Geosynthetics Engineering: In Theory and Practices
Prof. J. N. Mandal
Department of Civil Engineering
Indian Institute of Technology, Bombay

Lecture - 42
Geosynthetics for Embankments on Soft Foundations

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 lecture number 42 module 8 lecture 42 geosynthetics for embankment on soft foundation.

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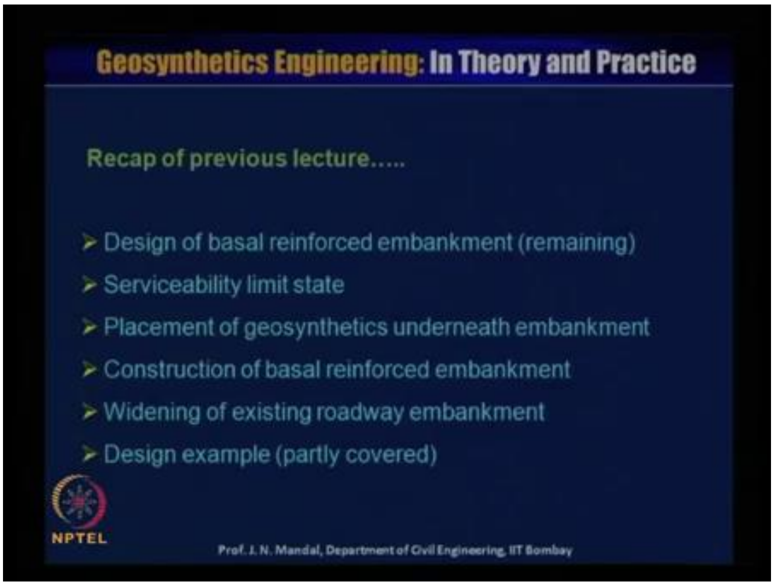

Now, I focus the recap of previous lecture that is design of basal reinforced embankment part is remaining. Then I have covered serviceability limit state, placement of geosynthetics underneath embankment, construction of basal reinforced embankment, widening of existing roadway embankment, and design example partly covered. So, I now continue with the design example which I have partly earlier covered.

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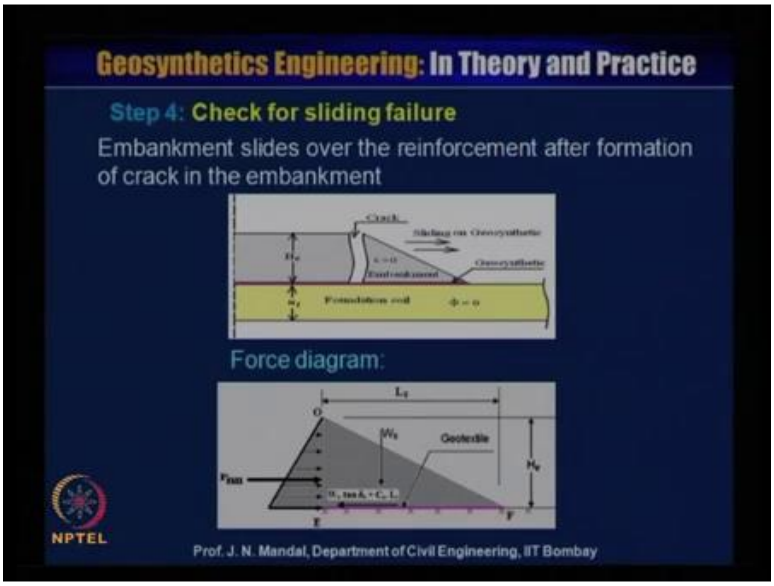

Now, step 4 check for sliding failure. Here, embankment slides over the reinforcement after formation of crack in the embankment, so here you can see here is the foundation soil and this is cohesive soil. So, phi is equal to 0 this is the geosynthetics material is placed between the embankment and the foundation soil. This is the height or the depth of the foundation soil and this is H e is the height of the embankment. Now, you see that embankment slide over the reinforcement after formation of crack. So, this is sliding on geosynthetics, so here the basal reinforcement is intact there is no failure of the reinforcement.

What we did the earlier in step three and there the embankment slide over the foundation soil this embankment slide over the foundation soil and then formation of crack. There is a rupture of the reinforcement, but it is not this case here reinforcement has not been ruptured here reinforcement is intact only embankment slide over the reinforcement after formation of crack in the embankment. So, two cases are different, so here we wanted to check what will be the factor of safety against this kind of sliding failure here.

That force diagram is given here it is a P fill is acting along this direction and this is the weight of this slide zone w s, this is the geotextile material this is H is equal to height of the embankment and this is the length L s that means this is e f L s. Now, this due to this load there will be a resisting force here, so this force will be equal to this w s into tan of delta f plus this is C a into L of s because this is the length L s.

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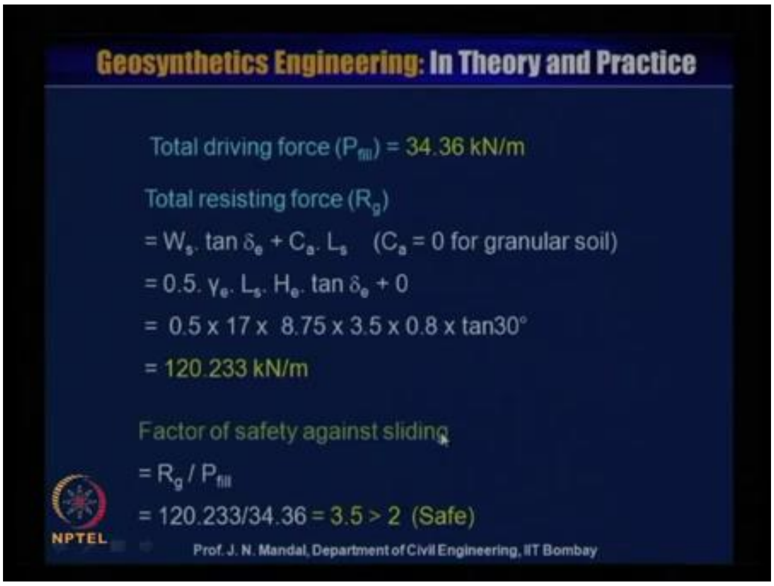

So, we see next that what will be the total driving force, so this force that is P fill which we have already calculated that is you know half into K into gamma h square. So, already we have calculated total driving force P fill is equal to 34.36 kilo Newton per meter, now total resisting force that is R g. So, here it will be resisting force see, so this resisting force will be equal to w s is the weight in to tan of delta of e plus C a into L of s, but here you see C a is equal to 0 for granular soil because this embankment this filling material is granular material. So, this is only phi there is no there is no C a, so this value is 0 because it is a granular soil not like the other case that foundation soil where phi is 0, but here it is C a is 0 or granular soil.

So, you can write that w s will be equal to this is w of s this equal to this is the area this is area triangle. So, this is half into this is L s this is L s and this is height H e, so half into L s into H e, so you can have here w s that means half into L s into H e into gamma e because unit weight of the embankment. So, this will give the what will be the weight what will be the weight, so half area into unit weight of the embankment will give the w s into tan delta e plus because C a is 0 for granular soil. So, you can have total resisting force R g is equal to this, now you are substituting this value so 0.5 gamma e unit weight of embankment is 17 L s know 8.75.

H e height of the embankment 3.5 and tan delta e we have considered eight percentage of tan phi, so phi value is given 30 degree, so this will be the 80 percent 0.8 into tan of 30 degree. So, this is 0.8 into tan 30 degree, so this will give the total resisting post R g is equal to 120.233 kilo Newton per meter. Now, you have to check the factor of safety against this sliding, so this will be equal to R g divided by P fill, so you know R g is 120.233 divided by this driving force P fill is 34.36. So, this will give the factor of safety against sliding is 3.5, so it is greater than 2, so it is safe.

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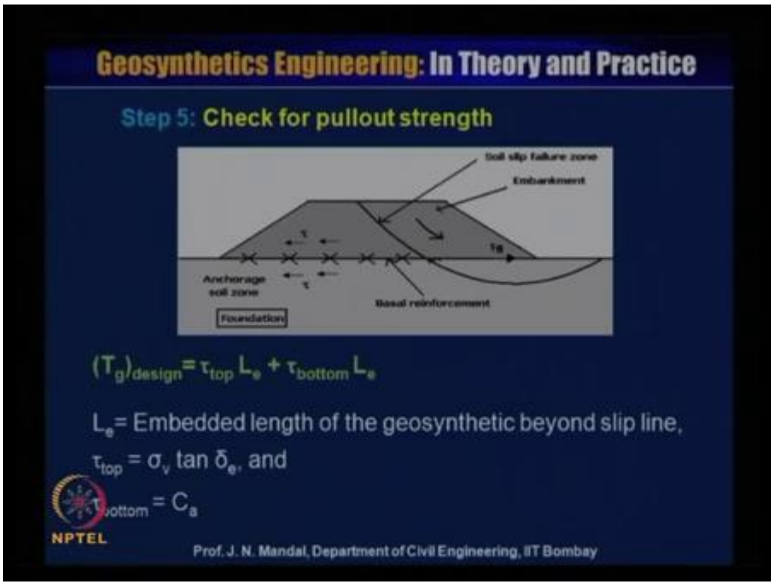

So, now step 5 check for pullout strength, so here you can see this is the foundation soil. This is the basal reinforcement and due to the pullout there is a mobilization of the friction between the soil and the basal reinforcement this is tau at the top and tau at the bottom. This is the anchorage soil zone and this is the embankment and this is the soil slip failure zone this is the soil slip failure zone. So, you are pulling that is T g you are pulling and this is the length which you call the embankment length or it call the bond length this is L of s. So, here this is t design will be equal to this is tau top into this distance L e divided by tau this is bottom into L of e, so I can show you later a representation like this.

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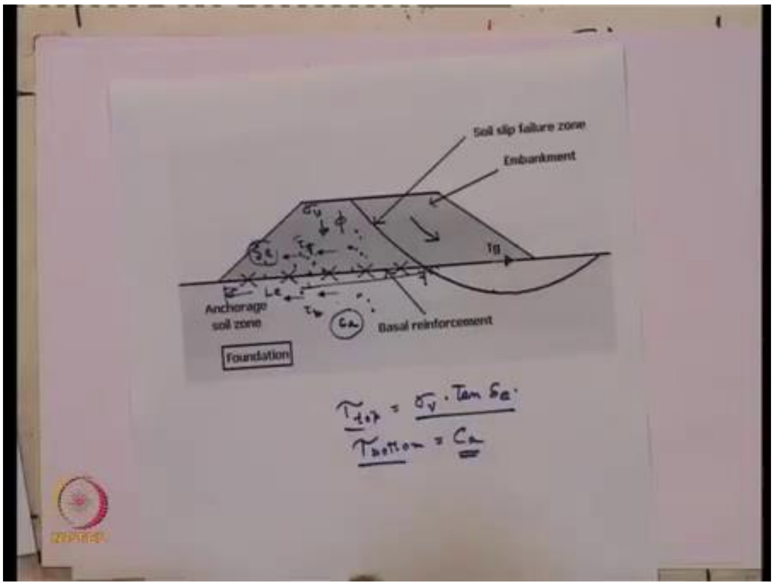

So, you are pulling like this, so shear stress is acting this is at the top tau t because embankment fill material as a phi value no c value and this is the foundation material has a c value, but not the phi value. So, there will be the friction between the basal reinforcement and the embankment this is the embankment. So, this is top that mean this tau top is the mobilization of friction between the embankment and the basal reinforcement that is tau t. Whereas in case of foundation soil the characteristics of the foundation soil is different.

So, there will be the friction or variation between the basal reinforcement and the foundation soil which is denoted as tau of B that means shearing stress at the bottom. This is shearing stress at the tau because material property for the embankment and the foundation soil is different and this distance is what you call the L of e this is the failure surface. So, this is the embedment length of the geosynthetics beyond this slip surface, so this tau top will be equal to what will be the vertical forces acting and what will be the friction between the basal reinforcement and the embankment.

So, let us say that is delta of e, because here is a phi so that will be the friction between other material means angle of friction between the basal reinforcement and the embankment is delta of e, so that is why this will be tan of delta e. So, tau top that mean tau of top will be equal to sigma of v into tan of delta of e, but in case of tau of bottom that means, this is bottom this will be only C a because there is a adhesion between basal reinforcement and the foundation soil. Foundation soil is saturated this is a cohesive soil, so this we can have only the C a that is why tau bottom will be this and tau top will be the sigma v into tan of delta of e. So, that is why here it is region T g design will be tau top into L of e and this is tau bottom into L e and this is embankment and this is C a equal to 0.

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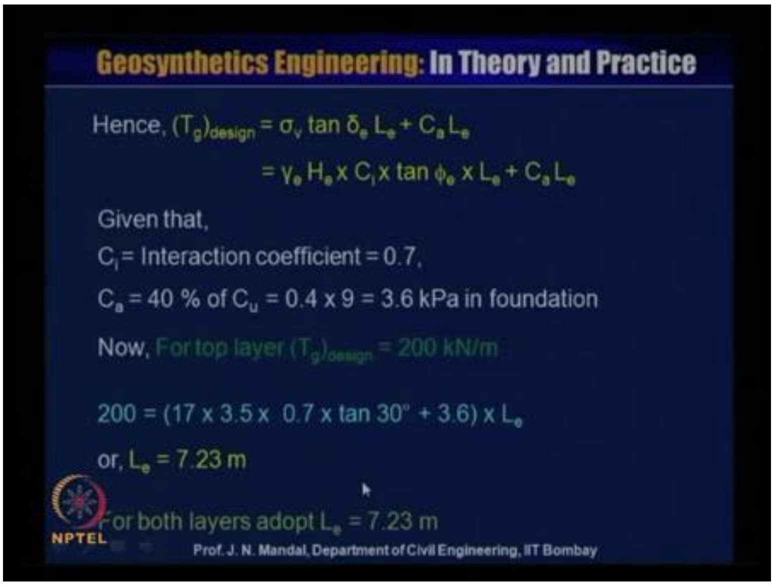

Now, you can write means T g design will be sigma v tan delta e and length is L e up to that length it is functioning plus C a into L e due to the bottom. Again, that this sigma v is equal to gamma e into H e because if unit weight of the embankment fill is gamma e and its height of the embankment H e. So, this will be gamma e into H e and this tan delta can be written as C i into tan phi e where C i is interaction coefficient and this interaction coefficient value is taken as 0.7.

So, this interaction coefficient value also you can find out from the pullout test you have to perform the direct shear test and also the pullout test and then you can find out the interaction coefficient that C i is 0.7. So, that is why it is written C i into tan of phi of e you know that what will be the friction angle of the embankment, and this into L of e plus C a into L e this is for the foundation soil and this per for the embankment and the basal reinforcement.

So, because this C a we are considering forty percent of C u you know the undrained shear strength of the foundation soil is 9, so C a can be taken 0.4 into 9 that is 3.6

kilopascal in foundation, because foundation is cohesive soil. Now, for top layer that is T g design we have checked or provided the tensile strength of the basal reinforcement at the top is 200 kilo Newton per meter.

So, you have to check that this is 200 T g design you can write 200 gamma e unit weight of the embankment is 17 into C i and this C i interaction coefficient is 0.7. So, you have taken 0.7 and H e is height of the embankment 3.5 and then tan of phi e phi e is equal to 30 degree, so tan 30 degree plus this is C i into L e, L e is common for both. So, this is C of a is 40 percent of C u that means 3.6 this is 3.6 and then L e, so this is the L e, L e is common so you have to check what will be the value of L of e. So, from this equation you can calculate that L e, so L e is equal to 7.23 meter so for both layer adopt the L e is 7.23 meter.

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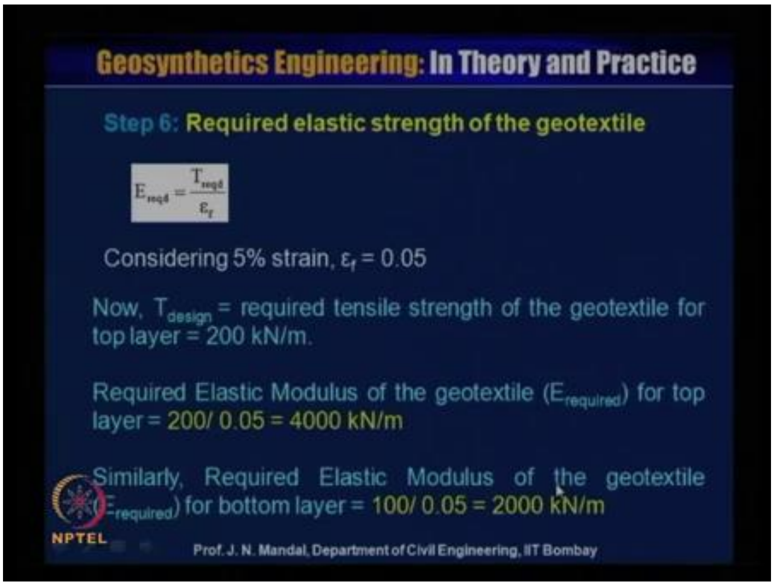

Now, step 6 what will be the required elastic strength of the basal reinforcement or geotextile. Now, you know that e require will be equal to what is t require divided by epsilon f considering 5 percent strain and epsilon f is equal to then 0.05. So, it depend up on that what will be the type of the soil then accordingly you can select that what will be the strain value. Let us consider for here the geosynthetics strain value you have taken 5 percent, so epsilon of f will be equal to 0.05. Now, T design is required tensile strength of geotextile for top layer is you know 200 kilo Newton per meter. So, what will be the required elastic modulus of geotextile e required for top layer that will be the t require is

200 divided by strain epsilon f is equal to 0.05.

So, this will give the required elastic modulus of the geotextile about 4,000 kilo Newton per meter. Similarly, you can also find out the required elastic modulus of geotextile e require for the bottom layer and we have provided the bottom layer that T g value is equal to 100 kilo Newton per meter. So, this e require that means required elastic modulus of geotextile at the bottom layer will be 100 divided by 0.05 will be 2,000 kilo Newton per meter.

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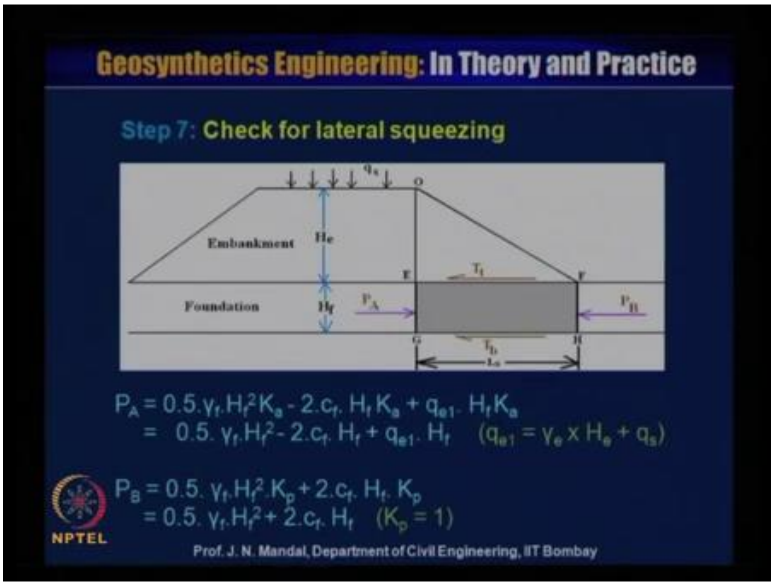

So, you know that how to calculate the modulus value for the basal reinforcement for the two layer system when it is 200 kilo Newton per meter and as well as when it is the 100 kilo Newton per meter. Now, step seven check for lateral squeezing you can see sometimes, there is a possibility of the failure due to lateral squeezing here. So, this is the active pressure which is acting here and this is the P B passive pressure is acting and the shear forces are acting in the top T t of top up to here and the bottom is T b. This is the L s that is g and h it is like a block while it is acting and this is the foundation the depth of the foundation H f this is the embankment height is H e.

There is a surcharge load q of s, so you know that P A will be equal to half into this is the foundation soil half into gamma f into H f square into K of a minus 2 of C of f into H f into K a plus q e 1 into H f K a, so this is due to the surcharge load. Now, what is q e 1 that is this is the height of the embankment H e and if gamma e is the unit weight of the embankment. So, here it will be gamma e into H e plus this is surcharge load q s, so that is why gamma e into H e plus q s due to surcharge load, so then q of e 1 is gamma e into H e plus q of s.

So, we can write this is 0.05 gamma h H f square and k you know one so k is 1 minus 2 into C f into H f again K a is equal to 1 plus q e 1 into H of f because again K a is equal to 1, so you can have P A is equal to this equation. Now, similarly you can calculate that what is P B, so P B will be equal to half into gamma of f into H f square into K p this is the passive force plus 2 into C of f into H f into K p.

So, here again K p is equal to 1, so you can write that passive force P B is equal to 0.5 gamma f H f square plus 2 into C f into H f because K p is equal to 1. So, we will use this equation for active force P A is equal to this equation and for passive force P B is equal to this equation and there are also that T t and T b. So, we are assuming that q s is equal to 0 that mean this part will be the 0.

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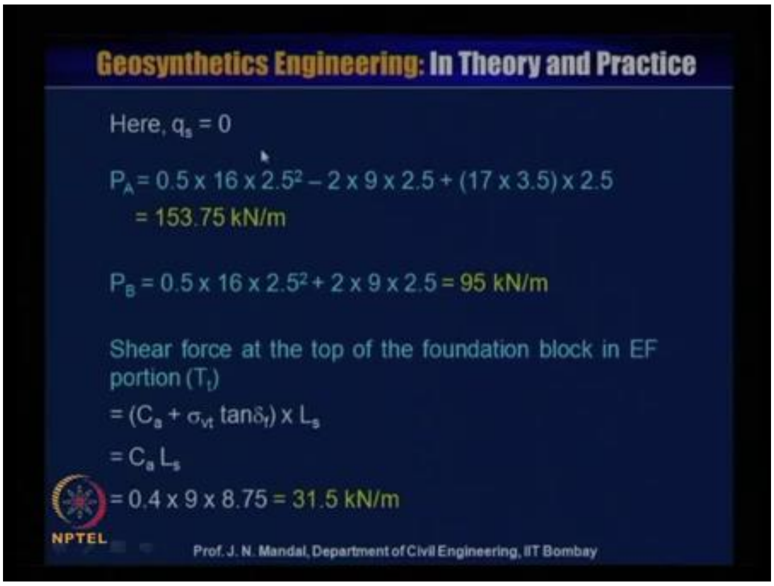

So, we are assuming the q s is equal to 0, so then P A will be 0.5 half here gamma f is the unit weight of the foundation soil is 16, so 0.5 into 16 into this is H f square that means height of the or depth of the foundation. So, this will be 2.5 square minus 2 minus 2 into C f into H f minus 2 into C f, C f is foundation cohesion value is 9 into height of the foundation soil or depth of the foundation soil 2.5 meter plus this is plus q e 1 into H f because q e one again gamma e into H e into q s.

We are assuming q s is 0, so it will be only gamma e into H e, so you can write here that this is gamma e unit weight of the embankment 17 and height of the embankment is 3.5 and this is acting for this 2.5 this will be this into 2.5. So, this P A value will be 153.75 kilo Newton per meter now. Similarly, you can calculate P B, P B is equal to 0.5 here gamma f gamma f is equal to 16 into this is H f square that is 2.5 square because this is the height 2.5 of the foundation 2.5 square plus 2 into C f into H f, so plus 2 C f is the 9 foundation soil cohesion value into this H of f.

So, this H f is equal to 2.5, so this is all H f is equal to 2.5, so P B the passive force will be 95 kilo Newton per meter. So, we calculated what will be the active force and what will be the passive force. Now, you have to calculate that what will be the shear force. That means, here is acting at the top that means e f portion and also shear force which is acting at the bottom that is g of h. So, shear force at the top of the foundation block that is e f portion that is T t is designated as T t, so T t will be equal to C a plus sigma v t because for top vertical force into tan delta f because for tan delta f in the foundation soil this is 0.

So, we can write the equation T t will be C a into L s that is why T t is equal to C a into L s now this C a value you have 40 percent of the C value undrained shear strength of the foundation soil, so that is why 40 percent mean 0.4 into 9 into L s, L s we calculated earlier that is 8.75. So, this will give you that shear force at the top of the foundation block that is T t is 31.5 kilo Newton per meter here T t at the top is 31.5 kilo Newton per meter. Now, that shear force at the bottom of the foundation block in e f portion T b that means here what it would be…

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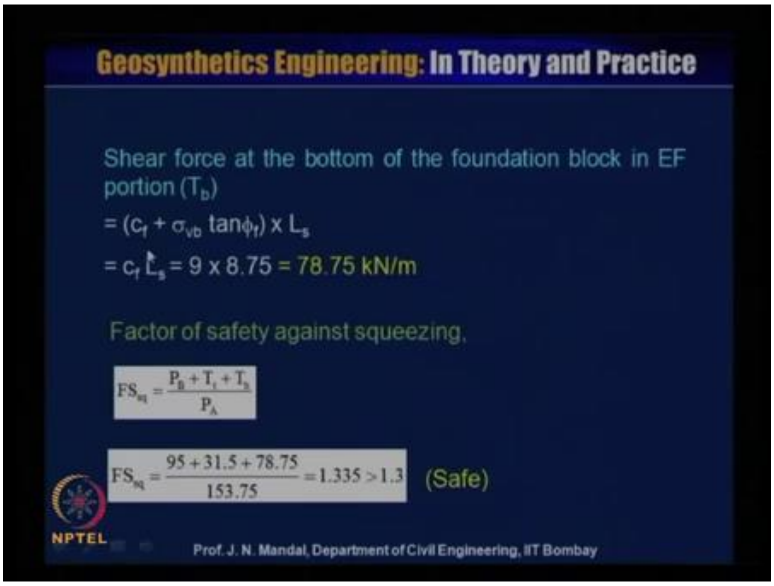

So, here again that C f plus sigma v b that mean this is the vertical force g 2 that is the bottom into tan phi f into l of s because this portion is equal to the 0 because this foundation soil where there is a only that c of f, but not the phi f. So, you can write C f into L s and you know C f value is equal to undrained shear strength of the foundation soil is 9 into L s is 8.75 so this will give you seventy 8.75 kilo Newton per meter for T b.

Now, you have to determine the factor of safety against the squeezing so factor of safety against squeezing will be equal to P B plus T t plus T b divided by P of A. So, you can have from here this is P A and this is P B plus this is T t and this is T b all are acting in this direction, so P B plus T t plus T b will be equal to P of A. So, you can write the factor of safety against squeezing is P B plus T t plus T b divided by P of A, so P B we have calculated that is 95 T t we have calculated. This is P B we have calculated 95 and also we have calculated T t 31.5 this is 31.5 and also at the bottom here T b we calculated 78.75. This is 78.75 this divided by P of A P of A 153.75 here we have calculated P of A 153.75. So, that is why 153.75, so here substituting this all the value of P B, T t, T b and P A and then you calculate, what will be the factor of safety against squeezing and this we found 1.335 which is greater than 1.3 that means it is the safe. So, we checked against the squeezing and this is on the safer side.

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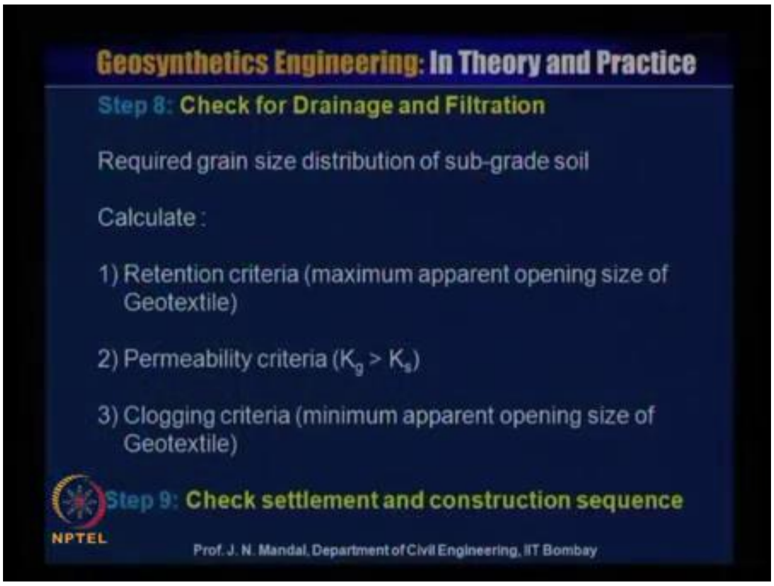

Step eight check for drainage and filtration and whenever you will design this embankment on the sub soil, or whenever you are introducing this basal reinforcement in between the foundation and embankment soil you should check the drainage and filtration this is very important. So, you require grain size distribution of the sub grade soil you have to calculate one retention criteria that means, what will be the maximum apparent opening size of the geotextile material to permeability criteria.

That means coefficient of permeability of the geotextile should be greater than coefficient of permeability of the soil it is always. If coefficient of permeability vary depending up on the code or the specification you use as per ASTM, this coefficient of permeability of the geotextile should be ten times the coefficient of permeability of the soil.

As per the coefficient of permeability of the geotextile should be greater than equal to five times of coefficient of permeability of the soil and number three clogging criteria that means, what should be the minimum apparent opening size of the geotextile. That means 95 or equivalent opening size of the geotextile, so these are the three criteria must satisfy. Step nine, check the settlement and the construction sequences you can check the settlement as per the conventional geotechnical engineering problem.

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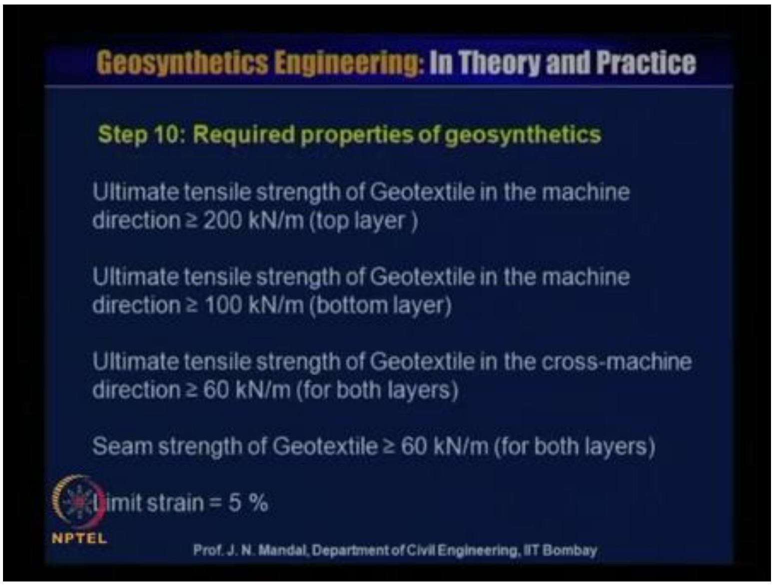

You can use any basic soil mechanics book and can check that what will be the settlement, and also you should check the construction technique step ten required properties of geosynthetics. So, ultimate tensile strength of the geotextile in the machine direction it should be greater than equal to 200 kilo Newton per meter in the top layer. So, what we mentioned that you need because it is a very high strength of the basal reinforcement it is about 300 kilo Newton per meter. So, we have divided into the two layer of the basal reinforcement, and the top layer the strength ultimate strength of the geotextile in machine direction is 200 kilo Newton per meter.

At the bottom layer this ultimate tensile strength of geotextile in the machine direction should be greater than equal to 100 kilo Newton per meter also spacing between these two basal reinforcements is kept about 200 millimeter. Now, ultimate tensile strength of the geotextile in the cross machine direction should be greater than equal to 60 kilo Newton per meter for both the layer. So, here it is required to check the what will be the ultimate tensile strength in the machine direction, what will be the ultimate tensile strength in the cross machine direction because in the cross machine direction also plays also very important role.

In case for the design of embankment using the basal reinforcement and then accordingly you have to select the basal reinforcement from the manufacturer side. So, sometimes you avoid that the strength in the cross machine direction, but you must check and embankment design is quite confusing. So, you have to be very careful for the design of embankment using geosynthetics material on soft foundation and seam strength of the geotextile should be greater than equal to 60 kilo Newton per meter for both the layers. You require also the limit strain and the limit strain is equal to 5 percentage, so this is the way you can design and then you are mentioning here.

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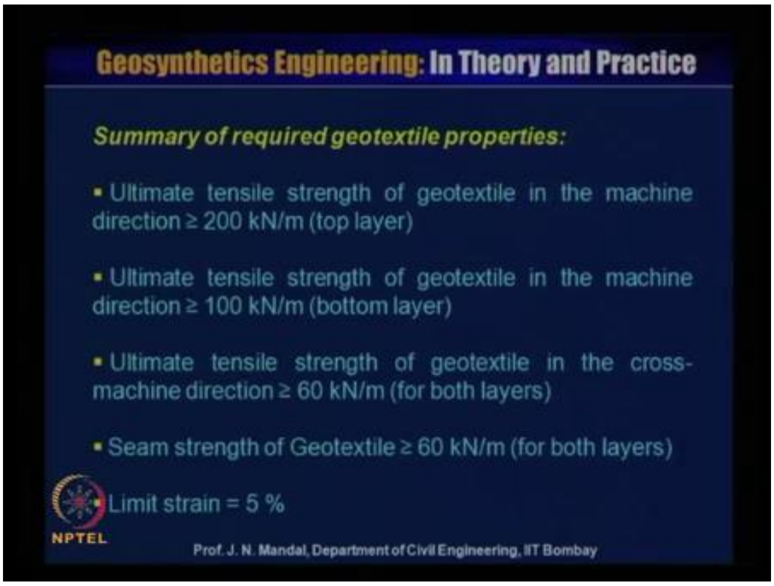

The summary of the required geotextile that property ultimately you have to give this property that, you know that ultimate tensile strength of the geotextile in machine direction greater than equal to 200 kilo Newton per meter. Top layer ultimate tensile strength of geotextile in the machine direction is greater than equal to 100 kilo Newton per meter. Bottom layer ultimate tensile strength of the geotextile in the cross machine direction greater than equal to 60 kilo Newton per meter for both layer seam strength of geotextile greater than equal to 60 kilo Newton per meter for both the layer and limit strain is 5 percent, so this is the required geotextile property.

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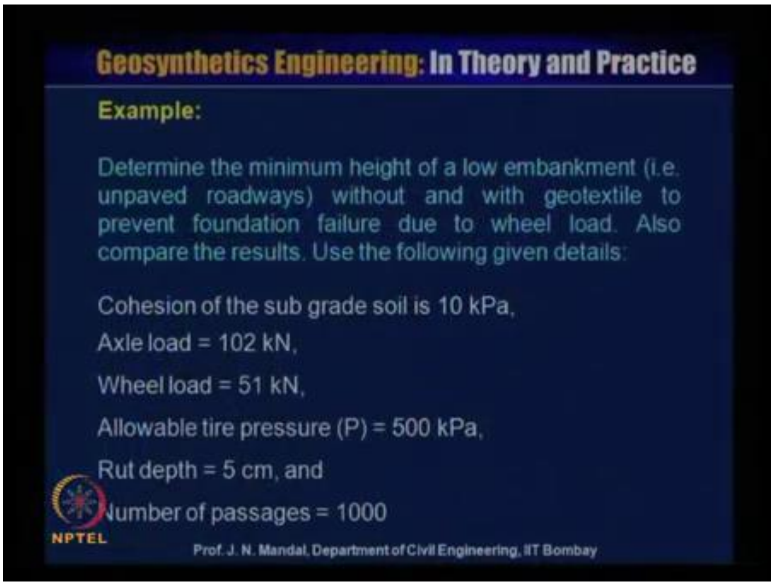

Now, we are giving another example determine the minimum height of a low embankment that is unpaved roadway without, and with geotextile to prevent the foundation failure due to the wheel load. Also compare the result and you can use the following given detail. So, here cohesion of the sub grade soil is 10 kilopascal axle load 102 kilo Newton little bit higher than the standard. So, wheel load will be the half of the axle load that mean 102 divided by 2 is about 51 kilo Newton. Allowable tire pressure P is 500 kilo Pascal and rut depth is 5 centimeter and number of passage is 1,000. We have also described earlier how you have to design the unpaved road by the given by the Giroud and the Noiray, and also US army cops then other different method here in this example.

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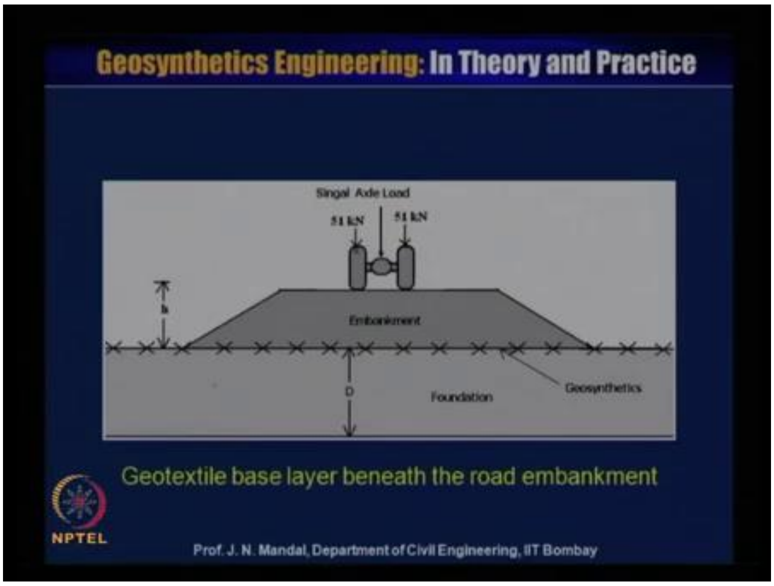

This is the geotextile base layer beneath the road embankment and this is small h is the height of the embankment. This is single axle load know this is 51 kilo Newton this is 51 kilo Newton due to single axle load and this is the embankment. This is the geosynthetics is placed between the embankment and the foundation soil.

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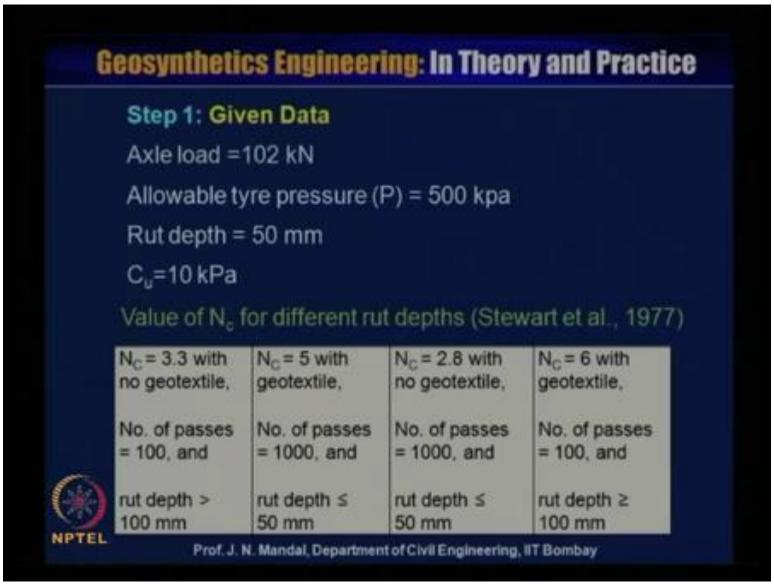

Step one, given data axle load is equal to 102 kilo Newton allowable tire pressure P is equal to 500 kilo Pascal rut depth is equal to 50 millimeter and C u undrained shear strength of the soil is 10 kilo Pascal. And value of N c for different rut depth is given by

Stewart et al 1977. They have performed the extensive field test with and without geosynthetics material. They have obtained this chart the N c value is equal to 3.3 with no geotextile N c value is equal to 5, with geotextile N c value is equal to 2.8, with no geotextile N c value is equal to 6 with geotextile.

So, here when number of passes is 100 and rut depth is greater than 100 millimeter, when N c value is 5 number of passes is equal to 1,000 and rut depth should be less than equal to 50 millimeter N c when 2.8 number of passes is equal to 1,000 and rut depth is less than equal to 50 millimeter. Here, N c is equal to 6 with geotextile number of passes equal to 100 and rut depth greater than equal to 100 millimeters.

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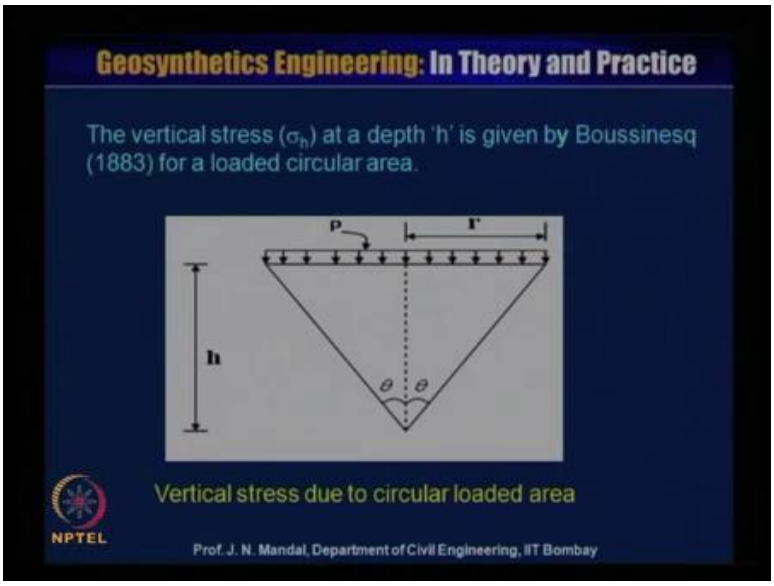

We will check in our example where it lies, now the vertical stress sigma H at a depth h is given by Boussinesq 1883 for a loaded circular area. So, you can calculate the what will be the vertical stress due to the circular loaded area, so this angle is equal to theta this is also theta this is the P and this is height h.

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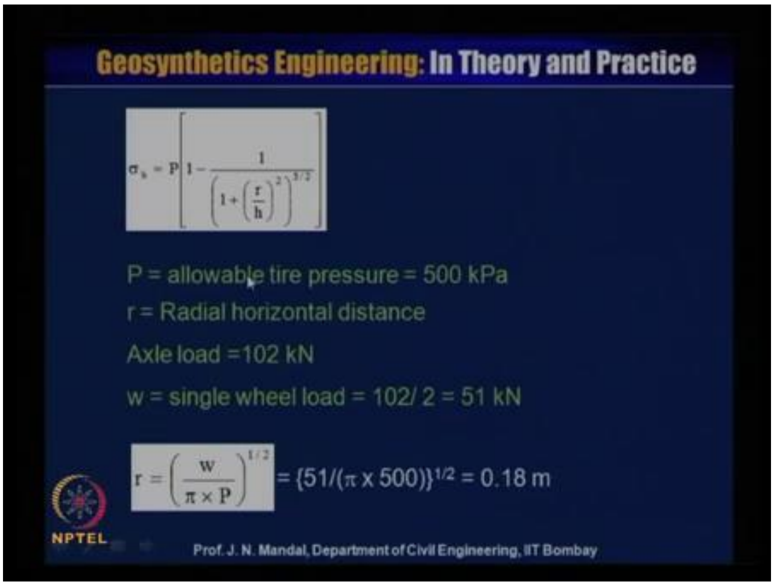

So, we know this equation from Buoussinesq that sigma h is equal to P into 1 minus 1 divided by 1 plus r by h whole square whole to the power 3 by 2. So, where P is equal to allowable tire pressure is 500 kilo Pascal and r is equal to radial horizontal distance. Here, the axle load is 102 kilo Newton and single wheel load w will be equal to 102 divided by 2 that means 51 kilo Newton.

We know the equation r is equal to w divided by pi into P whole to the power half, so this w is equal to single wheel load is 51 kilo Newton. So, this is 51 kilo Newton this divided by pi into P and P is allowable tire pressure that is 500 kilo Pascal whole to the power half. So, you can calculate the r value, so r value is 0.18 meter, so we know what is r value here 0.18 meter.

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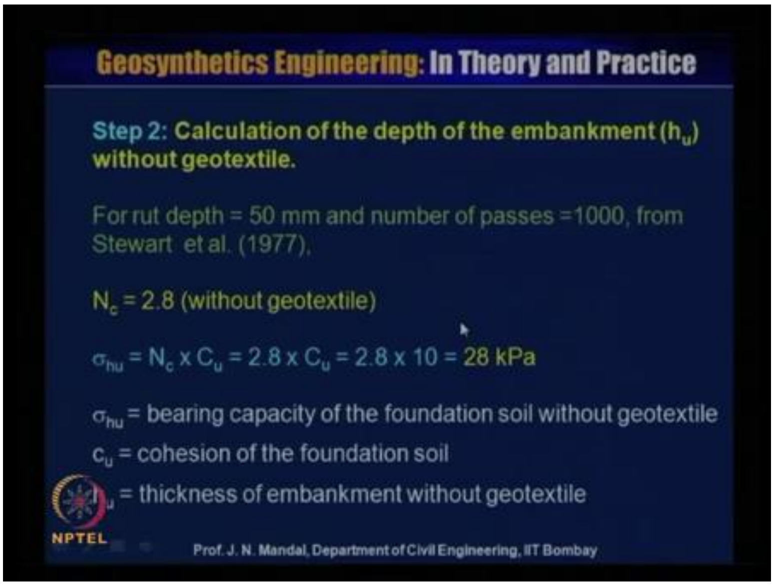

Now, step 2 calculation of the depth of the embankment h u is designated as a h u without geotextile, so for the rut depth of 50 millimeter and number of passes is 1,000. So, we can make use of the Stewart chart that is Stewart given by et al in 1977. So, N c value is 2.8 without geotextile you can see from this chart here because number of passes is 1,000 and rut depth less than equal to 50 millimeter, so N c value will be 2.8 with no geotextile. So, we will take this column, so then you can see here that N c value is 2.8 without geotextile because rut depth is 50 millimeter number of passes is 1,000.

Now, sigma h u which is the bearing capacity of the foundation soil without geotextile we are considering bearing capacity over here that equal to N c into c v. So, N c without geotextile from the chart we obtained 2.8 into C u, C u is the undrained shear strength of the soil that mean that is ten which is given so 2.8 into 10 is 28 kilopascal. So, we obtained that sigma h u that mean bearing capacity of the foundation soil without geosynthetics is 28 kilo Pascal and we have considered that height, or thickness of the embankment without geotextile is h u.

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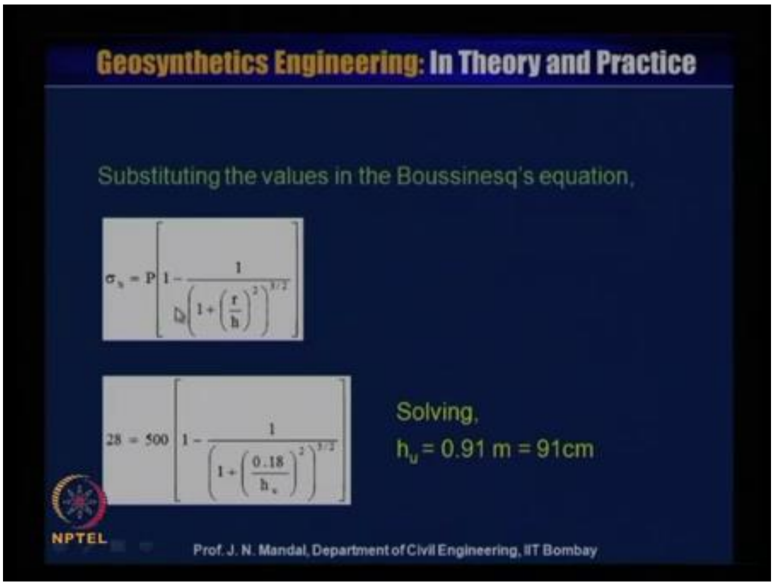

Now, substitute the value in the Boussinesq equation, so we know sigma h is equal to P to 1 minus 1 by 1 plus r by h whole square whole to the power 3 by 2. Now, here unreinforced case where sigma h that mean sigma h u, so sigma h u mean this is 28 unreinforced case. So, this is 28 and P you know 500, so P already we have we know that P value we have calculated that is 500, so this is 500 into 1 minus 1 upon 1 plus r we calculated is 0.18 r just we calculated here r value calculated 0.18 meter.

So, this is 0.18 meter divided by h u that h u is the thickness of the pavement without geosynthetics material. So, you can see that all values are known except h u. So, from this equation you can solve, and find out what should be the thickness of the pavement without geosynthetics that is h u is equal to 0.91 meter or is equal to 91 centimeter. This is the thickness of the pavement without geosynthetics material.

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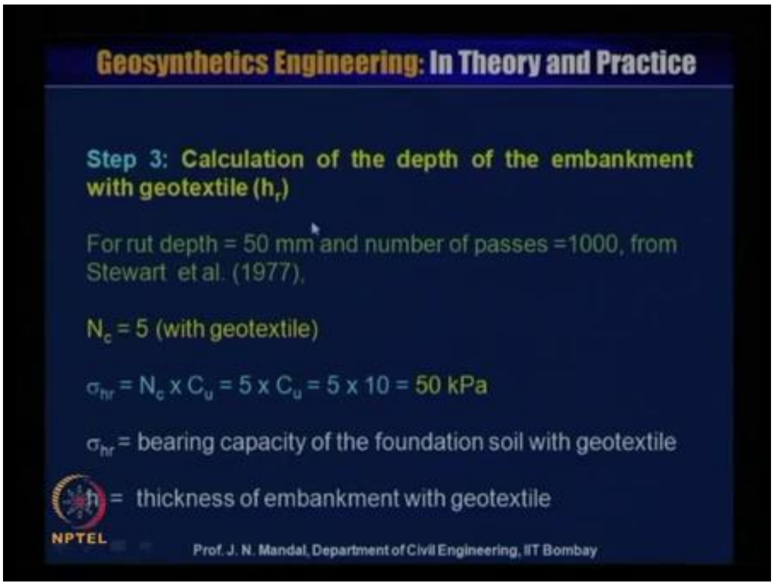

Now, step three calculation of the depth of the embankment with geotextile which is designated at h r. So, again for rut depth 50 millimeter number of passes 1,000 from stewart et al chart 1977 N c value will be 5 with geotextile, you remember rut depth 50 and 1,000 passes. So, N c value will be the 5, so you can use this design chart number of passes is 1,000 N c value 5 with geotextile rut depth is 50 millimeter shown in this column.

So, you are telling N c value is equal to 5, so here N c 5 with geotextile, so sigma h r that mean bearing capacity of the foundation soil with geotextile will be equal to N c into C u. So, N c value with geotextile 5 into C u value is 10, so 5 into 10 is equal to 50 kilo Pascal. So, bearing capacity of the foundation soil with geotextile is 50 kilopascal, now we are assuming h r is equal to thickness of embankment with geotextile.

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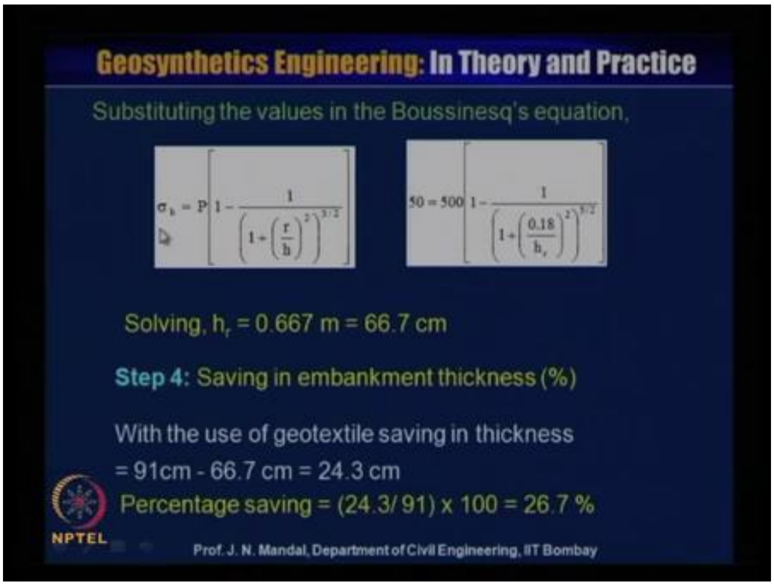

Now, we are substituting the value by Boussinesq equation this is the equation, so here the sigma h value mean bearing capacity sigma h r in case of the reinforcement 50 kilopascal. So, this is 50 kilopascal P is 501 minus 1 plus r is 0.18 and this is h r the thickness of the pavement with geotextile the whole square whole to the power 3 by 2.

So, now if you can solve this equation, so you can obtain the thickness of the pavement with geotextile is 0.667 meter or 66.7 centimeter, so you see that with geotextile you are having 66.7 centimeter whereas, without geotextile you are getting 91 centimeter. So, we have to check what should be the saving in the embankment thickness in terms of the percentage. So, with the use of geotextile saving in thickness that is 91 centimeter minus 66.7 centimeter that means 24.3 centimeter. So, percentage of saving will be 24.3 divided by 91 into 100 about 26.7 percentage, so you can see that with the introduction of the geosynthetics material and how you can reduce the thickness drastically.

So, this amount of the good quality aggregate also can be the same, so in this part I showed you that, what are the design for the embankment using the basal reinforcement. Then also that for the road construction for the embankment that if you can use the Boussinesq equation and you can also, use that Stewart chart and depending up on the rut depth and the number of the passes and the axle load.

So, you can also calculated what will be the thickness of the pavement without and with geosynthetics material and we you also check that what percentage of the saving, but you require proper kind of the geosynthetics material selection. So, these are part which we have covered for the embankment using the geosynthetics material. Please let us hear from you any question?

Thanks for listening.