Groud Improvement
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Lecture No. # 34
Design of Embankments on Soft Soil Using Geosynthetics

Today, we will be talking about Design of Embankments on Soft Soil using Geosynthetics. This is the thirty-fourth lecture in this series.

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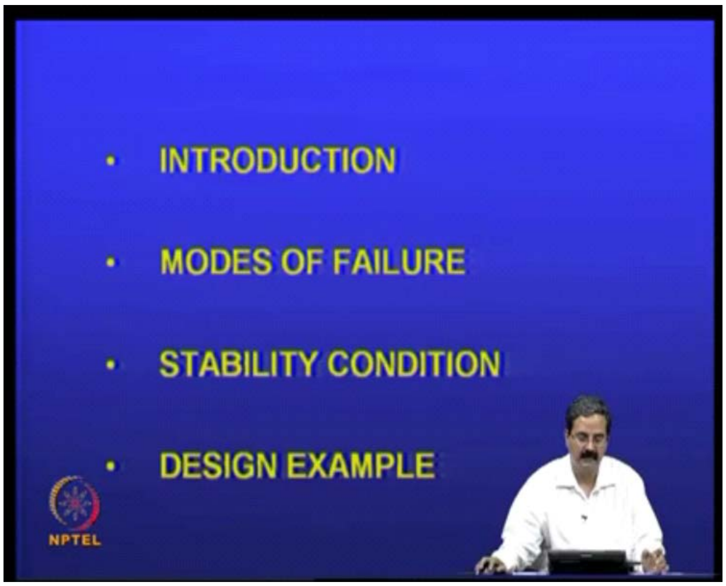

We will have some introduction, what are the modes of failure of the embankment in soft soils? What do you mean by stability condition? Now, I will give an example as well.

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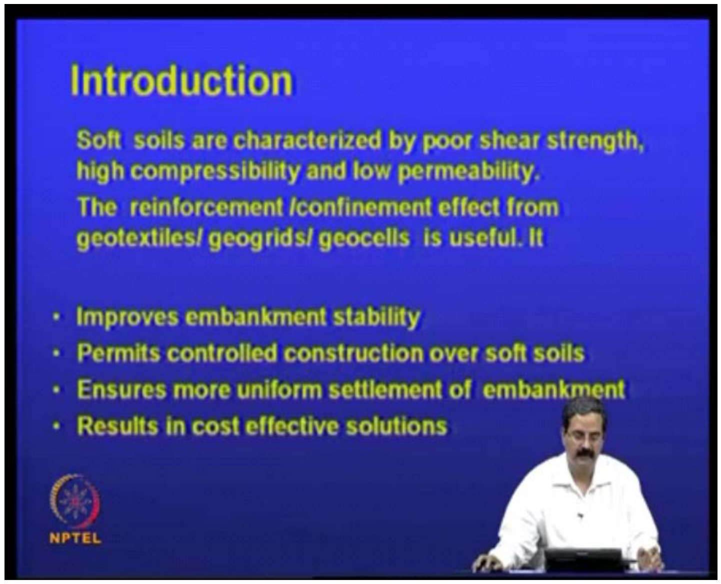

We know that soft soils are characterized by poor shear strength, high compressibility and low permeability, and if we are able to use a reinforcement effect when you have a geosynthetics or you know, we have different types of materials that we studied, when you have a geotextile or a geogrid or a geocell, they introduce, you know, reinforcement function; actually, it is also called pseudo confining pressure.

We have seen that when you put a reinforcement in the reinforce soil, like if you apply pressure, there is some it is similar to like, it does not strain much, because there is some resistance, because of the friction. So, that we call it a pseudo confinement; we have studied that in the using the concept of Mohr circle earlier; like you know, you apply load and it deforms vertically and horizontally, but if you place reinforcement, it does not deform that much, that effect we try to equate it to horizontal stress - equivalent horizontal stress - that is what we studied.

So that is, that can be even obtained by a geocell, you know geocell is nothing but a three-dimensional structure in which you just put some material, and then, you try to compress the circumferential action, you know, of the geocell prevents the movement and that is called confinement effect. So, the reinforcement and confinement effect, if you can make use of in the soft soils, that is going to be very useful. It improves stability of the embankment, then it permits a controlled construction over soft soils. In fact, what happens is that in many of the soft soil areas, you try to use this, you know the soil is so soft, and you bring in some other material like sand, and then, if you start constructing, actually normally embankment has to be constructed with a good material like reasonably, say for example, sand or whatever.

So, if you start putting on the soft soil this embankment, there is a always a loss of this embankment material all that sometimes, you know to the extent of even 20 to 30 percent, if you have a geotextile at the interface, and then start constructing, that loss could be prevented, the mixing of soil and the sand could be prevented. And now, one can properly account for how much exactly is the amount of sand used, and what is a settlement in the clay, what what is the effect of sand and all that, one can study. So, it permits controlled construction over soft soils and it ensures more uniform settlement of the embankment; settlements cannot be completely eliminated, because the soft soil has some settlements and you can only preempt the settlements. Right? We have studied in the case of preconsolidation or the prefabricated vertical drains and all that; we can accelerate the settlement, but at the same time, it we can make it more uniform, that is what is important here.

Like if you place a geotextile or a geogrid, what it just because it is a flexible in nature, then because of this whole material, load acting on the soil through this geogrid or a geotextile, the settlements are uniform; because it just just in such a way that the settlements are uniform that is very important for us. Because sometimes, you know, for example, you have a road on the embankment and it is a differential settlement that leads to cracks and all other problems; it is not the total settlement. So, if you have an embankment, highway embankment, on the soft soil and if it is some uniform settlement is there, it is ok. It is a little bit of... It is not bad.

But at the same time, if you are able to prevent a different settlement, it is very good. So, that can be possible by a geogrids or a geocells and all that. And of course, people have seen cost effective solutions, that is why, you know, lot of work is being done on this lines and people have done it extensively.

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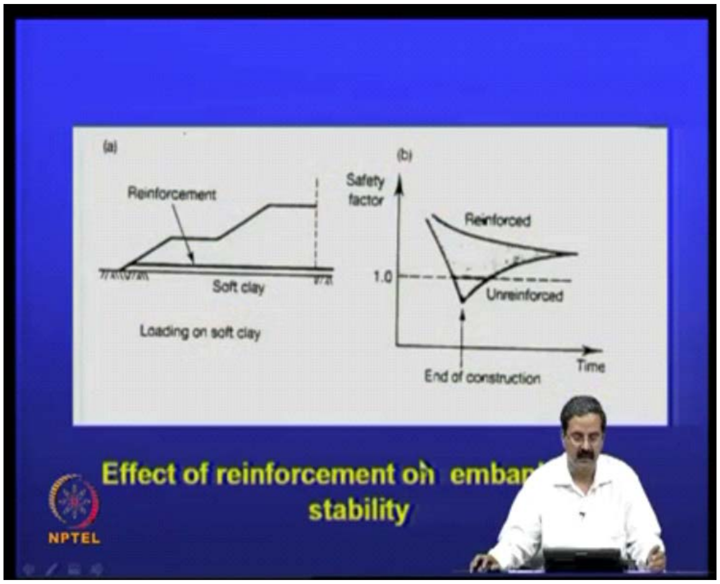

So, what is that effect? We will see; say for example, I will show you an example, how do you construct an embankment? This is a soft soil is here, and then you try to put this embankment material, if series of you know, it compacting layers of, say for example, half a meter and you go on constructing.

And, you cannot construct very fast, because the rate of consolidation here of the clay is very slow, very poor. The soil is very consolidation you know, the time, soil is, the permeability so low that it will not really respond to the rate of loading; if the rate of loading is faster, the what happens? The consolidation can be still rate of consolidation is still lower, what happens, it results in undrained conditions.

When the undrained conditions prevail, what happens? Effective stress comes down. So, the rate of... That is a reason why, say for example, you are trying to construct a reinforced embankment; see this is a, you know, you start with time you start constructing, you start loading, there is a possibility that they, you know, the undrained conditions prevail, and the effective stress is lower. Right? So, the factor of safety will come down, and it can be, you know, we say that, if it is less than one and at the end of construction it could be…So, which means it is lower, right the it is less than one, and then it likely to fail.

And after that what happens? The consolidation is slow, but then effective stress slowly increases, and you will have a higher factor of safety. So, our objective is to see that you should always construct the rate of construction, in such a manner that the this condition should not come in the field.

Even in the construction of embankment on soft soils, we do that; we do it, we call it stage construction, this is one way of stage construction, in which you just put say 1 meter of sand and then wait for it, you have some instrumentation also for that, you measure a poor pressures in the field.

You know, the movement you put the sort of embankment, the you have settlement gauges, you have poor pressure sensors all that, you know, all that one can install, and then see exactly, what is happening, and then you can even check.

So, if the poor pressures are going to be very high, then in fact, I was just mentioning one equation it is called CU by P equation, you know, shear strength of the undrained shear strength of the soil is there, and then there is an effective stress also.

Actually, it the CU by P equal to 0.3, because it is a simple equation; for example, it shows that it gives an idea that P is nothing but the extra stress that it you have to put, you know the effective stress. So, how much is that effective stress you have to put on the soil, if you know the undrained shear strength is available in, you know that information is available.

So once you know that information, one can really, slowly construct this embankment, but rate of construction is so slow, you know you cannot wait, you would like to construct the embankment very fast, and if you want to do that, this condition is there.

So, to avoid that best is to place a reinforcement; if you place a reinforcement what happens, it is a reinforcement that they that takes care of the embankment loading.

So, you can see that if you have reinforcement, it will take the load, that is a beauty. Like, all the surcharge load, whatever you are getting from this embankment construction, it does not allow the all the load to go to the soft soil. We see that, it only, you know, if that is taken care of with the embankment that the reinforcement here. So, that is what is the purpose of the reinforcement or even confining action can be here, we will see that.

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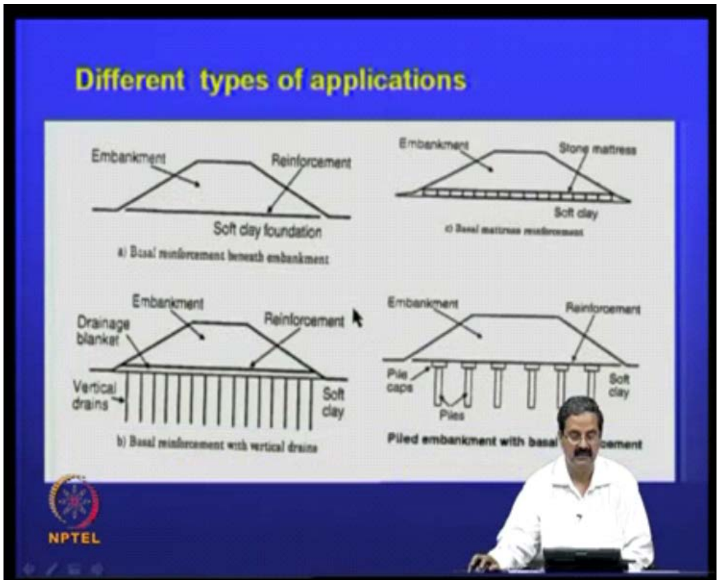

So, what are the applications? There are too many here, actually, wherever there are soft soils, it is well established, and you have an embankment here, you put a reinforcement like this, it is called Basal reinforcement beneath embankment.

Then, there is another case, where we have seen the embankment on soft soils, like you know, you have a prefabricated vertical drains, but then, you have a reinforcement here that helps a lot, in designing this whole thing.

This can be even stone columns also, the this can be a combination of stone columns, this can be, you know, prefabricated vertical drains; what we are exactly doing is that we are putting a reinforcement here, and to see that the loads that you are getting here or you know, lesser than, lesser or it can be done faster and all that; that is an advantage here.

Then, this is another one, which is called geocell embankment, which will show you some figures; I will show you, where you have in a cell stone mattress, stone mattresses material is kept here, and that is one way of doing it along the length of the embankment.

And then, you know, the other one is another interesting case, you know, for many of the railway lines, in soft soils, railway projects or highways these things are all done. You know, you have pile pile foundation and to reduce a load under piles, you put a reinforcement layer here.

Actually, codes are available; in fact, you go to Scandinavian countries or many of the Netherlands and many other places where soft soils are abandons, even in UK, you all these techniques are used very well. If you are a geotechnical engineer, you will be very happy to deal with some of these problems, because you see these theories, applied so well and you get the benefit out of this technique.

Say for example, there is one, which I was directly related with one project in Berlin, where you know, the soft soil is so poor, but then you have a high speed drain going on the... It is it is like this, this type of construction, in which you have a railway embankment constructed with geogrid, and then, you have a combination of piles and geogrid combination. So, it was very effective, and train speeds are not less than 150 or 100 more than kilometers per hour or something, that is very very good.

So, what I want to say is that, this is a technique has lot of applications.

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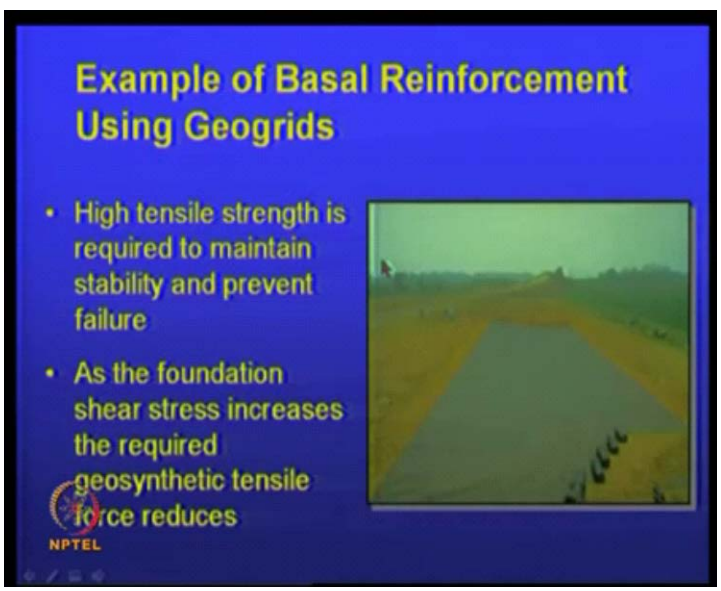

So, this is the way that we put, like you have a geocell as I just mentioned, this is actually a geogrid, and we need high tensile geogrid to maintain the stability and prevent failure, and as a foundation shear stress increases the required geosynthetic tensile force, you know, the like there is another condition that the you know, what exactly happenings happens is that you have shear stress induced in the embankment as well as soil. So, the if the foundation shear stress is higher, then there is then there is no need to the... Because of the, I mean steeper material or better material, then the geosynthetic force can come down.

So, essentially what you are trying to do here is that you are trying to place this high tensile reinforcement to prevent this lateral spreading and increase confining effect and all that.

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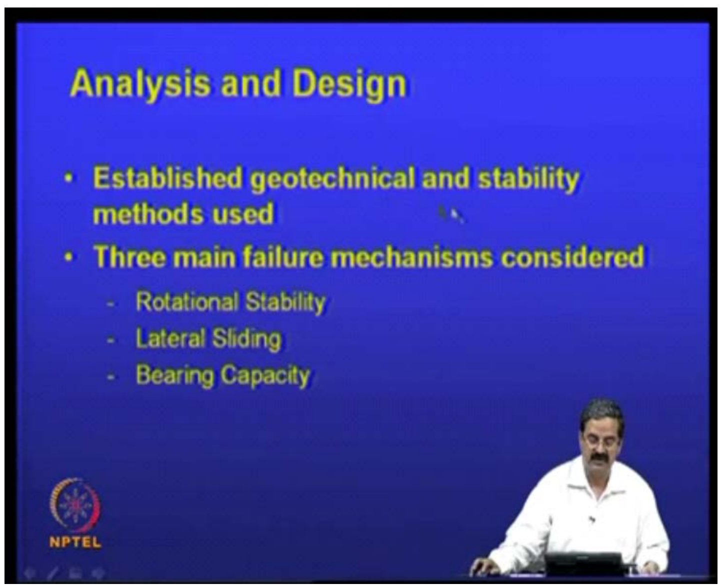

So, what are the mechanisms that we can see here, and we always used established geotechnical methods in this case, and there are three mechanisms that we should address: one is called rotational stability, the second one is called lateral sliding, the third one is called bearing capacity.

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See, because we have placed, why is it the internal stability important? As I just mentioned, you are placing reinforcement, and the reinforcement should not lead to any difficulty or failure.

Say, so what is important in that case is that you know, the embankment tries to slide, and if you have a if you the reinforcement can prevented by having a a good resistance at the interface, then it is fine. So, that is one failure criteria.

Then, the overall stability is that the slippage across the foundation can happen like, it can... I will show you that and stability in the foundation is another issue.

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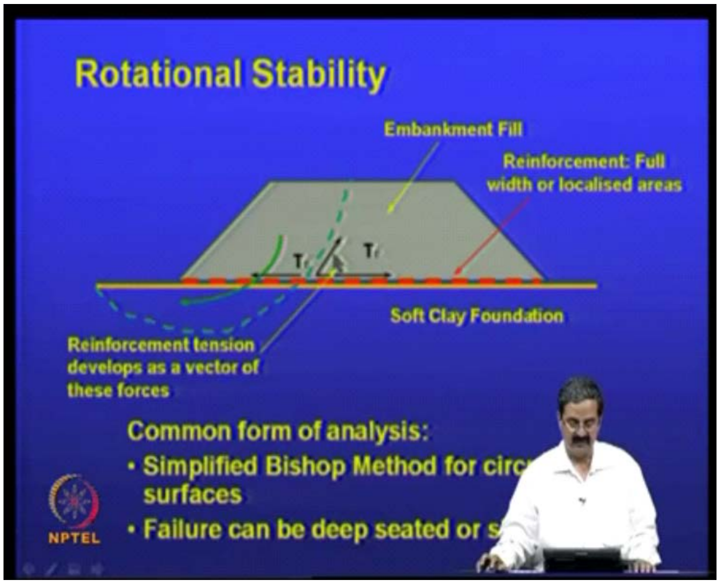

And then, so what is this rotational stability? Like, you know I was just trying to… The example is that, say for example, this is that failure surface right; if this is a failure surface and the driving forces are like this, and then the resisting forces are in the opposite direction. So, if this driving force… This is the embankment material and this is reinforcement.

So, when there is a tendency for the reinforcement slide, there is a a component of tensile forces that gets mobilized here, and what happens is that the direct sliding is, you know the rotational sliding is prevented, you know what happens - there is a one component of the tensile forces that interacts with this, and then it it reduces the driving forces, you know, this is a driving forces and this a component of the tension force acts in this direction.

So, this is one mechanism, in which it helps, and to assess this rotational stability, you know rotation of this material. In fact, Kandla port test, I have seen couple of failures in which, you try to stock a material, and if there is a soft soil is poor, then the whole material gets collapsed and you are only see finally, a water body you know, because the soil is fully saturated.

What we try to do is that we try to have this simple methods of analysis like bishop method for circular surfaces, which we know that we try to take a the slices - vertical slices we divide, and then wherever this is you you know, the factor of safety is calculated, considering the moments or the vertical forces and horizontal forces that is what is done in the any of the stability analysis methods.

So, one introduce a reinforcement, said for each slices, what that you have here? Say, for example, you have a slice here, here. So, you have components of the tensile force that comes into picture that enters these stability calculations, and then that gives you the factor of safety - improved factor of safety using this geocell, geogrid reinforcement. So, failure surfaces can be deep sheeted or shallow depends on the thickness of the clay here.

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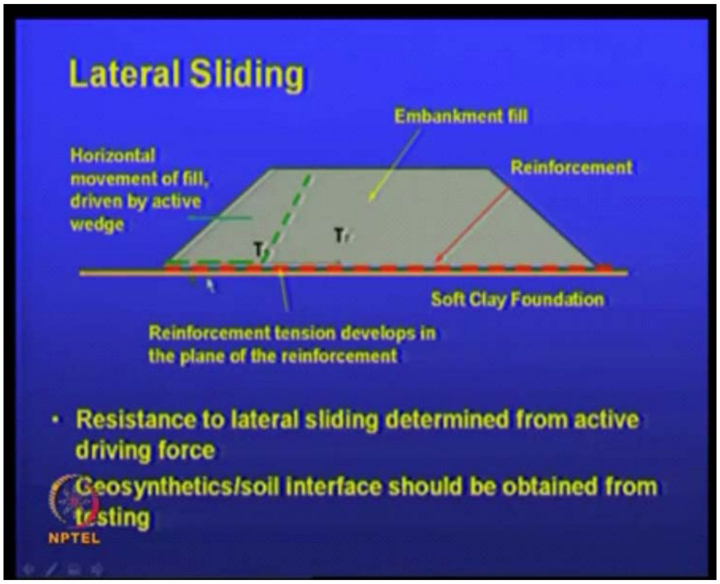

So, that is one way of handling the overall stability, then what is this lateral sliding? As I just mentioned, the movement you address the overall stability, then you need to address this also.

Like you know, what happens, there is a... You have a structure like this, and there is a tendency that this material would like to go out of this, like you know, this is a material that it likes to come out. So, this is called the horizontal movement of the fill driven by active wedge. These are a wedge, which is trying to push out of this embankment. So, what we do is that we have a reinforcement force that acts in the opposite direction, which will prevent this wedge from moving out.

So, reinforcement tension develops in the plane of the reinforcement. In the same section, we will see that. So, the resistance to lateral sliding is determined from the active driving force. So, the geosynthetic soil interface should be obtained from testing that is another important factor that we should see.

So, if you are able to handle this lateral sliding by considering this resistance to sliding, then it is fine. So, we know how to handle the overall stability or the global stability and lateral sliding.

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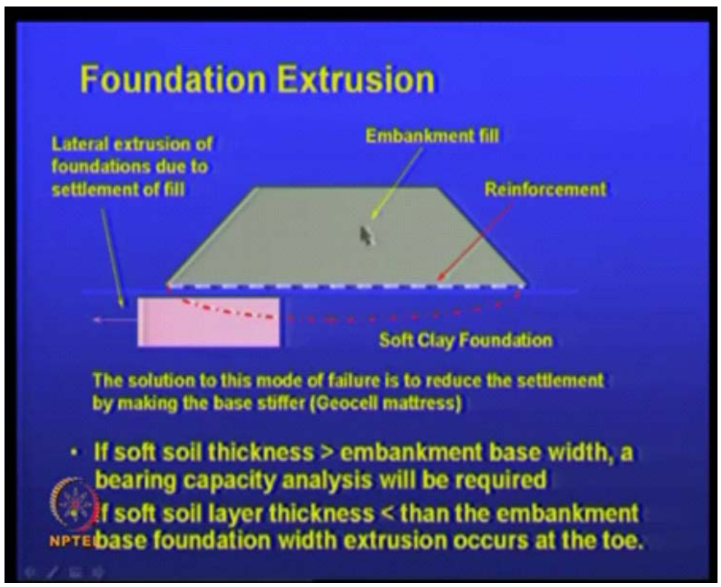

Now, what is this foundation extrusion? What it means is that see, you have put a reinforcement is there everything is fine, but then the possibility is that if the if the soft soil thickness is more than the thick you know, embankment base width.

Say for example, this is the... You have say for example, 10 meters is a width of the embankment; say for example, what is a typical width may be, say for example, 3, 4 meters or something like that, and then you have a height of 4 meters, and then this is 1 is to 1 slope, and it will be you know, say for example, this is say 4 meters, this is 8 meters, this is 4 meters so, totally 12 meters.

And soft soil is a 15 meters. There are so quite natural in some places; if this soft soil thickness is more than the embankment base width, a bearing capacity analysis is required in some places, you know, because it can failure bearing capacity may be it is nice that you can construct, but then the possibility is that if the if the whole thing are sinks, it is a risky things.

So, you need to do a bearing capacity analysis, and that is a reason why you may have to even provide stone columns and some cases, you know, why do so that the bearing capacity analysis shows that. The the other case is that if the soft soil layers thickness is less than the embankment; this thing; embankment base foundation. So so for example, instead of 12 meters now, as I said this is 8 meters, this is 4 meters and this is 4 meters; instead of 12 meters now, it is less than that may be 6 meters.

So, the possibility is that still the plastic squeezing we call it, we call it extrusion, you know there is a plastic material, it just tries to come out; there is whole block come out of this material, it does not want to support, because it is weaker. So, how do avoid that or how do you analyze that, it is something very important right.

So, this what sometimes we do is that solution for this is to reduce a settlement by making a base stiffer, we try to put some material, if it is say for example, shallow depth, you know, may maybe 2 meters or something one can put a geocell mattress that is what we do.

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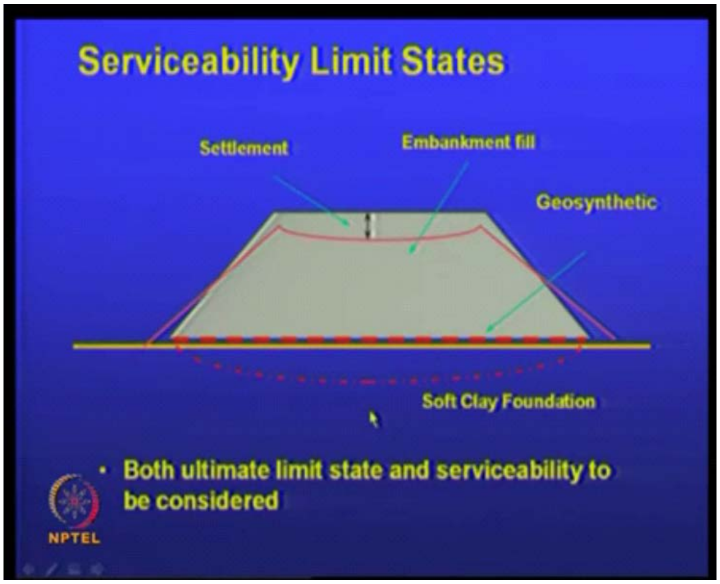

Then, these are all what is called ultimate limit states; ultimate limit state means factor of safety and stability is an issue, then you have to go for deformation; deformation is in terms of the serviceability requirement, which is like you do not want lot of settlements in the embankment; total settlements you know, say for example, if the settlements are like this, that is may be 100 mm 200 mm, it is very bad. So, you want to you want to see that settlements are minimized that can be only possible by having a stiffer geogrids, stiffer materials; you know, geotextile anything can work as a reinforcement material, but a stiffness is very important. So, stiffness will lead to resistance to deformation; higher is stiffness, higher is a resistance to deformation.

So, these three these aspects need to addressed in design so, both ultimate limit state and serviceability to be considered in the whole analysis.

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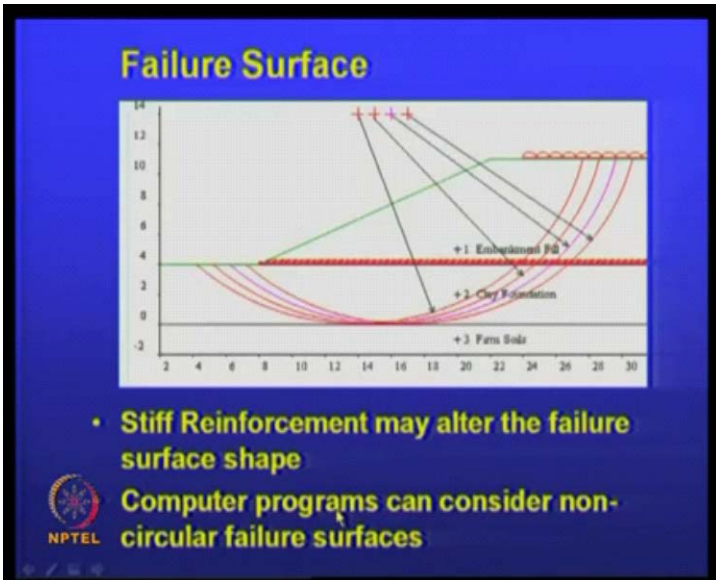

So, this is what I was just mentioning that if you have a reinforcement, you have to consider this, do a slip circle analysis and you know, the what happens, the thing is that the stiffer reinforcements will alter the failure surface that is what happens, you know, because as I said there is a component of tensile forces that comes into play here and that will alter the failure surfaces, and it will search for a new failure surfaces, may be it it is initially it could be like this, and the factor of safety may be 1 or 1.1 or less than 1.

But the moment you put it, it shifts the reinforcement, and then there is a higher resistance mobilized and all that; and fortunately, there are many programs that are available to consider both non-circular and circular failure surfaces.

Like based on bishops methods, Morgansanns price method and Fernald method there are so many methods that and considering lot of assumptions that are involved in the slice, slices and all that like the slice function there are many issues there. So, one can have use all those programs in an intelligent manner, and then I have it what is a tensile force required to keep this embankment stable that is a point here.

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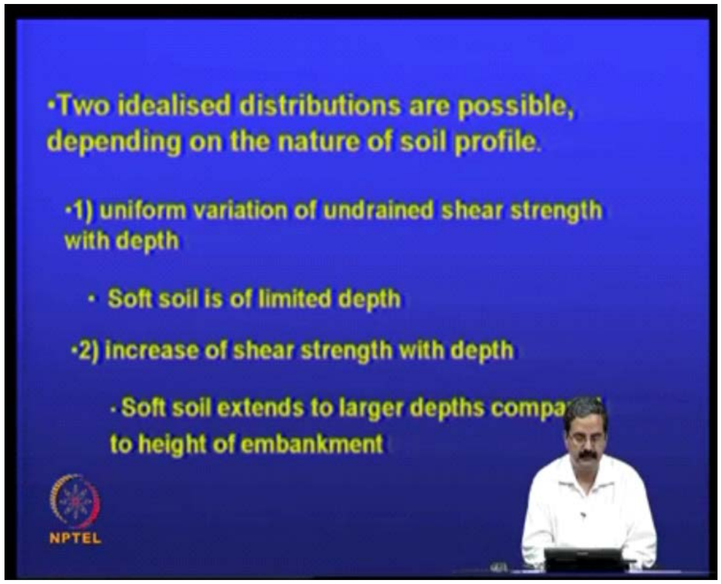

Another point that I would like to highlight is that when there is a soft soil, there are a they how does shear strength vary with depth? Actually, if the soft soil is a two shallow, one can assume uniform variation of undrained shear strength with depth.

Like, you do a CPT - Cone Penetration Test and if it shows a vertical line roughly varying along a mean value, then you can take that the variation of shear strength with depth is constant, and that is applicable in soils of limited depth.

But there is some cases where the strength increases to depth; again, one can get the information from Cone Penetration Test, and if the soft soil extends to deeper depths, you better considered that whatever is there you know, because of the with increase in depth always shear strength increases right.

With increase in, say for example the Vane shear strength value will be higher at a deeper depth than when you have a sample at a shallow depth. So, that information is quite important, because when you try to do analysis, should I do that - it is just based on limited depth or it is unlimited depth is also useful, because the it will as you said the failure surfaces. Right?

The failure surfaces, they keep on searching and if you make… Since, here the depth is higher with the with depth, there is a shear strength increase; it will have a higher factor of safety than considering this. Like, you take a case where the shear stress is uniform for 5 meters, and you take the same thing, shear stress is increasing with depth.

The the case with which the shear stress increases with depth, it gives a higher factor of safety than the this former case, in which the shear strength is assumed as constant. Why because we know that there is an additional component of strength that comes into picture and it is a... We know that the stress of the soil is non-linear, you know, that factor is taken care and all that.

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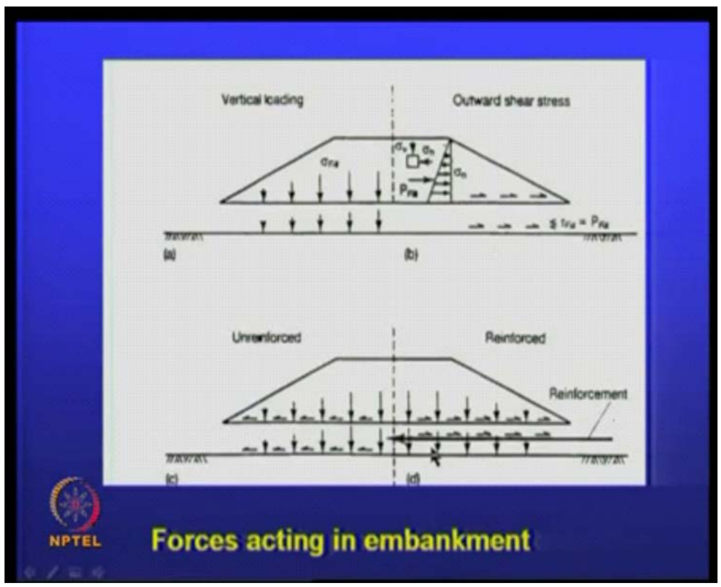

So, how do you make all these calculations? So, if you are looking at, this is the actual example. So, the thing is that you have a vertical loading from the embankment is there, this is how the outward shear stress is develop, this is how the outward shear stress is develop and you have the P the earth pressure from that fill.

So, that fill has is that the horizontal outward shear stress, this is a shearing, you know, shearing is taking place, if you just keep on constructing that is because of the vertical loading. Now, you put a reinforcement, what is happening? Because of this reinforcement, there is an opposite force that you have introduced, what is called invert shear stresses. We have introduced invert shear stresses, there is an outward shear stress, and there is now that you are trying to nullify by using some invert shear stresses.

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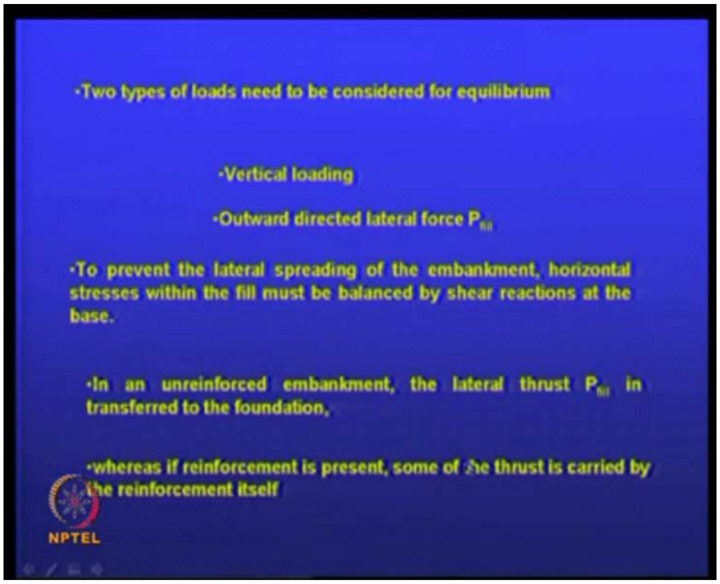

So, if you want to analyze that you have to see this; see, what is a vertical load that we have? And what is an outward shear stress that is coming from this fill? So, to prevent the lateral spreading of the embankment, the horizontal stresses within the fill must be balanced by shear reactions at the base.

So, in an unreinforced embankment, the lateral thrust P fill in the is is transferred to the foundation right; whereas, if the reinforcement is present, some of the trust is carried by the reinforcement itself.

So, that is a nice thing; like so, you are trying to balance the outward shear stresses and inward shear stresses; and what is happening there? It is because of the the main factor that contributes to this is that the moment you include a reinforcement it allows a preferential direct sliding occurring at the surface of the reinforcement layer. And slippage occurs, if the available reinforcement at the resistance, there is resistances like you know, shear shear resistance which you have introduced. See, there are shear resistance actually you know, there is a clay clay is there, then there is a sand or you know embankment material.

So, if you places reinforcement at the interface at the interface, you have to normally place at the interface. So, you have a resistance here, which is nothing but like, you can calculate like this, the direct sliding force at the interface is nothing but it is a given in terms of the alpha, you know, we have seen in the geogrids calculations that the the coefficient of direct sliding, one can calculate; you know it is the... Like you know, it is nothing but the variation of shear stress as a function of normal stress. So, that coefficient is a normalized ratio right.

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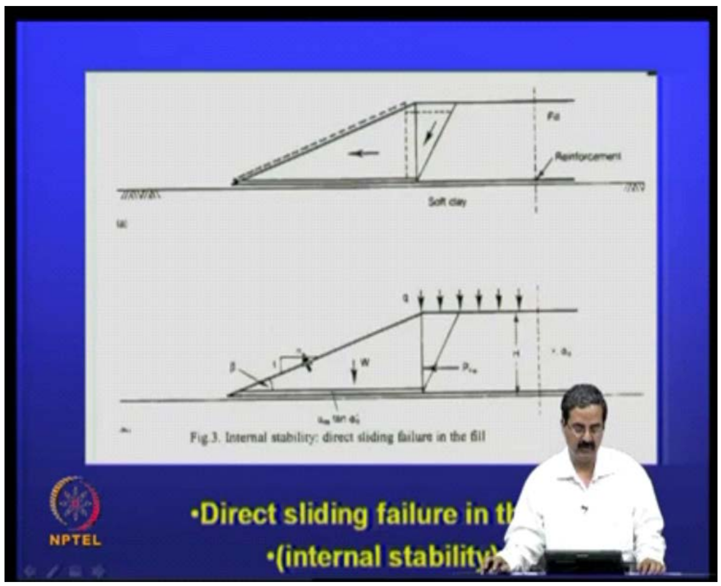

So, that you will get, and one another important thing is that I am trying to express that in terms of n H. If n is a slope of this H height, H is a height of the embankment I said 4 meters. So, if I want to express it is to 1 is to 2, you know I should say n equal to 2. So, n becomes 2. So, it it will be… 2 H will be the horizontal slope. So, this is 1, this is 2; so, this n is also important.

So, what I am trying to do is that I will try to calculate gamma is a weight, n H is a horizontal force, height is a vertical. So, gamma H square by 2 into n, you know, vertical and horizontal both will come into picture, and then the this is a vertical force acting and I am trying to convert into direct sliding force. So, this is a factor that we know, we have to use and this is one thing right.

So, this is actually the resistance available; and what is a active force? This is actually, the resistance that you have from this fill, and the active force is nothing but gamma H square by 2 plus q H; q H is from the surcharge, K a is the earth pressure. So, alpha D s tan phi D, and this is that P fill and you have to equate both of them. Right?

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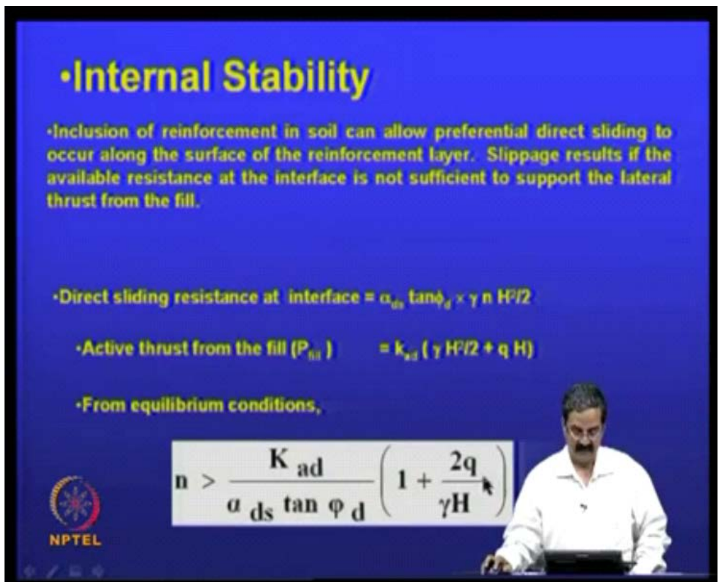

So, once you equate it, you get a factor which is n, you know, you just equate both of them and simplify this.

And then, what is that n you have to minimum you have to keep, you know this is K a is nothing but 1 minus sin phi by 1 plus sin phi right; like you know, we know the embankment material properties, like you know, say assume we are using a sand. So, you can use 1 minus sin phi by 1 plus sin phi.

So, then q is a surcharge and everything is known. So, n what should be n should be minimum you will get, what is n value you should provide, one can get that is one thing

Like, what is the n value? If you make it very steep, then it is going to fail, but what is the n value minimum you have to you will get from that. So, that you can design based on this alpha D s factor; alpha may be say for example, 0.8 it could be 0.6.

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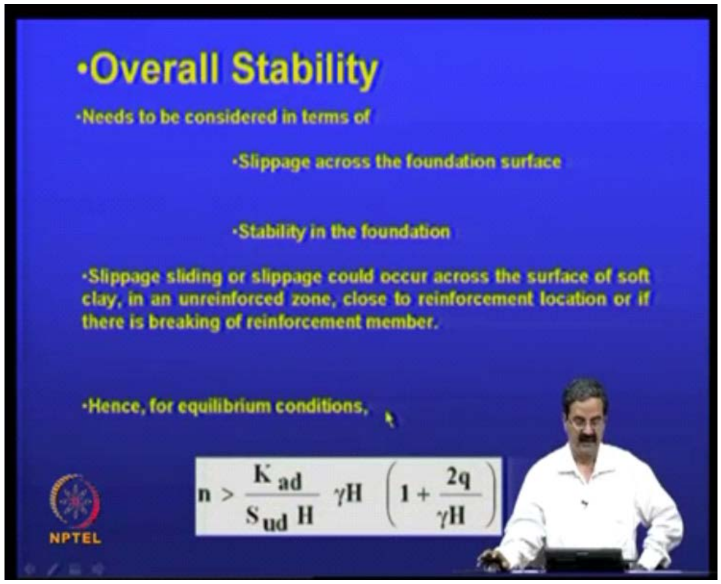

That is have the one one more thing is that slippage across the foundation surface, you know, in fact, it should not the see as I said, it it should not slip through the reinforcement, and then it should not also slip through the soft soil.So, we have used a factor alpha, D s when it is trying to slip through the across the reinforcement, but when you want to say across the foundation surface, foundation has what is called the shear strength of S ud.

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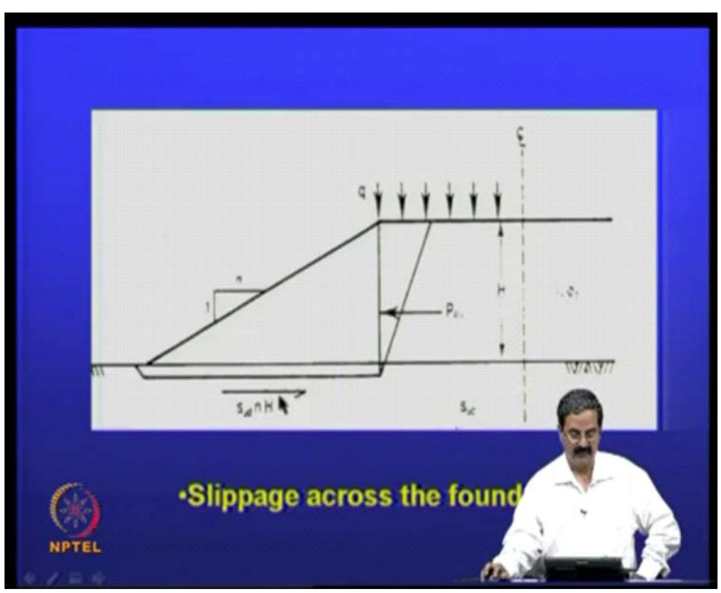

That actually again, here what we do is that. This is a slippage across the foundation right. So, we say, shear strength of the soil into n H will be the resisting forces, and active force is this; which is nothing but you calculate it from gamma H square by 2 into K a into that surcharge and all that.

So you again, you just equate that thing, and then you are getting n value. It is simple that the resistance series S, n, S ud H you are trying to equate it to this; that is it. So, you get another one more n value, whichever is higher you take it, whichever higher you take it.

And, So that way, you have got the n value, which is required to see that it does not fail across the reinforcement or through the clay layer both n values you could get that is very useful.

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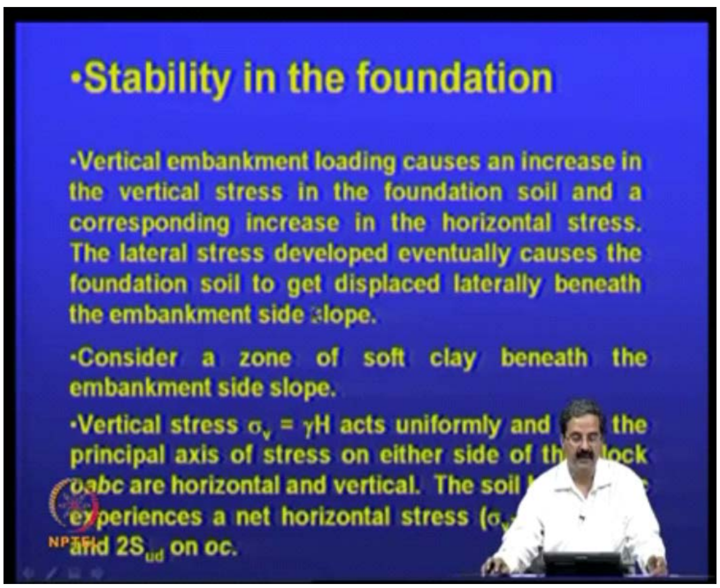

But then, you should go further, then what is that that I was mentioning about the found extrusion right. See, vertical stress causes an vertical stress in the foundation soil and a corresponding increase in the horizontal stress. The lateral stress developed eventually causes the foundations soil to get displaced laterally beneath the embankment side slope; why is it it is just leaving? It is, because a vertical stresses are going to be high, and then they become horizontal stresses, and then it tries to go out of the direct loading.

So, they does not want to take load that is what is happening. So, how do analyze that? It is just like this, you know, you take a vertical stress which acts uniformly.

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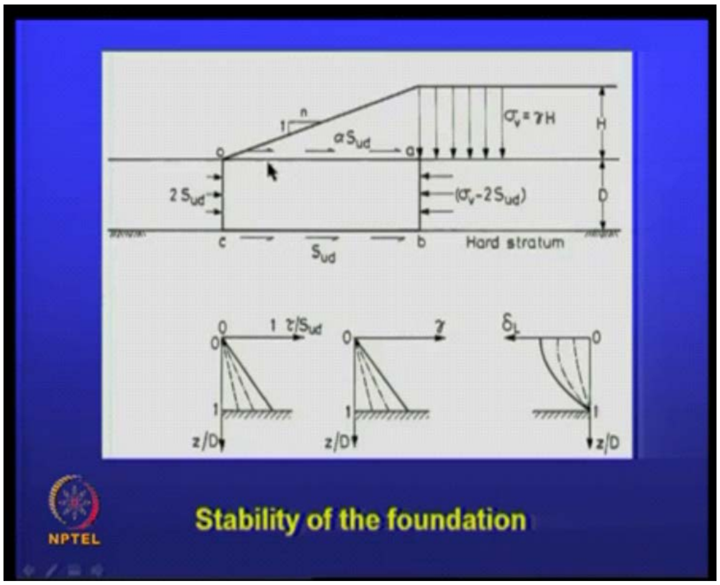

And what happens is that the block that we have here, you know, you can see the block here; So, if it is of limited depth, you have vertical stress acting, and then there is also alpha S u d is another coefficient that you have, you know some portion you know, because shear strength is there here acting, you know the vane shear test, you can get a Vane shear test value, you can get the Vane test value and sigma v minus 2 S ud is a...Or the thing is that vertical stress is... See, there are two surfaces here, you know, one is this S ud is acting here, S ud is also acting here right.

So, you can say that it is the there are two surfaces acting, and the other possibility that you have is that the... You take this as alpha is equal to 1, when alpha is equal to 1, it becomes 2 S ud; this side one, and this side one, and then when you come here, see the what is a vertical see the the thing is, it becomes vertical stress is sigma v here, you know vertical stress in the soft soil this sigma v, and is total stress is so much and sigma v minus 2S ud, because you have to say that the shear strength is, you know, reducing that that much.

So once you... So, this is somewhat lesser value here, then as you come here, it is higher, I mean in the sense, 2S this is a horizontal, you know forces on either side, and why this is happening is that it is because of the principle stress rotation.

Why why what is that principle stress rotation? Under that load, it is sigma v minus 2S ud, but then once you come here, you know it is a like you take an element next to the load and then the other one just next to that whatever is a major stress here, and then there is a minus stress here, for this element it becomes a major stress here for the just above this this thing. So, we call it principle stress rotation.

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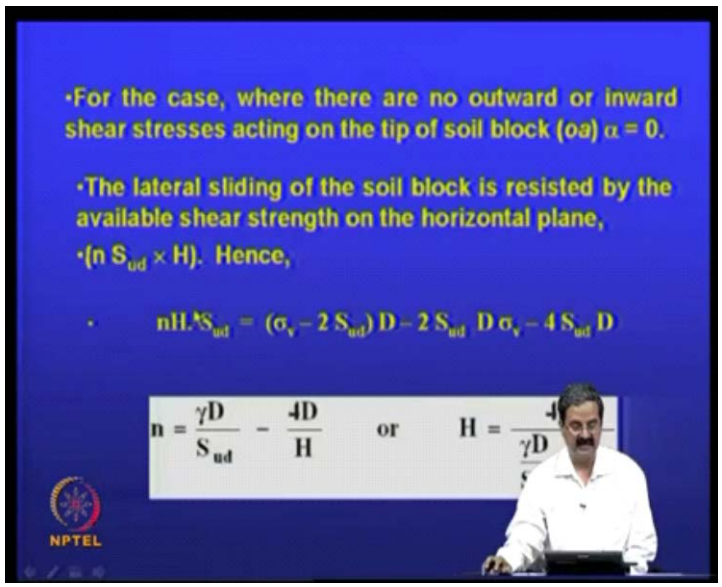

And that can be, this understanding can be used to calculate what is called like this, say for the case where there no outward or inward shear stresses, we can say that the alpha is 0, you know, there is one case that it is just under equilibrium.

And the lateral sliding of the soil block is resisted by the available shear strength of the horizontal plane. So, that is nothing but n S ud into H, you know, very thickness of this soft soil, the it is actually the height of the embankment.

So, n S ud is nothing but this is one equation equal to 2 sigma v minus 2S ud into D minus 2S ud, this is that you should use, and once you simplify that, you will get a term called n based on this considerations; again one more n, which is nothing but which prevents you to reduce the soft the plastic squeezing. So, this is another term that is a simple direct equation that you get from here. Let me just elaborate it again here.

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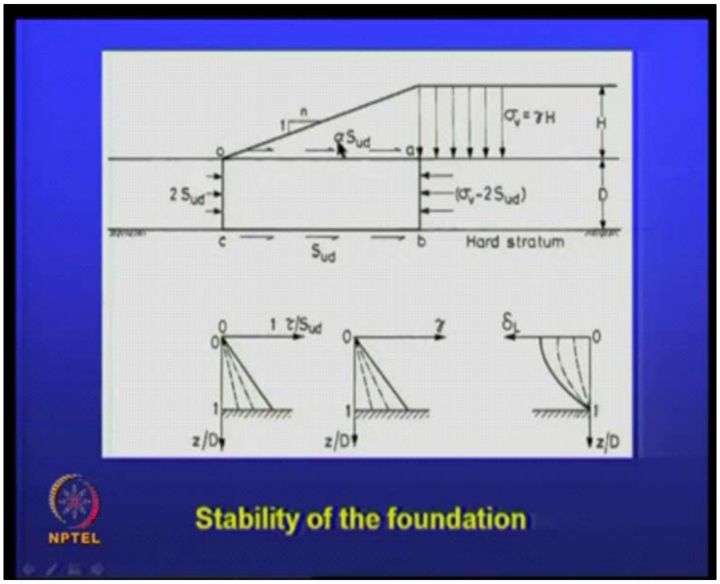

This is a simple equation that you get here, which is nothing but by considering this when the outward shear stress are equal to inward shear stresses then, alpha is 0; like, I will I will just show you some more examples here and...

This is a variation of shear stress with depth you know, this is the variation of shear strength with depth, this is a variation of displacement with depth.

And see the thing is that when see this is the... Assume that this is a rigid foundation, which is available at some depth D right, this is a D. So, the shear strengths are, you know, as we just the, you know displacement is maximum here.

And it is like, it it depends on the how much of inward shear stresses and outward shear stresses have balanced. If the thing is that if the shear stresses are not... See the thing is that outward shear stresses are something, inward shear stresses are some they are equal, then still there will be some settlements, but if the inward shear stresses are where going to be much more than the outward shear stresses, then the displacements are less.

So, if the inward shear stresses and outward shear stresses are equal, then you still have some settlements that is just, because of the equilibrium conditions, you will get some displacements.

But if the inward shear stresses are going to be higher, then definitely you will have stiffer lesser lesser displacements, and that is how these two also come into picture. Like, the resistance in the foundation it just that is what will as a function of shear strength is like this, when the outward shear stresses are equal to inward shear stresses.

But if the inward shear stresses are going to be higher, then it will come down. So, if you can design a proper reinforcement, such that you will have a very good inward shear stress resistance, then it is going to be excellent.

That is what we do it do it, you know, when there are no outward or inward shear stresses acting on this tip of the soil block, this is what we say, and we write a simple equilibrium conditions, we get some n equation for n.

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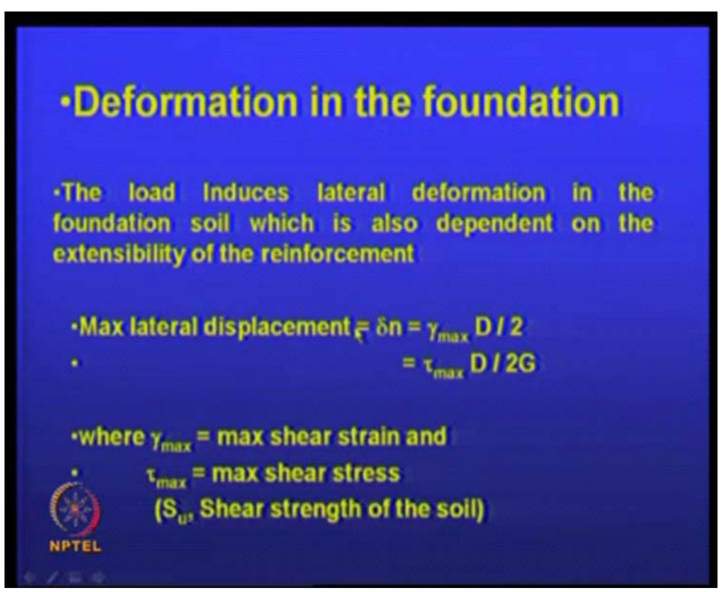

So, that is one thing; so, it is all direct simple mechanics and how do you calculate the deformation in the foundation; like you know the thing is that when you apply load, how much of shear strain it comes.

Actually, this comes from you know, the shear stress D is the... As I was just mentioned D is a depth of the soft soil; maximum shear strain is you put in terms of the gamma, gamma max and we assume a distribution like this, because at the rigid boundary, it is 0; at the top, it is maximum. So, it is by 2, we use.

And, the the shear it is nothing shear strain is nothing but shear stress divided by the shear modulus; right maximum shear stress induced divided by shear modulus. So, you are able to get even the how much of lateral displacement is taking place, and what is that maximum shear stress? Maximum shear stress is nothing but the shear strength of the soil where it is a straight forward equation.

So, you are able to even get how much of lateral displacement is there, one can get here. So, that will all calculate and why is it? Say, our objective is to see that this is reduced and to the minimum.

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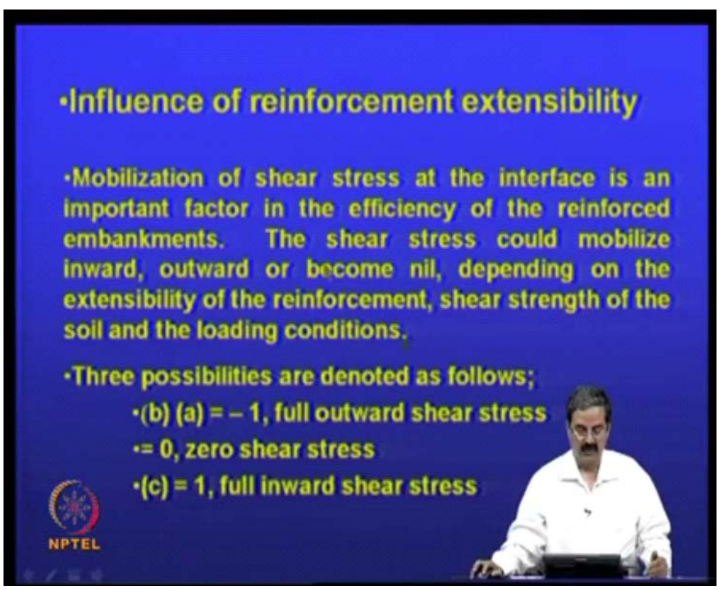

So, how is that reinforcement is helping here? As I just mentioned, the mobilization of shear stress at the interface is an important factor in the efficiency of the reinforced embankments, the shear stress could mobilize inward, outward are become nil depending on the extensibility of reinforcement, shear strength of the soil and a loading conditions.

What happens? There are three conditions, like if there only outward shear stresses, you have you know, the it is minus one, if the inward shear stresses are equal to outward shear stresses they are 0, then there is a full inward shear stresses, it is called, you know, it is an excellent condition that we want.

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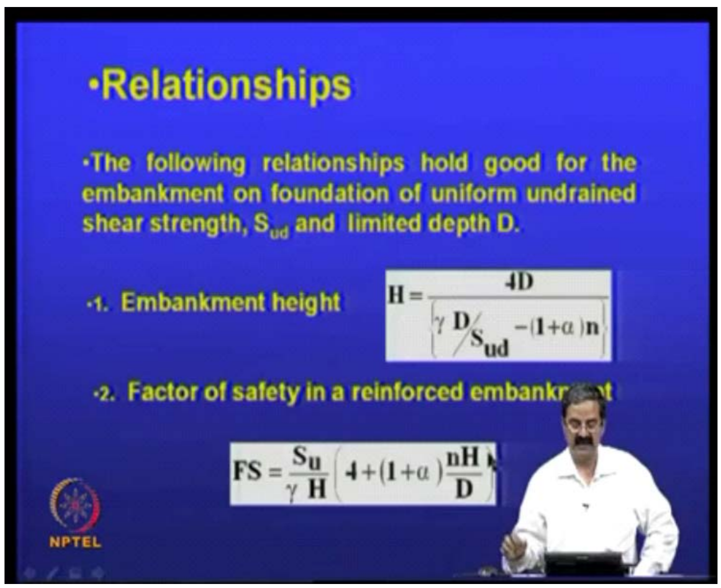

So, based on that actually, we are using that factor what is called alpha here, you know, just to… See, I said inward and shear stresses they are equal, then you try to calculate the block equilibrium, and then equate it to what is a n required that is what we have seen.

On the same logic, you can even calculate the height of the embankment that which is in fact, so, if alpha is 0, the inward shear stresses are equal to outward shear stresses; but if alpha is going to be quite substantial, then it comes into picture; this is again a simple equilibrium equation that one can derive.

And, see the following relationships hold good for the embankment on the foundation of uniform undrained shear strength S ud, and limited depth D. All these equations that I am going to present now are valid for cases where the depth of the soft soil is limited.

Say for example, may be 5 meters is the height and 4 meters is the thickness of the soft soil. So, something likes that. So, we actually as I just mentioned earlier also that it can be even, you know, different like it can be shear strength can increase with depth also.

But then, I am not giving those equations, and actually this is a work that is presented by Juvel, you know a Juvel, who wrote a very good book on the embankment on soft soil that is a very good chapter in his book.

And, and the there are number of papers in geotextiles in geomembranes. He gives lot of information on derivation of these equations, their applicability, case studies and all that. So, from that literature I have taken these equations, where the they are valid for just the depth of the soft soil is limited, and you have an embankment construction.

So, say for example So, say for example, you are trying to construct a 4 meter high embankment, soft soil depth is 4 meters, how do you handle this? And if you want have more details, one can see those papers in geotextile in geomembranes.

So, the embankment height is known like H equal to 4 meters 4D as one can derive this equation, and then a factor of safety of the reinforcement is also one can do, like you know, it is simple that it is a simple equilibrium equation, and this equations you should one should remember to solve some these problems here.

Like, it is again, higher is the the embankment a factor of safety can be calculated using the simple expression, it is nothing but the driving forces to resisting forces, nothing else, it is just a horizontal equilibrium.

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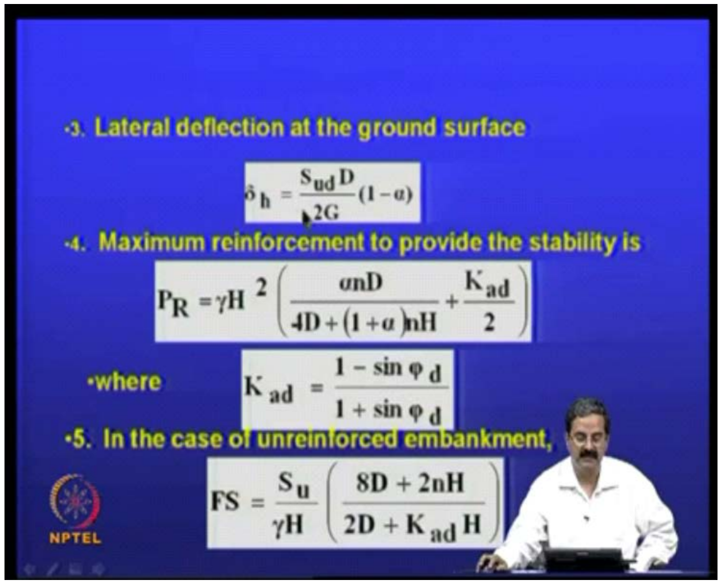

And what is a displacement also we have seen is simply that I just mentioned S ud by 2 G, we have already seen that, but how is that alpha is coming into picture, alpha is that when inward shear stress equal to outward shear stress alpha is 0, and if you have alpha term, how does it influence; because alpha is another important variable and that what we see; that is one term.

The other important thing that is that how do you calculate the reinforcement force? You also have a simple equation that one can derive that is nothing but P R, you know, P is nothing but it is in terms of this again all these parameters gamma H square into alpha n D divided by 4D plus all these terms will come.

And, and in the case of unreinforced embankment, the factor of safety reduces to the previously I have shown you the factor of safety for reinforced embankment, the factor of safety reduces to this. So, you have all the equations to solve this particular issue, and see that is for the case of an embankment, which is resting on a soft soil of limited depth.

One one can even go for other case, where the embankment is resting on soft soil of unlimited depth that equations are also available literature.

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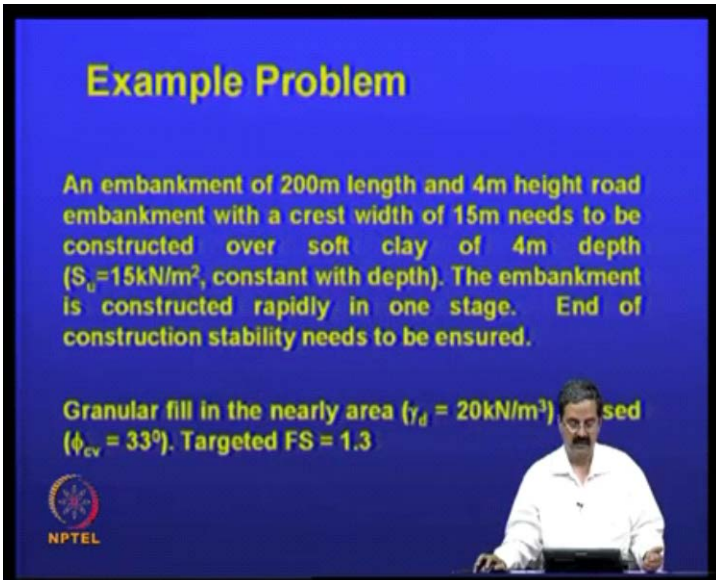

I will just try to use this equations to illustrate their applicability, it is just the principle is illustrated here.

You have a 200 length of the embankment; just a small approach road between two places may be and height of the embankment is about 4 meters, and the width of the crest is a 15 meters; like, 15 meters is a width of the road, and a soft soil is about 4 meters depth, and a shear strength, I know 15 kilonewton per meter square, and its constant with depth the embankment is to be constructed rapidly in one stage, and end of construction stability needs to be ensured.

So, we need to calculate what is this the factor of safety with with reinforcement, without reinforcement, you should be able to select a reinforcement force, which will give you reasonably safe factors as well as like factor of safety, I said target factor of safety is 1.3 right.

So, here the embankment needs to be constructed at one stage; I have it is very clear that I would I cannot construct at 1 meter, 2 meters, then wait for two months, and then again construct two meters; I would like to construct all the embankment needs to be finished in one go with I put a reinforcement then start going, you know, I want faster that is objective; I showed you the diagram in which the factor of safety at the end of the construction is minimum actually, because they as So that, so, we have to sure see that end of construction stability needs to be ensured that is there.

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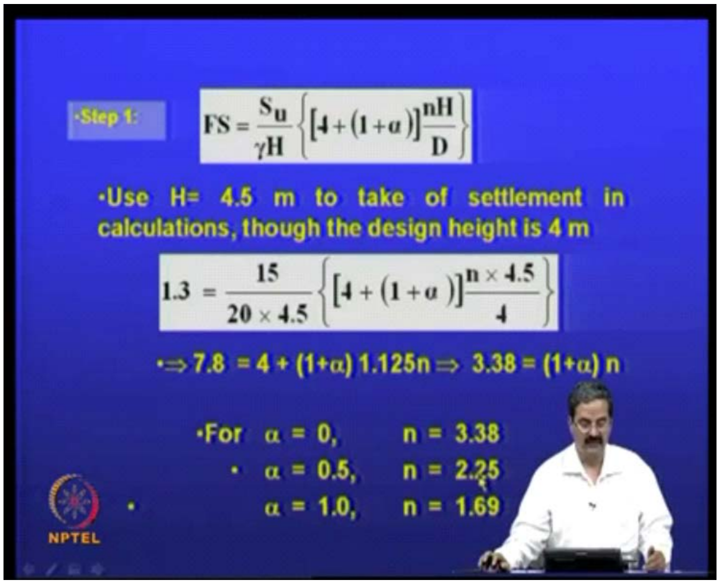

So, for that step one, like the factor of safety of one, you know, factor of safety using this reinforcement is this equation; sometimes, though I have the and a problem we know that the it is a 4 meter is the height of the embankment, you can even take a 4.5 in calculations to be on the safe side, that is one thing.

So, at the target factor of safety is 1.3, S u is given 15, gamma is known, height is a 4.5 I am taking, alpha plus this is a equation that we have, and if you simplify, if alpha equal to 0 as I said, you know n value little steeper, but if you know the thing is that alpha value like if you want high full inward shear stresses right this is, so is excellent reinforcement is very effective right.

Full inward stresses the n is 1.69 only, the you can see that, you are able to number one construct with for the target factor of safety of 1.3, here n value can be 3.38 if you take a lower geogrid quality or if you take a somewhat, where the inward shear stresses are going to be higher, the n is 2.25, and if you take a very good geogrid material or geotextile material, it is 1.69.

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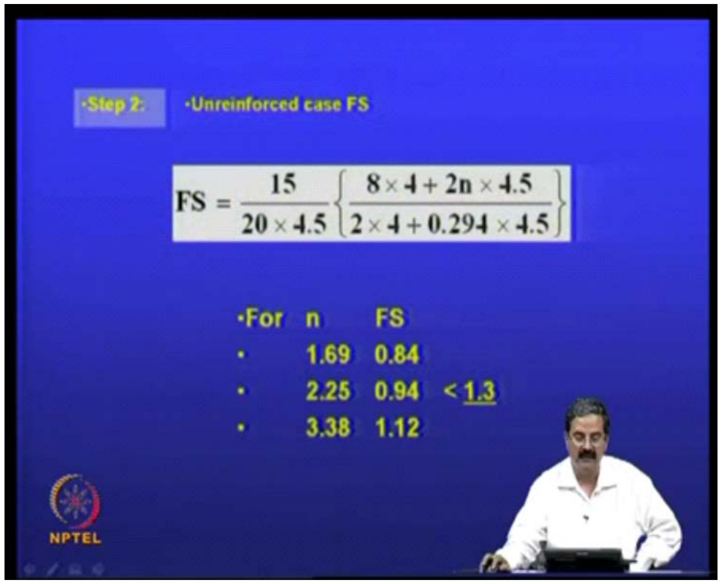

So, what you have done here is that you are able to normally, like I will show you that without factor of safety what happens, like if you without reinforcement what happens, you can use again the similar expression that I have given.

For all these n values that we got like you know I got 3.38, 2.25 and 1.69 for different values of alpha, which characterize the relationship between the inward and outward shear stresses.

And for the same n values you can see that the factor of safety is are you know, its 0.84 here, and 0.94 here, 1.12. So, under no conditions, I can get without reinforcement, I cannot get a factor of safety of 1.3 without. So, with reinforcement only, I am getting you know, the the I got a this is a expression for without reinforcement.

So with reinforcement, I am getting a factor of safety of 1.3, because I have used it in equation and with if higher is a stiffness, higher is a n the lower is the n value. So normally, you can see that if you the see, this is a without reinforcement actually, you know, as we know that if the embankment is the steep the factor of safety is less.

And so, its 2.25 means it is much more flatter point factor of safety 1.94, and 3.38 it is a flatter and 1.12; what is a difference between all these three things is that the area of cross section, you know, see the thing is that area of cross section of the sand embankment material required; if I go for a very stiff geogrid, I can only go for 1.69 and the area of cross section that is required is reduced.

Like, say for example, it is meeting a target factor of safety of 1.3, and at the same height, if 4 is a height of the height, 1.69 into 4 will be the horizontal width, have the width in the this thing.

So, otherwise it it is 3.38 where you need large quantity of sand or embankment material, which is going to be quite expensive right; in a place like soft soil where exist in say Kerala or Andhra or any other place; like, say for example, Kakinada or Paradip or you know any of the soft soil areas.

So, this is a very important thing that one can understand that if higher is a thickness of the reinforce stiffness of the reinforcement, better is a savings achieved, and also you will get a good factor of safety, which is targeted.

This is unreinforced.

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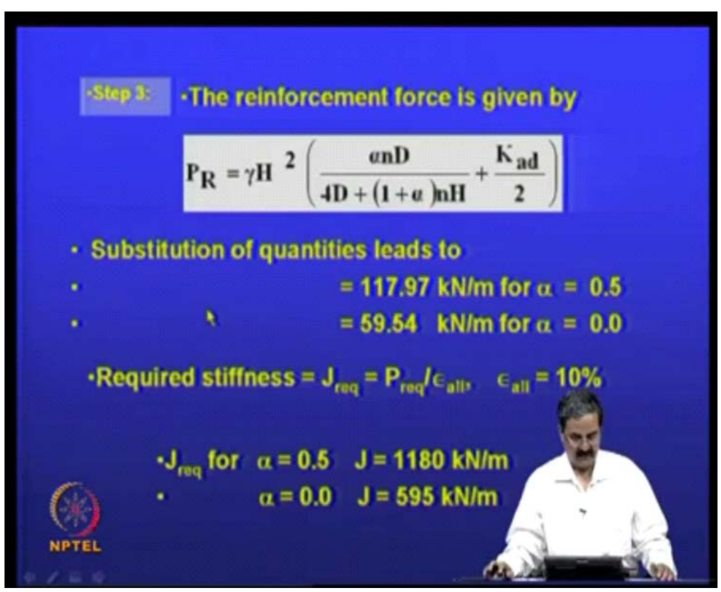

Now, how do you get the reinforcement force? Now, I know that yes, there is a if higher is a stiffness, its fine, but how do you calculate the reinforcement force? So, this is an equilibrium equation that I have we have given earlier, and you substitute all the quantities required and you will get a geogrid strength 157, seen in this case 117 or 118 kilonewton per meter for alpha equal to 0.5.

And if I am just going for simple alpha less than equals to 0, where inward shear stresses are equal to outward shear stresses, you do not need to go for high quality geogrid; fine actually, 60 kilonewton per meter, it is also, you know, it is a you know, expansive compared to you know, in soils and conditions you know.

So, 60 kilonewton per meter is one thing, and you can see this almost double, of course, this has to directly with this, and you can see that, this is the end of the at at the design strength of the geogrid and now, what its stiffness? Stiffness is… You have to calculate the stiffness also, because manufacturing companies will give you the geogrid, tensile strength, stiffness properties all the properties are given.

As I said, stiffness is also very important quantity related to reduce settlement. So, what is the J we use a term. So, actually allowing the 10 percent is available strain - shear strain required like assuming strain compatibility that we discussed earlier.

Like, P required divided by P available will give you that you know, in fact, it is 0.1. So, it comes to about 1180, you know, this 117.97 divided by 0.1 actually. So, which means, it comes to roughly 180, 1180, and then here 595.

So, 600 kilonewtons per meter length will be the stiffness of the geogrid and this is the force.

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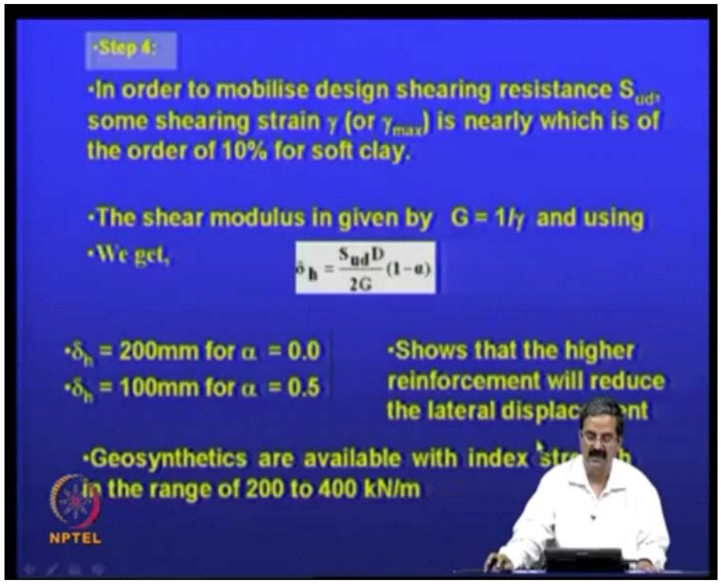

So, how does it really matter in in terms of the displacement? So, in order to mobilize design shear resistance S ud, some shearing strains is nearly is required, which is actually, why I just, what is a basis of this 10 percent, like you know, you see a you do, what is that Vane shear test right? Vane shear test if you do, it just you know, you do the Vane shear testing it give some number which is ultimate shear strength.

Actually, the you take the same sample in the lab and then, conduct a stress and curve that will be roughly about 9 to 10 percent large drains only its mobilized, because the soil is normally consolidated, most of the soft soils are normally consolidated; and the strains are much higher and we assume that at 10 percent of the strain level, the strain gets mobilized.

So, we use the term and now, you know that is why I said 10 percent, the shear modulus is given by we know that this is a term, and delta h is a horizontal displacement. So, if you use this expression, how do you get? In fact, you can see that, for a steeper grade of the reinforcement, horizontal displacement how much it moves is 100 mm and it is 200 mm in the other case.

So, this shows that high reinforcement force will reduce lateral displacement that is very important. Now now we know, how much is the reinforcement force required, and you know how much is a stiffness required, you have some rough idea of what is influence of this alpha factor also, and all that factor of safety everything is fine.

Now, you have to choose a geogrid and the information is that geosynthetics are available with index strength in the range of 200 to 400 kilonewton per meter; one company the different companies have and how do you choose that based on this.

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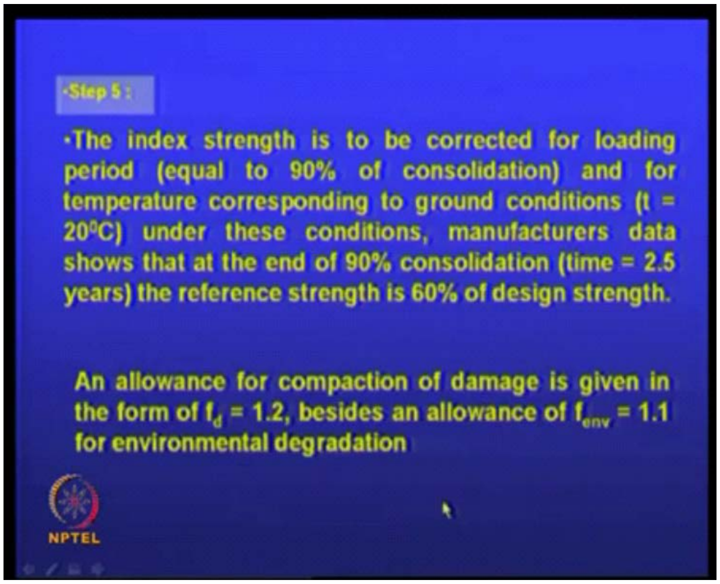

So, the the index strength is to be corrected for loading period, which is equal to 90 percent of the consolidation, and for temperature corresponding to ground conditions; assume that it is temperature 20 degrees.

And and under these conditions, the manufacturing data shows that at the end of 95 percent 90 percent consolidation time equal to 2.5 years, the reference strength is 60 percent of the design strength.

So, why is that 90 percent? The consolidation has to take place, and the reinforcement has to be there right, reinforcement has to be effective till in all its complete process right. So, we take it as 90 percent, and it is say for 90 percent of that it takes for the soil, clay - clay soil it is 2.5 years right.

So for 2.5 years, the reference strength of the geogrid, you know, it is a 60 percent of the design strength; whatever is that earlier we have chosen that should be reduced by this number and allowance for even this damage and has to be done; environmental conditions has to be done.

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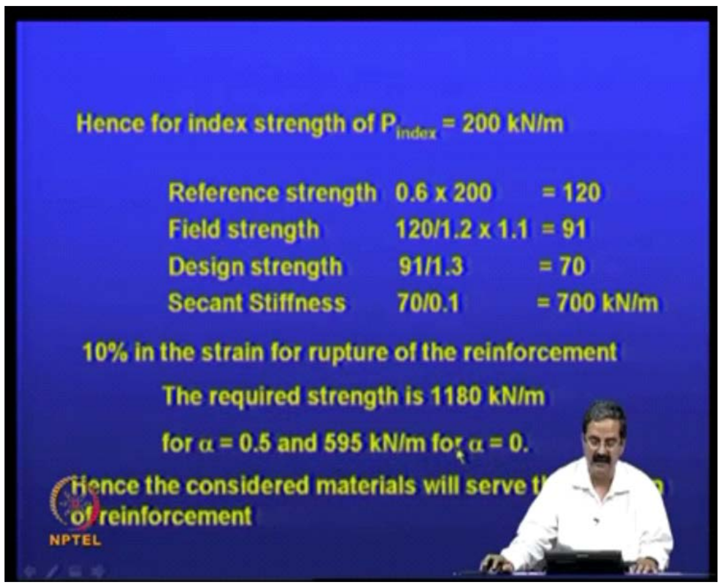

So, if you do all that you take a an index strength of about 200 what happens, so, reference strength is 0.6 into 200, it is so 120, and then the field strength values again 120 divided by 1.2 into 1.1, so 91; design strength is now again, you need to have another factor of safety of 1.3 global.

So, 91 divided by 1.3 is 70. So, the stiffness is 70 divided by 0.1, shear strain is 700 kilonewton per meter. So, so you if you take this 200, the it will serve this purpose right.

So, the and if you take 0.5 case, it is again you can choose another one like you know, instead of 200 you can take 401. So, what I want to say is that see, this in the previous case we have calculated the other one also.

So, you based on these two things, the reinforcement functions, say the thing is that if you want to both this whatever 200 to 400 kilonewtons or whatever one can make an a choice -

appropriate choice of the geogrid materials right.

Like, as I just mentioned. So, here the construction sequence is quite simple, where you just do that the you know, the clear the ground, put the geosynthetic material, then start putting the embankment construction, even it can be in layers also, normally we we assume that do you remember that we just assumed only one layer, you know, the interface shear stress resistance is going to be, say for example, you take it can be measured in the laboratory also, you have to do a direct shear stress to do that alpha a alpha factor and all can be calculated.

So, it is a this example clearly shows that one can design the a reinforcement, I mean reinforcement, one can design the reinforcement function for embankment in the soft soil, and one can arrive it suitable quantities of the whatever properties, and the all other issues that are related with this like stiffness, then the the other factor what is called the design strength, stiffness and the alpha D s, they are three factors that are important from the foundation design in this case.

And with this I will conclude; actually I want to tell you that there is one geotextile embankment are also we have done in long back when I was in central road resistance institute; we installed a particular case in one place, where the the soil is so soft in the in the evolution like a paddy area, and then embankment was constructed the in this paddy area, you know, which is something very soft actually.

So, the geotextile here was put, and then after embankment was constructed, and it was put to use immediately, earlier it was not possible at all. So, with this I will conclude; and we will see some more aspect of the same thing like use of geocells and how what are the other applications and case studies in the next lecture. Thank you.