Ground Improvement
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Module No. # 08

Lecture No. # 29

Bearing Capacity Improvement-II

Today, would be talking about improvement of bearing capacity in soft soils using geosynthetics. In the previous class, we just understood how the bearing capacity of sands could be improved using (( )) method. And then we also saw that the bearing capacity improvement is possible. Because the thing is that, we try to calculate how much is; the tension force required, because of the friction between the soil and enforcement. That is, what we do, do there and we also saw that the length of the reinforcement can be curtailed, if you use anchorage concept. You know the thing is like concept of anchorage in which there is a apart from frictional resistance. There is a bearing resistance that gets mobilized.

So, that frictional resistance plus bearing resistance can be very useful in the improvement of bearing resistance. So, we will see how it can be done in soft soils, because we know that soft soils are naturally poor, like the bearing capacities could be very low particularly when you know, you go to coastal areas the soft soils are off you know quite you see them quite often. And you know you need to construct some structures, buildings and all that. And I just gave some brief introduction earlier to this method on how it can improve the bearing capacity.

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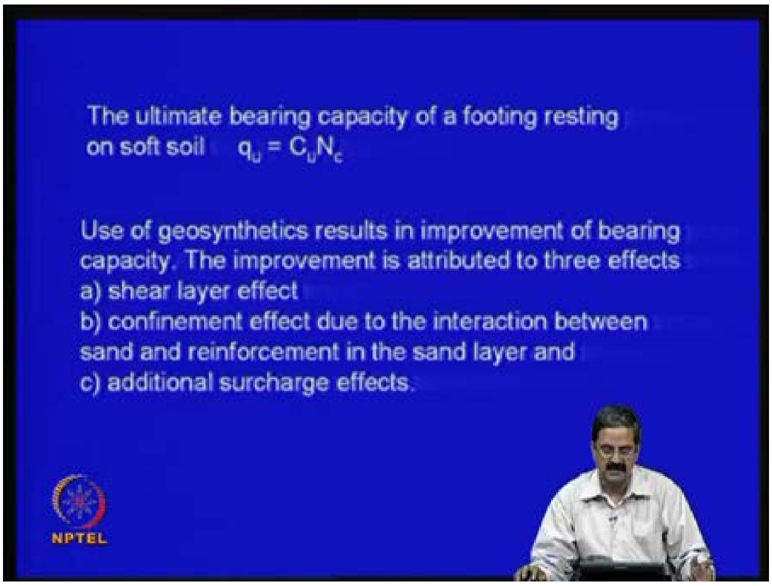

In fact, we know that the bearing capacity of the soft soil is given by C N c like, we call it C and you have, this term u it is called untrained cohesion and then N C is the cohesion factor in bearing capacity equation. In fact, in bearing capacity equation we have three terms N c N Q N gamma, which are nothing but the bearing capacity factors. And actually, when we have this; you know ,what we do is that when you are having soft soils, what we do, is that the best method is to put on the soft soils, some sort of sand. You know, so that it improves bearing capacity and if you are putting sand you can; as well put reinforcement inside the sand.

So, we have; if you do that there are some three mechanisms that we have, so that we can design the reinforced foundation conceding this effects. One is called shear layer effect the other one is confinement effect due to interaction between the sand and reinforcement in sand layer and addition surcharge effects.

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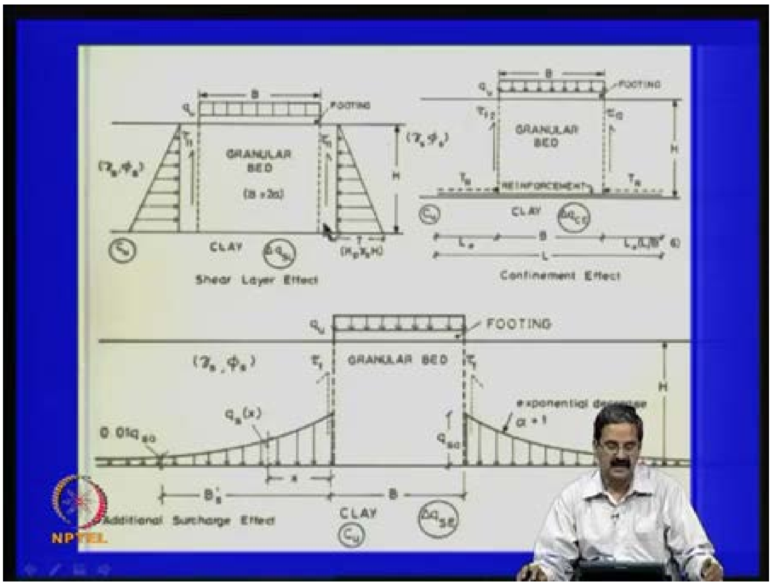

This is what I meant, like you have a granular soil here, as i just this is clay bed. And when you have a foundation here, what we do, is that you in this; the tendency for this material is to go like this, but then if there will be a passive resistance in the sand that is given by k p gamma H. Instead of k a gamma H we know, that is the active pressure, but here it is a resistance is being given by the soil. So, we call it passive resistance we say k p gamma is H. So, then you have this is called you know, we call it shear layer effect, what we did was that, you; we have introduced a shear layer of about H thickness and it helps in bearing capacity improvement. So, whatever is that like you know, the load is not directly now coming on to the clay, it is coming on to the soft soil?

In the same material, if you put a reinforcement here, see you have reinforcement here in fact you can calculate the total reinforcement force and you can divide that an anything can be done. And the advantage you know, if you put a reinforcement at the bottom, what we are trying to do, is that we try to provide a confinement effect, in the sense that when there is a load applied vertically. Then, there is some sort resistance that get mobilized, because of the friction between the soil and reinforcement. Because of the friction between the soil and reinforcement, there is a tension force t r develops. Then, you have one vertical component of the tensile force that acts in this direction, which will resist a bearing capacity. So, you have bearing capacity improvement because of this factor, like we call it you know shear layer effect or we say T f one.

Then, there is another term T f 2 you can say shear resistance that gets mobilized at this plane. You know, we have taken this is a plane and then, this is a shear resistance that gets mobilized. And now, apart from these two so, this is called confinement effect and it is actually the length of the reinforcement is l and this is that effective length is l e. So, this related to; say for example, it can be 2.5 or 3 d (( )) or whatever. So, this leads to some sort of confinement effect that is, what it means and when you have; you know, effects like this, like both this effects are now acting; they act as something like you know, some surcharge effect actually, because you know in this reinforcement layer you know the you have these two combinations, you have what is called the; it is a surcharge effect we call it and this decreases with distance exponentially.

And there are some theoretical formulations for this and we try to say that when s naught is; q s naught is this much and then at a distance one percent of it this effective width to some extent we can call it. Of course, lot of work has been done on these lines in Japan particularly. Where you know the; you have all highlands there you know, all have highlands and you have to construct some apartments there. And you have to see the soil is already there will be a water actually you know, it is not even soil you cannot call it is highly liquid soil. So, you need to really put some sort of sand, put some sort of reinforcement and then start constructing allows it consolidates.

We have to do many operations there and finally, you know, you want to get a very good bearing capacity then, there is lot of effort require there I will show you some of those results and so, as I just mentioned.

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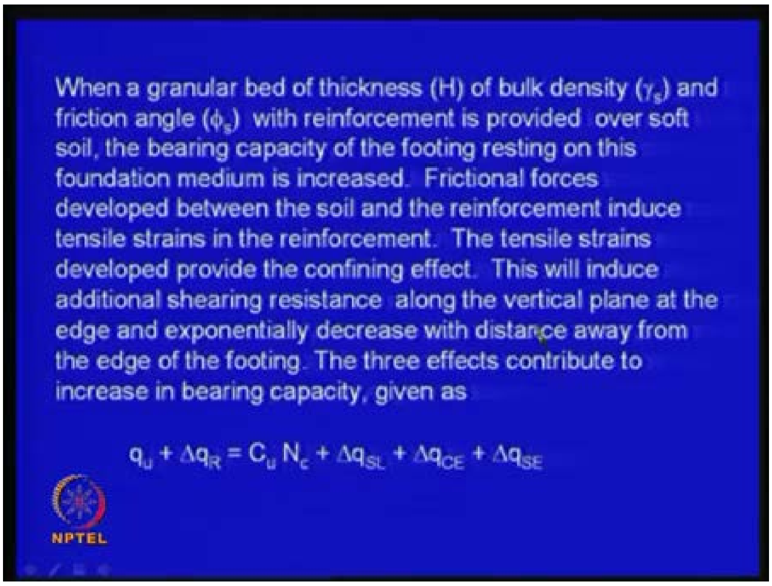

When, you have a granular bed of thickness of H of bulk density gamma s and friction phi s with reinforcement is provided over soft soils. The bearing capacity of the footing resting on this medium is increased, that we know. Because it helps that, there is some resistance. Frictional forces developed between the soil and reinforcement induce tensile strains in the reinforcement. The tensile strains developed provide the confining effect. This will induce additional shearing resistance along the vertical plane at the edge and exponentially decrease with distance away from the edge of the footing.

So, even this additional shear resistance that you get. You know, there is another component that we have and so, all the three things put together like if you just say q is the original bearing capacity plus delta q r. Because of the reinforcement and surcharge effects and also that sand layer effects you can just say, this three deltas will add up to the add and then increase the bearing capacity.

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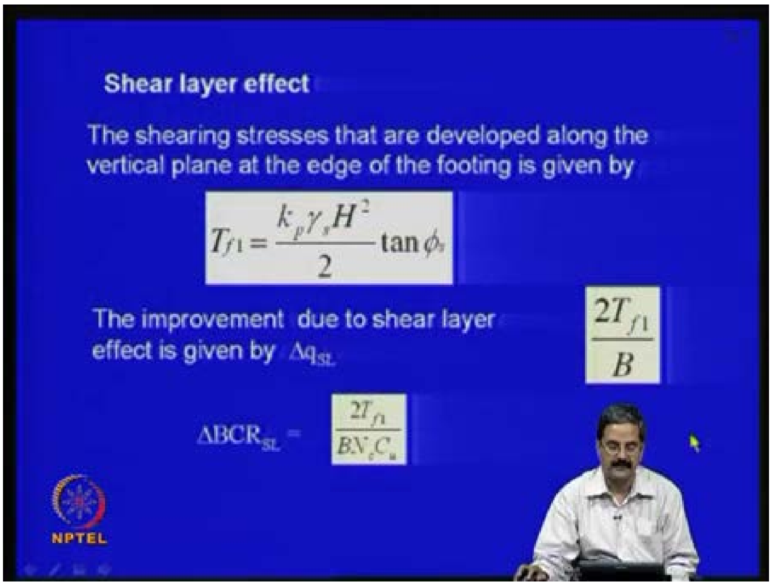

So, how do you find out as I just mentioned, when you talk of shear layer effect. The shearing resistance that are developed along the vertical plane at the edge of the footing is given by like, as I just said you know, k p gamma H so, k p gamma H square by two in tan phi s, because we need the vertical component of it. So, like this is that and then the improvement due to shear layer effect is suppose, you say delta q into S L. It is nothing, but it is that two edges is acting. 2 f 1, 2 tau it can be tau or whatever so by B. So, then I mean by you know this is what per meter length we are calculating.

So, what is actually the improvement is nothing, but you know this divided by N c C u. This will be the bearing capacity ratio. How much is the bearing capacity of ratio? What we are trying to say is that it is; it should be either say 1 to 1.5 something like that. What is that number we are trying to get here that will see.

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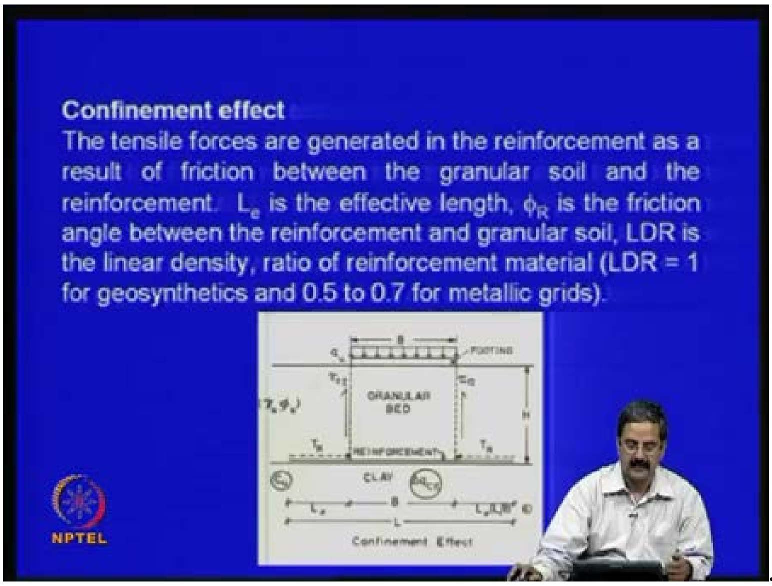

Now, as I said it is a confinement effect, the tensile force are generated in the reinforcement. As a result of friction and l u is the effective length; phi r is a friction angle between the reinforcement and soil. Like you know it can be two-thirds phi or like suppose you are using, a georgic or you know, very good material like you know. If you have normally, we take as two-thirds phi, but if I have bearing resistance also added up, it can be even very high. You know, It actually it varies from 0.6 to point; you know, actually one. One means it is a very good rough material you know, the thing is that there is a most you know, the it is a friction resistance is very high.

Like in the case of soft materials the frictional resistance could be much lower like, it can be 0.3 or 0.4, or something. So, two-thirds of tan five something 0.6 and because of georgics, it can be 0.8 and in some places it can be 0.5 and 0.67. So, it could be higher also. So, what I want to say is that, this term already mentioned about the linear density ratio earlier. Like you know, you are trying to put the reinforcement across this material. So, you have some sort of spacing and length and all that so, if it is geotextile like a sheet you call L D R is equal to 1 and for some metallics grids are georgics, it can be little less also. And there are two terms now frictional resistance is something friction angle between the reinforcement and granular fill and L D R and also the effective length all these things are important.

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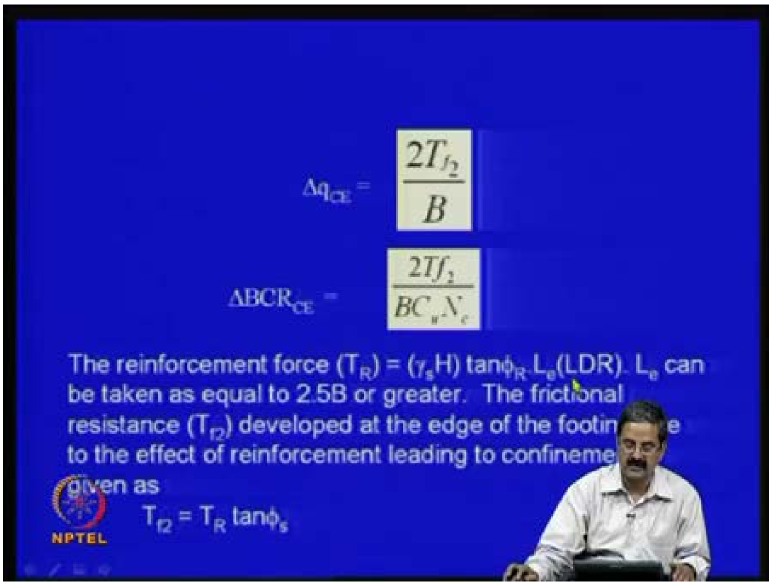

And based on this, we should calculate at tensile force. How do we calculate the tensile force? It is like this, the reinforcement force is nothing, but gamma s into H is the overburden acting into tan phi R into L e L D R, you know linear density. This is a term that we use it is nothing, but there is a weight of that materials acting and into it is friction angle between the soil and the reinforcement into L e, what is a length it is over which it is acting and all that. And normally, it could be 2.5 to; it can be even three b four b and all that. So, that T f 2 developed at the edge of the footing due to the effect of the reinforcement leading to confinement is T f 2 is T R tan phi s. So, you can get again that term so, essentially once you get that T R and; so, essentially, what you are doing is that I will just, I think in the next slide.

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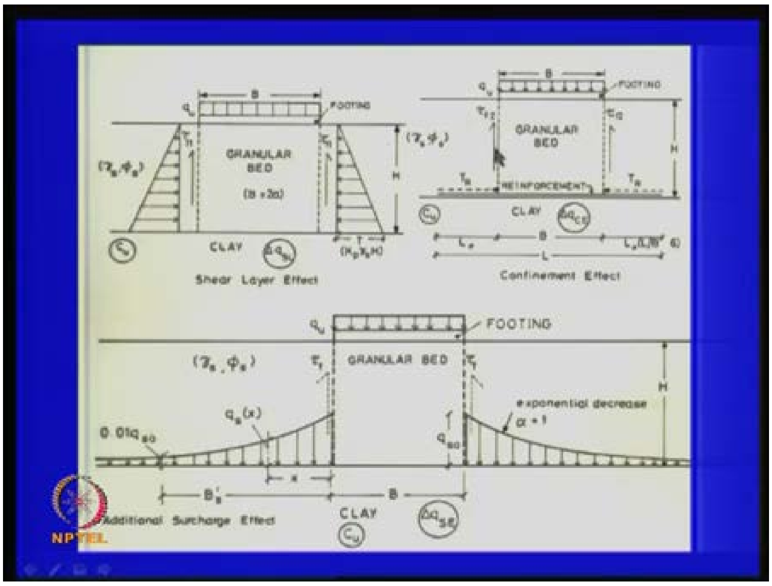

It is there (No Audio From: 11:23 to 11:35) this one like, this is what you are trying to find out. You know the T R and then multiplied by the tan phi s, you get this vertical component that is what we did here.

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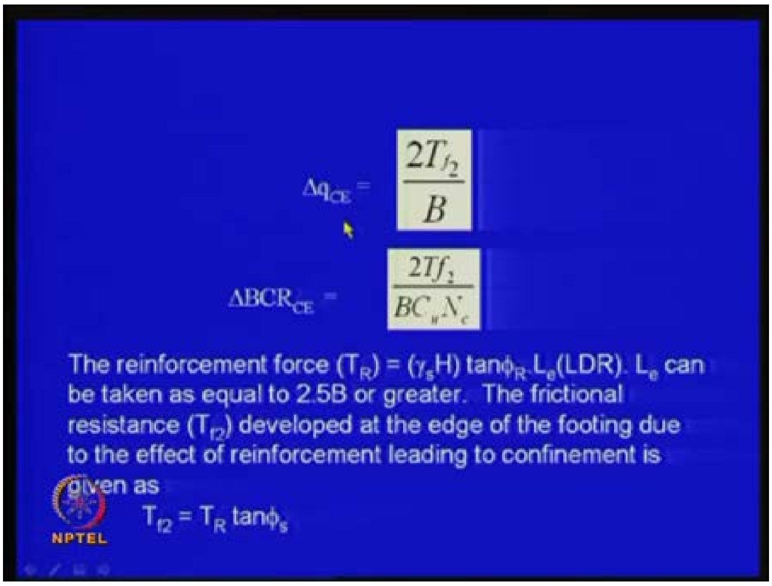

T f 2 is T R tan phi s once you know that and then once we know. So, we know the improvement in bearing capacity due to confining effect. This is what you are getting here.

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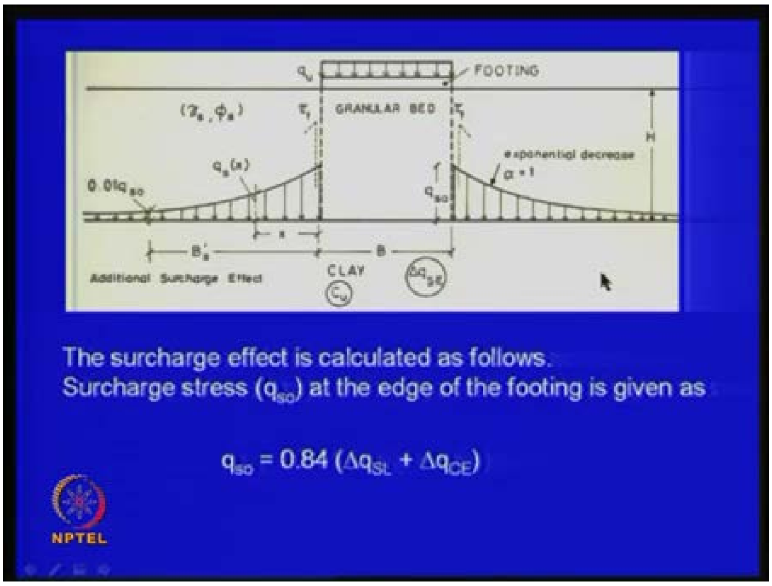

So, the there is a simple expression actually in given in one of the good papers. Like all these two both these two effects shear layer effect and exponential effect will add up in this form. And then, you know, you actually, you need to integrate. You know, actually there is an distribution function for this and all that. And once you integrate and you want to get the number here, you know actually, what you are trying to get, what is the value here is, what you are trying to find out? It is a; there is a simple expression, that we have, but it can be obtain with some simple calculations, which are given in the literature. And you can take it for the time being that it is point; if you take it has exponential distribution, it is 0.84 times into whatever, you have completed previously. So, based on these three things, you are able to get all the three effects.

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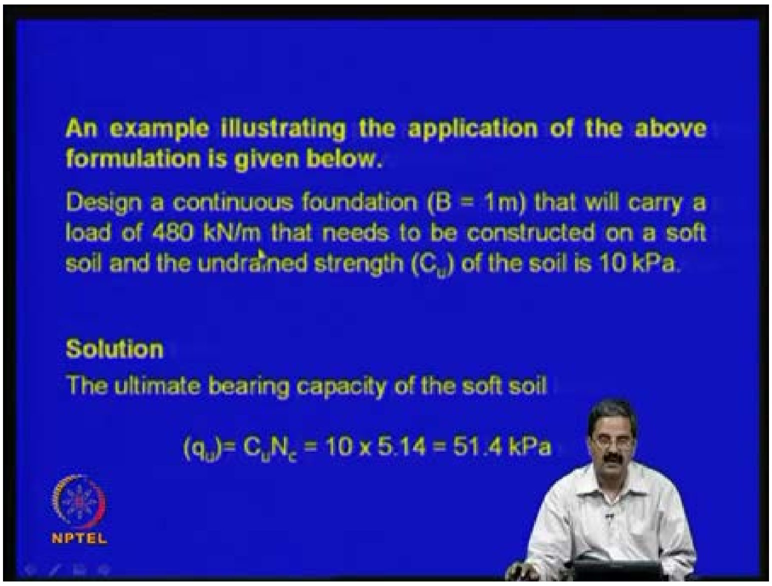

So, let us see it in the case of a problem that we saw earlier design a continuous foundation of B equal to 1 meter that will carry a load of 480 tons that needs to be constructed on the soft soil, on the untrained strength of the soil is 10 k P a. So, you can see that it is 480 Kilonewton is a load and we know now, the bearing capacity is only 51 k P a, it is 5.14 into C u like 10 k P a so, this is a very low value.

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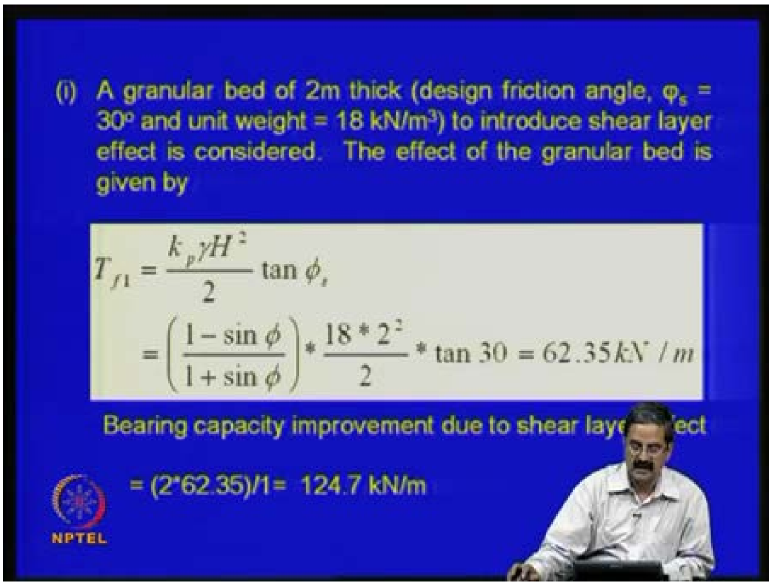

Now, you would like to improve it and say let us take 2 meters, as a thickness of the sand that sand cushion, you are going to have and unit weight is 18 kilo Newton per meter cube and that acts as a shear layer. You know, what the shear layer is that it observe all the shear strength. Now, you have this strong k p gamma H square by 2 actually it is one plus sin phi by one minus sin phi. This is a; it should be reverse and it is you will get some number. So, you will calculate that it should be one plus sin phi by one minus sin phi into gamma p into 18 into 2 square tan 30 and all that we have. It is one plus that you should we know that.

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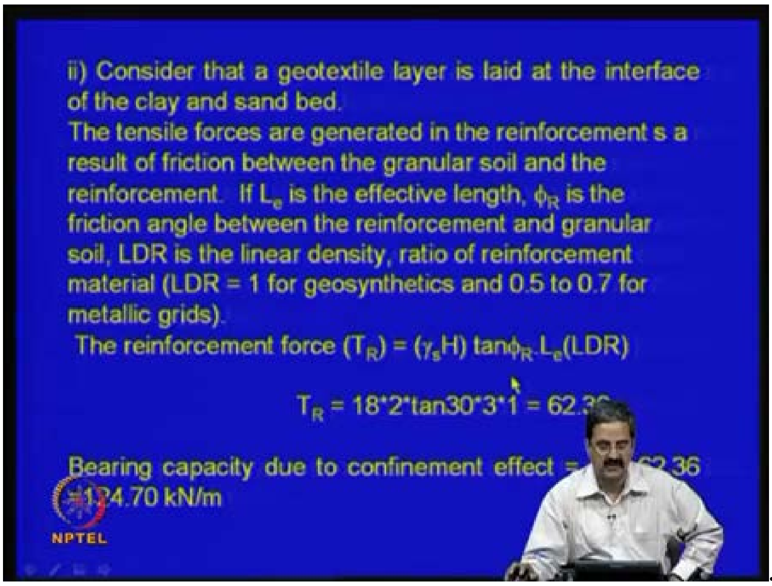

So, you will; you have a number which is something you got an effect of shear layer effect, which is reasonably good. Like you know, what I meant was that.

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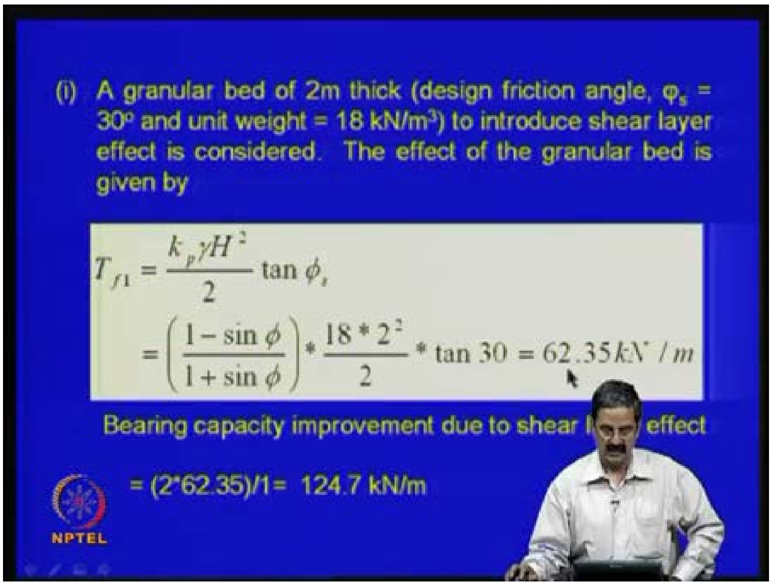

You have, 62.35 kilonewtons and you are trying to take an both sides and so, it is 124. And it is actually, if you see the bearing capacity ratio it is actually original one was 51 k P a and it is now, you got a higher value.

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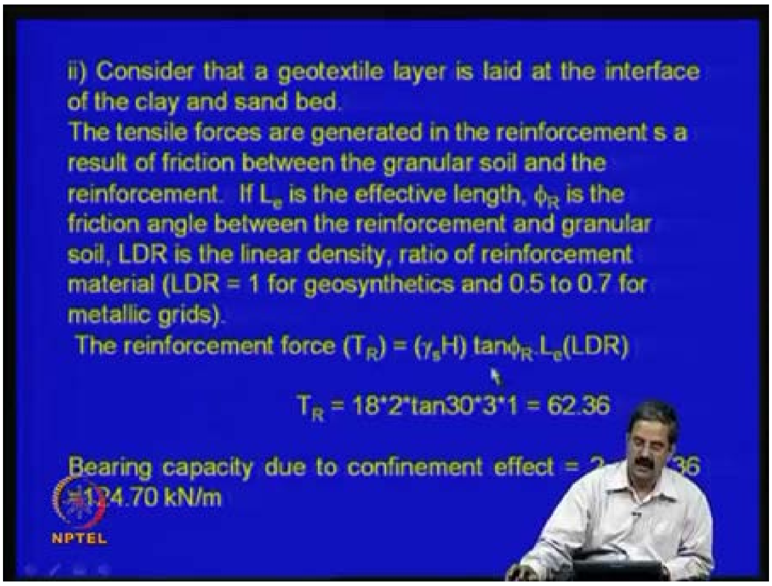

Now, let us take the case of reinforcement effect. Considered that a geotextile layer is laid at the interface of the clay and sand. The tensile forces are generated in the reinforcement as a result of friction between the granular soil and reinforcement. So, we take it as L e is the effective length and phi R is a frictional angle that we have seen. And we use a various terms like gamma s into H into tan phi R into L e. So, I am trying to use this terms like 18 ton per meter cube 2 or whatever. Actually 18 kilonewton per meter cube and 2 and tan 30 and 3 meter is the length of that L e and L D R is 1 and you get some number.

So, you again see that and bearing capacity due to confinement effect is there one 124.70 now, it is quite good. Whatever, you want to also draw to your attention is that. Now, you have a 62 kilonewton per meter is the length of the; strength of the reinforcement actually. See, you can even put any material like you know, as I said, what I did here is linear density ratio is one I have taken. But you can even put a wire mesh you know, steel wire mesh and with sand and all that, if you know how to calculate this material it is all right. Like you know, you can even calculate per meter length say for example, if you are putting a wire mesh, you can calculate the area of cross section of the steel available. Like you know, say for example, if it is just a three mm wire at all that.

So, in one meter length, what is the diameter of that you can calculate and you know, the tensile capacity of the steel and you can calculate this number also. So, you will be able to even check whether the; this is actually the; this is a load that either tensile force generated, because of the load. So, you can even check you know based on the, what you have provided, what is the tensile resistance available, one can; even get a factor of safety here. So, we can even two meters, we have kept actually two meters is one thing that we have kept. One can make it four maters, is it three meters, is or four meters one can make a parameter study and if you want to make a very stiff reinforcement here. One can keep it here, all that things could be done.

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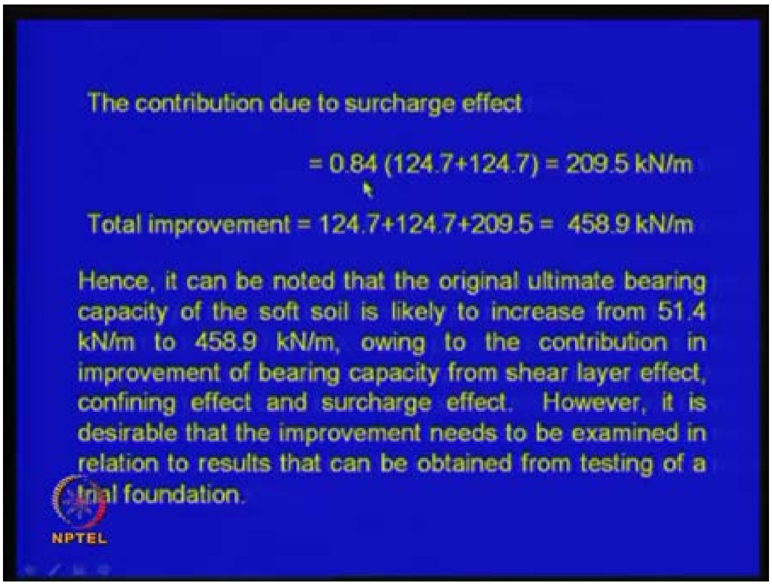

Now, the contribution due to surcharge effect also one can make, as I just mentioned one can calculate all this things. So, all this thing put together it is about 500, 458 kilonewton per meter. So, what I wanted was; how much? 480 do you remember so, if you remember the problem is 480 kilonewton per meter, if you remember. So, we are able to get close to that number and one can alter some of this numbers like you know, you can just go for; say for example, higher thickness little higher thickness and all that and see that it is 480 kilonewton per meter. The requirement, if you remember it is about 480 kilonewton meter so, we are close to that.

So, definitely one can make some of the adjustments and get this numbers say for example, they we have number of design variables here. Like here itself, you can make something here like lot of things could be made here, thickness of the sand. First one is the thickness of the sand layer and second one is the effect of reinforcement and this another one. So, it is possible to use this technique and improve the bearing capacity considering all the three effects that is, what I would like to say. And in fact, i would like to draw your attention to ground reclamation methods in Japan.

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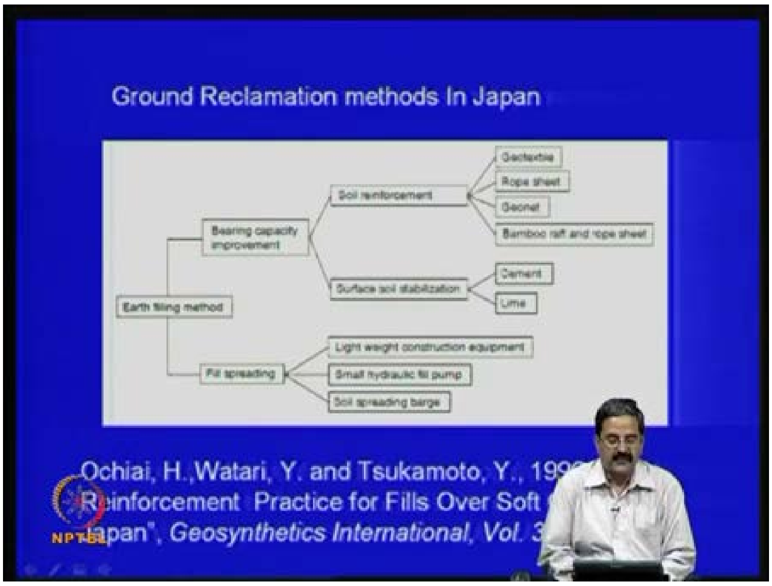

In fact, our country is big and there is not; I mean, we have lot of soft soil problems, but particularly in Japan, know they have lot of soft soils in fact, there is one institute call institute of low land technology, you know there is a saga. You know they develop lot of local techniques, which are quite effective to construct in the case of soft soils. And in fact, they also discuss on the type of filling that you have to do and type of materials that you should do in the case of; you know, soft soils, these are typical example earth filling method. You know, you are trying to go for bearing capacity improvement it is nice.

You can say for use soil reinforcement or surface soil stabilization. We have seen many techniques, like using lime, using cement and all that one can use like here, these are all the methods given here. And if you using reinforcement, do you want to geotextile, you want to rope sheet, you want to genet, you want to bamboo and you know anything is possible. So, people have been using this and this is about bearing capacity improvement and about feeling, how do spread the fill? Like you know, you go out some sand so light weight construction equipment, small hydraulic fill pump, soil spreading barge in fact, so there all required.

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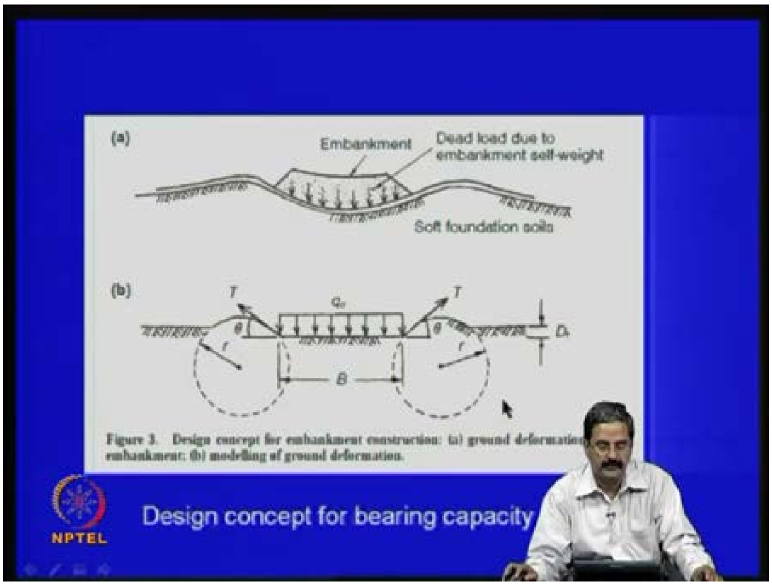

So, they also have a similar design concept, i would like to just highlight, you see they do not have, suppose they do not have sand, where do get sand? So, what you do is that you put a geomembrane some reinforcement layer here and we assume that it acts like a tension membrane. You know, we apply a load and the load resistance is like you know, you any material can hold a anything so, you dump some material here like, if I just say this, like this is a sheet of paper. And if I; there is a building here and it is called; there is a load applied and it deflects like this. And there is a tension component here and the building will not further go that is, because the vertical component of the tension force will nullify the vertical load coming. So, that is what is called we call it tension membrane concept.

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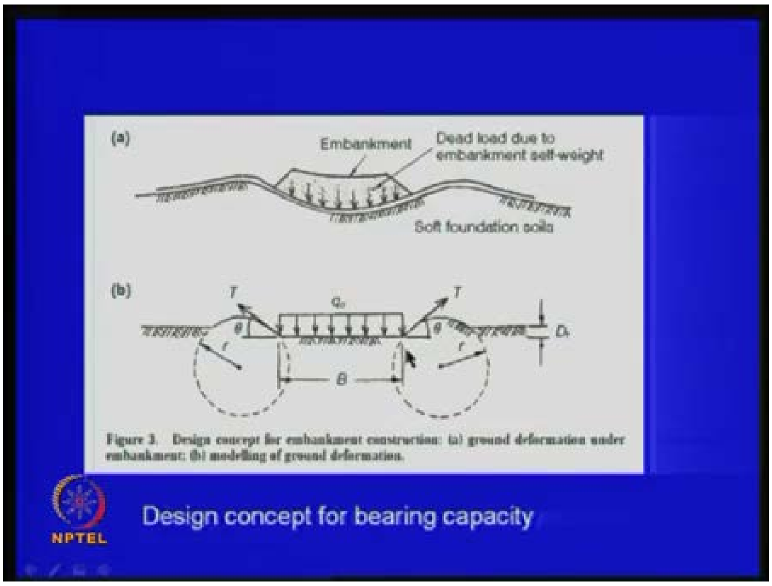

And the same logic we have here some load applied, say for example, this is an embankment that you are trying to have and you just have this sort of embankment. And you assume that, there is a tension membrane, which acts like this and the tension membrane or the tension force has some sort of circle here. And there is an angle here theta and r. And then, the depth of the foundation is D r D f, they just remember that and will just see how it helps.

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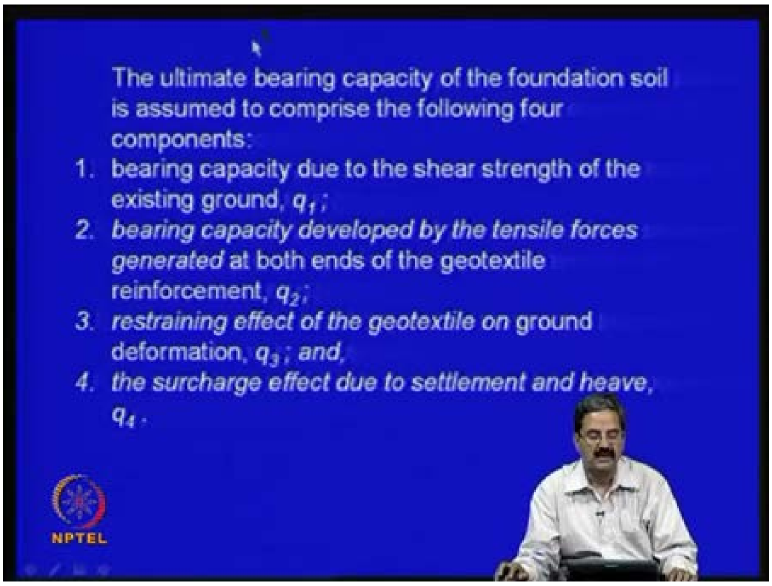

Now, in the case of so, they have a simple approach similar to this. Like the ultimate bearing capacity of the foundations assumes to comprise of the four following components, one is the bearing capacity due to shear strength of the soil. We know that it is q 1 is C N c. Bearing capacity developed by the tensile forces generated both ends of the geotextile reinforcement it is q 2, which is nothing but because of the tension. The third one is the restraining effect of the geotextile on the ground deformation. Actually there is another one that they have considered it is called q 3, where the deformation apart from improvement in bearing capacity the deformation is also prevented and restraining, effect is there. And then the surcharge effect due to settlement and heat, there is another one.

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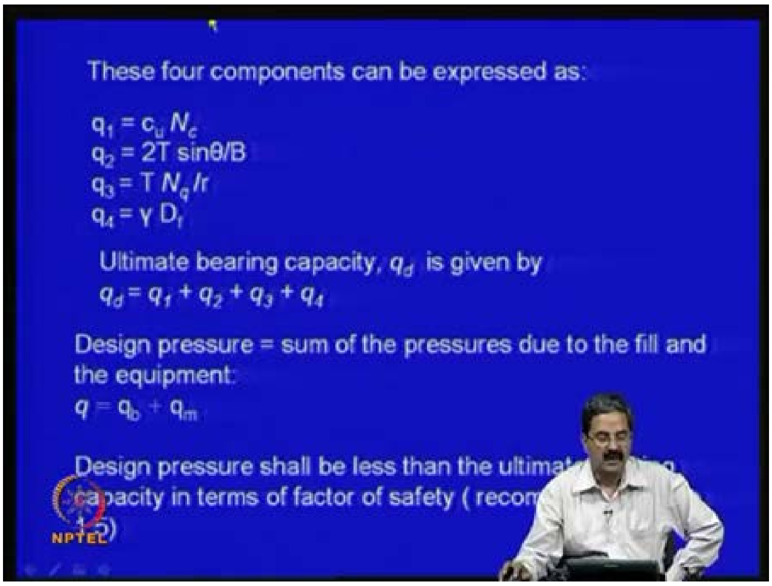

So, they are all you know simple expressions are being use for that it is q 1 is C u N c, I told you and q 2 is nothing but tension is mobilized 2 T sin theta by B, B is the size of the footing and per meter length. q 3 is nothing but T into N q by r gamma, sorry into by this thing r actually and I will show you, then q 4 is gamma D f, this surcharge effects so, all put together or the ultimate bearing capacity. So, the; now, what is that you have introduced? That tension force is introduced and the ultimate bearing capacity now, is given by this all three; summation of all the three terms, earlier it has only q 1 now, because of this, there is some increase and one can calculate does increase based on this.

So, what does, it was that design pressure should be equal to the some of the pressures due to the fill and the equipment. Like you know, what is that? You know, you have constructed and embankment and there is a traffic load coming and then the equipment. So, the total load should be equal to q b plus q m, you know due to backfill and the manufacturing thing. So, the design pressure should be less than the ultimate bearing capacity in terms of the factor safety that is what we normally expect.

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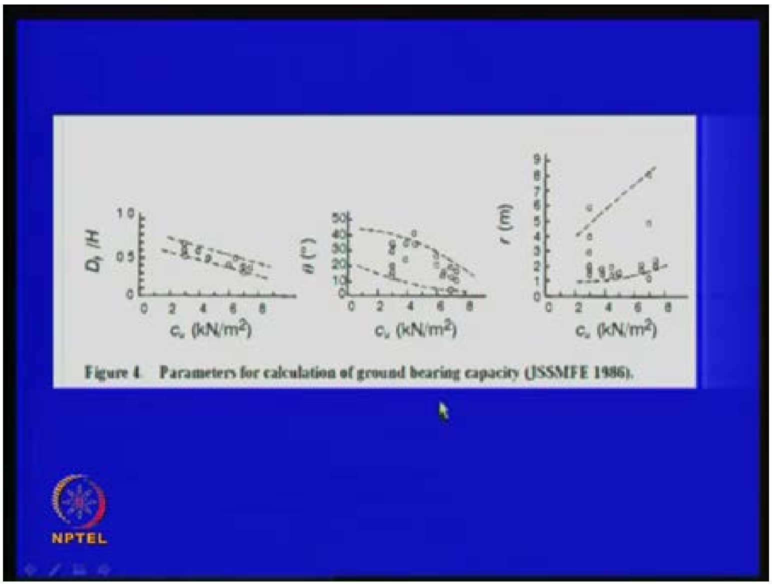

So, their own guideline show that parameters for bearing capacity calculations, it is Japanese society for solving mechanics and foundation designing in Japan. You can say that D f by H is something, if you see u is about; say for example, 4 they just go to a depth of 0.5 or whatever you know, they use a particular number. So, for example, 4 is 0.5, 0.6 here, in this case of four it can be that angle of rotation theta, what you saw earlier it is about 40 degrees and then r radius is something like. Here also about some range they have given, you can see is a bigger range, but they have done some method some analysis method have that.

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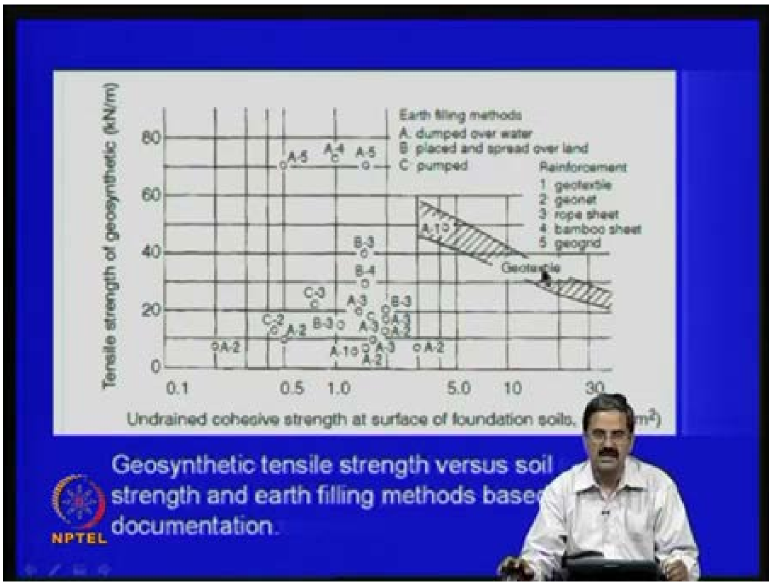

I also want to highlight, you very important point here that, they have use some of these information and got the improvement in bearing capacity and they have trying to put in the form of a chart. See, if we are depending on the untrained shear strength this is here, you can see that the values are very low like point 0.1, 0.5, one k P a. It is very low actually it is like you know; it is like a less than, more than liquid limit actually it is 5 k P a here 10 k P a here. So, actually beyond this; see beyond you know, 1.5 you know beyond three, they have used geotextile here. And because, you know it is very difficult to work in to; whatever we deposits like.

So, they have used in fact, see the different earth filling methods also dumped over water A, like you have all of this materials A, A-4. If the; here see that the these are all; this strength is very low 0.5 to 1 and then under water, when there is a water so, you have dump and then put a geotextile. And that tensile strength requirement is about you know, you can see tensile strength of the Geosynthetics about 80 to 100 klionewton per meter. Then, suppose you have this is all A-5, A-5 is the dumped over water and geogrid. F 4 is also bamboo sheet you can see, they are all here then A-2 is something that it is here A-2 is also a geonet, A-1, A-2, A-3 they are all you know, at there have this materials what about B, B is nothing but the placed and spread over land.

So, there is another type, you have some material here B-1, B-3, B-4 and all that. Then, even one can do pumping also, this is another type. So, what I want to say is that these are all you know, practiced in Japan. I just want to highlight you and in fact, we have used text tensile in many of the bearing capacity problems, many of the soft soils they can have effective increased in bearing capacity using this method.

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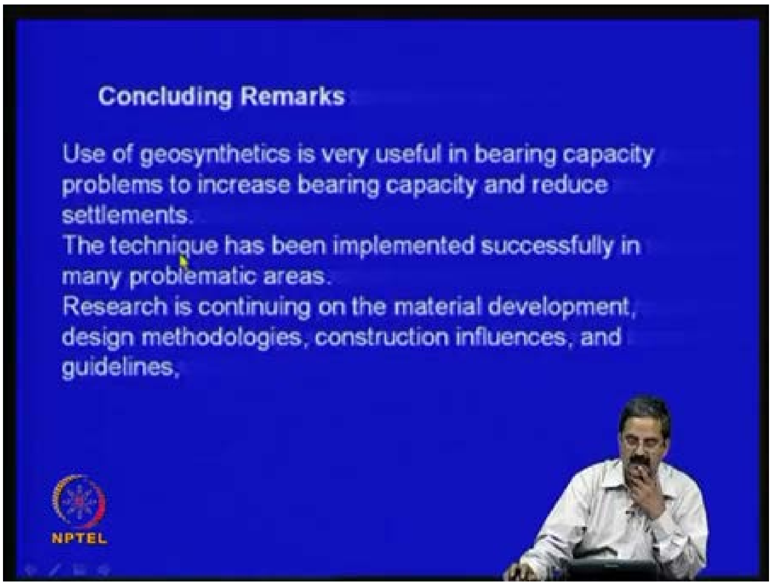

So, what I would like to say is that use of geosynthetics is very useful in bearing capacity problems to increase the bearing capacity and reduce settlements. The technique has been successfully implemented in many problematic areas. And the fact is that the research is continuing on material development, in fact people have been working on you know, different types of materials they can be very stiff also. Like you know, the thing is that the soil is super soft soil like, but then how do increase it is bearing capacity, it is more almost like a liquid, but you want to have this structure there.

So, people are looking at georgic material testing development then design methods are used also like, you know. Of course, we saw two design methodologies actually in when it try to add up the (( )) method for sands and also. Just saw, we have saw in the case of soft soils two design methods one is by; you know, considering the three failure mechanisms like shear layer effect then confining effect and surcharge effect and also. The Japanese practice that, we saw and there is lot of scope for many more design approaches here, because one can do lot of modeling here using appropriate constitute models and see, if there all; all right. And they can get lot of other insight also about other methods.

So, then there could be construction influences we saw that if you know, dewatering is an issue in some places so, these are all construction issues. And you know some places you may have; you have the dump the; what is there, but still you have to dump the soil on that. And this there are lot of work being done on those lines and any useful anything that can contribute to practice in this direction and the improve the professional practice is going to a boon in this area. Lot of work is being done, but still there is still a lot of score that is, what I want to say so, thank you. And now, I will just take up the other one which is a very important again, which is (No Audio From: 29:17 to 29:28) the slope stability improvement.

This slope stability improvement is something that is, we need for every wherever you have a slope you need to. If the factor of safety is less than one, you have to improve it there is no other solution here. And what I would be covering in this slope design is that.

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Why is it reinforce soil is required? Or why is that reinforcement helpful in these slopes? Then, we discuss some design methods and one of the popular methods that I will discuss. And we will discuss, what are the design parameters in that? And there are so many parameters there, we will see that. And what are the design values, how should you choose design values. Then, what are the steps in design? And we will also see from an example.

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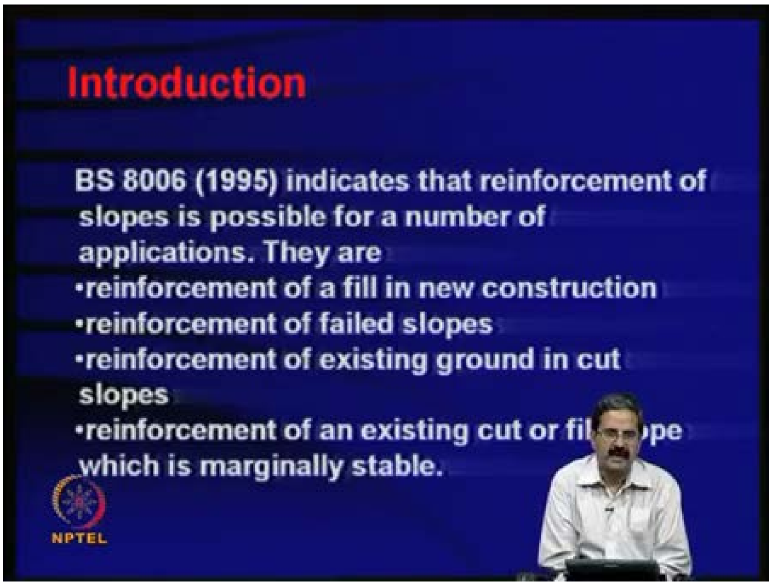

I told you earlier, that a British code B S 8006 is something very standard in the case of reinforce soils and slopes, this is one of the earliest codes that came on this in this area. And because if it is there is lot of advancement you know, main people have been constructing reinforce at wall slopes and all that. The difference between a slope and wall is that the wall is vertical, whereas a slope have some inclination varying from 90 degrees to 35 degrees, or 20 degrees angle of repose. You know, the thing is the slope is having an angle of repose then, it is somewhat stable. But as a slope angle is increased and it approaches verticality then, the problem is that the idea unstable.

So, in fact there are number of methods of handling this and B S 8006 in the case that the reinforcement of slopes is possible for a number of applications. One is reinforcement of a fill in a new construction, reinforcement of failed slopes, reinforcement of existing ground in cut slopes, reinforcement of an existing cut or a fill slope, which is marginally stable. Actually we had a most of this applications and I will show you some examples here.

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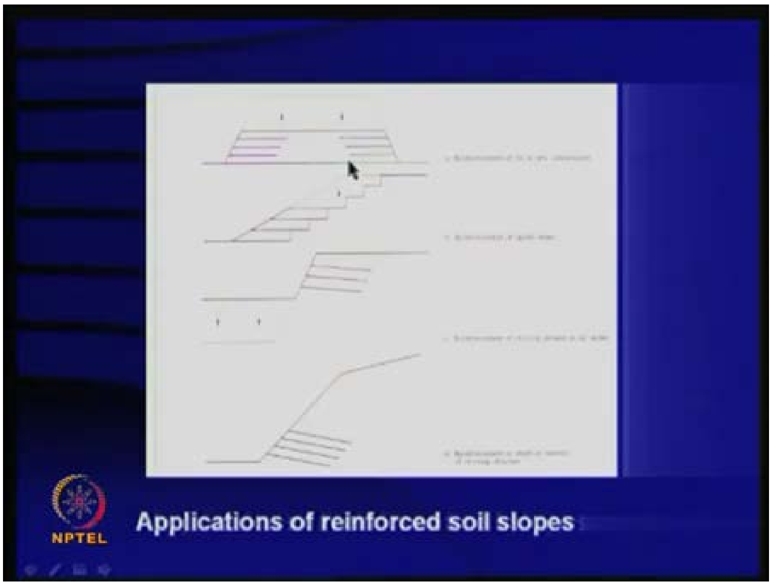

Like say for example, reinforcement of a fill in a new construction, like say you are trying to go for construction. And if the bearing capacity of the bottom soil is not sufficient, you can increase the bearing capacity or slope stability say for example, what exactly doing is that the addition of this fill, the stability could be you know, there is a possibility that is; there is a slip circle failure like this. There is a; so, you would like to avoid that you place reinforcement like this then construct. The other way is that some slopes can fail. So, one can really, you know this is another one, you know reinforcement of the field slope one can do like this also, they can do and filling. You know, the thing is some of this things are quite simple to do. And reinforcement improve the existing structures, like you know suddenly we realize that, the slope is not stable and one can do that.

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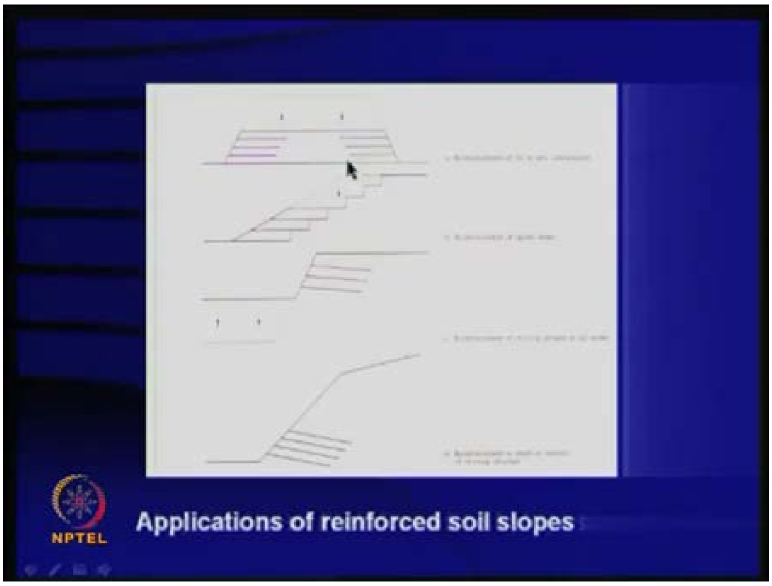

(No Audio From: 32:57 to 33:03) So, there are many applications of this, how do we do this? In fact, on the design we know the classical steps of this method. If this height of the embankment, we know that these are driving forces. So, the resisting forces are from the slip circle, length of the slip surface we know. And there is some surcharge and all this things are acting these are all some notation that we know standard notations. What we know is that based on the slip circle analysis. Like you know, how do we do this slip circle analysis, you may remember that. You have to take see, this is the slope you have to divide that in the number of slices and then for each slice, you should see there.

See that, if the conditions of sigma v sigma h and sigma m are satisfied. Like, the resisting forces are from the shear resistance of the soil and the driving courses are from the weight, or it can be even from an earth quake, it can be even from seepage. So, all this things, one should consider and then calculate the factor of safety. In fact, you have so many programs now a days to calculate slopes stability, like it gives in terms of the factor of safety and if it is finite element analysis? Yes, it is also again possible. And this slopes; the slopes stability can be computed even you can also related to deformation in. If you are using flakes say for example, flake if you are using, one can calculate the factor of safety and also the deformation.

Because the use strength reduction technique for factor of safety evaluation where this c plus sigma tan for this ten parameters are successively reduced till the slope achieves a condition of failure. So, once you know that this stability is not there, what we do is that we put some sort of reinforcement here. So, like we again; you know, this can it is a matter of design here like you have a some sort of reinforcement at some spacing and some length and all that. And calculate again the factor of safety, what happens is that if this is a slip circle, this is a slip surface and you have reinforcement here, the three d reinforcement layers.

You know, you try to; as I just explained the principle of reinforce soil earlier, that the; if you just resolve this tensile forces in the reinforcement, it acts to; it reduces the discharge reducing reinforces, it increases the resisting forces, that is what we saw that equation we also we know. What is the extra shear resistance, because of the reinforcement and it is location. Even we have seen, what is the optimum angle and all that. So, based on that, we know that, if you put some sort of reinforcement of adequate length, because the moment you put the reinforcement you should not come out also. So, we have to provide adequate length and that is what we do?

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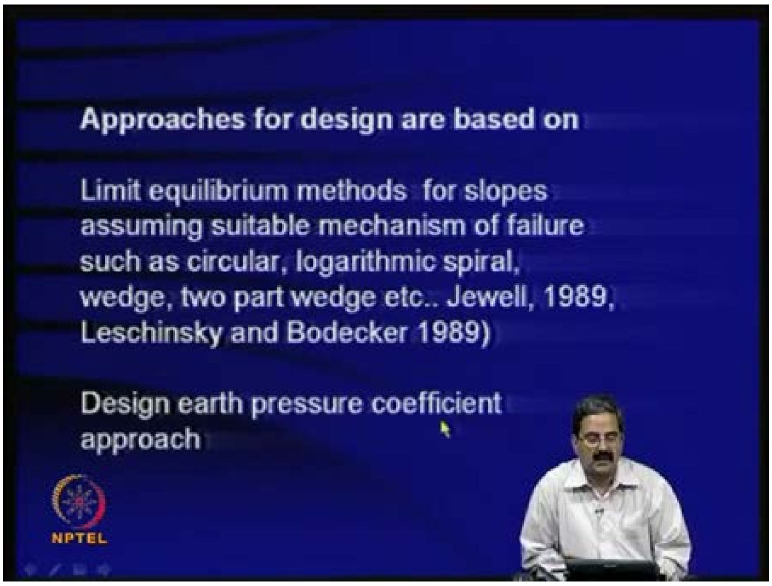

So, there are many methods to understand this problem, we call them as limit equilibrium methods. And what we do here is that we assume a suitable failure mechanism like you know it; If you assume that, it fails in the form of a circle, like a beautiful slip circle. Then, we also assume that it can be a logarithmic spiral, it can be a wedge, instead of a single wedge it can be a two part wedge. So, the number of assumptions that one can make and calculate you know, the assumption is essentially to know that.

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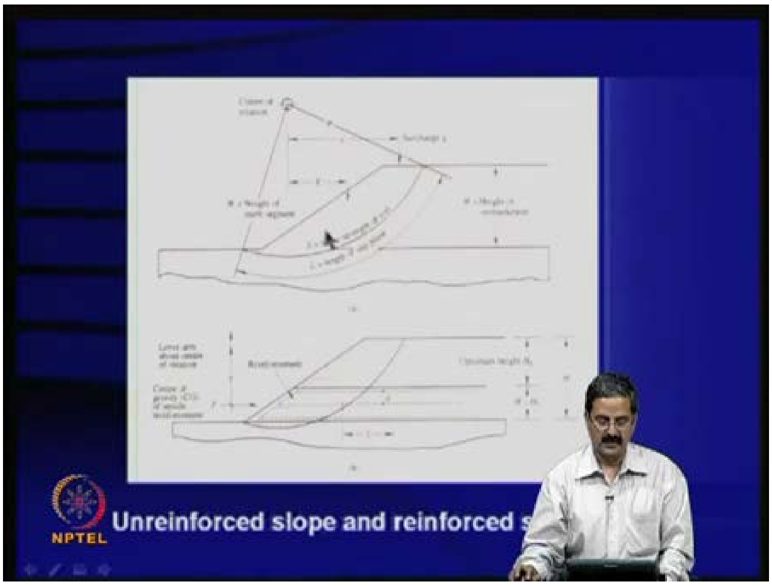

Like as I just mentioned the previous thing that we have to make an assumption about the failure surface. Once you know the assumptions as I just mentioned and if you put some sort of reinforcement. You can calculate, what is a tensile force required to have a factor of safety of 1.5, is it not. You can always put some sort of reinforcement elements like this and then you know, you write a there are so many slopes ability programs now a days in internet and even commercial software. And you can just calculate, what is the; now, factor of safety without reinforcement and with reinforcement, what is that? And how much, say for example, I want a factor of safety of 1.5 and what should be the length of the reinforcement and the tensile force all can be made. And you have lot of opportunities there.

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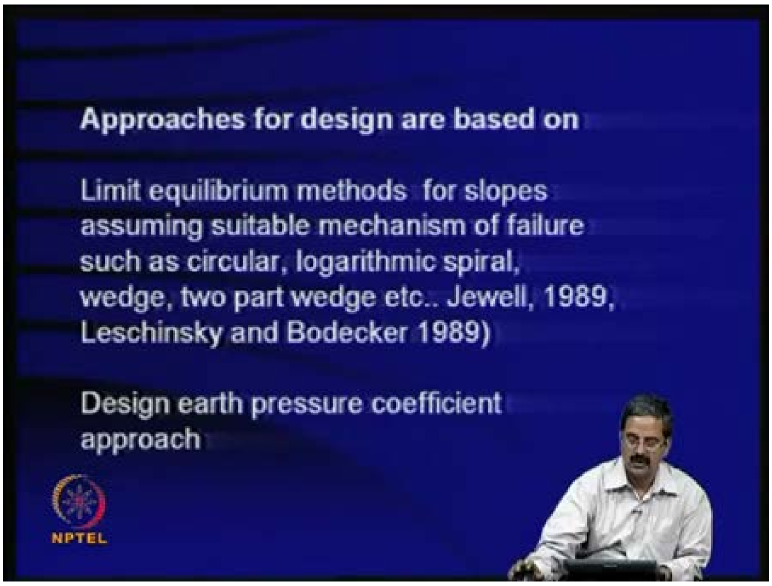

So, these methods are essentially dependent on the failure mechanisms and one more thing one should be very clear that; the mechanisms are something that; or we have to assume here like then only you know, it is possible to calculate. Now, there is another one you know, what we try to do say? There is a many people who work done this lines, like the calculation of earth pressure coefficient using limit equilibrium methods is a classical problem. You know, in fact if you want to calculate the earth pressure k P a, or k a how do you evaluate it, you have to assume some; I make an assumption about a failure surface where it can be a wedge, where it can be a circle, where it can be a; you can calculate.

Once you know the earth pressure rest one can define and then, calculate what should be the value corresponding to certain angle like phi or certain properties like you know. We know that say for example, the; why we know the earth pressure how much of earth pressure is coming and how much of earth pressure is to be designed. You know, which is the; which will be the design coefficient for the earth reinforcement one can find out here. So, there are couple of people who worked on this lines in fact, we also get some work on calculation of earth pressure coefficients for seismic different for seismic conditions and all that.

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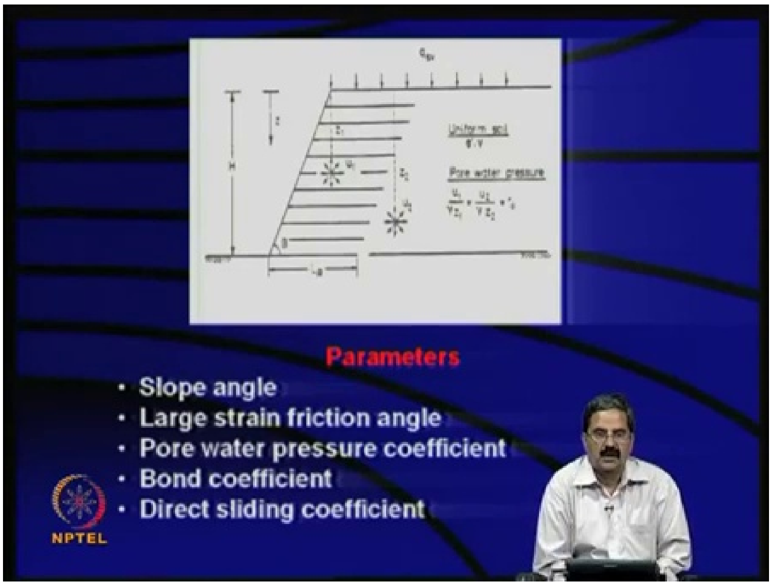

So, when you trying to design the reinforced soil slope normally, you have some parameters, one is; what is the slope angle so, what is the angle that you need so is that beta you know, beta is a slope angle can be; it can be even vertical also. But you know say, what is a 70 degree slope I want, I can say that. So, then large strain friction angle in fact, as I just mentioned friction angle of the back fill, this is the back fill. Then, pore pressure coefficient is something that; I should introduce it to you know, in the sense that we know the inform soil is there.

And pore pressure coefficient is nothing but u 1 by gamma z 1 u 2 by gamma z 2. Like, what is the ratio of pore pressure to; it is over burden pressure is something that, we say u 1 by gamma z 1 and u 2; we just say they are all constant may be; suppose you say that it is one meter you know you pore pressure raise. Then, you know how to measure the pore pressures? You have to measure using some sort of equipment. Actually, the pore pressure is nothing but it is in terms of the weight, the water column heights. Suppose you say that it is one meter height into the unit weight of water as we know one divided by gamma z 1, we know roughly it could be gamma is; z is same you know z is same and then in the same, it could be half.

If the pore pressure is fully mobilized, say pore pressure how do we measure, it is nothing but the z 1 into gamma w, gamma w is a weight of water. So, z 1 gets cancelled and it is just a ratio of unit weights of this water as well as the soil. So, it could be roughly about 0.5 and so that is called pore pressure coefficient. Then, if you are placing a reinforcement like this, the requirement is that you need to have a bond (( )) see the thing is I said the reinforcement should not fail by tension or by bonding. So, bond coefficient is; what is a bond coefficient? Like you know, you say that the bonding is provided, because of the friction and the georgic. Suppose, you are using georgics, the bond coefficient you should calculate.

In fact, if you remember the example of the bearing capacity problem, we calculated the bond coefficient there we took sigma b by sigma n if you remember and we have an expression also. Which is in terms of the tan phi of the soil and the failure mechanism and we did that. So, bond coefficient one can get based on those assumptions and calculations and direct sliding coefficient is nothing but tan delta I mean, tan delta which is nothing but two types of tan phi. So, that is one thing so, all put together there is some expressions in fact I advise you to go to library and read the book by Jewel. You know, it is a very good book on reinforce soils, please read it. And I am just essentially following that book for this particular lecture.

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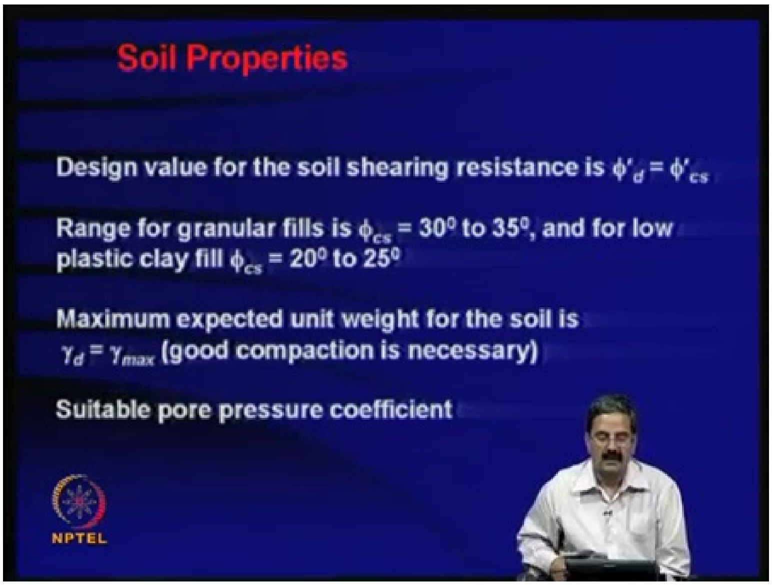

Then, you know, these are all some soil properties and all that, you know how do you like see the moment you want to design the slope you need soil properties. What type of soil is there? So, design value for the soil shearing resistance is nothing but phi by d is nothing but phi dash c s, which value of phi I should take, is it a peak value? Is it a long large strain value? So, here we are taking a critical state large strain value actually. And experiments I shown that, this phi c s is in the range of 30 to 35 degrees for granular soils and low plastic clays may be 20 to 25 degrees.

Then maximum expected unit weight is nothing but gamma d, we know that. Then, suitable pore pressure coefficient for example, we know that this soil is going to be dry, there is a good drainage so, water may not stand. So, pore pressure in the case of a dry slope is zero. Like, as I just mentioned pore pressure is what? U by gamma z, even u zero pore pressure is zero, or when there is a water had or there is some partial saturation there could be some water had and you can say that pore pressure going to say may be 0.3,0.1 or 0.5, maximum is 0.5. But as I just said, it is a ratio of unit weight of water to the unit weight of the back fill. So, if the unit weight of the back fill is going to be less then, you have to make it make appropriate corrections.

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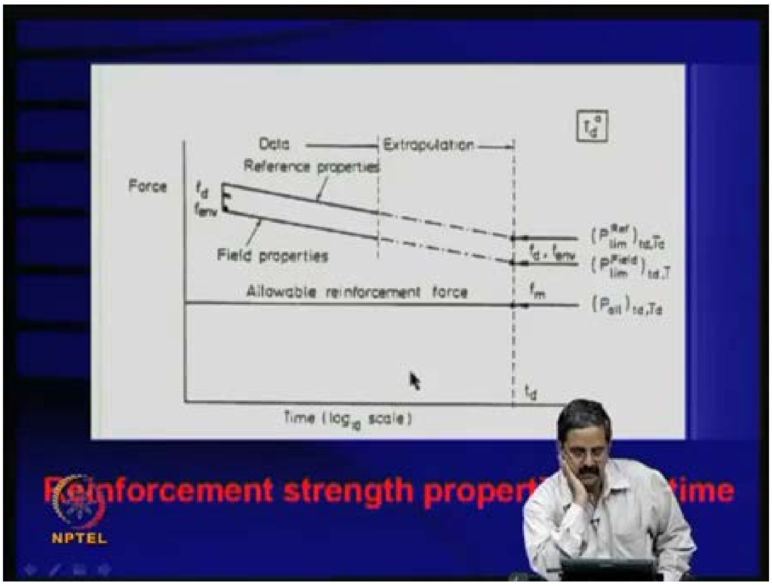

Now, how do you chose the reinforcement, as I just mentioned we are using georgics and geotextiles and even geocomposites, as I just mentioned in a Visage kanakadurga temple they have used a geocomposite. And how do you select the geosynthetic material, that is very important. We know that, there the; why do we chose reinforcement? Reinforcement we know we need, because it develop some force in the reinforcement. There is some force that gets mobilized, because of the reinforcement that friction between the soil and reinforcement. So, the reinforcement force should act till it is design life is complete. Say for example, if the design life is t d so, that design force should be you know, what I in this figure what you shows is that, you have some allowable force and you have, what is you get from the manufacturing side.

Say for example, a particular material you can choose and you can get that, what is the allowable you can calculate from calculations. The way so, the; what is in this material should be always more than, what is actually required? Or what is allowable? You know, there is some mineral value here. So, actually f d is nothing; they are all damage factors, f is environmental factor and we always see that, this materials are always here, such that the allowable reinforcement force is there all the time. Say for example, if you are trying to construct a slope the force the slope should be stable for 50 years.

So, when it is 50 years, you may have a reinforcement force like this, which is in the beginning that it may come down with time, it is about; say for example, 50 years. So, that force should be more than; what is required here that is very important. And as I just mentioned these are all manufactured materials in the some standard conditions. They will have some damage, they have some environmental factors and all that, you have to make all those corrections and see that this is all right so, that is what I want to say.

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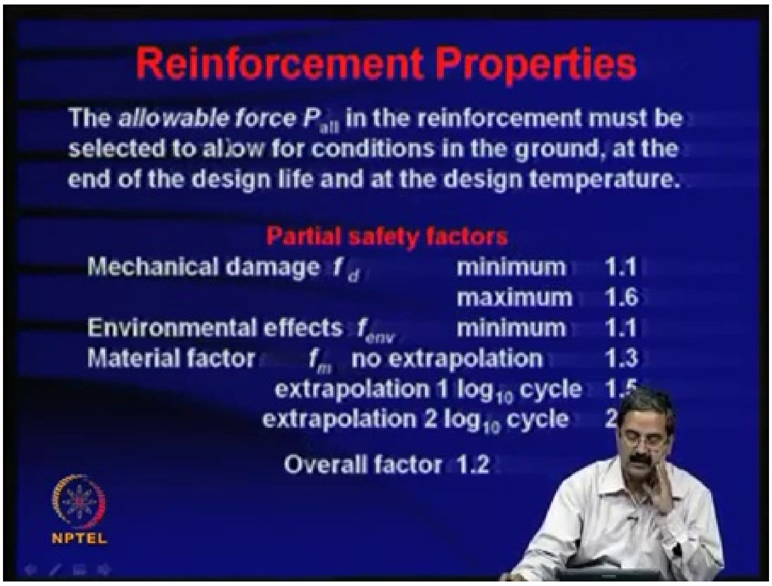

The allowable force P allowable in the reinforcement must be selected to allow for conditions in the ground at the end of the design life and the design temperature.

Actually many of the geosynthetic materials are plastic. You know as, I said, they are all polyethylene polymers essentially and they have; you know, they respond to temperatures and biological conditions also, sometimes so, one should be very careful. And so, we have some partial factors of safety here mechanical damage 1.1 maximum is 1.6 environmental factors 1.1. And if you have a not much data it is 1.3 and if you are trying to extrapolation to one log cycle it is this thing.

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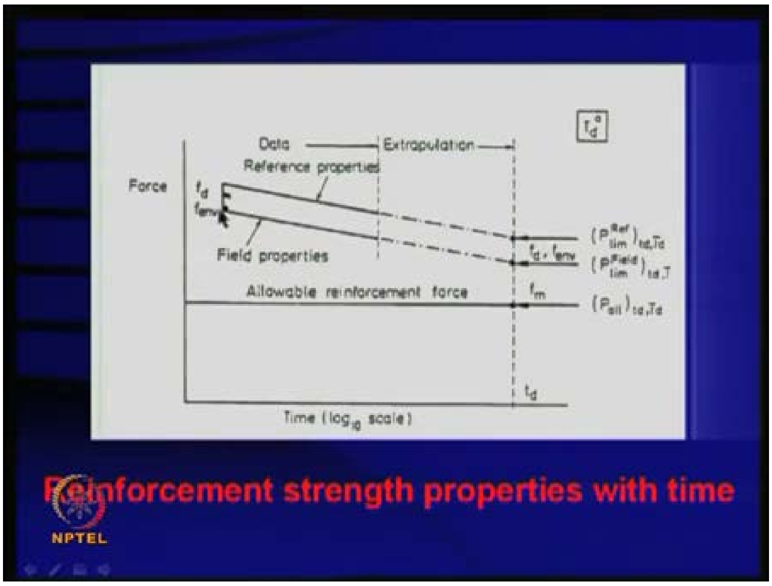

See, you have reference properties and this is one log cycle say for example, this is log 1, this is log 10, this is log 100 so, this is one log cycle this is second one is second log cycle. So, if you have that the correction factors are 1.5, 2.2. So, you apply all this correction factors to that and also a overall factor again one more you can; if you depending on the importance of the structure one can make. You know, these are all material partial factors and the overall factor of safety is also given and this is based on the companies literature.

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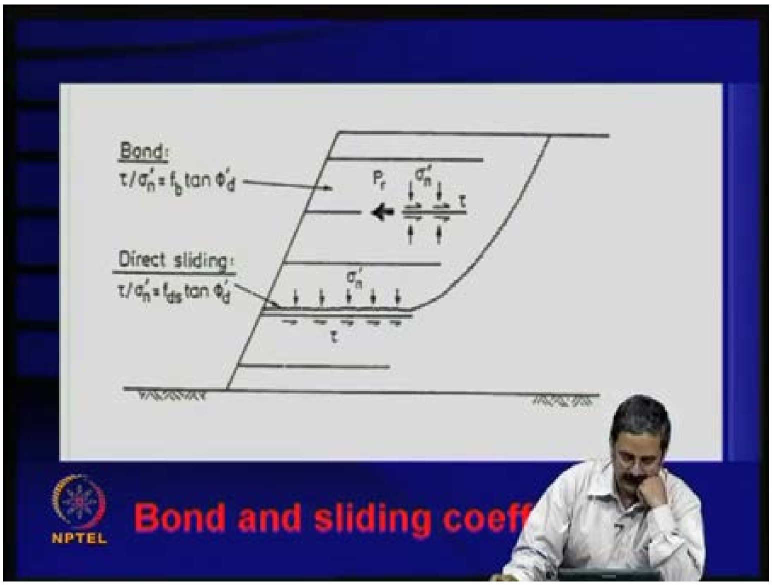

Now, once we know that the; we know about back fill soil, we know about the reinforcement to some extent. I want; I just gave some information about this, what is the difference between bonds and sliding? So, as I just mentioned sigma n is the normal stress, tau is the shear stress so, tau by normal stress is nothing but f b into tan phi d. So, f b is nothing but the bond coefficient. And in the case of georgic, you can imagine that, it is not easy to work, it is not easy to pull out, because of the grids and all that and there is some operation so, all that. So, this is one thing that is bond resistance is going to be higher and it is a function of normal stress and you have also, what is called direct sliding, you can see that the you know, nice slip circle is formed and then it is getting slide on the previous thing.

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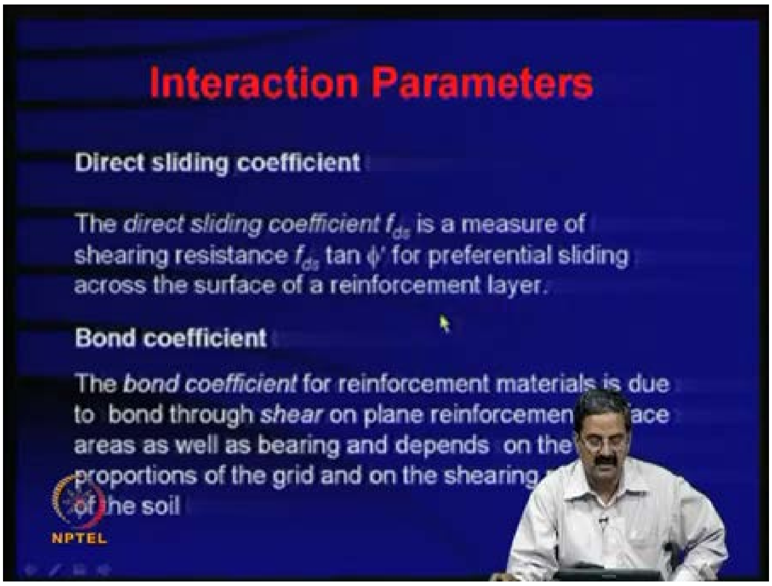

So, you are able to understand, what is these two so, the direct sliding coefficient is nothing but it is a measure of the shear resistance of the soil. And it is normally given in terms of the f d s tan phi for preferential sliding across the surface of the reinforcement layer. The bond coefficient is the due to bond through shear on the plane reinforcement surface as well as, bearing and depends on the proportion of the grid and the shear resistance of the soil. Like, as I just mentioned now, if you have a georgic when the shear takes place there is a contact between the soil to soil and assoil to georgic and also bearing resistance there are couple of things there, because of which the bond coefficient will be higher.

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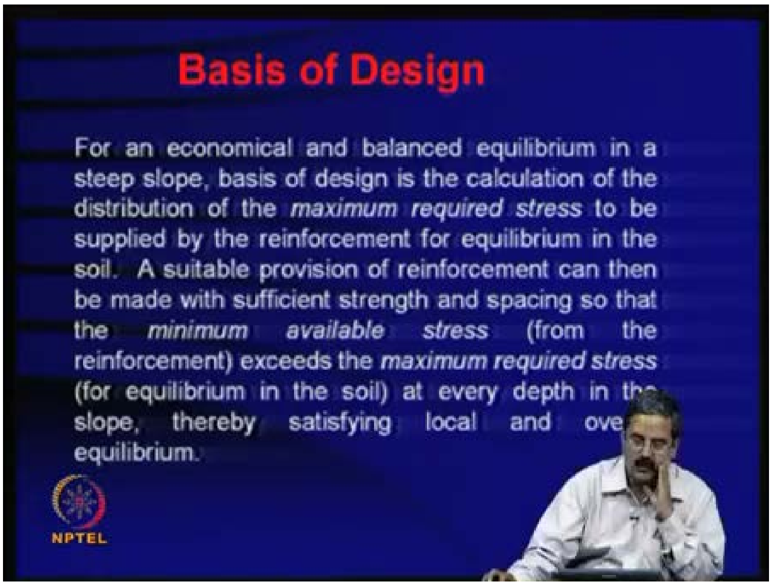

So, what; how do you do this design, if you have a reinforcement, we see that, if you do? You remember that, there is some lateral force coming up and if you put a reinforcement that we have a maximum. See, we have to have what is called the basis of design is a calculation of distribution of maximum required stress to be supplied by the reinforcement for equilibrium. In fact, if you introduce a reinforcement it will introduce some stress into inward stress. You know, the thing is that use it is like this you know, there is a outward stress, but then if you put a reinforcement there is an inward shear stress. And so, that is; because of the tension between the soil and reinforcement. And so, the calculation of the maximum required stress to be supplied by reinforcement for equilibrium means, the material should be stable the slope should be stable and that depends on the required stress, or the maximum stress.

So, a suitable provision of reinforcement can then be made with sufficient strength and spacing so that minimum available stress from reinforcement exceeds the maximum required stress. What is that, we are looking at actually whatever is that; there is some stress that is coming and if the stress supplied by the reinforcement is much higher than the stress that is required? Then, we are safe at a all levels. Like, say for example, we know that k naught into gamma h will be the earth pressure into s v into s h. Say for example, s v is the vertical spacing and s h is the horizontal spacing.

So, k naught into s v into s h will be the horizontal force and if you put reinforcement that is nothing but the force mobilized in the reinforcement. So, we try to see that the reinforcement has sufficient length and spacing. And it is always safe such that, the suitable provision of reinforcement can be made with sufficient strength and spacing to see, that available minimum stress. You know whatever is that, you have provided from reinforcement is always more than the maximum required stress for equilibrium soils at every depth that is what is a principle here. And to do that in fact, how do calculate the maximum required force? One; see, the thing if the wall is vertical, how do calculate the maximum vertical force? It is k a into gamma h square by two, is it not.

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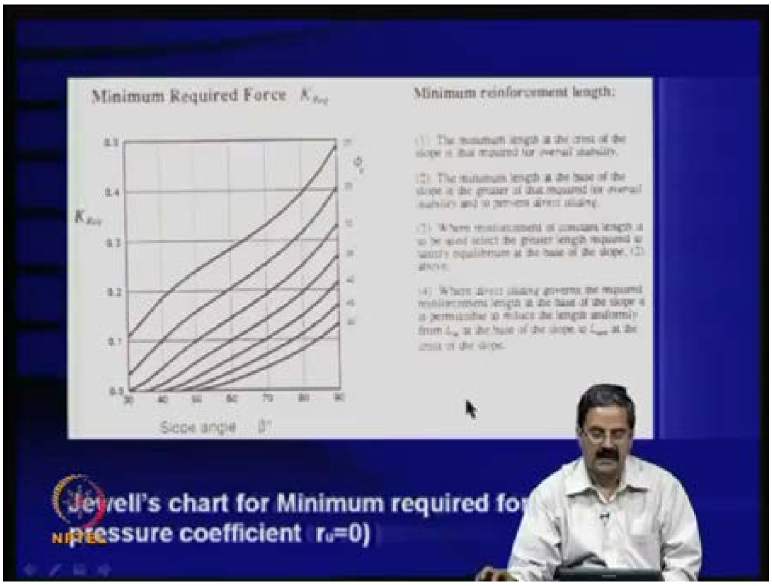

Then, if the there is some inclination we say that we also allow a as the walls slightly comes down then there is a reduction the earth pressure, we say that k a will come down. So, earth pressure and then when they finally it approaches the angle of repose the earth pressure is 0. So, that is what we are trying to do here like you know, earth pressures are calculated in fact, this is a chart design chart given by Jewel. And you can see that for different friction angles phi d is here and k required is this and slope angles. Say for example, slope angle is 90 and if the friction angle is 20 degrees, the k required is higher you know. Like say one minus sin phi in the case of a vertical wall how much is that say for example, if you take friction angle is 30, one minus sin phi one can calculate you will get some 0.33.

So, this is the standard one and the advantage of this float is that, it gives you the; what is the required force? So, this is to be supplied by the reinforcement so, this is one thing. And actually once you get the required reinforcement force from say for example, what you are going to do? Is here in this chart is that, if I know the sand material that you are using for the back fill say for example, 30 degrees and if the slope angle is say 70 degrees, it will be; the 0.2 will be the required earth pressure coefficient. So, 30 degrees is here and then 70 degrees is here so, slope 0.2 this you should remember. And this type of charts are prepared for pore pressure equal to 0.25 and 0.5 all that, that is a simple matter that he prepared.

Once, we know that this much of a force is required from the reinforcement to keep the stable slope, I mean slope stable whatever is the angle then the length is also important. Because they are two things that we have here, one is the length required for stability. You know minimum length of the minimum length; see, there is some you place reinforcement in the slope at the earth pressure, at the top is less at the bottom it is higher. And the minimum length at the top is the crust is that required for all overall stability. Actually, there is another we have a different consideration this is from tension consideration and the other one is overall stability considerations and sliding considerations.

See, in any anything like see the moment you construct something, you should not lead to failure. Like, you should not lead to failure by; first thing is the reinforcement force should have adequate internal resistance should give that and also you should not fail by overall considerations and also you should have sliding also will see that. So, the minimum length at the crest of the slope that required for overall stability, the minimum length at the base of the slope is the greater of the required for overall stability and to prevent direct sliding. In fact, we calculate the length of the reinforcement at the bottom by sliding considerations and also overall stability considerations. And whichever is higher you take actually greater of the required will take it.

And when they; where the length they say for example, if the length of the reinforcement as I said, if you remember that the; at the top the earth pressure is less. And but then the polite resistance you know, but you cannot provide a short length, because over burden is less and polite resistance has to be more so, the length is little more. So, length is little longer whereas at the bottom, the earth pressure is somewhat higher and the do the overburden is higher that consideration, the length could be you know little, you know, the; you the tension force governs the design here whereas pullout resistance governs the length of the reinforcement at the top.

So, what we do is as via media in for some small heights, the length; the reinforcement will be of constant length, like if seven meters or ten meters is the height of the wall we say 0.7 times is the length of the reinforcement. Then, where the reinforcement of consistence to be used we select the greatest strength required to satisfy the base of the slope. We normally provide I will show you that. And when direct sliding governs, the required reinforcement length at the base of the slope, it is permissible to reduce a length uniformly from L d s at the base of the slope to L overall at the crest of the slope.

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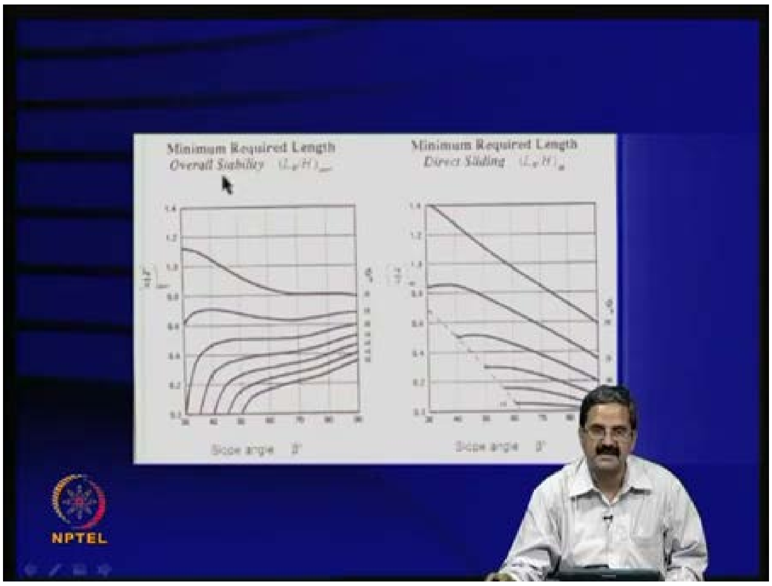

These are diagram that will see; will discuss this much more after the break. In fact, the; you know, the length of the reinforcement is; you know, for different angles and all that one can get, what should be the length and there is a minimum length required from sliding considerations also. So, for any slope one can get this, I will stop at this stage.