Geosynthetics Engineering: In Theory and Practices
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Lecture - 37
Geosynthetics for Steep Slopes

Dear student, warm welcome to NPTEL phase two video course on geosynthetics engineering in theory and practice. My name is Professor J. N Mandal department of Civil Engineering, Indian Institute of Technology, Bombay, Mumbai, India, this module 7 lecture 37, Geosynthetics for Steep Slope.

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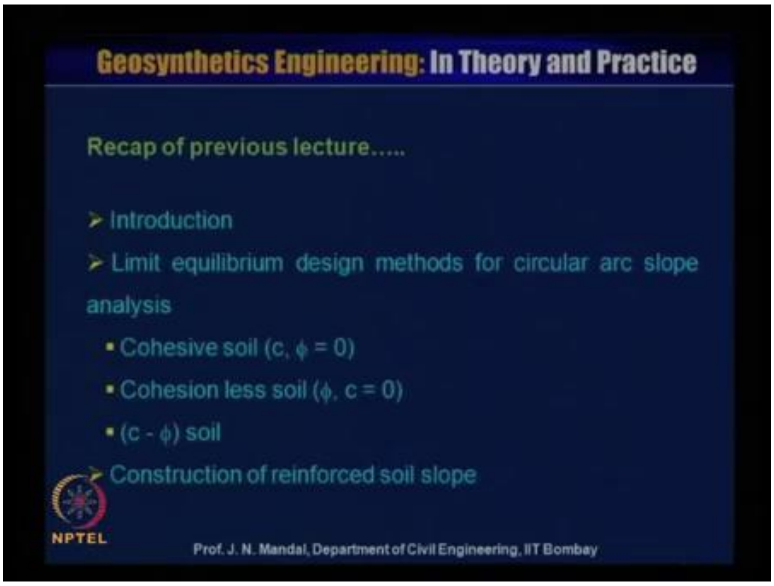

So, you the recap of the previous lecture, that is introduction limit equilibrium design method for circular arc slope analysis cohesive soil, that is c phi is equal to 0, cohesion less soil that is phi c is equal to 0, c phi soil, construction of reinforced soil slope.

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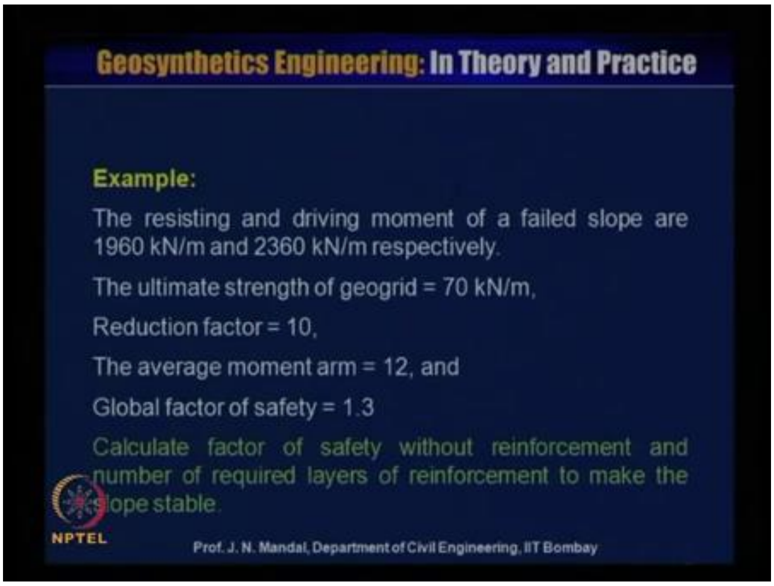

Now, I will present an example, the resisting and the driving moment of a fail slope are 1960 kilo Newton per meter and 2360 kilo Newton per meter respectively. Ultimate strength of the geogrid is 70 kilo Newton per meter, reduction factor 10 average moment arm 12, and global factor of safety 1.3. Calculate the factor of safety without reinforcement and number of required layer of reinforcement to make the slope stable.

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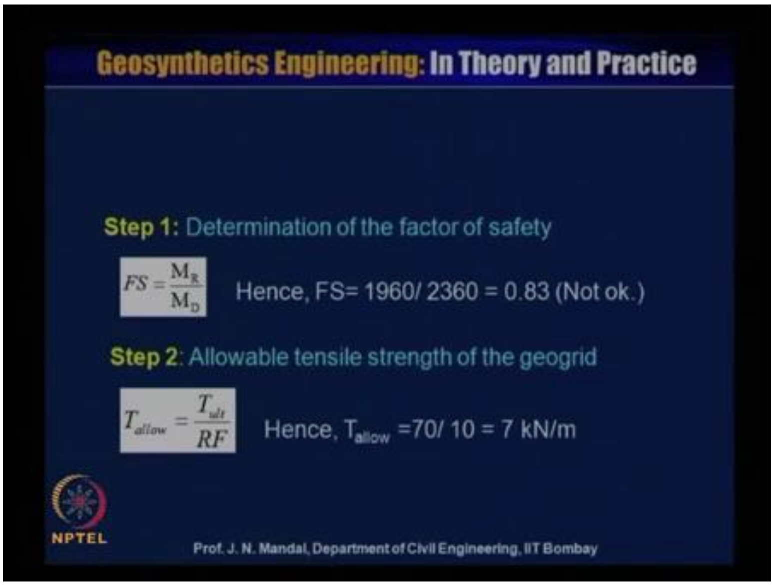

Step one, determination of factor of safety, so you know factor of safety is equal to resisting moment by driving moment. So, FS is equal to 1960 by 2360 is equal to 0.83, so it is less than 1. So, it is not ok; step two, calculate allowable tensile strength of the geogrid, so T allowable is equal to T ultimate by reduction factor. Hence, T allowable will be equal to 70 by reduction factor 10 is equal to 7 kilo Newton per meter.

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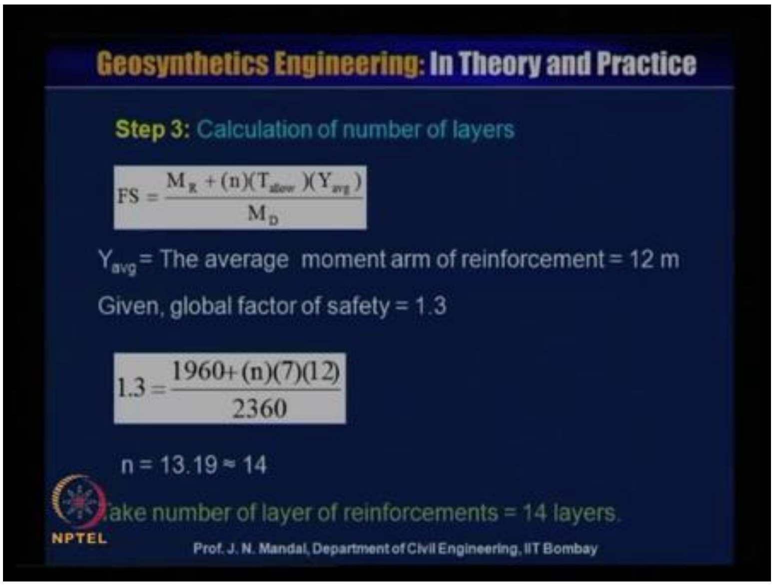

Step three, calculation of number of the layer. So, you know F S is equal to M R plus n into T allowable into Y of average divided by M D where Y average is average moment arm of reinforcement that is 12 meter. Given the global factor of safety 1.3, so you substitute the value of global factor of safety 1.3 is equal to resisting moment M R 1960 plus n into T allowable we calculated 7. That average moment on arm of the reinforcement 12 meter divided by M D is 2360. So, if we calculate we can obtain n is equal to 13.19, let us say 14, so take the number of the layer of the reinforcement 14 layer.

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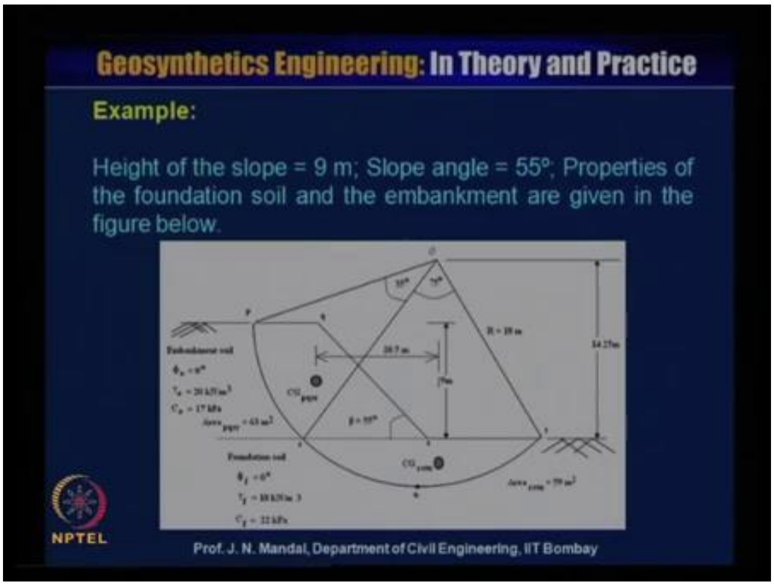

Now, this is another example. Let us say height of the slope is 9 meter, so this is a 9 meter height of the slope and slope angle is here 50 degree and properties of the foundation soil and embankment soil are given foundation soil phi F is equal to 0 gamma F is equal to 18 kilo Newton per meter cube and C F is equal to 22 kilo Pascal and that embankment soil here. That is phi e is equal to 0 gamma is 20 kilo Newton per meter cube and c of e is 17 kilo Pascal and this spot is the embankment. This part is the foundation soil and which is making at an angle of this is 75 degree and this is 35 degree and r is the radius this is yet in meter.

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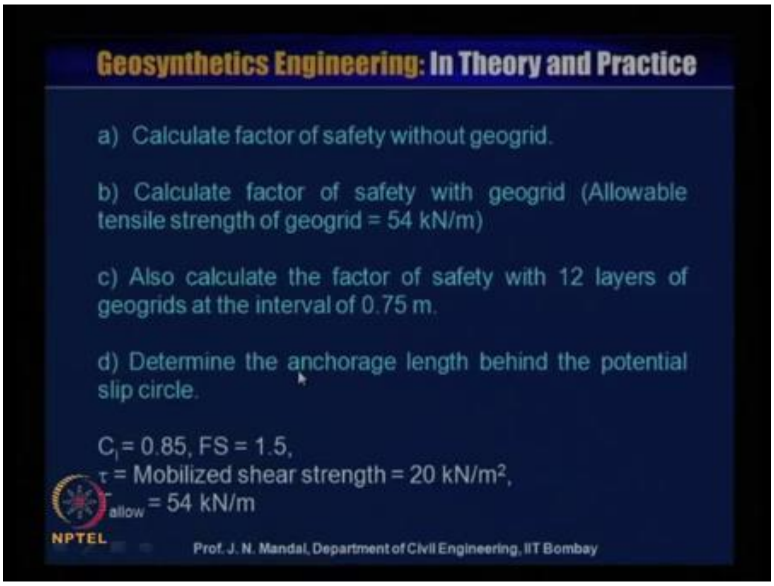

Here also for this zone this zone this is the C g and also for this zone this is C g, so C g of this area. So, first of all calculate the factor of safety without geogrid b. Calculate factor of safety with geogrid allowable tensile strength of geogrid is equal to 54 kilo Newton per meter. Also, calculate the factor of safety with 12 layer of geogrid at the interval of 0.75 meter. Determine the anchorage length behind the potential slip circle C i is equal to 0.85 F S is equal to 1.5 tau is mobilized shear strength is 20 kilo Newton per meter square and T allowable is 54 kilo Newton per meter.

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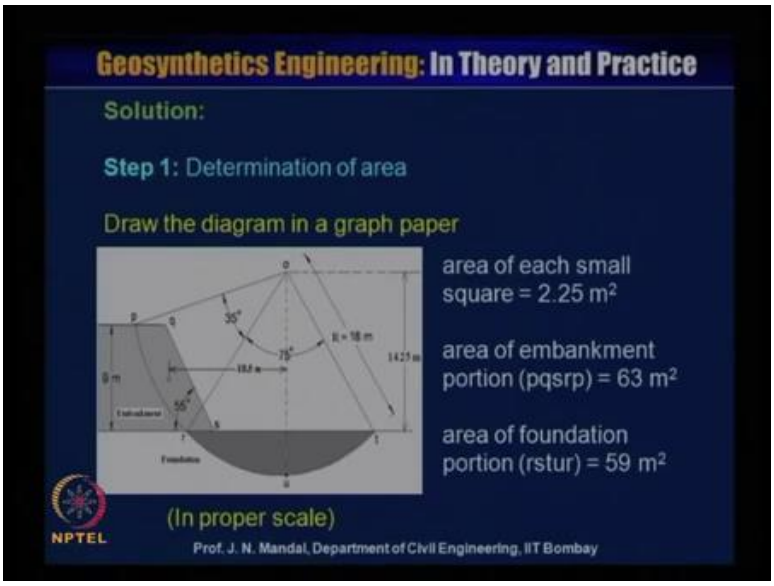

Now, the solution step a determination of the area. So, draw the diagram in a graph paper and you consider that in the graph paper the area of each small square is equal to 2.25 meter square. So, you have to check you have to check that what will be the area of this is the embankment. So, area of the embankment; that is p q S r p, so this area is equal to 63 meter square, because you know area of each small square is 2.25 meter square, so this embankment area will be equal to 63 meter square.

Now, this is the foundation, so area of the foundation portion will be equal to r. Then S T u r, so this area is 59 meter square, because area of each small square is 2.25 meter square. So, this area is 59 meter square, so you know what will be the area of the embankment and also you know what will be the area of the foundation. So, you can find out the area for both the embankment as well as the foundation. So, this has been done in the proper scale.

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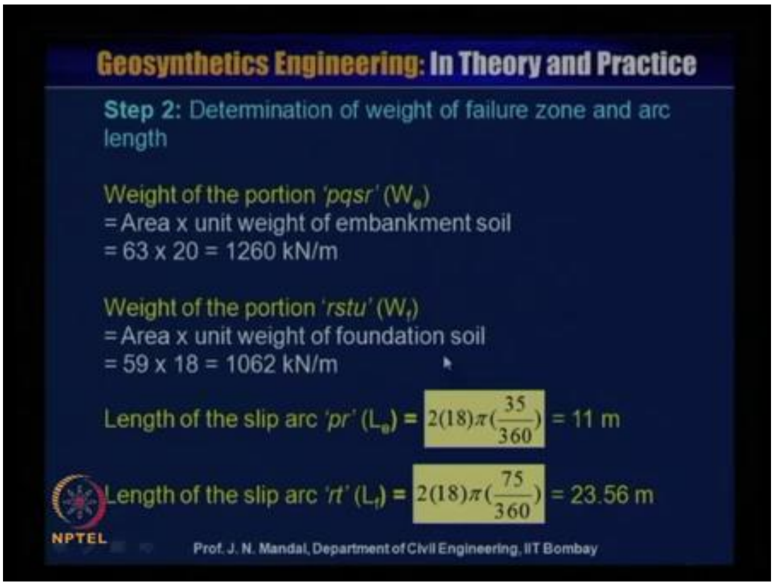

Now, step two determination weight of the failure zone and arc length, so weight of the portion of the p q is r; that is weight of the embankment W e. That is area into unit weight of the embankment soil. So area you have seen this is area is 63 meter square, so this 63 unit weight of embankment soil is given 20, so 63 into 21 260 kilo Newton per meter. Similarly, weight of the foundation that is r S T u that is W F; that means area into unit weight of foundation soil area is 59.

So, this area is 59 meter square into unit weight of foundation soil 18, so 59 into 18 is 1062 kilo Newton per meter. Now, you have to calculate what will be the length of the arc slip arc this length and for the embankment also you have to calculate, what will be the slip arc for the foundation? That means this is F u, this is t, and this is p of r for the embankment this length and for this length. You see this angle is 35 degree for the embankment. This arc length for the embankment this is 35 degree and for this arc length r u T and this angle is 75 degree.

So, we can calculate the length of this slip circle that is p of r or, which we can say the L of e. This is L of e so L e is equal to two pi r 2 pi r is the radius of the circle 18 meter. This is 18 meter and 2 pi r into theta by 360, and this is theta is 35 degree for embankment. So, 35 by 360, which will give that L e value is 11 meter. Similarly, length of the slip arc r T for the foundation this is this part and using making angle of 75 degree and this radius is 18. So, 2 pi r; that mean 2 pi 18 into 75 by 360. So, this will give that L F value is equal to 23.56.

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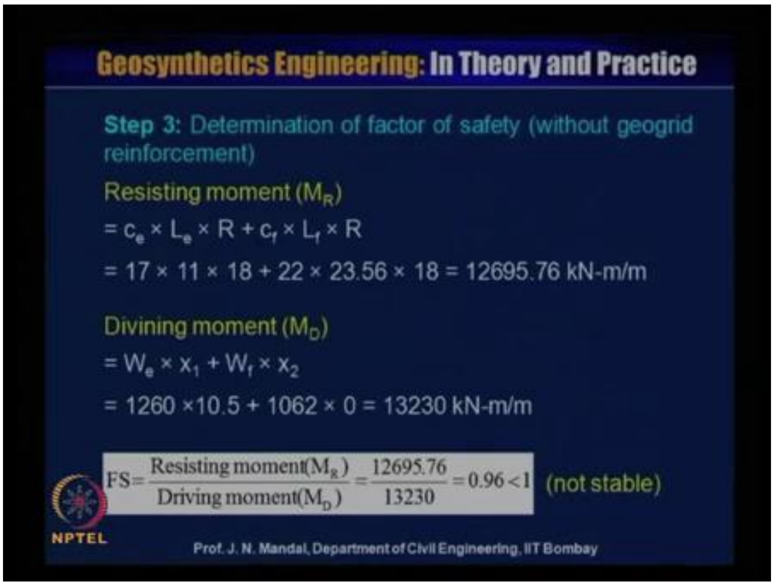

So, we know what is the L e we know what will be the L of a. Now, step three determination of factor of safety without geogrid reinforcement. Now, what is the resisting moment? So, resisting moment will be equal to c e into L e into R plus c F into L F into R. So, resisting moment mean this is the whole is the resisting moment. Now, this resisting moment is due to the embankment and also due to the foundation soil, so we know what is L e and we know what is c e of embankment. We know what is this arc weld r u T and also we know what is c of F that cohesion value? Also, we know that what is the radius? So, this is the resisting force, which is acting along the plane of this surface. Now, you can take a moment and you know that is the radius is 18 meter.

So, we can write the resisting moment M r that is c e into L e for the embankment part into R and for the foundation c F into L F into r so c e is given embankment soil; that is 17. L e we calculated 11 meter r is 18 meter radius plus c of F foundation soil cohesion 22 L F value we calculated 23.56 and R value is 18. So, resisting moment M r will be 12695.76 kilo Newton meter per meter and at the same time you have to calculate driving moment.

So, driving moment M d is equal to W e into x one and W F into x 2 here W e is the weight of the embankment and W F is the weight of the foundation and x 1 and x 2 distance. They are showing this is that x 1 will be this distance. You can see here, this is the weight of the embankment and from the centre of origin here. So, this distance that mean W e into x 1; that means it is 10.5 meter and W of F which is acting along the o centre of this axis o.

So, here x 2 will be the 0. If it is on this side, then you could say for embankment W of F into x 2 or something, but because it has passed through this o. So, that is why x 2 is 0 so we will take into account only weight of the embankment into this distance that is 10.5. So, that is the driving moment, so we know what will be the weight of the embankment we calculated. So, W e into x 1 and W 2 whatever it is acting at the foundation W F that is will be x 2, because it passes through the o origin.

So, that is why we can write W e weight of the embankment 1260 into x 1. I showed you 10.5 plus W F weight of the foundation 1062 and x 2 is passing through the origin. So, it is 0. Therefore, the driving moment is equal to 13230 kilo Newton meter per meter. Now, you know factor of safety is equal to resisting moment M r divided by driving moment is equal to 12695.76 divided by 13230 is equal to 0.96, which is less than 1. So, it is not stable, so you check that factor of safety against this moment.

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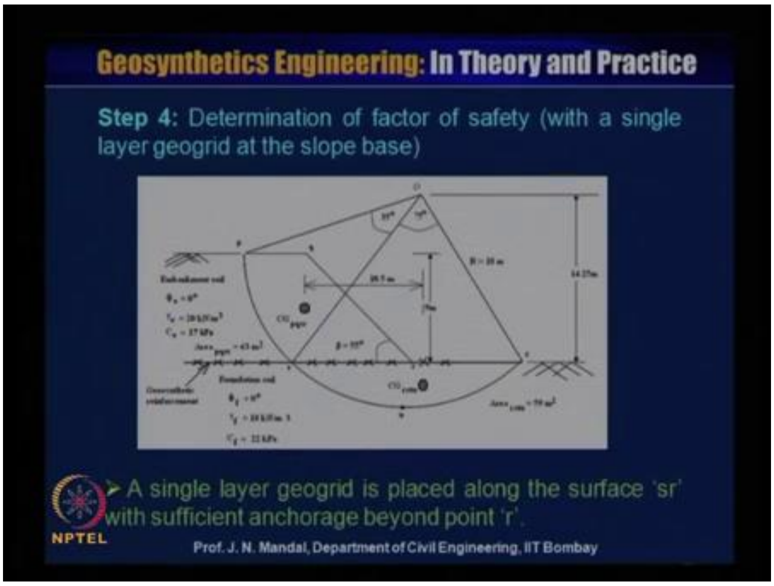

Step four, determination of factor of safety with a single layer geogrid at the slope base. Now, if we introduce wall layer of the geogrid material or geosynthetics material in between the embankment and this is the foundation soil. So, here a single layer geogrid has been placed along this surface; that is which is beyond this point, which is sufficient this is the anchorage length, this is the sufficient anchorage length.

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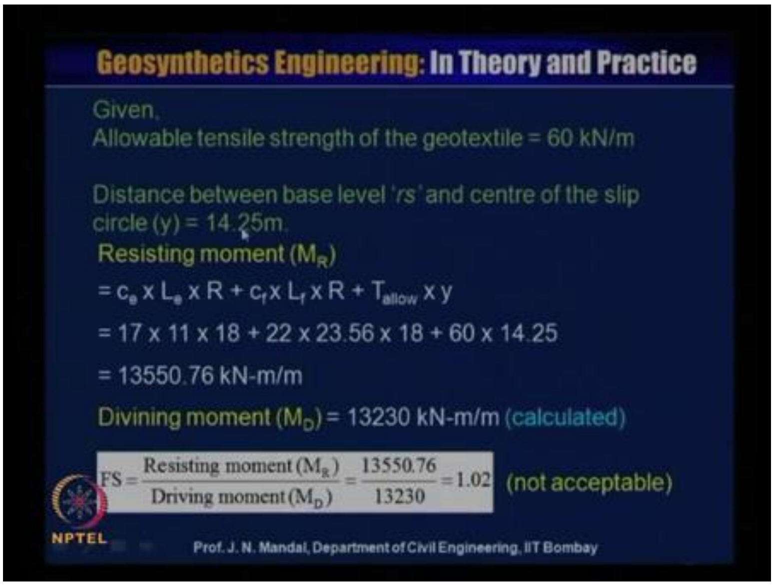

So, given allowable tensile strength of geotextile 60 kilo Newton per meter. Now, distance between the base level that is r S and the centre of the slip circle that is y this shall be in the base level here r S. The centre the circle here, so this distance is 14.25. So, it is here 14.25, now you have to take resisting moment M r that is c e into L e into r for the embankment c F into L F into r for the foundation in addition to that for the geosynthetics material. This will be plus T allowable into y that means; this is the T allowable this is T. T into this distance this is the y that means y is equal to 14.25 and this is the T the tensile strength of the geogrid material. So, T into this, so we can write the resisting moment will be equal to this, this part for the geotextile that is T allowable into y, so you know that T allowable is 60.

So, you substitute c for embankment cohesion is 17 L e, we know 11 r radius of this 18 plus c of F cohesion for foundation 22 L F for foundation 23.56 again r radius 18 plus T allowable is 60 plus y. I have shown you 14.25, so this will give resisting moment M r is 13550.76 kilo Newton meter per meter, so driving moment M d will be equal to 13230 kilo Newton meter per meter, which has been calculated. So, we check up what will be the factor of safety; that is the ratio of the resisting moment M r and the driving moment

M d? So, that means is equal to 13550.76 divided by 13230 is equal to 1.02, so this is also not acceptable.

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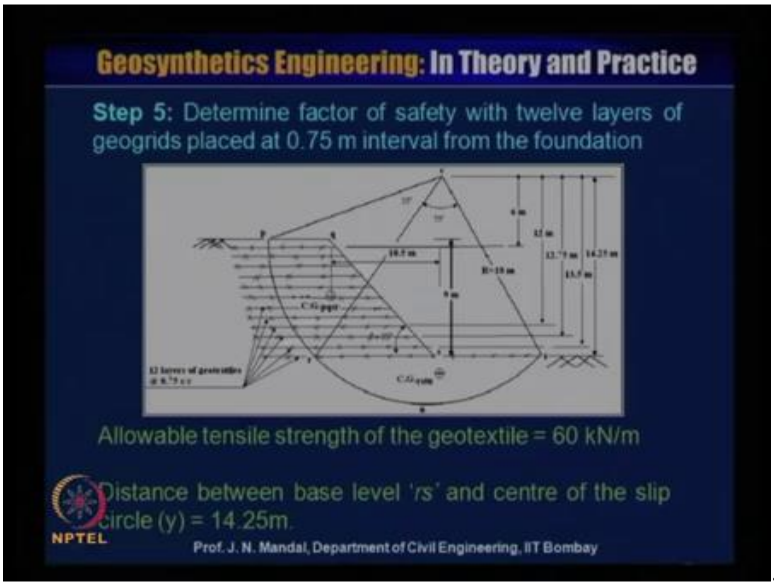

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Step five, determine the factor of safety with 12 layer of geogrid placed at 0.75 meter interval from the foundation soil, so here this is the slope. So, 12 layer of the geogrid has been placed at a interval of 0.75 meter centre to centre and this slope angle is 55 degree. So, we know from here to here y is 14.25, then you put another layer of the geogrid, which location will be 14.25 minus 0.75, which will give 13.5 meter then again for this layer it will be 13.5 minus 0.75. This will give that 0.75.

Then next layer will be 12 meter, like that you can have here from here to here almost at this crest of the slope this is almost about 6 meter, so this is the 6 meter. So, you are introducing the number of the layer of the geogrid reinforcement material, so we are providing 12 and at a spacing of 0.75 meter. So, allowable tensile strength of geotextile is known 60 kilo Newton per meter and distance between the base level that means this r S level and the centre of the slip circle 14.25.

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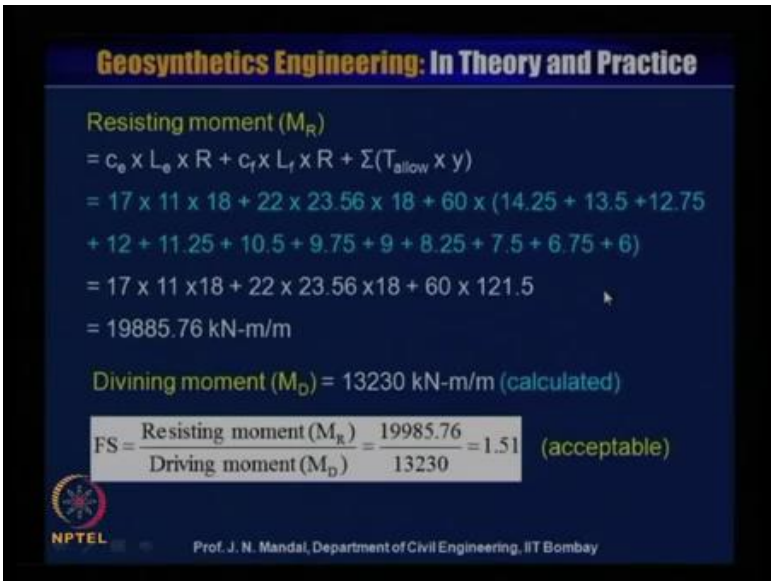

So, you have to calculate what will be the resisting moment, so we know resisting moment c e into L e into r c F into L F into r plus summation of T allowable into y, because we have introduced number of the layer of the reinforcement and the slope. So, this you know c is 17 L e 11 R 18 plus for foundation c F 22 L F 23.56 R 18. So, first one is 14.25 so 14.25, then plus next is 13.5, so that is why 13.5 next is 12.75. So, that is why 12.75next is plus 12, so next is plus 12 like that you can continue the difference of 0.75. So, it will give a element 0.25 plus 10.5 plus 9.75 plus 0.75 difference 9 again defines point plus 8.25 again plus 7.5 and 6 0.75 and at the end this is 6, so it is 6.

So, if you calculate you can have 17 into 11 into 18 plus 22 into 23.56 into 80 plus 60 into this will be 121.5, so this will give the resisting moment M r is equal to 19885.76 kilo Newton meter per meter. So, driving moment M d is equal to 13230 kilo Newton meter per meter, which has been calculated. So, you can check that what will be the factor of safety that is the ratio of resisting moment M r divided by driving moment M d.

That means resisting moment you know, 19885.76 divided by the driving moment M d 13230 is 1.51, so if it is a 1.51 it is acceptable, so slope is stable. So, you see that when that initially single layer of the reinforcement it was not stable because the factor of safety value is less than 1. Now, when you use the 12 layer of the geogrid material at a spacing of 0.75 meter and you find the factor of safety is 1.51, so it is a stable. So, you can say that the reinforced soil c b is stable.

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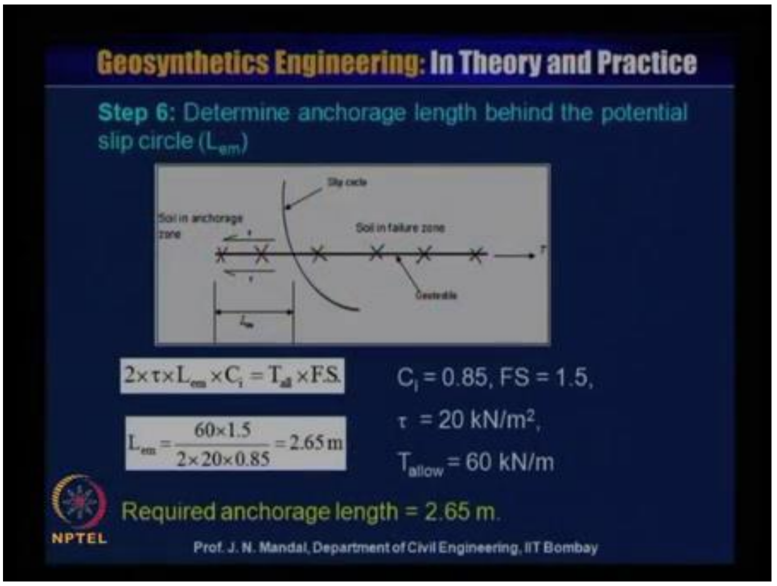

Now, step six; you have to determine the anchorage length behind the potential slip circle. Suppose, this is the reinforcement this is the failure slip circle failure. This is the soil in the failure zone and this is the soil in the anchorage it is like a pullout, you can see there is a development of shear stresses tau between the soil and the geogrid reinforcement. This is the length L of e m, which is called that anchorage anchorage length, this is the anchorage. So, we know that this is tau and tau top and bottom of the geogrid material, so 2 into tau into this is L e m and this is the C I is equal to what will be the allowable tensile strength of the geogrid; that is T allowable into factor of safety.

So, from this equation we can calculate that L e m, so L e m will be equal to T allowable into factor of safety T allowable you know 60 divided factor of safety is 1.5. This divided by 2 into tau value is given 20 kilo Newton per meter square into C i value is given that is 0.85. So, L e m will be equal to 2.65, so required anchor length will be 2.65, so you know beyond the slip circle what will be the anchorage length. So, anchorage length should be 2.65, so that also you have to take into consideration for the designing.

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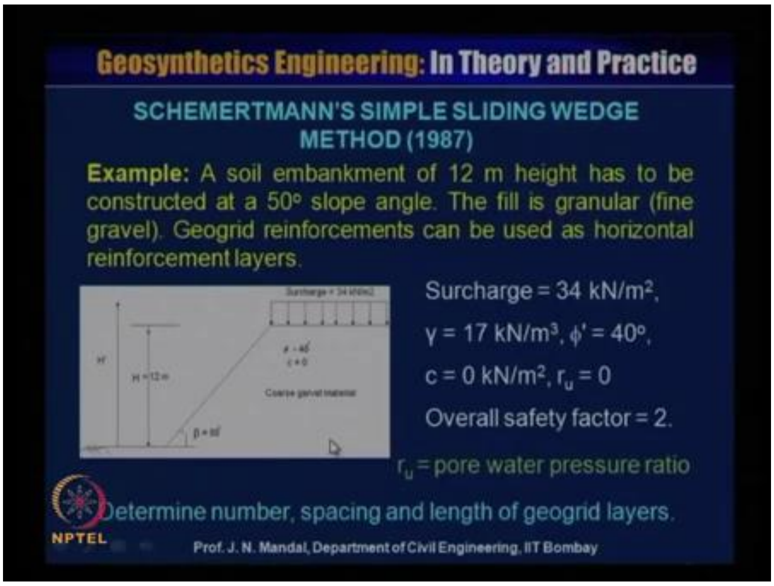

So, end this second example, so you have some idea how to calculate the number of the layer of reinforcement in the first example and from the second example you should know that, when we can make a stable slope? So, initially you have to check whether a factor of safety is more than 1 or less than all you find it is less than 1 in unreinforced case. Then you introduce the one layer of the geogrid material, then you find that it is not also the stable because this is almost insufficient 1.0 something value has come. So, always in the slope stability analysis is preferable that you should achieve the 1.5 the factor of safety.

So, when you introduce the 12 layer of the geogrid reinforcement at a spacing of 0.75 you find that it is the stable. Now, we will discuss Schmertmann's simple sliding wedge method in 1987. One example you are giving a soil embankment of 12 meter high, this is the soil embankment height is about 12 meter has to be constructed at a 50 degree slope angle. This slope angle is 50 degree here and there is a surcharge that is 34 kilo Newton per meter square and also the soil gamma is equal to 17 kilo Newton per meter cube phi dash is equal to 40 degree c is equal to 0 kilo Newton per meter square. r u is the pore water pressure ratio and overall factor of safety is equal to 2, so you have to determine the number and spacing and length of the geogrid layer.

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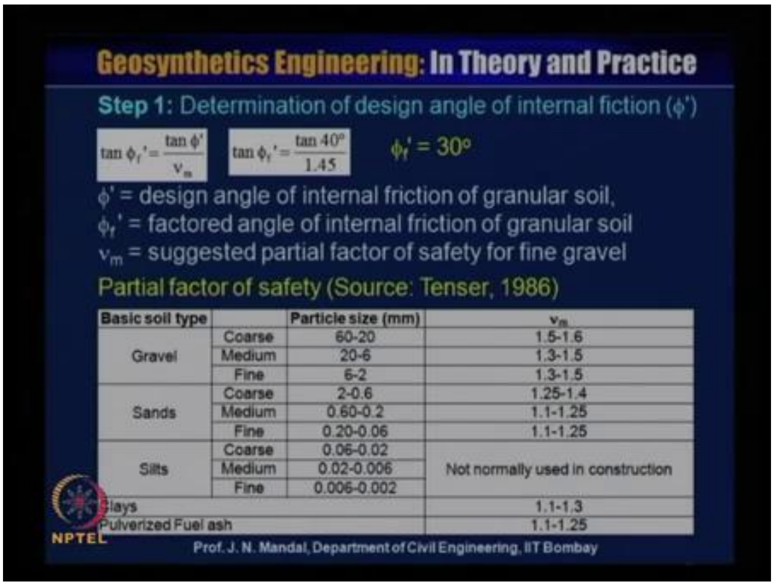

So, this is the example is given, now you have to step one you have to determination of design angle of internal friction that is phi dash. So, tan phi r dash is equal to tan phi dash by nu M, so tan phi dash F is equal to this value is given 40 degree. This value is given tan phi dash value is given, we have seen that this value is phi dash value is 40 degree is given, so tan 40 divided by this factor of safety 1.45.

So, we consider 1.45 and this 1.45 that nu of m value that depend upon that what should be the type of soil has been used? So, this partial factor of safety source Tenser 1986 is given. This is basic type of the soil whether gravel sand or slit or clay or the pulverized fuel ash and whether it is a coarse medium fine etcetera. In case, of gravel soil what will be the particle size? What will be that nu m value?

That means suggested partial factor of safety for the fine gravel, we consider, let us say fine gravel or the medium gravel. So, where these factor of safety this nu m value will be lying between 1.3 to 1.5 like this. So, here we assuming this nu m value is 1.45, so you can calculate phi r dash value is equal to 30 degree. So, you can calculate that what should be the design angle of internal friction phi r dash.

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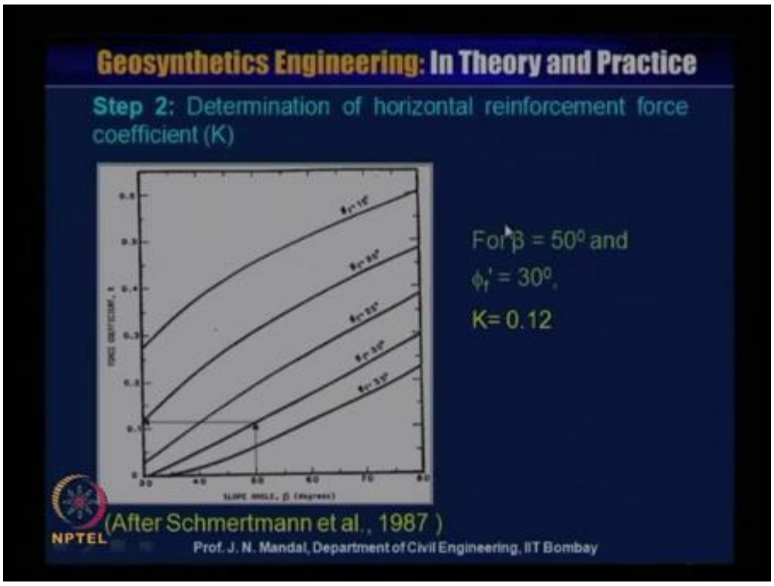

Now, this is the design chart is given by the Schmertmann 1987, so this part is the slope angle x axis is the slope angle and y axis is the force coefficient is equal K for the different value of phi F dash. This it may be your 15 degree, it may be 20 degree, 25 degree or 30 degree or 35 degree. So, from this chart you have to calculate what will be the reinforcement force coefficient. We know what is slope angle and we know what is phi of r dash. So, you can calculate that what should be the force coefficient k?

So, from this chart you know, beta is 50 degree. You can see here is the beta 50 degree that you move up and you know, phi r is 30 degree. So, phi r is this is 30 degree and then you move left to the reinforcement coefficient site K value. So, from here you can calculate K value, which will give 0.12, so from this chart you calculate it K, which is important to us.

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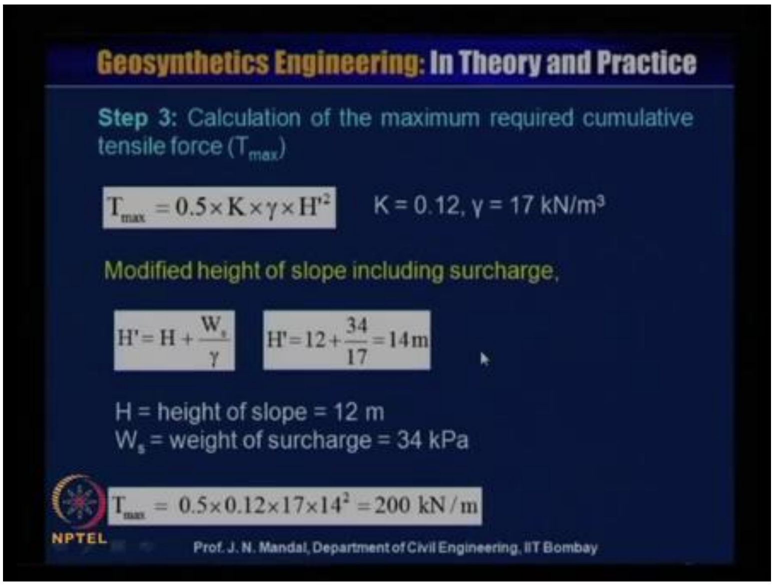

So, K is equal to 0.12; that means reinforcement force coefficient you calculate. Now, step three, calculate the maximum required cumulative tensile force T maximum. You know that T maximum is equal to half into K into gamma into H dash square. So, K value is known you calculated 0.12 and gamma value is given 17 kilo Newton per meter cube. What is H dash? That is modified height of the slope including surcharge. Now, you know this height of the modified height is H dash, this will be H dash square. So, H dash square is equal to H plus, this is surcharge by lambda W S by lambda. So, this W S is given 34 surcharge and gamma is equal to 17, so H dash is equal to H this is height of the slope is 12 meter plus due to the surcharge that is 34 by gamma 34 by 17 will give H dash value 14 meter.

So, we know that what should be the H dash value, so T maximum will give a 0.5 K 0.12 gamma 17 H dash is equal to 14 square. So, from here you can calculate T maximum is equal to 200 kilo Newton per meter, so your surcharge load is 34. So, you know that what is T maximum? So, here we include the surcharge load.

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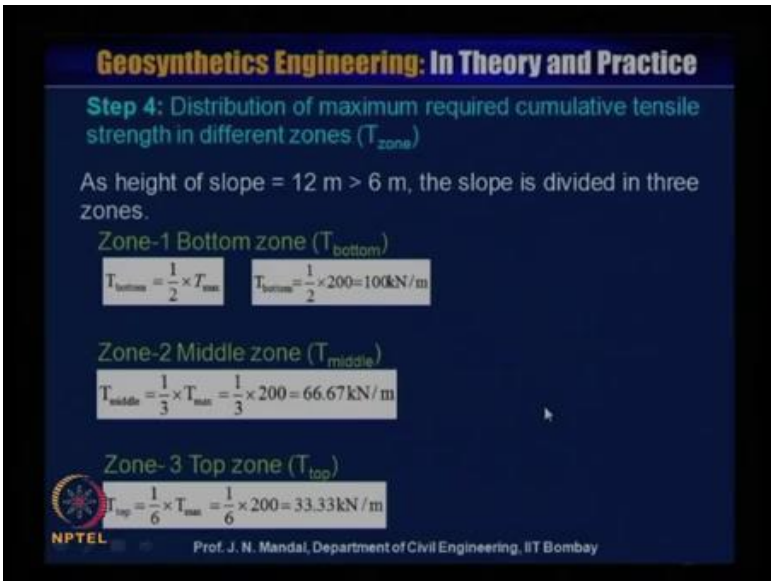

Now, step four; distribution of the maximum required cumulative tensile strength in the different zone that we call T zone as the height of the slope is 12 meter; that means it is greater than 6 meter. So, slope is divided into the three zones, so we can divide the slope into the three zones; the zone one bottom zone that is T bottom. So, T bottom the equation for this T bottom is equal to half of T maximum, so you calculate what will be the maximum 200 T maximum 200 for the zone one. Bottom zone that is T bottom will be equal to half into 200 is 100 kilo Newton per meter.

Now, for zone two middle zone which is called T middle that means T middle is equal to one third of T maximum. This is the equation given, so is equal to one third of T maximum is 1200; that means this will be 66.67 kilo Newton per meter. Zone three is the top zone that is T top. T top is one sixth of T maximum that means equal to one six of 233.33 kilo Newton per meter.

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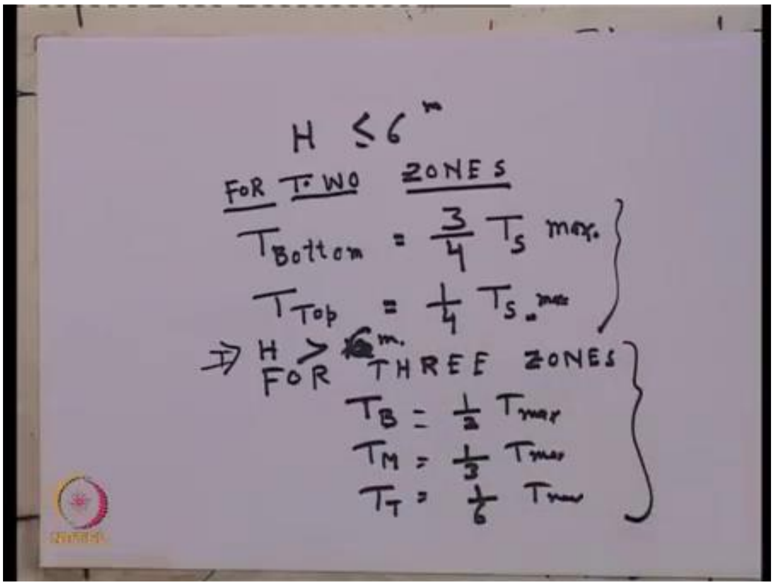

Now, here I would like to say that if the there are two cases. One is that if H is less than equal to 6 meter. So, then you can make a two zone you have to make two zone for two zone, so T bottom will be three of fourth into T of max and T top will be equal to one fourth of T of maximum; that means this is the total required tension is its zone is found by this following equation. If the H by less than equal to 6 meter and for the three zone for the three zone, I mentioned that T of bottom T of middle and T of top.

So, this I have shown you that is this will be the half of T or bottom is a half of T of maximum. This is the equation is given and for the middle one third of T of maximum and this is one six of T of maximum. If that H is greater than that 12 meter, because in our case is this because H is 6,12 meter sorry, this will be 6 meter H is greater than 6 meter. So, if it is greater than 6 meter, this is the equation and I height of the slope is 12 meter, so that is why we are adopting this equation. So, here what it is shown T bottom up, T maximum, T middle one, third T maximum and T top one six of T maximum.

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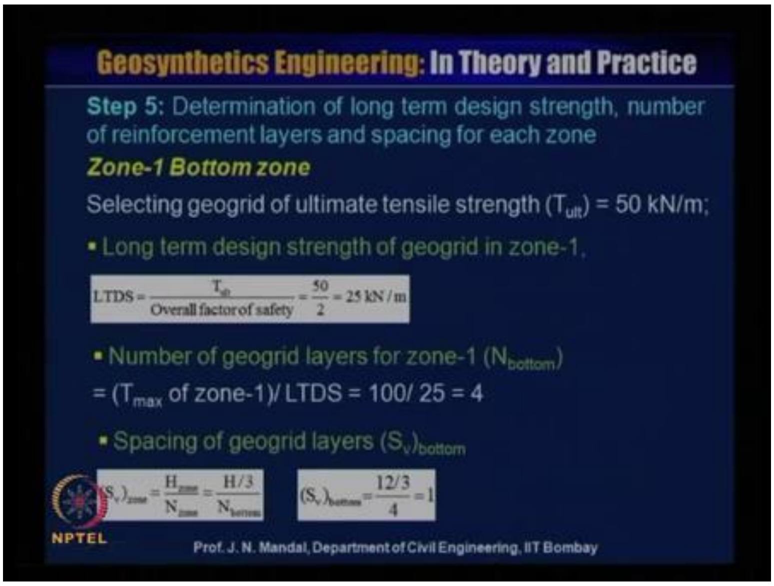

Now, step five; determination of long term design strength number of reinforcement layer and spacing of each zone. So, zone one is the bottom zone, so selecting the geogrid of ultimate tensile strength T ultimate you select 50 kilo Newton per meter zone one bottom. So, long term design strength of geogrid in zone one; that is long term design strength L T D S is equal to T allowable by overall factor of safety. So, T allowable here T ultimate we took about 50, so 50 divided by 2 is 25 kilo Newton per meter.

So, you have to calculate what will be the number of geogrid layer for zone one n bottom that will be equal to T max of zone one divided by L T D S. So, T max of zone one is you know that is 200 earlier, T max here we know that is 100 here. So, 100 divided by this 25 L T D S, so there will be a 4, so this will be the 4, so number of geogrid layer for zone one bottom will be 4. Now, spacing of the geogrid layer S v bottom; S v bottom is equal to H of zone divided by n of zone; that means this zone is equal to H by 3 divided by n bottom. So, S v bottom will be H is equal to 12 because height of the slope is 12. This divided by 3 divided by number of bottom here is that 4, this divided by 4 is equal to 1, so spacing will be 1 meter.

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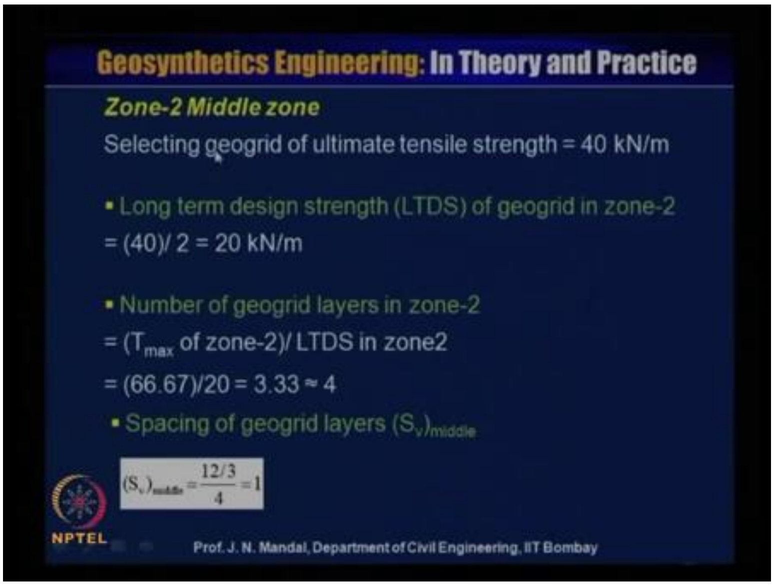

Similarly, zone two middle zone select the geogrid of ultimate tensile strength 40 kilo Newton per meter. Long term design strength L T D S of geogrid in zone two, so that means you know this is 40 divided by 2 is equal to 20 kilo Newton per meter. So, number of geogrid layer in zone two will be T maximum of zone two divided by L T D S in zone two. So, T maximum of zone two is 66.67, we have calculated earlier this divided by L T D S is 20 kilo Newton per meter this 20, so this will give 3.33. Let us say approximately 4. So, spacing of the geogrid layer S v middle will be S v middle is equal to 12 divided by 3, H by 3 divided by that mean 4. This is 4, so this will give 1, so at the middle it is 1.

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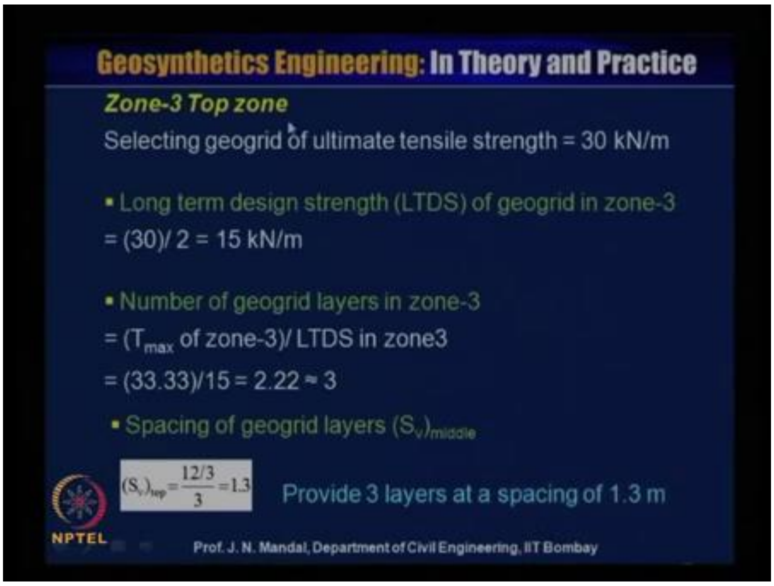

Now, for zone three top zone selecting the geogrid of ultimate tensile strength 30 kilo Newton per meter. So, long term design strength L T D S of geogrid in zone three is 30 by 2 is 15 kilo Newton per meter, number of geogrid layer in zone three is T max of zone 3 divided by L T D S in zone three. So, this is 33.33, we calculated earlier this divided by 15 L T D S is equal to 2.22. Let us say 3, so spacing of the geogrid layer S v middle top this will be S v top will be equal to 12 divided by 3, H by 3 divided by this 3, it is 1.3. So, we provide three layer of geogrid at a spacing of 1.3 meter, so you can at a spacing of 1.3 meter we can give.

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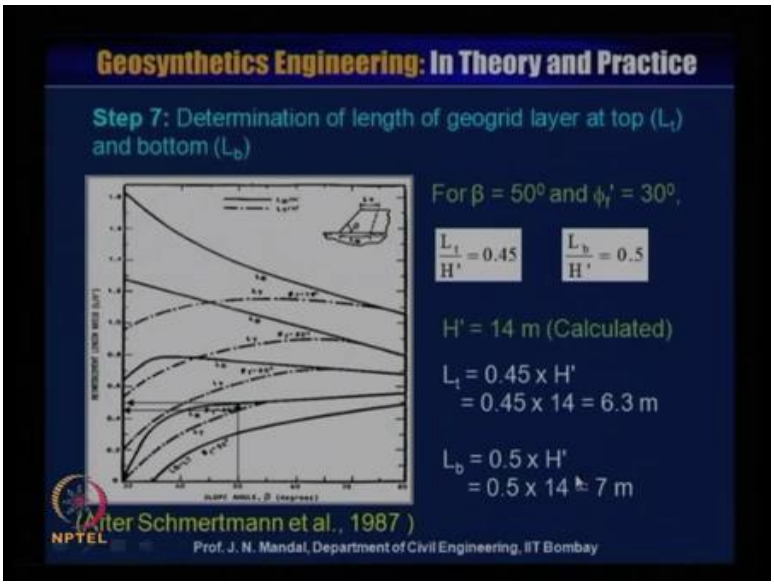

Now, step seven, determination of length of geogrid layer at the top is L t and at the bottom is L b. So, this is the design chart after Schmertmann et al 1987 and this is the L b bottom. This is the L t top and this angle is slope beta and this is firm line is L b by H dash and dotted line is L t by H dash [FL] length at that top and length at the bottom and H is equal to height of the slope. So, here you can see that when a one is the firm line another is another is the dotted line.

This is relationship between the slope angle that is beta degree and also this is the what should be the ratio, whether it is a L by b ratio what will be the L by b ratio? That means it may be L t by H or it may be L b by H. If it is a L b by H that is firm line and if it is a L t by H is the dotted line that means either top or the bottom and this is the angle defines angle is given. So, it may be 20 degree, 30 degree, 35 degree etcetera different angle is given here.

So, from this chart, so you know that beta angle of the steep slope is 50 degree and phi of F dash is given 30 degree. So, this is 30 degree so L t by H dash you have to calculate from here you have to calculate from here L t by H mean dotted line. So, when the beta slope angle is 50 degree. Here you move up you reach to the dotted line when phi F dash value is 30 degree and then you move horizontally. Then you will have here L t by H dash, so L t by H dash is equal to 0.45 that is why it is L t by H dash is equal to 0.45.

Similarly, for the firm line which is the bottom L b by H dash, so you know slope angle 50 degree move up and phi F is equal to 30 degree. Then this is L b by H dash firm line then you move here you can have 0.5, so you obtain L t by H dash is 0.45 and L b by H dash 0.5. We have calculated H dash is 14 meter that when we considering the surcharge load that is 40 meter, so from this equation you can calculate L t is equal to 0.45 into 14 that means 6.3meter. So, L t this top length will be 6.3meter similarly, bottom length you have to find out from this equation L b by H dash is equal to 0.5. So, L b is equal to 0.5 into H dash, H dash is equal to 14, this is 14. So, 0.5 into 14 is 7 meter, so L b is equal to 7 meter. So, L b is equal to 7 meter and L t is equal to 6.3 meter, so this way you can calculate what will be the length of the geogrid at the top and the length of the geogrid at the bottom.

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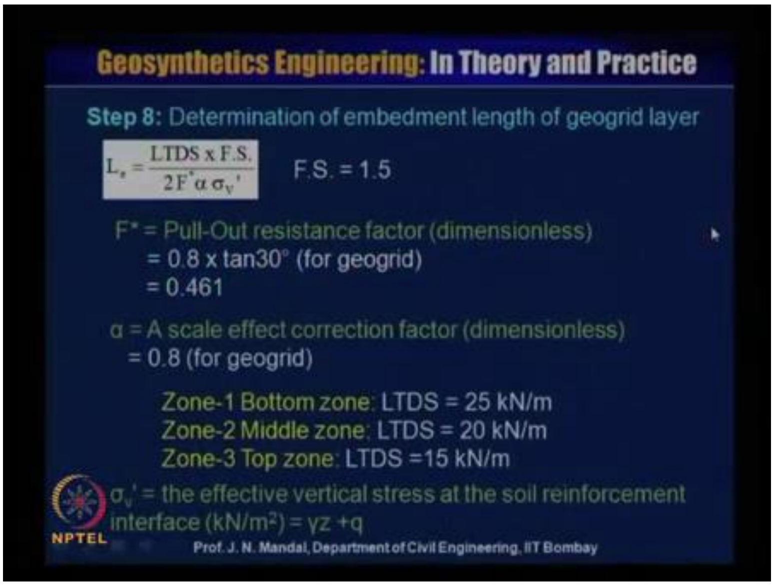

Now, step eight, determination of embedment length of the geogrid layer. So, you know L e is equal to L T D S into factor of safety divided by two F star alpha into sigma v dash, where F S is equal to 1.5 and this F star is the pullout resistance factor this is dimensionless and that you consider 0.8 times of tan 30 degree for geogrid. That mean this will give F star value give 0.461. So, you know F star value what is alpha? Alpha is equal to scale effect correction factor that also dimensionless and for geogrid it is 0.8.

So, this alpha value is 0.8, now for the zone one or bottom zone L T D S is 25 kilo Newton per meter zone two that means middle zone L T D S is equal to 20 kilo Newton per meter. We know zone three top zone L T D S is 15 kilo Newton per meter. This sigma b dash, so sigma b dash is the effective vertical stress at the soil reinforcement interface that is in kilo Newton per meter square is equal to what is gamma z into q, you know the unit weight of the soil you know the what will be the depth and you know the surcharge. So, then you can calculate sigma of v dash, so all this value is known to you, so you can calculate L of e.

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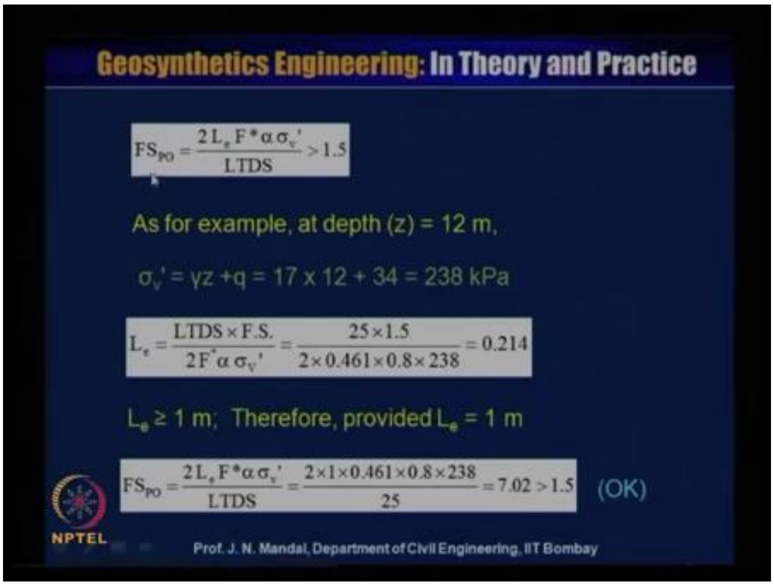

Now, you see that you know that factor of safety against pullout is equal to be 2 into L e F star alpha into sigma v dash by L T D S, it should be greater than equal to 1.5. So, as for the example at a depth of z 12 meter, so sigma v dash will be gamma into j plus q that means gamma is 17 into z is z, z is 12 plus 34 is the surcharge. So, it will sigma v dash is equal to 230 eight kilo Pascal. Now, you have to calculate L e, L e is equal to L T D S into F S divided by 2 F star alpha into sigma v dash.

We know L T D S is 251, so 25 F S is 1.52 F star is 0.46 one alpha is equal to 0.8 and sigma v dash is 238. This is 238, so this will give L e value 0.2, 0.4. So, in all cases that L e should be greater than equal to 1 meter, it must be. Therefore, you have to provide L e 1 meter, now you have to check what would be the factor of safety against also pullout that means you know 2 into L e F star alpha sigma v dash by L T D S. This L e we consider now 1.0, 0.214, so one into F star it is given 0.461 plus alpha you calculated 0.8 and sigma v dash is 238 divided by L T D S is 25, we found this factor of safety against pullout 7.02, so it is greater than 1.5, so it is.

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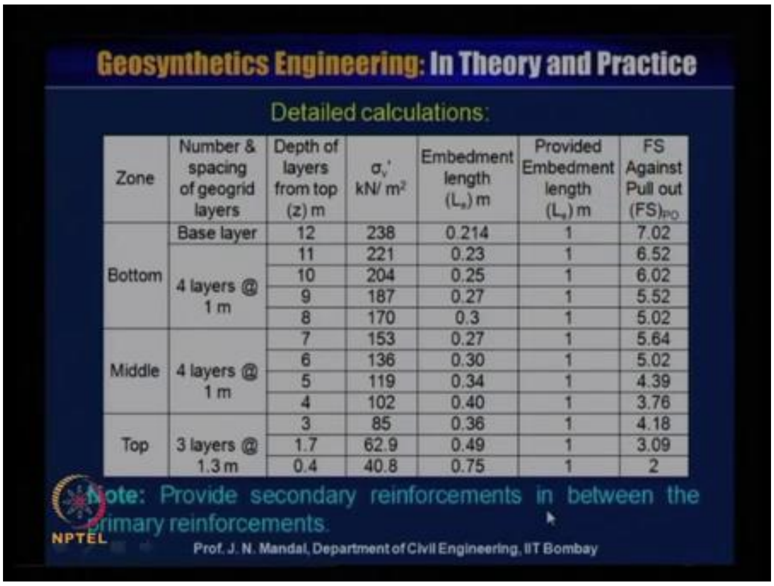

Zone	Number & spacing of geogrid layers	Depth of layers from top (z) m	σ_v' kN/m^2	Embedment length (L_e) m	Provided Embedment length (L_e) m	FS Against Pull out $(FS)_{PO}$
Bottom	Base layer	12	238	0.214	1	7.02
	4 layers @ 1 m	11	221	0.23	1	6.52
		10	204	0.25	1	6.02
		9	187	0.27	1	5.52
		8	170	0.3	1	5.02
Middle	4 layers @ 1 m	7	153	0.27	1	5.64
		6	136	0.30	1	5.02
		5	119	0.34	1	4.39
		4	102	0.40	1	3.76
Top	3 layers @ 1.3 m	3	85	0.36	1	4.18
		1.7	62.9	0.49	1	3.09
		0.4	40.8	0.75	1	2

Now, detailed calculation is shown here, so this is the zone. I have shown one for bottom middle and top the number of spacing of the geogrid layer, this is the base layer. Then bottom layer you require four layer in at a spacing of 1 meter. Then middle you have to provide four layer at a spacing of 1 meter. The top in three layer at a spacing of 1.3 meter, which we have shown so this is the depth of the layer from the top that is z meter; that is 12, 11, 10, 9, 8, 7. This is 1 meter interval, then again for four layer 1 meter interval that is 7, 6, 5, 4. Then three layer 1.3 meter spacing that mean 3 and then, because this is 1.3 meter interval then next will be one point 7 and then 1.3 is equal to 0.4.

So, sigma v you calculated this is starting from 2.38 and then it is gradually decreasing to 40.8. We find that embedment length 0.214 to 0.75, but we have to provided embedment length minimum L e should be 1 meter. So, this is the 1 meter, so you check the factor of safety against pullout, so factor of safety against pullout it is here 7 .026, 0.526, 0.2 like this you can see you can having here is, so it is all same. So, suppose if sometimes the spacing is more you have provide with the secondary reinforcement in between the primary reinforcement. Now, you have some idea that what you have to space this what will be the spacing between the reinforcement and what should be the embedment length, what should be the factor of safety against this pullout? So, all is known to you.

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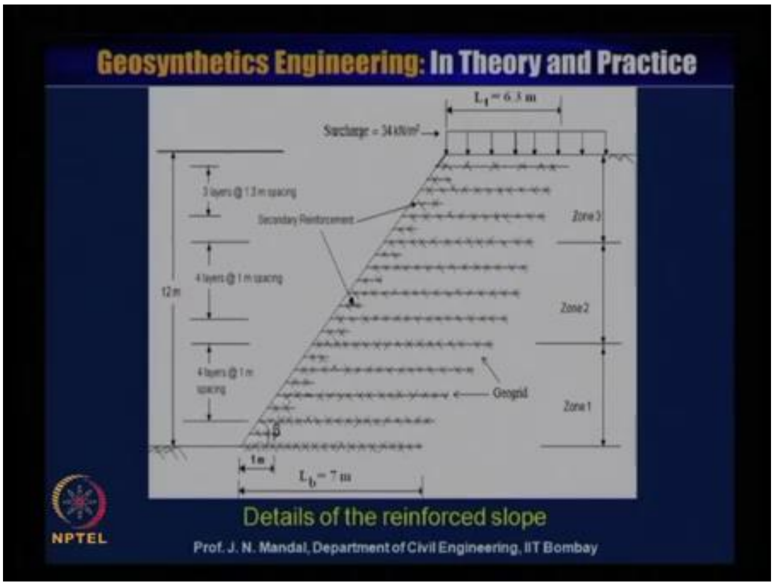

Now, here you have to show the detail layout of the reinforcing slope, so you can see here this is a height of the slope this is 12 meter. You are providing here three layer at the top at the spacing of 1.3 meter and there is a surcharge load 34 kilo Newton per meter. The top L t is 6.3 meter and bottom we calculated L b is 7 meter. This is for 3 meter, this is zone three. So, three layer at a spacing of 1.3 meter and then four layer at a spacing of 1 meter, this is zone two. Then the four layer at a spacing of 1 meter, this is zone one.

So, you see that if it is a 1 meter, 1.3 meter or the 1 meter of spacing. Then it is required that you should use some sort or the secondary geogrid. This is the secondary geogrid between the primary reinforcement and the adjacent to the slope. This will act to compact this soil as well as this will also control the surface erosion. So, you must provide with the secondary reinforcement or it is a short reinforcement whose length is about 1 meter.

Otherwise, something there is a possibility for sloughing along the face of the slope and also it will be sometimes too difficult to compact the soil at the facing of the slope. Therefore, you must provide with a one secondary reinforcement or short reinforcement with length 1 meter is to be provided and there is also possibility for the surface erosion. So, these you must keep in mind if the spacing is... Let us say 1 meter or even then more than 1 meter.

So, we know that how to how to design the steep reinforced soil slope even then if there is a surcharge load and then how you can modify the height of the slope? That height of the slope, how we can take into consideration for the design and also you check that what will be the height of the slope, whether it is less than equal to the 6. Then you can consider only the two layer system bottom and the top and if it is a more than 6, but in our case it is a 12 meter, so it is a more than 6 and that is why it is divided into the three zone and it is a top bottom and middle. You see that how we have distributed the tensile strength of the geogrid material in the different three zone.

Equally, we have calculated this long term desired strength and check that what should be the spacing and then if you know that what will be the spacing and also from the chart we have determined, what will be the length of the geogrid at the top and what will be the length of the geogrid at the bottom? Because you know the slope angle you know the friction angle, so you can calculate what will be the length at the top and what will be the length at the bottom and you also find that what should be the spacing. As I said, also earlier if the spacing between the two geogrid material is 1 or more than 0.5. Then you must provide with a secondary reinforcement, which can prevent the sloughing or any kind of the surface erosion and also this will help you for the proper compaction. So, with this I finish my lecture today, let us hear from you. Any question?

Thank you very much for listening.