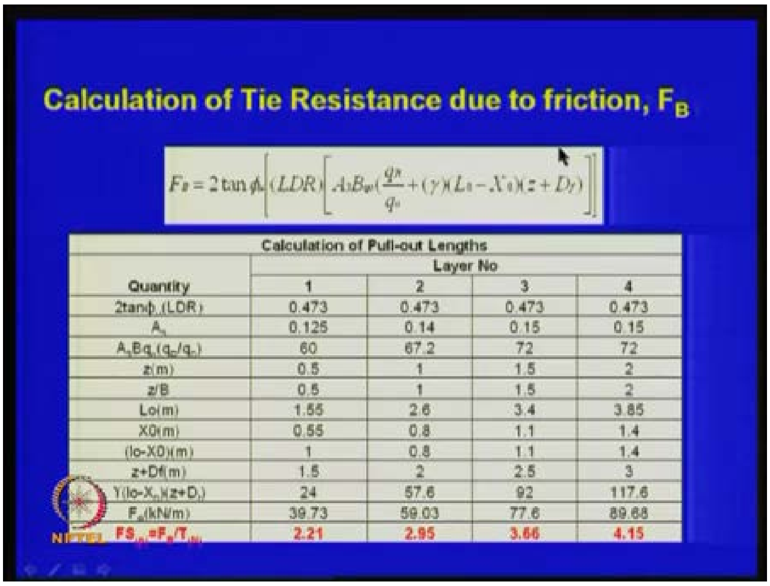

Now, you go to the second term F B is nothing but, the calculation of tie force tie resistance due to friction you know pull out resistance. Here also what we do is that, again I will try to put up the same quantities in a simple, because their 1, 2, 3, 4 layers, it is easy to calculate like this. And you have this factor, A 3 in this, 2 tan phi and mu into L D R, they are all known, A is 3 is known all that quantities I am just simply calculating here.

The X naught is what we calculated in the previous thing; L naught is nothing but, the length corresponding to like you know that minimum stress level, like it can be you know again it is it comes from the previous plot that I just mentioned, one of the previous plots.

So, once you know all this parameters, you will get substitutes in this numbers and factor of safety you will get. So, what is the factor of safety required? We saw that in the example problem that, the factor of safety required against pull out was 2, and bearing tie breaking is 3 (Refer Slide Time: 32:56).

So, we have to see that the we adhere to this (Refer Slide Time: 33:05). So, in this case the factor of safety is more than 2, and top 1 it is lower why? Because, over burden is less as we just go down, the over burden increases and hence the pull out resistance increases. So, you can see the other one, which is something like L naught, L naught is something it it gives you the length of the reinforcement actually.

L naught is nothing but, it is 1.55 meters here first level, second level the reinforcement is 2.6, third one is 3.4 and fourth one is 3.85 meters on one side, one side of the foundation. Now, on both sides it becomes twice, like for 1 meter foundation, you have to go for about 3.85 into 2 it is too big.

So, you have to really somewhat reduce any how we will see that, but you can make increase the diameter the footing size, like say B equal to 2 meters or 1.5 meters and try to do some more modifications, that we will see how modifications could be done. But, just this, this gives basic idea that you can calculate the tensile force required and also the pull out resistance and other factors.

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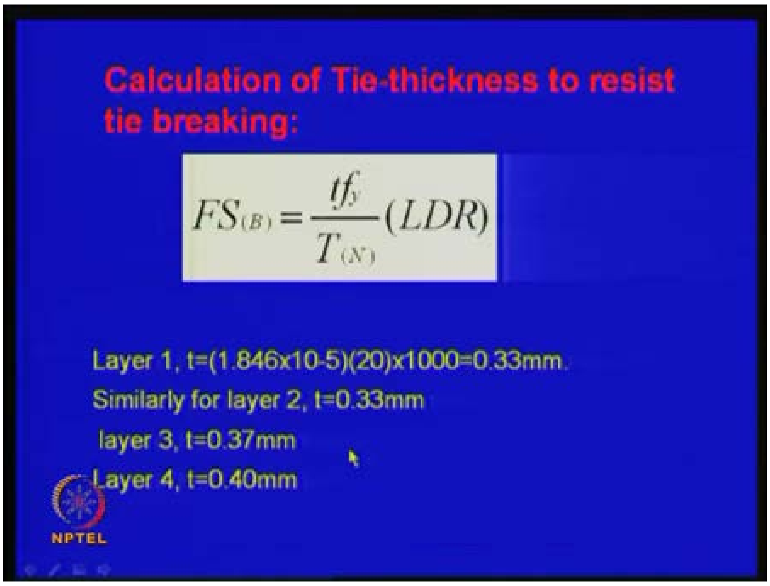

As I just mentioned now we know, what is the factor of safety required. So, one way of calculating see the thickness requirements say for example, I have fixed up the width of the tensile member, it is 65 mm; everything is trial and error here as long as you are able to economize and then cost effective design is something it should be cost effective, it should be satisfying all the design calculations requirements.

So here, I use a factor of safety against breaking is 3. So, if I just put that number, I can calculate for you know I know, what is the tensile force in each member; I calculated for layer 1, what is the tensile force there mobilized. Then like that one can calculate and you you can get this thickness required you can see that, the tensile requirement is very I mean maximum the thickness required is 0.4 mm.

Actually, I want to tell you that this in this book, I have given you all the examples most of the things that would be covering from now on. I will have lot of information compiled in this book I have this and I will try to use to some extent this material as well as updated material in this rest of the course.

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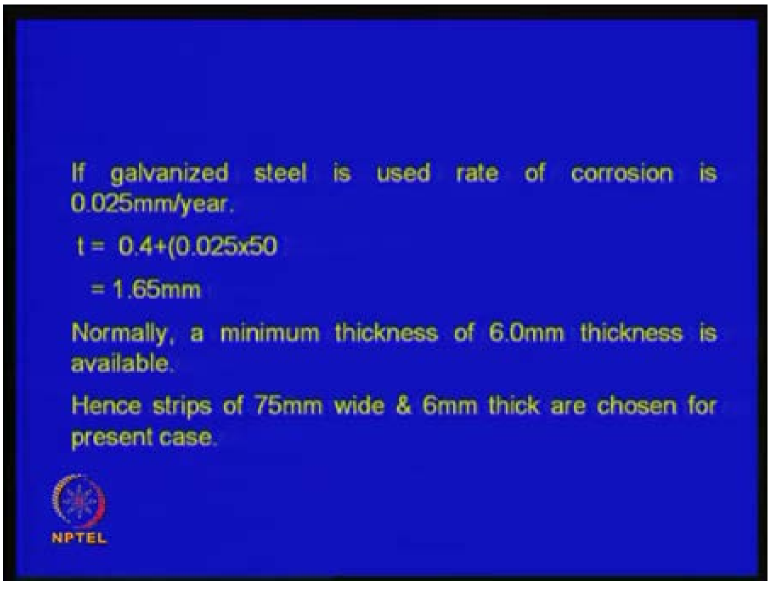

So, thickness you can see that, minimum of all this highest is about 0.4 at for corresponding to different layers. And I need to also provide for corrosion resistance, what I do is that, if the galvanized steel is used the rate of corrosion is I know that, 0.025 mm per year.

Now, I know that it is for 50 years, so 0.025 into 50, I provide as extra allowance plus 0.4; so, 1.65 mm is sufficient. But, then normally a minimum thickness of in the market, if you just see minimum is 6 mm, so it is fine for us 6 mm is too small. So, you are just using a 6 mm thickness to get a bearing capacity improvement of 3 or even 480, 48 ton per meter square you are giving you know it is very good.

So, hence strips of 75 mm wide and 6 mm thick are chosen for present case. This is a simple example I mean it is just to illustrate you the principles.

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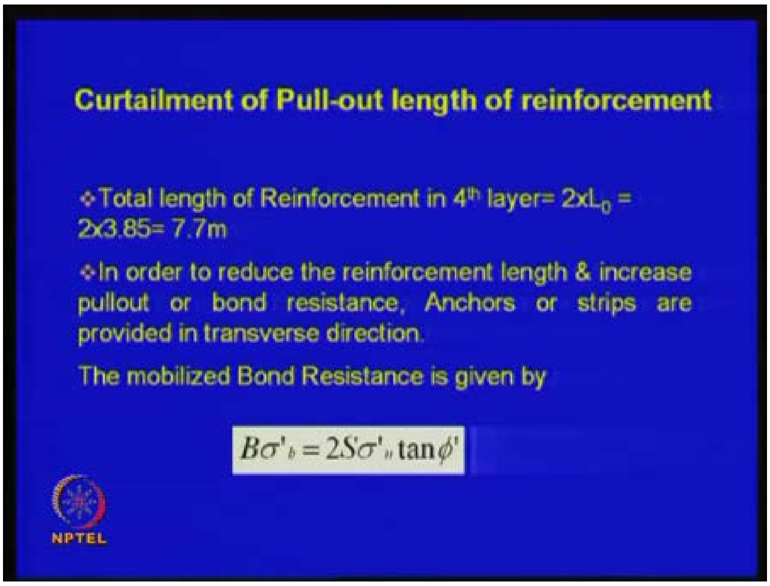

And one thing you have seen that, the length requirement is somewhat little higher here, previous case like you know as I said 2 into L naught will be the length required and it is about 7.7; and for 1 meter footing is 7.7 then neighbor next neighbor may just shout against me, he will not be happy with what is this, why are you having reinforcing to my house. So, then we need to curtail this you know.

Actually I just mentioned the mechanisms of reinforcement one is by friction you know; if the friction is not good, it can be long length like two-third of tan phi is what we have taken. Imagine that, you take tan phi equal to tan phi mu, length will come down. Then the other one is bond resistance say for example, there are two things like you know you put some sort of angles which will improve create bond bond you know.

The thing is that, it should not be able you cannot pull out easily there should be some sort of bond resistance developed like you know; you can see, in the case of a pile foundation, you have a formula that failure surface develops like this and all that. Similar to that, we should do that and we have see for example, as I said we have geo textiles and geo grids, why geo grids came? Geo grids came into picture, because you have a nice bearing members that are present.

So, in order to reduce this, the whole objective is to reduce the length of the reinforcement, because you do not want to pay lot of it, it could be expensive. So, what we do is that? We try to put some sort of bearing members or bearing resistance.

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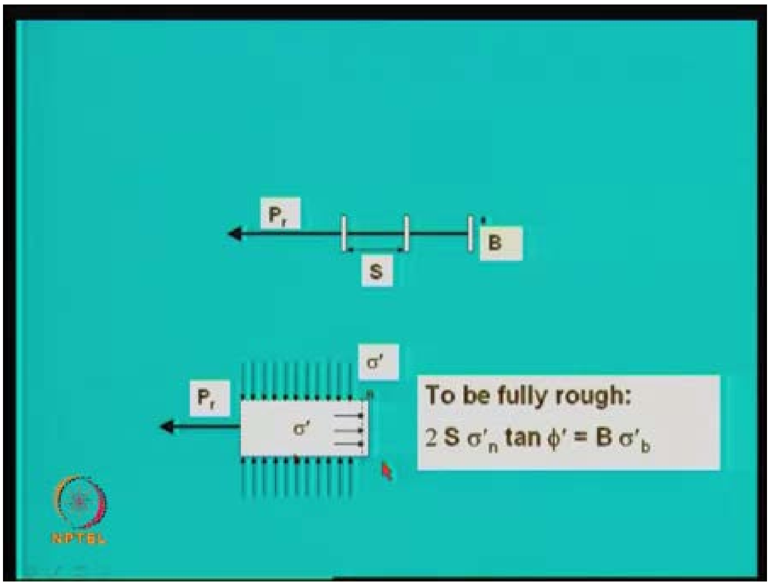

This is a simple expression that we will use (Refer Slide Time: 38:16), where I will just show you that, you try to put reinforcement here; and you have a tensile member here, like a member here and this is normal stress acting normal stress acting and this is a bearing stress and this is actually the bearing stress is acting over here width B.

And actually this is what I am mentioning B all this, this foundation with B and so, you can put depending on the spacing of this, you can appropriately do that. And what I was mentioning? Earlier, there is a friction only here along the surface; now because of this bearing member it will be like this, the failure surface will be like this. Because, it is just we call it a rough footing rough to be rough you know in the sense that, there is no fully it is effective. So, what we do is that, we try to take two sides and S is spacing and sigma n is a vertical tan phi is to B to sigma b. This is what, we use the terminology called rough otherwise it is smooth.

And we try to get back, what is the spacing required based on this. We also have some theoretical expression which is quite useful. A theoretical relationship exists between bond stress ratio and the back fill soil properties obtained from limit equilibrium consideration using bearing capacity theory (Refer Slide Time: 39:56).

Sigma dash b by sigma dash n is a simple expression that we see if you just see the bearing capacity theory; so, we will have this equation which will give you; because, the objective is we need to calculate as I just mentioned in the previous slide, the bearing resistance this is the bearing resistance. How do you calculate, the bearing resistance is a function of normal stress as I said normal stress is also applied here.

So, bearing stress, how do u get, so I must get that. So, that is the reason, why I have an equation like this (Refer Slide Time: 40:22), which is the function of the phi of the soil. So, depending on the depth at which I place say for example, shallow depth, because normal stress is slow, I will get some bearing ratio, because I finally have to use this term in this equation to get S.

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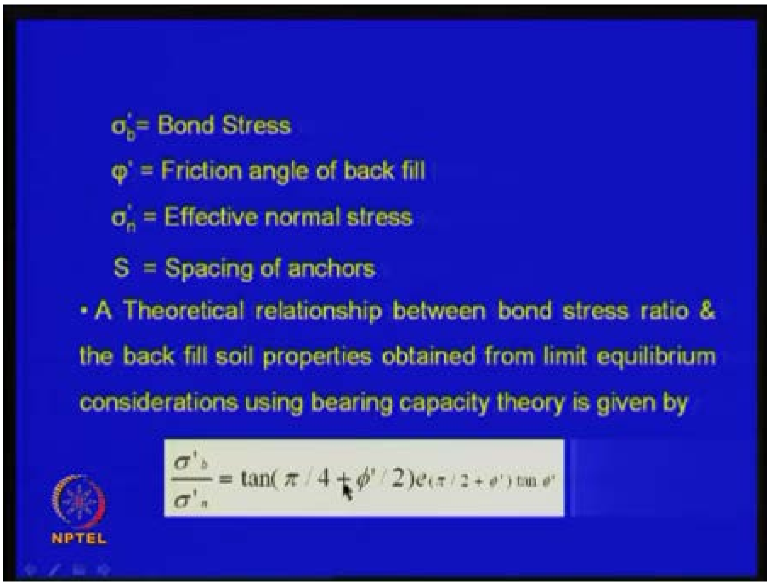

So, you will have this expression and then once you use this friction angle of the soil like phi equal to 30 and you will get the ultimate bond stress ratio and have some factors there. And you just put some numbers here, what happens is that, you will get an idea that, the length of reinforcement is taken as 3 meters, instead of earlier I have taken much bigger 3.87 or something; now, I will just take B is 1 equal to and it is total length is 3 meters only like 1.5.

So, the you should also have seen that, X naught numbers, X naught is one thing which is something a part of it. X naught plus see total length is L naught, L naught minus X naught will you give you the pull out resistance, and X naught is the length at which directly that max location of maximum shear stress all that.

So, with this spacing one can go ahead and if you want to just calculate how it looks like, you can see that, is it I want to check. So, I just calculated z plus D f and then effective normal stress 24 k P a, 32 k P a, and all that you can calculate; bond resistance per anchor you can calculate.

Tensile force per meter is already given; we got from the previous table each letter, in the factor of safety against the pull out like you know I calculate use that particular equation, and then get this numbers to calculate the bearing stress also. And now, you see that the factor of safety is more than required; and the fact is that, now this B equal to 3 only not so, when the B is 1.5 meters and you are trying to its ok. If you want, you can even reduce there are different ways of see now you got the bearing resistance has an important contribution.

So, very in fact the ground anchors that they were using in the olden even now we will be taking it taking it up in the other lectures. So, bearing resistance and anchorage resistance is something that is very important in many of the ground improvement projects. So, you can see clearly that this is very useful here.

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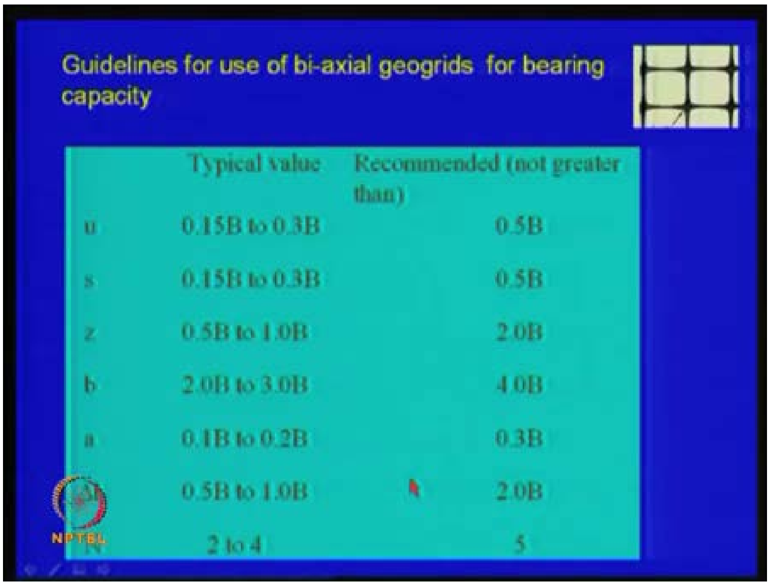

Another important thing is that, there are certain guidelines. The guidelines say that, the based on the extensive work in fact, even we did about some 10 years back based on some master's thesis, where guidelines for use of geo or the geo grids bi-axial like as a bi-axial means the it should be the stress distribution should be same in both direction; unlike, you have a mono oriented geo grids.

So, the typical numbers are that, first layer of the reinforcement u is nothing but 0.15 B to 0.3 B; so, the recommended value is 0.5 B in fact, research shows that 0.3 B is alright 0.3 B; so, but then they go for 0.5 B. But then spacing of the reinforcement like what should be the spacing between the two reinforcing elements, again 0.5 B like some numbers you know.

Then z is another number, b width of this thing. These are all various elements that are involved here; and number of elements this is 5; it is all just that you know, one should the these one need not go by some of these actual numbers, the fact is that one should be able to cross check and verify. And there are many theories also, this Binquet Lee theory is just the first theory that was done; but after that, there are many theories that came in this line.

One should cross check, take a particular example of the same thing and how what each theory can give, what is a bearing capacity ratio you are getting; and in fact, lot of plate load tests results is also available. One can check which theory is fitting in a particular situation and say there are actually the some disadvantages are there in Binquet and Lee method.

I would like to highlight to you that, see what the thing is that, you are assuming that it works as a pulley there at that point. Like now, you have seen that the failure mechanisms we have seen that we made an assumption that, it works as a pulley; but it may not be totally like you know to work as a pulley there, you are ignoring the presence of soil itself.

See what it means is that, the moment I say, you have reinforcement like this it just goes like this and there is vertical stress acting, there is a tensile force like this; you are ignoring the actual presence of the medium itself there; in the sense that, there could be a friction and all that. In fact, they assumed you are getting some bearing capacity improvement here, but what you actually get in the field may be much more than this, because of varieties of reasons. In fact, I will show you in the next class that, it can be higher also from field studies.

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So, additional information on this would be that we will we will handle what you have seen in the case of soft soil in the sands how the bearing capacity could be improved. And bearing capacity could be improved as I just mentioned, because of the actual response of the reinforcement element; we have tensile force developed, we also have frictional, we have because of the tensile forces are developed, because of the friction and also the bond resistance.

That was fine in the case of sands, because sand even aggregates you know like you take some aggregates that we see in roads pavement; particularly, if you see in the pavement design, you are using geo grids and I mean, aggregates you can put a layer of a geo grid on the top of the Granular Sub Base, we call it G S B layer, and bearing capacity will be very good.

Also one can even check how much will be the bearing capacity improvement that one can get. But, when you have soft soil, what are you going to do? Soil is so soft that it is not even possible to walk across or you know you have to again, say the load has to be you have say for example, many soft soils exist on the coastal areas; and you need to improve the bearing capacity, because the bearing capacity is low there.

And we have seen various ground improvement techniques, like stone columns, you have seen pre fabricators vertical drains, chemical grouting admixtures, there are so many issues that we have seen. But here, again reinforcement is also another technique that one should examine; because the thing is that in the ground improvement, you should examine all the possibilities and whichever is cheaper only you can take whichever is feasible you know.

The thing is, if a particular technique is not going to be useful or it cannot be practically implemented in the field then there is no point. Because, and then time say for example, there should be an experience contractor available everybody should understand the principles and then start doing it. So, if you try to say that, there is an innovative technique and I gave that technique and if they cannot use, then there is no use.

In this sense, we have the geo synthetics have been quite useful. And I must say that, particularly when you are trying to talk about soft soils; what we should do is that, we cannot use the in the case of soft soils, if you put a reinforcements, there is no friction you know delta I mean, tan delta will be very low. So, we do not want to have this type of issue here.

And what we do is that, you have a soft soil we put a layer of sand, 1 meter sand or 2 meters of sand that acts as a loading platform or something whatever you can call it. Because, the whatever is the load that can come is just getting absorbed in the sand layer, and the shear stress that can come on the clay layer could be much less than the shear strength of the soil. That is an assumption that we thought we should one should normally make.

But, if you are using sand and aggregates it is fine, but apart from using sand and aggregate. It is actually sand sands are required, sand and aggregate is required you cannot walk on the soft soil, you have to put some loads of sand and aggregate then only you can do something; because, as I just mentioned, they distribute the loads.

So, in the same, when you are putting sand and aggregate, why do not you put geo textiles, geo grids, and geo cells there that is an obvious question. So, we do that, we do that here; and we have a couple of ways of doing it here. And say for example, if you place a geo first a sand material and then you know then put reinforcement also.

There are different mechanisms by which it can improve. As I said, the understanding of mechanisms is very important, because you should know how to calculate. You assume some mechanism then the mechanism gives you method of calculation. So, we can improve the soft soil bearing capacity.

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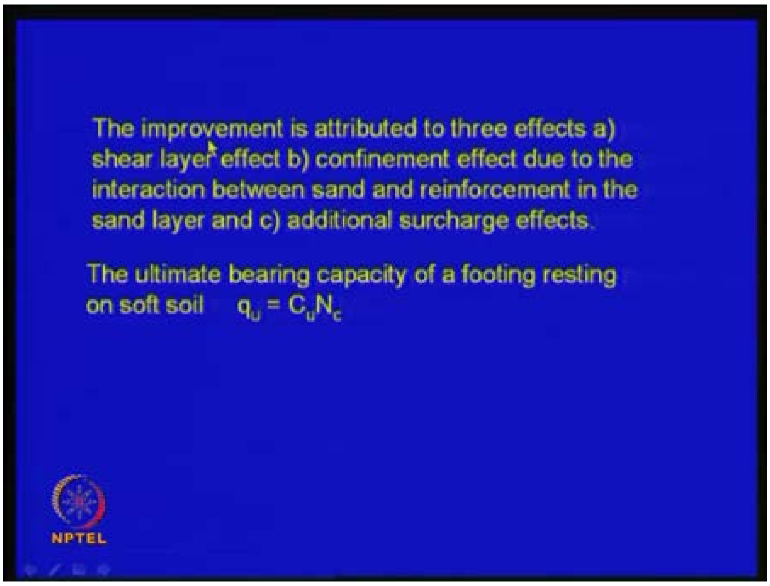

And what we do is that, we put sand some sand layer and also put some reinforcement in between; and we say that, there are three effects that will help us. One is a shear layer effect and second one is a confinement effect due to the interaction between the sand and reinforcement in the sand layer and additional surcharge effect, the three things.

And we know that, the ultimate bearing capacity of the footing resting on the soft soil is q u is C u N c, N c is 5.14. So, 5.14 C u is what we know like say, if 10 k P a is that so, it will be 51.4 k P a will be the shear strength ultimate value. And you use of factor of safety of 3, it is much less. So, how do you improve this is something that we will see. So, these are all effects that I am talking about.

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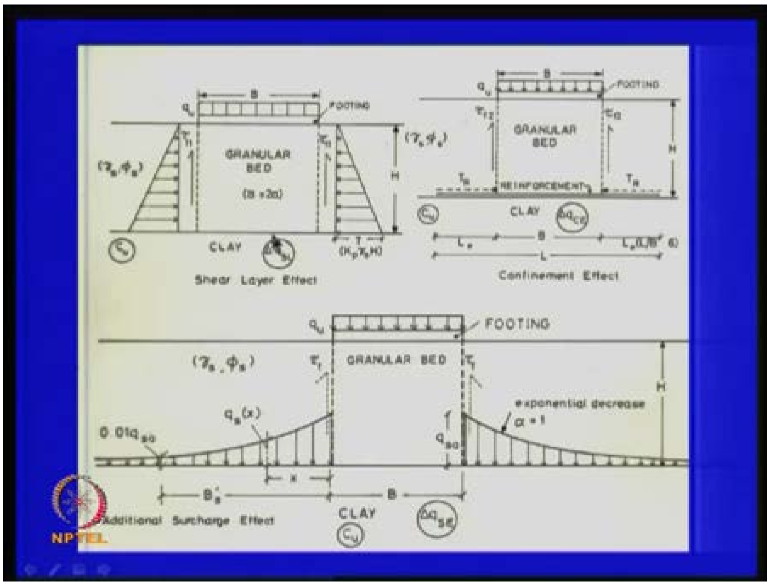

You have a clay soil here and it has a under shear strength of C u; and if I put some granular bed we call it granular material blanket or whatever. And this is the B, width of the foundation. So, what we do is that, if you put the loading is the load comes like this, then because of the shear layer effect, there is some sort of resistance you know soil has sand has some shear resistance compared to clay.

So, what we call, there is a shear resistance that gets mobilized here, in the both sides; this is shear resistance, because of shear layer effect. So, this we try to calculate that is in fact, how much is that half k p k p, k k h square. K a instead of k a, half k a gamma h square is, what we do in a conventional calculation, here it is passive pressure; it is passive pressure here, so, that is why we are trying to use, because it provides resistance here. So, we have to calculate k p, use k p here. So, half k p h square will be the pressure on both sides. So, now that is one important thing.

Now, since you placed reinforcement here, say for example, you are trying to place reinforcement here; what is that it is doing, you have already this affect which is because of this shear layer effect. The second thing is, what is called confinement effect it is providing confinement. Reinforcement acts in this opposite direction as I just mentioned, we just discussed about there is a friction. The moment, there is a tendency to come like this, there is a resistance here.

So, the resistance is developed on this on the friction this is a reinforcement member, like up to L naught X naught we have seen know X naught acts in the. So, you can calculate, what is the shear resistance and if you put reinforcement like this, it is complete reinforcement it is complete reinforcement and there is thing that is acting here; that is one thing.

So, because of the confinement effects we are able to get some improvement in bearing capacity; in fact, we say that delta q S L is improved bearing capacity due to shear layer effect, this delta there are three deltas is coming up here. And the other one, the other most important other one important thing is additional surcharge effect.

Actually, it has also has a surcharge effect, because the fact is that, it acts as a surcharge you know the thing is that, you place a reinforcement, it is not just about its confinement effect, it is just that it is also the additional surcharge effect is also there; you know like there is a load applied on that and its valid up to say for example, if length of the reinforcement is you know say for B s, it is a it goes up to 0.01 of the shear stress distribution.

So, these three things are very important. And if you are able to compute all the three things then, bearing capacity improvement is possible, even in the case of soft soil.

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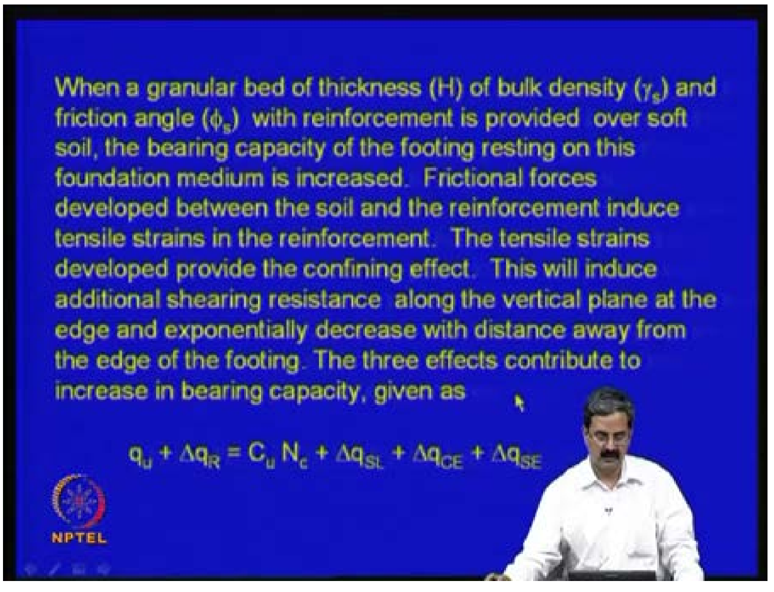

So, when a granular bed of thickness H of the bulk density gamma s and friction angle pi s is used with reinforcement is provided; so, the bearing capacity is increased. The frictional force is developed between the soil and reinforcement induced tensile strains. And tensile strains developed provide confinement effect; in fact, they also provide confinement effect.

This will reduce the additional shear resistance along the vertical plane at the edge; this will induce additional shearing resistance, because the that is another important component. Because, what is happening? As I said, at the edge it is creating additional shearing resistance and expert which increase exponentially with the distance away from the edge of the footing.

So, one is the surcharge effect the shear layer effect, next second is the confining effect, third one is a surcharge effect. All three of them, they just contribute and then increases this bearing capacity by these three terms three things. So, this is called the this is possible.

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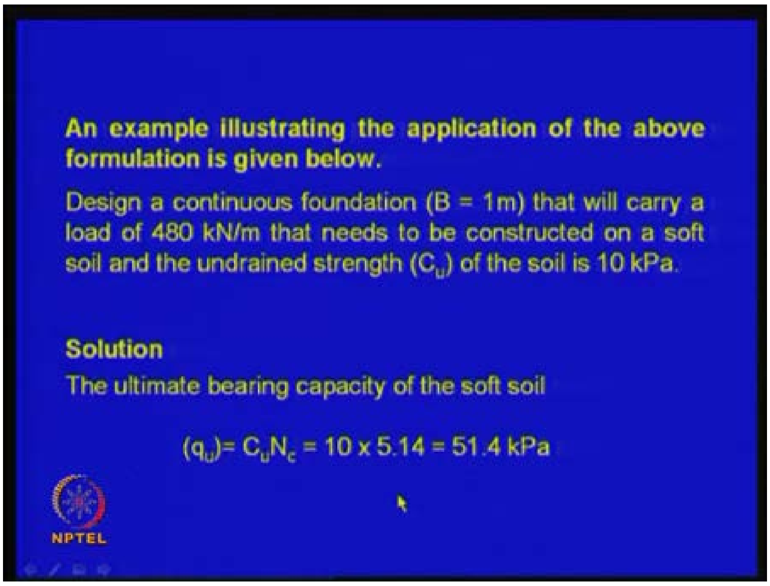

So, I would like to just take up a simple problem here which you can say that, it is a similar case that I discussed in the case of; you have sand in one case, but you also have a clay in some next nearby, but the load is same; how do you do that? The bearing capacity improvement is about we need 480, we have to see whether it can come; so, the undrained shear strength soil is 10 k P a.

So, essentially what I would like to say is that, even we can solve this type of problems using the soil reinforcement technique. And we will take up this in the next class, thank you.