Geosynthetics Engineering: In Theory And Practices
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Lecture - 40
Geosynthetics for Embankments on Soft Foundations

Dear student warm welcome to NPTEL phase 2 program 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 is lecture number 40 module 8, geosynthetics for embankment on soft foundation. Now, embankment construction on the soft foundation soil have a tendency to move laterally, because horizontal earth pressure are acting at the embankment. Therefore, this earth pressure causes the horizontal shear stresses at the base of the embankment, which must be resisted by the foundation soil.

And if the foundation soil does not have a adequate shear resistant, this embankment will fail. Therefore, it is essential that very high strength or the high modulus geogrid or geotextile as a reinforcement can be provided to increase the stability, and can prevent from the failure. So, this use of high modulus of geogrid or the geotextile can increase the design factor of safety, you can also increase the height of the embankment, you can also reduce the settlement and also you can reduce the displacement of the embankment.

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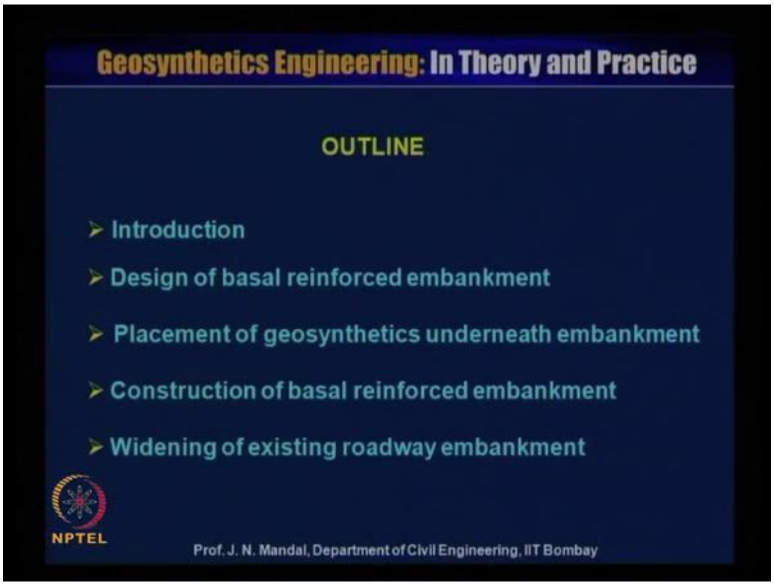

Now, outline of this course is introduction, design of basal reinforced embankment, placement of geosynthetics underneath embankment, construction of basal reinforced embankment, widening of existing roadway embankment.

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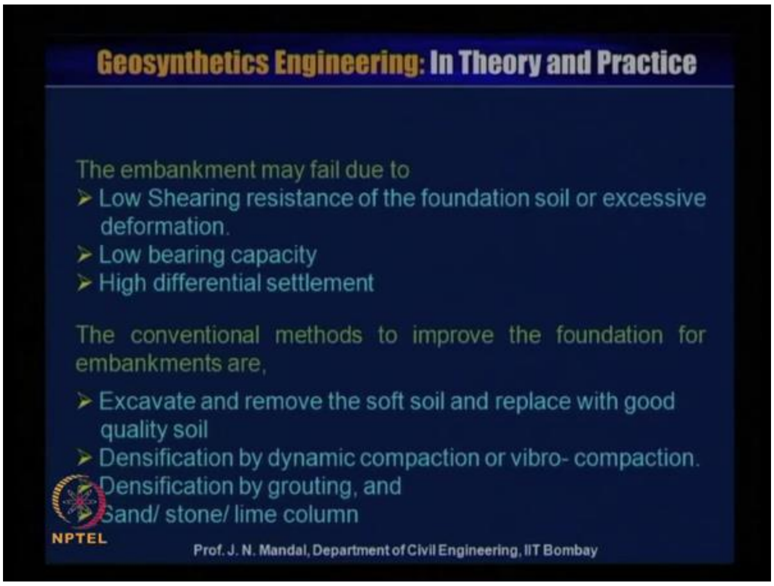

Now, the embankment may fail due to low shearing resistance of the foundation soil or excessive deformation, low bearing capacity, high differential settlement. The conventional method to improve the foundation for embankment are excavate and remove the soft soil and replace with the good quality of soil, or densification by dynamic compaction or vibro compaction, densification by grouting, and sand stone or the lime column.

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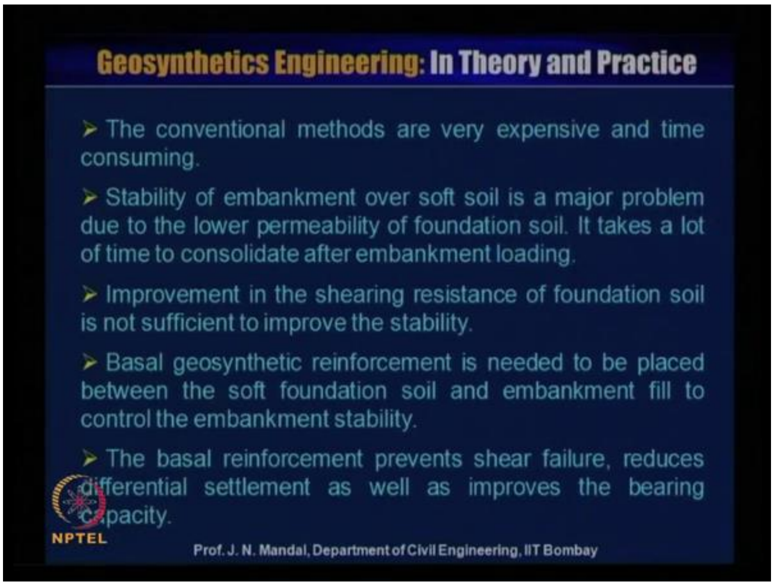

The conventional method are very expensive and the time consuming, stability of embankment over soft soil is a major problem due to the lower permeability of foundation soil, It takes a lot of time to consolidate after the embankment loading. Improvement in the shearing resistance of foundation soil is not sufficient to improve the stability, basal geosynthetics reinforcement is needed to be placed between the soft foundation soil and embankment till to control the embankment stability. The basal reinforcement prevent shear failure, reduces differential settlement as well as improve the bearing capacity of the soil.

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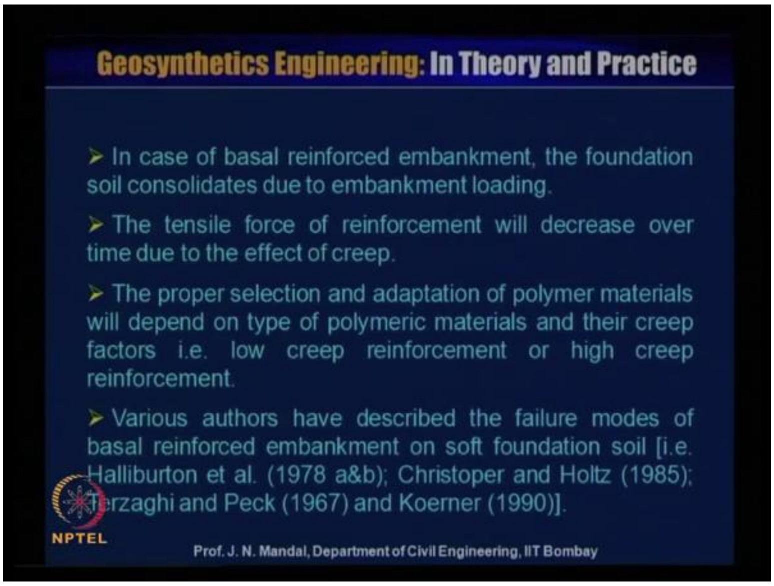

In case of basal reinforced embankment, the foundation soil consolidate due to the embankment loading, the tensile force of reinforcement will decrease over the time due to the effect of creep. The proper selection and adaptation of the polymer material will depend on type of the polymeric material and their creep factor, that is low creep reinforcement or high creep reinforcement. Various authors have described the failure modes of basal reinforced embankment on soft foundation soil, that is Halliburton et al 1978 a and b, Christopher and Holtz 1985, Terzaghi and Peck 1967 and Koerner 1990.

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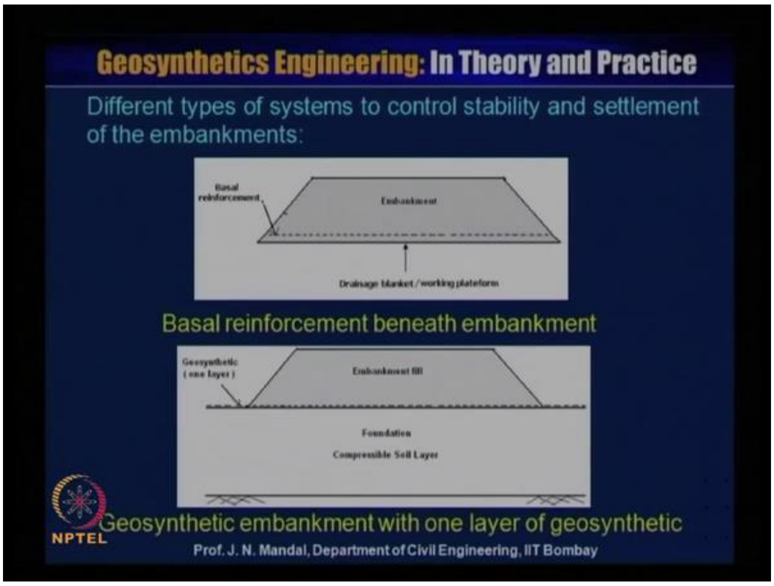

So, here you can see different types of the system to control the stability and the settlement of the embankment. So, this is basal reinforcement has been placed between the embankment and the foundation soil, you can provide a drainage blanket and the geotextile material for the working platform. So, you can construct the embankment using the basal reinforcement beneath the embankment, also geosynthetics reinforcement embankment with one layer of the geotextile material, we can place simply one layer of the geotextile material and also you can construct this embankment.

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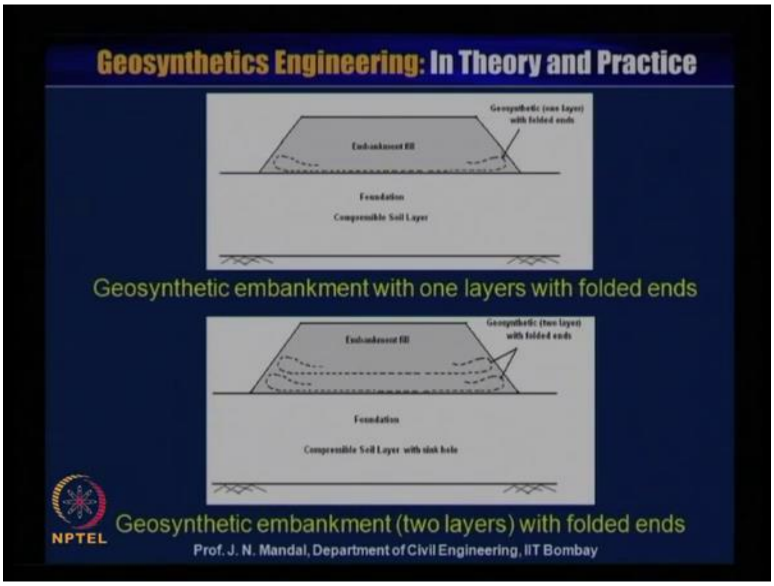

Now, you are constructing the embankment on a foundation soil which is compressible soil in nature. So, you can geosynthetics one layer with the folded end, you can wrap at the end. So, this system also can be used, so geosynthetics embankment with one layer with folded end, so this can provide you the good anchoring. So, it can restrain. So, there is a development of the tensile stress in the geosynthetics material then anchoring can help sometimes, it is required for pre-tensioning the geosynthetics material, even then in the foundation soil geosynthetics soil layer where there is a sink hole. So, you can provide with the double layer two layer with a folded end if the soil is soft and with the sink hole.

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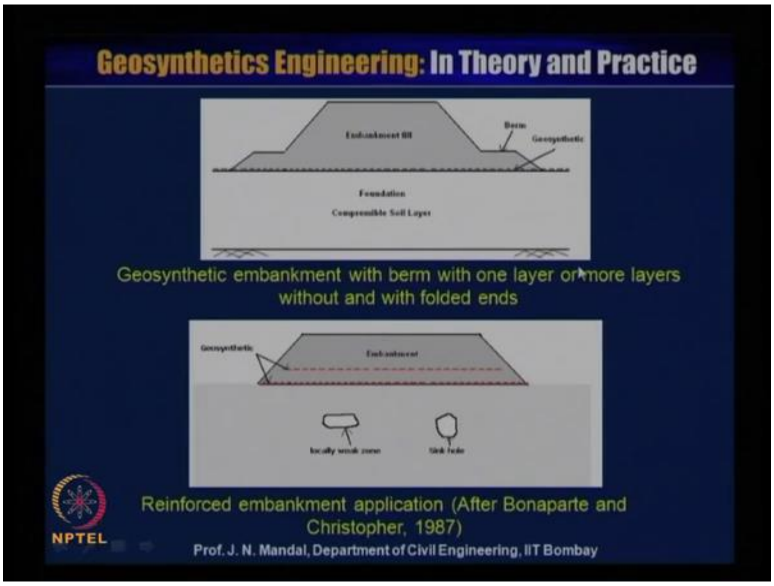

Here the reinforced embankment application after Bonaparte and Christopher 1987, you can see that this is the foundation compressible soil layer, this is the embankment fill and he has placed this geosynthetics material here, sometimes it is also require berm to stabilize the soil initially. Suppose, if you do not provide with the berm so you find that the embankment is unstable, but it is sometimes also necessary that you have to provide with some berm to make it a stable, next that reinforced embankment where you have used two layer of the reinforcement. I say that where there is a any locally weak zone or if there is a sink hole, so you can also provide with the two layer of the geosynthetics material.

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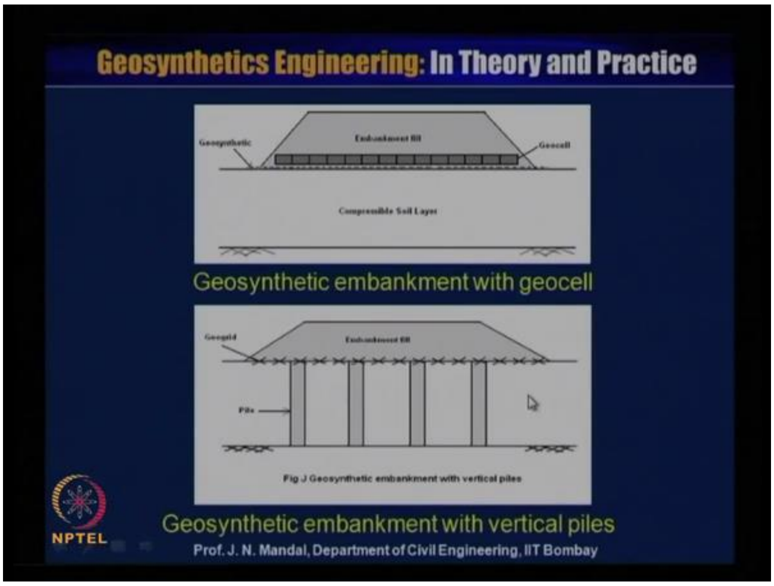

Now, here I am just focusing that that different types of the system or different types of the geosynthetics material how you can place and how you can improve the embankment here, this is a compressible soil layer and this is a geosynthetics material and you are providing with a what geocell, this is a three dimensional polygon structure. So, we will design later on this geocell structure how you can design this geocell, but you can also use the geocell for the stability of the embankment even then it has been used in the Singapore geogrid geocell and it will provide the very good confinement effect.

Now, here the geosynthetics embankment with the vertical piles, you can see here is the vertical pile and this is the geogrid material has been used even then pile, and pile cap can be reduced and spacing also can be increased, because this load can be transmitted from the embankment through the geogrid which will act as a tension membrane. So, that was the one of the reason that you can reduce the diameter of the cap and also spacing of the reinforcement can be increased.

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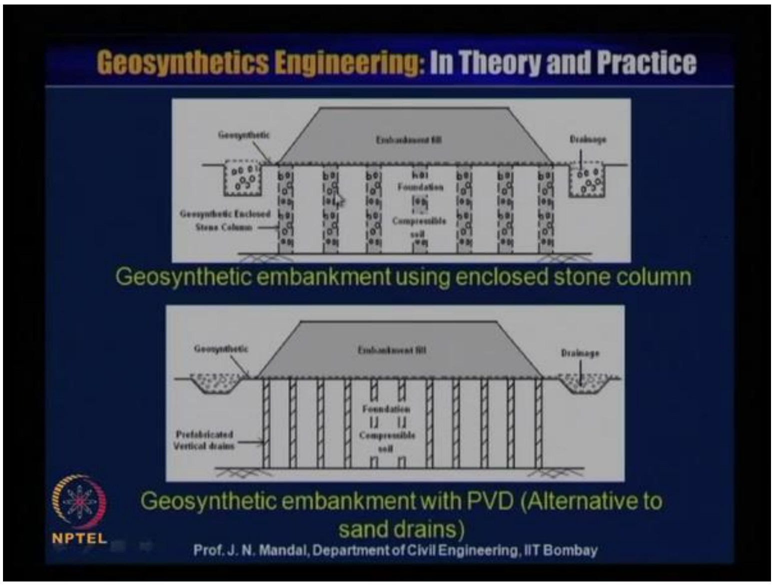

So, here geosynthetics embankment using enclosed stone column, this is geosynthetics and this is the stone. So, geosynthetics enclosed stone column also can be used for the stabilization of the embankment as you know that geosynthetics embankment with PVD prefabricated vertical drain or turn a dip to the sand drain also can be used. And we will design later on in our ground improvement course for both that how will you design, the enclosed stone column. And how you will design the prefabricated vertical drain or the sand drain.

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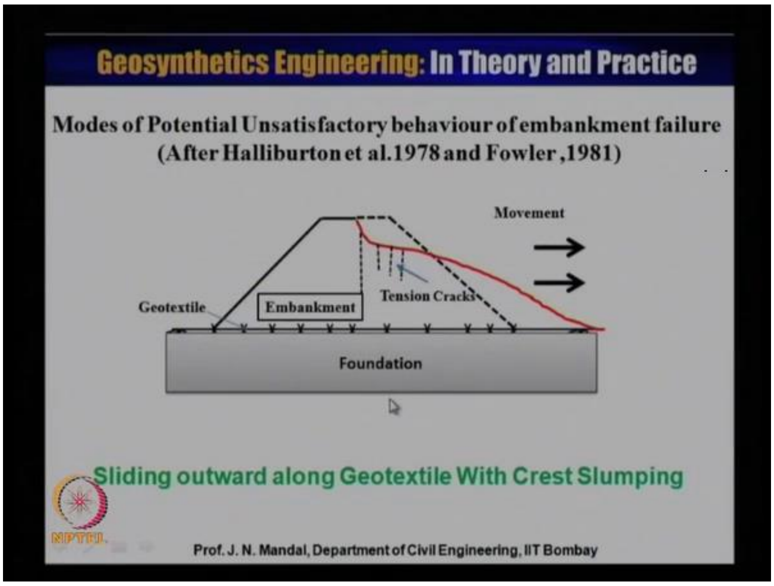

Now, mode of potential unsatisfactory behaviour of embankment failure after Halliburton et al 1978 and Fowler 1981, you can see this is the embankment. This is the foundation soil and then sliding outward along geotextile with crest slumping, you can see that what will be the potential unsatisfactory behaviour of the embankment failure. Even when you are providing with the geotextile material between the embankment and the foundation soil. And it slides outwards and there is a development of the tension crack and then we will see that how the earth pressure will develop and how we can design that how we can set the embankment by the inclusion of the geogrid material.

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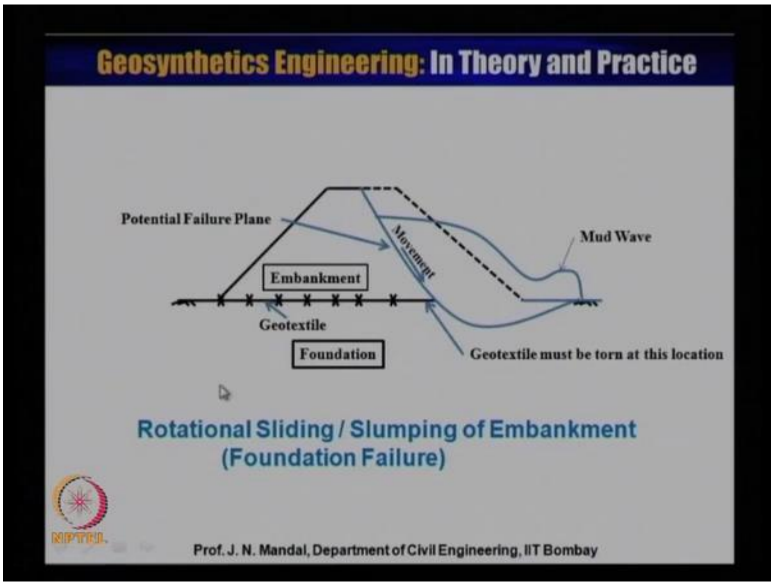

Now, here the rotational sliding or slumping of embankment, you can see here there is foundation failure, this is the embankment, this is the foundation and this is the geotextile material is placed between the embankment and the foundation. And you can see that how the potential failure plane, this is rotational slide is slumping, up there is a mud wave formation, here this movement is like this. So, here is a possibility of the geotextile must be torn at this location due to the rotational sliding or slumping of the embankment or this foundation failure.

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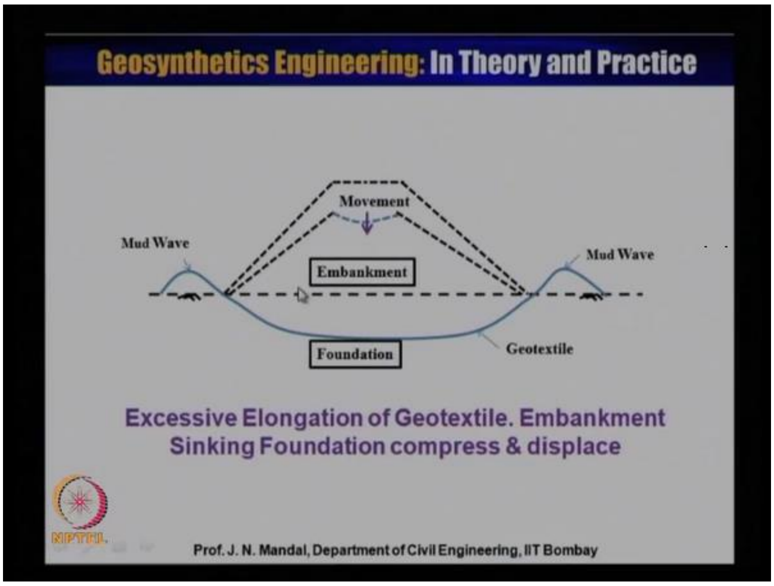

Now, here the excessive elongation, this is the foundation, this is the embankment, this is the geosynthetics material and due to the load you can see how it move downward. And you see that how the shape of the geotextile material, and there is a mud wave and this for excessive elongation of the geotextile and this embankment sink towards the foundation and compress and displace. So, these are the different types of the failure have been observed so you observe how is this excessive elongation you see that sliding and different types of the failure.

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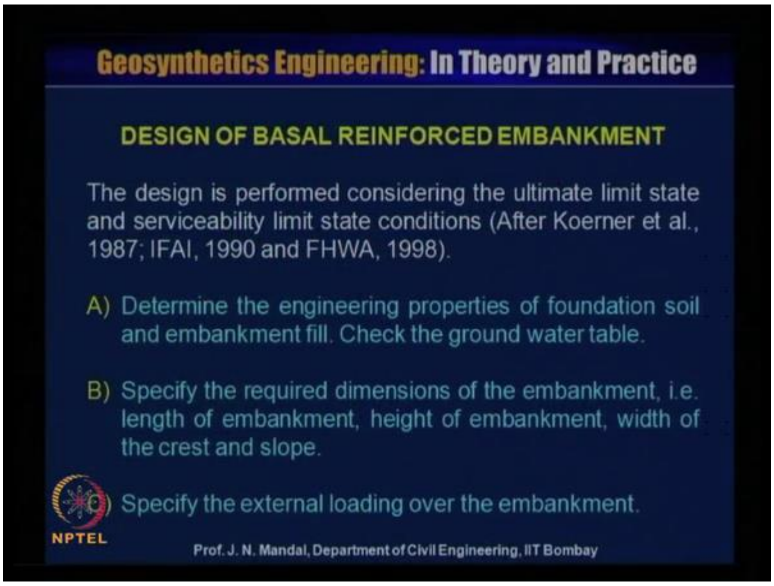

Now, design of basal reinforced embankment the design is performed considering the ultimate limit state and serviceability limit state condition after Koerner et al 1987, IFAI 1990 and FHWA 1998, determine the engineering properties of the foundation soil and embankment fill, check the ground water. Specify the required dimension of the embankment, that is what will be the length of the embankment, what will be the height of the embankment, what will be the width, the crest and the slope. Specify the external loading over the embankment. Ultimate limit state, you have to check local stability when you design this embankment on soft soil using geosynthetics material.

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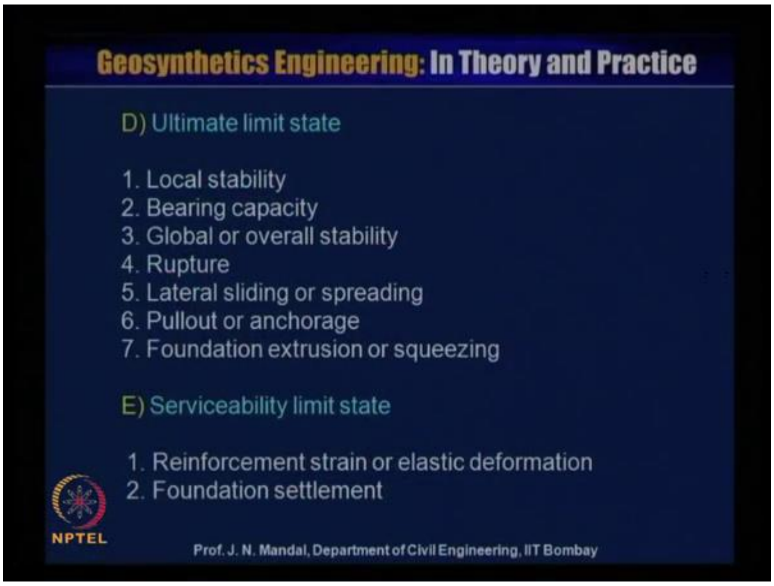

You should check the two thing, one is the ultimate limit state and the serviceability limit state. In ultimate limit state you have to check local stability, bearing capacity, global or overall stability and rupture. Lateral sliding or spreading and pullout or anchorage and foundation extrusion or squeezing. So, these are the type of the failure occurs and you must check all these it is in ultimate limit state. The serviceability limit state, reinforcement strain or elastic deformation and the foundation settlement. So, you must check this.

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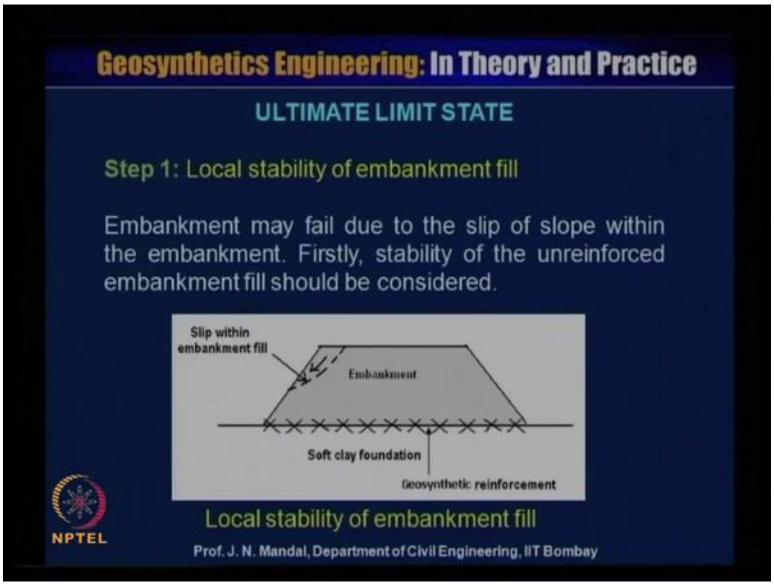

So, ultimate limit state step, local stability of embankment fill embankment may fail due to the slip of slope within the embankment here, slip or slope within the embankment fill firstly stability of the unreinforced embankment fill should be considered though you are providing with the geosynthetics material. Here on the soft soil foundation but you must check what will be the local stability of the embankment itself, otherwise there is a possibility for the failure slip failure within the embankment fill itself.

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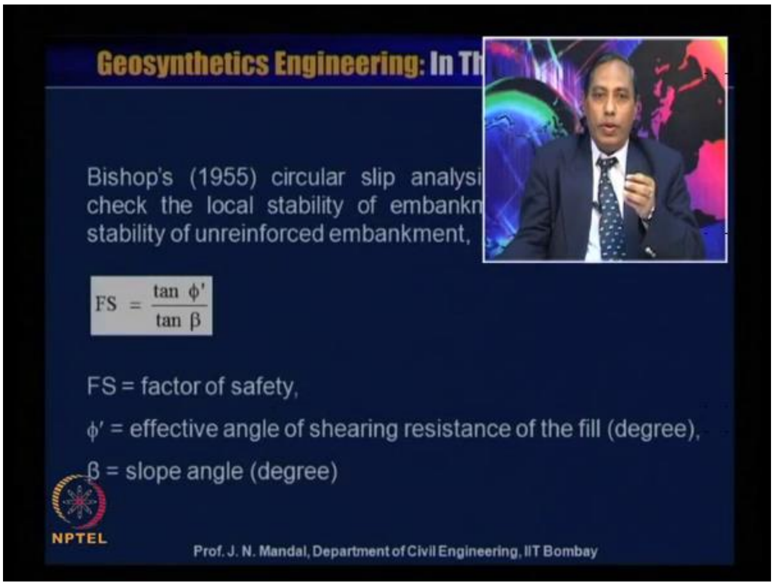

Bishop 1955, circular slip analysis is considered to check the local stability of embankment, fill check the stability of unreinforced embankment, that is factor of safety will be equal to tan phi dash by tan beta, where FS is equal to factor of safety, phi dash is effective angle of shearing resistance of the fill in degree, and beta is the slope angle degree.

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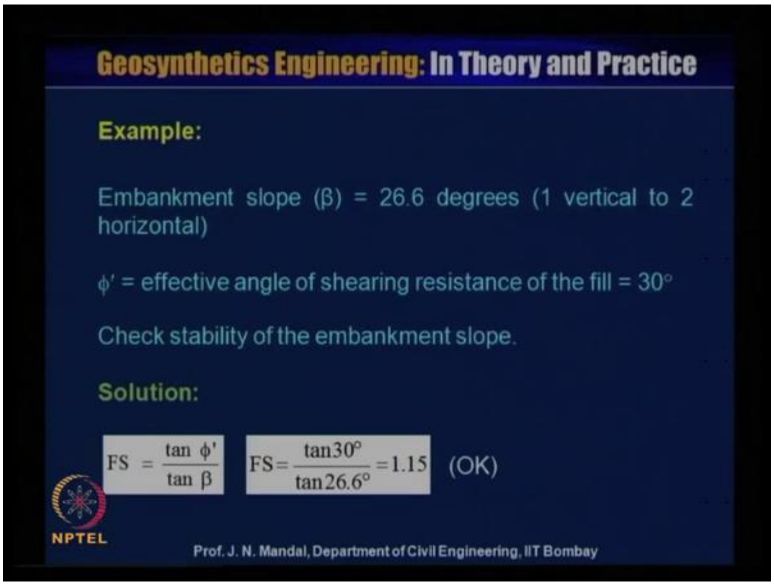

So, here I am giving one of the example that embankment slope beta, let us say is equal to 26.6, 1 vertical to 2 horizontal, phi dash effective angle of shearing resistance of the fill that is 30 degree. Check the stability of the embankment slope, the solution is FS factor of safety is equal to tan phi dash by tan beta, that means FS is equal to tan 30 degree by tan 26.6 degree is equal to 1.15, then it is so you should check this. Now, step two bearing capacity.

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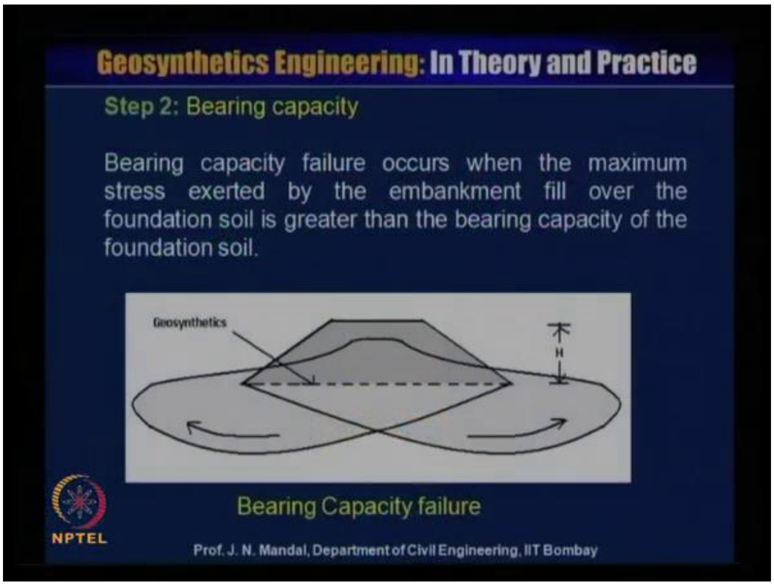

Now, bearing capacity failure occurs when the maximum stress exerted by the embankment fill over the foundation soil is greater than the bearing capacity of the foundation soil. If this is the embankment and this is the foundation soil, so when the maximum stress exerted by the embankment over the foundation soil is greater then the bearing capacity failure may occur, you can see that how the bearing capacity may fail and this is height of the embankment is H.

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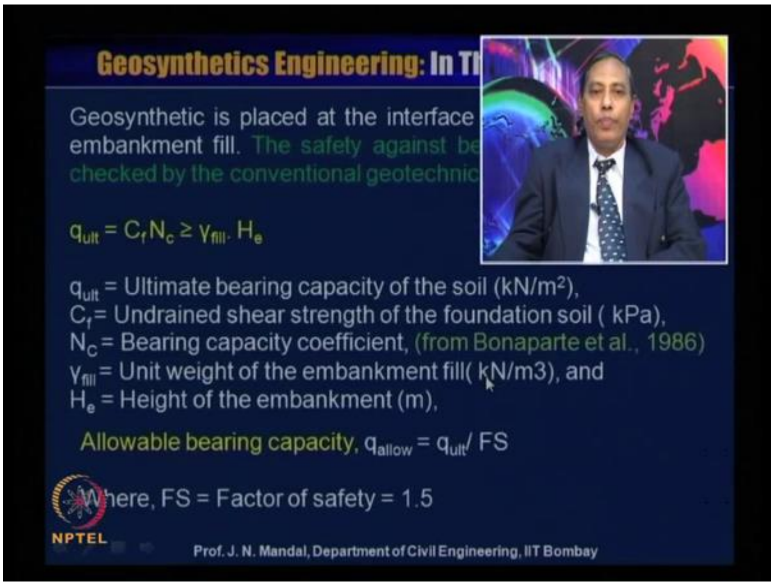

So, this is kind of bearing capacity failure. Now, geosynthetic is placed at the interface of the foundation soil and embankment fill, the safety against the bearing capacity can be checked by conventional geotechnical theory. You know that q ultimate is equal to C f into N c, it should be greater than gamma fill into H e where q ultimate is equal to ultimate bearing capacity of the soil in kilo Newton per meter square. C f is a undrained shear strength of foundation soil in kilo Pascal and N c is bearing capacity coefficient, this is from Bonaparte et al, 1986.

I will show you later and gamma fill is unit weight of embankment fill that is kilo Newton per meter cube and H e is the height of the embankment in meter. So, you check what will be the allowable bearing capacity, q allowable will be equal to q ultimate divided by factor of safety. So, where FS is equal to factor of safety is equal to 1.5.

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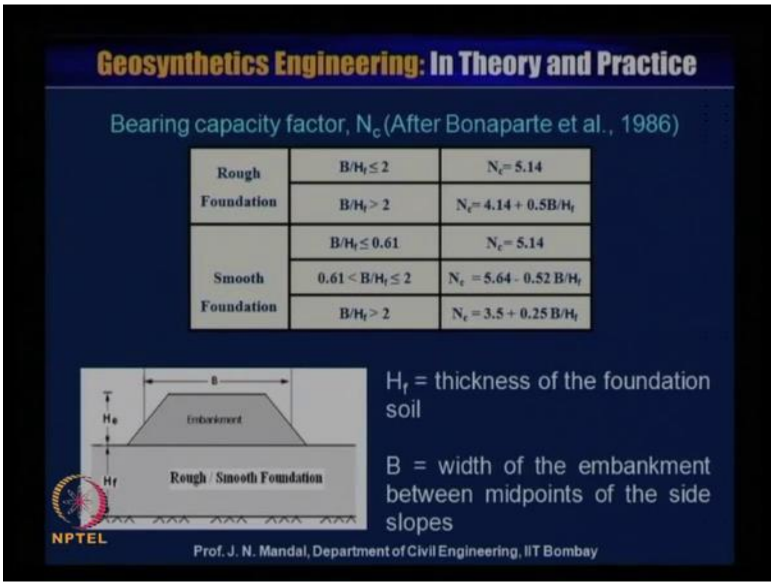

Now, bearing capacity factor N c, I told that after Bonaparte et al 1986, if it is a rough foundation and you can see here this is the embankment and this is the B, this B at the middle of the slope of this embankment. So, this is the B that is width of the embankment between the midpoint of the side slope, and this is the H f. This is the thickness of the foundation soil and this is the H e, this is height of the embankment. Now, this foundation it may be rough or it may be smooth.

So, Bonaparte el al has given this that if it is a rough foundation and B by H f, that means this B divided by H f is less than equal to 2 then N c value will be 5.14. If B by H f is greater than 2 then N c value will be 4.14 plus 0.5 B by H f, that is in case of rough foundation. If the foundation is smooth then B by H f less than equal to 0.61, N c value will be 5.14 and B by H f greater than 0.61 less than equal to 2, N c value will be equal to 5.64 minus 0.52 into B by H f. If B by H f greater than 2 then N c value will be 3.5 plus 0.25 B by H f. So, depending upon the foundation soil whether it is a smooth or the rough so you have to select that what should be the N c value based on the B by H f ratio.

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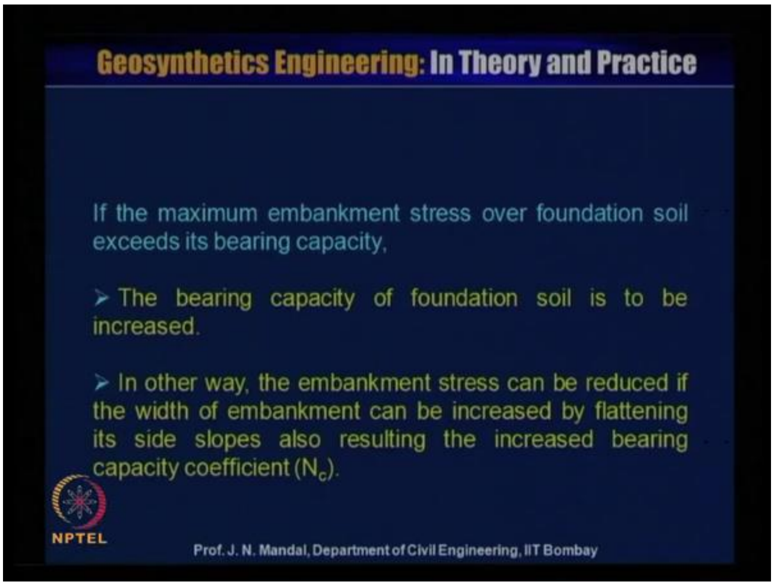

Now, if the maximum embankment stress over the foundation soil exceed its bearing capacity, so bearing capacity of the foundation soil is to be increased in other way. The embankment stress can be reduced if the width of the embankment can be increased by flattering its side slope, also resulting the increased bearing capacity coefficient N c. I will show you later with one example.

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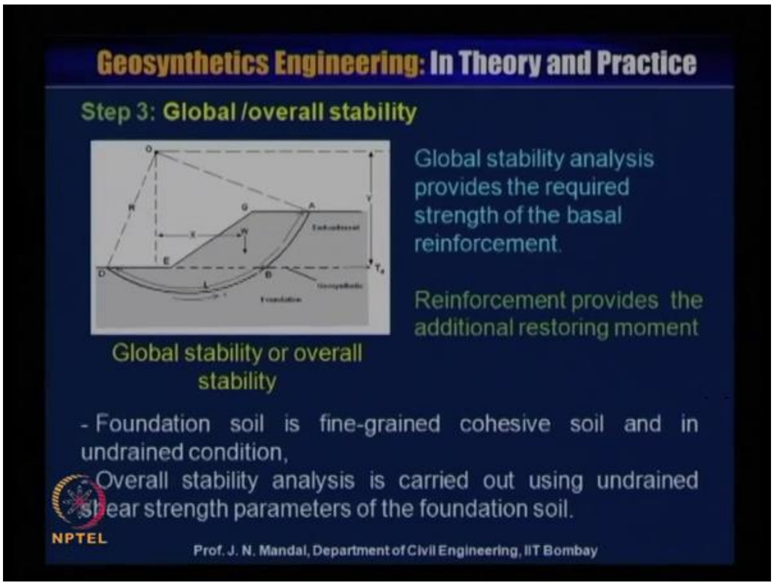

Now, step three global or overall stability, global stability analysis provide the required strength of the basal reinforcement. Reinforcement provide the additional restoring moment foundation soil is fine grained cohesive soil and in undrained condition. So, overall stability analysis it carried out using the undrained shear strength parameter of the foundation soil.

So, here you can see this is the foundation, this is the embankment, this is the geosynthetics material and there are two parts, one is the embankment, another is the foundation and this is the failure. Now, this failure this is through the foundation that means from D B to the foundation, and D B B A is the embankment and R is the radius of the circle and this weight this of the embankment, which is acting at a distance of X. And this is the geosynthetics reinforcement whose tensile strength is T g which is distance from the centre of rotation O is its distance is Y.

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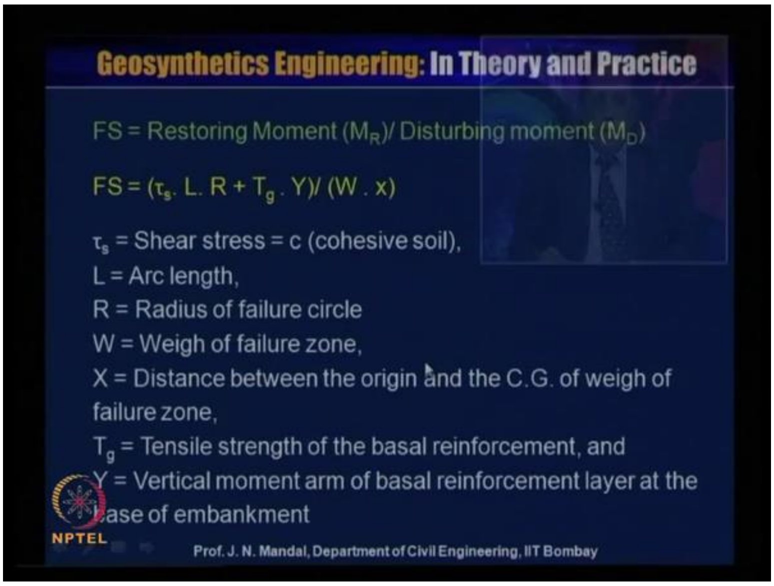

So, you have to find out what will be the factor of safety, that is FS should be restoring moment M R divided by disturbing moment M D. Now, factor of safety is equal to tau s L R plus T g Y divided by W into x. Now, tau s is the shear stress or c this is a cohesive soil. So, here somewhere here the tau s is equal to shear stress of the soil and L is the arc length, this is the L, L is the arc length that is DBA. This is arc length, R is the radius of the failure circles.

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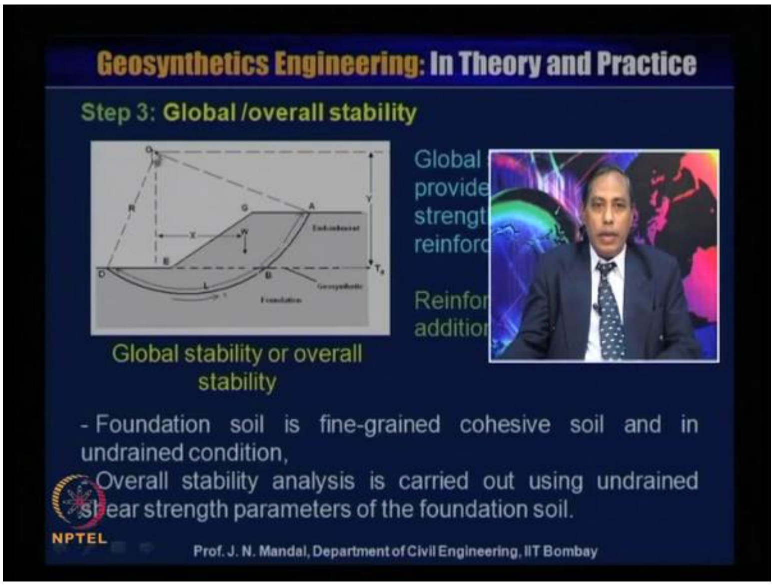

R is the radius of the failure circle and W is the weight of the failure zone, this is W is the weight of the failure zone and X is the distance between the origin and the centre of gravity of the weight of the failure zone. This is X and T g tensile strength of the basal reinforcement, this is T g tensile strength of the basal reinforcement and Y is the vertical moment arm of basal reinforcement layer at the base of the embankment, this is Y.

Now, this you can calculate what will be the factor of safety. Now, if the embankment soil differ with the foundation soil then we can calculate the factor of safety in a different way. Here in this slope, here is the same soil so that is why we are telling tau is equal to c. So, arc length is equal to l, so there is no difference in the properties of the soil either in the embankment or the foundation soil.

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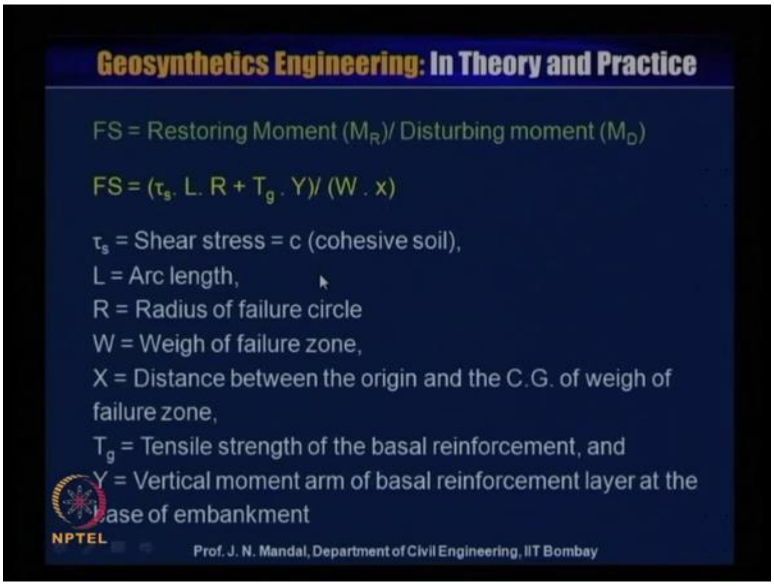

Now, if the embankment soil differ with the foundation soil, so we can calculate the factor of safety as follows. So, first of all you have to calculate without the reinforcement.

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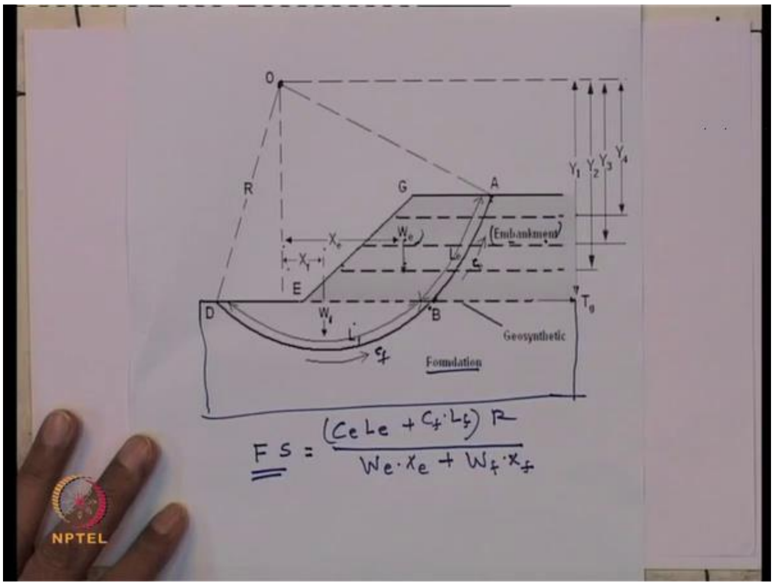

So, here you can see that this is the embankment and this is the foundation, this is the foundation, this is embankment and this is the radius of the failure circle is R. Now, here because this is the embankment part, so this B A that is L of e. So, L e is the length of the failure arc for embankment, L e is the length of the arc for embankment and this is the foundation.

So, DB that is L of f L f is the length of the failure arc for foundation, and this is W of e is the weight of the failure zone for embankment that is why W e and this is W of f is the weight of the failure zone for foundation, and this X of e that is momentum to the centre of gravity of failure zone in the embankment and this is X of f, that means this is momentum to the centre of gravity of failure zone in the foundation soil. So, then you have to calculate that what will be the factor of safety. So, case one we are considering that unreinforced case that means factor of safety will be, this is embankment and this arc length is L e. And let us say there is A C E C for cohesion of the embankment soil. C e is cohesion of embankment soil so that means c e into L e.

So, you can write C e into L of e this is for the embankment. If cohesion is C e, length is L e, so C e into L e plus for the foundation this is let us say C of f. So, C f into L f, so this is C f into L of f, this is for foundation. So, this into R you are taking O, so this is the radius so that means C f into L f plus C a into L e into R this divided by this is the resisting force, this divided by driving, this is for embankment W e into X e.

So, this is W e into X e plus this is for foundation, that is W f into X f. So, this is W f into X of f so you know this R, you know what is C e, you know L e, you know C f, you know L f. So, then you can calculate that what will be the factor of safety without geosynthetics material. So, we are not considering any geosynthetics material. Now, if we consider the case two with the reinforcement.

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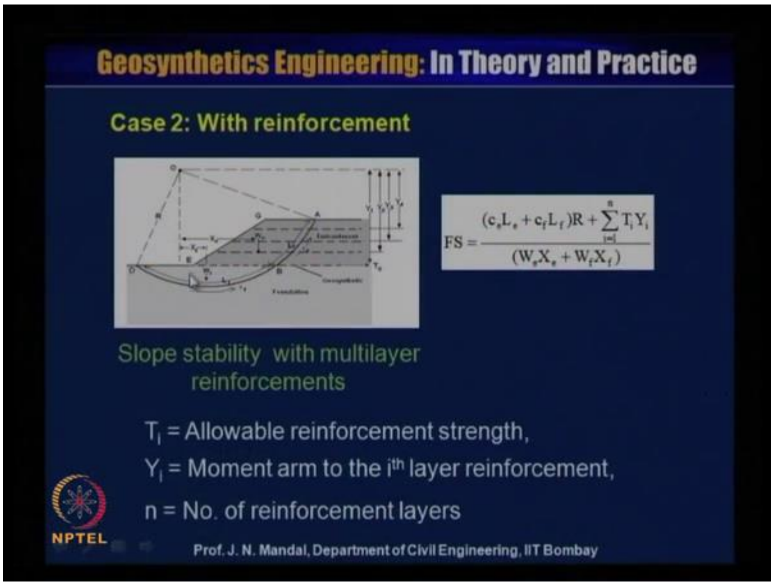

Here, the reinforcement is placed in between the embankment and foundation, you can add the number of the layer of the reinforcement in this slope. So, this is one strain of the geogrid which is this distance is Y 1, Y 2, Y 3 like this. So, then number of reinforcement you can add it so here that is if you say T i what will be the allowable reinforcement strength. So, in this slope you are using the multilayer reinforcement and this Y i is the momentum to the ith layer of the reinforcement. Let us we are using T i and it is the Y i and n is equal to number of the reinforcement layer.

So, due to the deployment of the basal reinforcement then this resisting force will increase, that means this part will be summation of i 1 to n into T i into Y i. So, this is the additional here due to the intrusion of the basal reinforcement in the embankment, now you can check what will be the factor of safety, you know what would be the tensile strength, you know the what will be the location of Y i. So, you can calculate and check the factor of safety.

First of all case one with the unreinforced case you have to check if it is not satisfying the desired factor of safety, then you can introduce the one layer of the basal reinforcement or you can give the multilayer of the reinforcement to satisfy this factor of safety.

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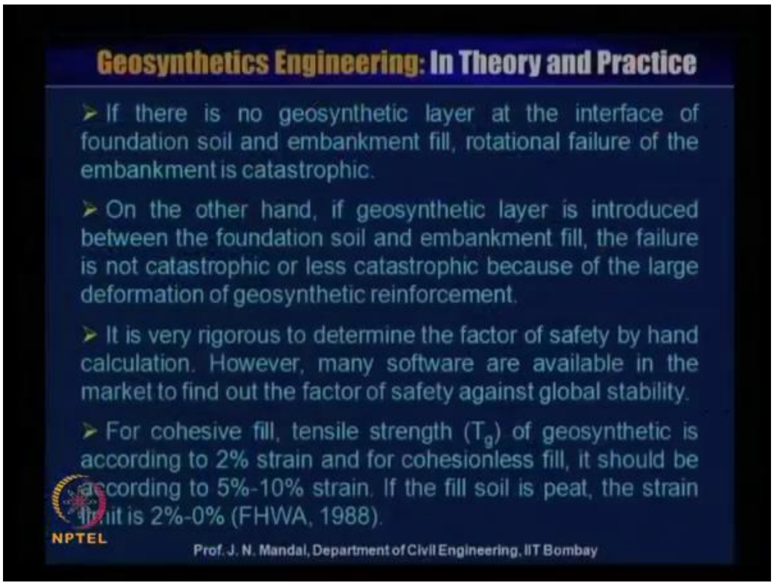

If there is no geosynthetics layer at the interface of foundation soil and the embankment fill and the rotational failure of the embankment is catastrophic, on the other hand if geosynthetic layer is introduced between the foundation soil and the embankment fill, the failure is not catastrophic or less catastrophic because of the large deformation of the geosynthetics of the reinforcement. It is very rigorous to determine the factor of safety by hand calculation, however nowadays many software are available in the market to find out the factor of safety against the global stability.

For cohesive fill tensile strength T g of geosynthetics is according to 2 percent strain and for cohesion less fill it should be according to 5 percent to 10 percent strength. If the fill soil is peat, this strain limit is 2 percent to 0 percent as per FHWA 1988. So, what you can observe that if there is no geosynthetics material between the foundation soil then it will be catastrophic failure but at least if we can provide one layer of the geosynthetic material then failure will not be catastrophic. So, it will deform, so it can give some warning then there is a possibility for the failure but it will not fail immediately as in case of fill in the unreinforced case, at least it will give some of the warning, it is not the catastrophic failure.

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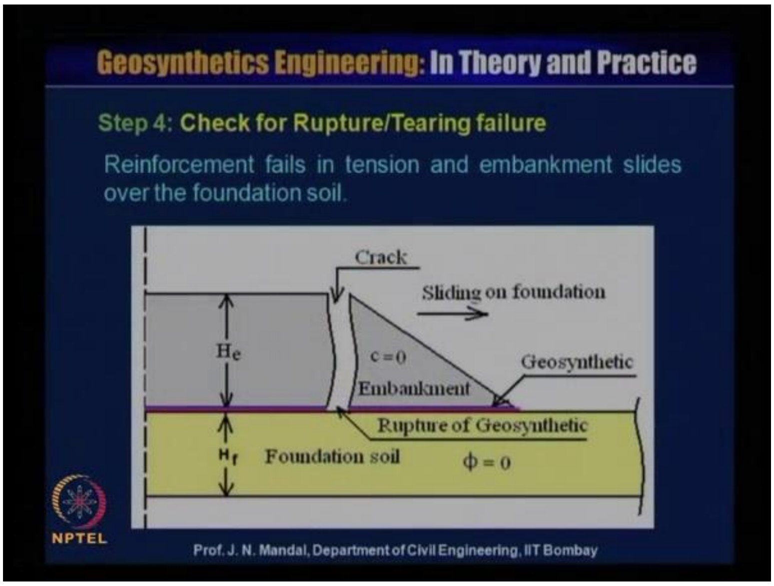

Step four, check for the rupture or tearing failure, so reinforcement fill in tension and embankment slides over the foundation soil. So, here you can see this is the foundation soil when phi is equal to the 0, this is embankment soil. C is equal to 0 and this is the height of the foundation soil and this is the height of the embankment. Now, this is the red colour, this geosynthetics reinforcement as a basal reinforcement which is placed between the embankment and the foundation soil. Now, you can see that how this is sliding on the foundation, and you can see rupture of the geosynthetics material and here it is a crack from. So, reinforcement fell in tension and embankment slit over the foundation soil, so this type of the rupture and tearing failure may occur. Now, I have to solve this problem, you can see what are the forces at the vertical edge section. So, you are taking that here this is embankment, this is the vertical section.

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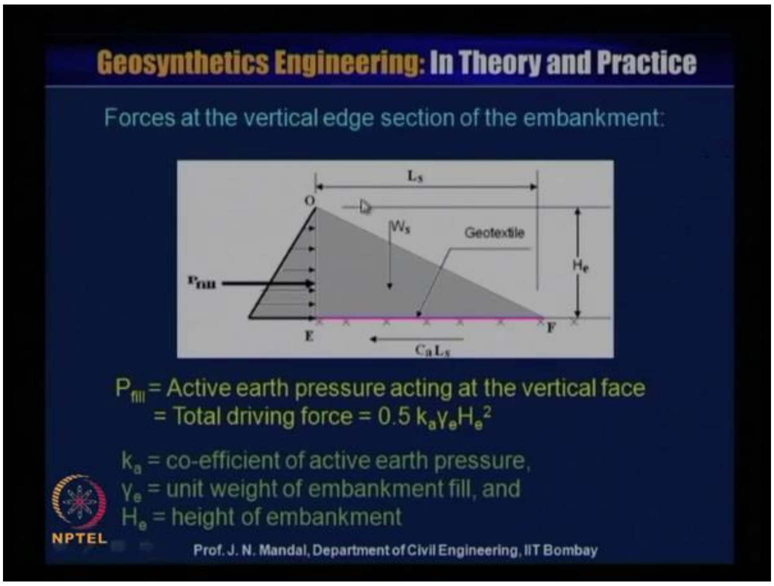

Edge section of the embankment here and this is the O E F and this is the basal reinforcement or geotextile and this is height of the embankment H e and there is a active earth pressure acting at the vertical face. So, this is the P fill which is active earth pressure acting at the vertical face. That means, total the driving force will be half into K a into gamma e into H e square, you can see this is a triangular distribution.

Therefore, half into K into gamma e into H e square, where K a is coefficient of active earth pressure, gamma e is unit weight of the embankment fill and H e is the height of the embankment. Now, that is resistant by this force here this is C a into L s, so this length is L of s, so this is resisted by C a into L s because you can see the phi is 0, only C a is there. So, C a into all along this length into L s, so we can write the shear force at the bottom of the embankment. So, shear force at the bottom of the embankment what may be the shear force this and then due to weight. So, that is C a into L s, it is acting along this and then W s that is sigma V into tan delta phi, this is sigma V into tan delta phi this is acting sigma V into delta phi. Now, here into L s so here delta f is 0 because there is no delta f in the foundation soil because it is phi is equal to 0. So, delta f.

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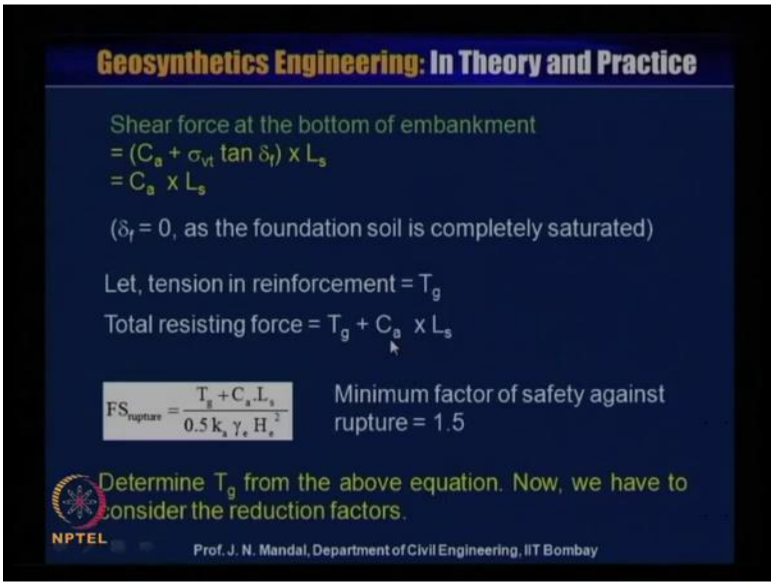

It is nothing is there, so delta with the because foundation soil is completely saturated. So, we can write that C a into L of s yet the tension in the reinforcement is T g, so we are considering the tension in the reinforcement T g. So, total resisting force will be equal to T g plus C a into L s, so you can write that factor of safety against rupture FS, rupture will be the resisting force T g plus C a into L s divided by P fill, that is 0.5 into K a gamma e into H e square. Now, you require minimum factor of safety against the rupture is 1.5. So, you can determine what should be the T g from the above equation. So, we have to consider the some reduction factor.

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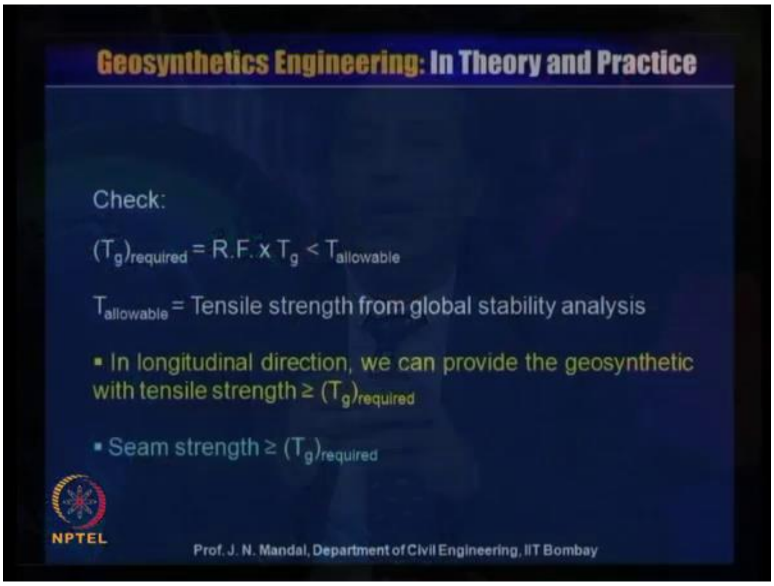

Now, check the T g required will be equal to reduction factor into T g which should be less than T allowable. So, T allowable is tensile strength from global stability analysis, so in longitudinal direction we can provide the geosynthetics with tensile strength should be greater than equal to what is T g required. You have also checked what will be the seam strength, and that seam strength should be greater than equal to T g required because in the embankment you know sometimes you require for the some joining of the geotextile material. So, you have to perform the seam strength, also you have to check that what should be the seam strength value, whether it is satisfying the criteria or not. And that seam strength of the geosynthetics will be greater than equal to what will be the T g required, that is we can provide in the geosynthetic with tensile strength.

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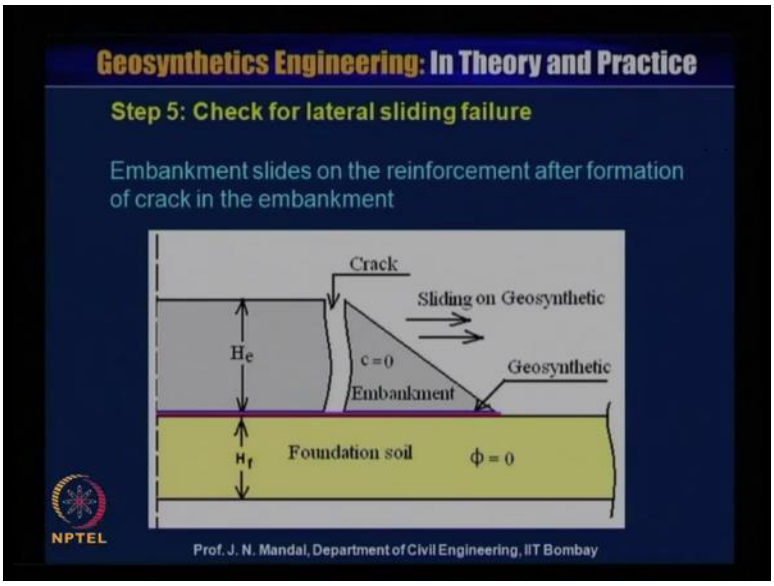

Step five, check for lateral sliding failure. So, embankment slide embankment slide on the reinforcement after formation of the crack in the embankment. So, embankment slide on the reinforcement after formation of crack in the embankment. Now, this is sliding on geosynthetics, so here is a geosynthetics material and here is a foundation soil, phi is equal to 0, embankment C is equal to 0. This is height of the embankment H f and height of the embankment H e and here the embankment slides on the reinforcement after the foundation of crack in the embankment.

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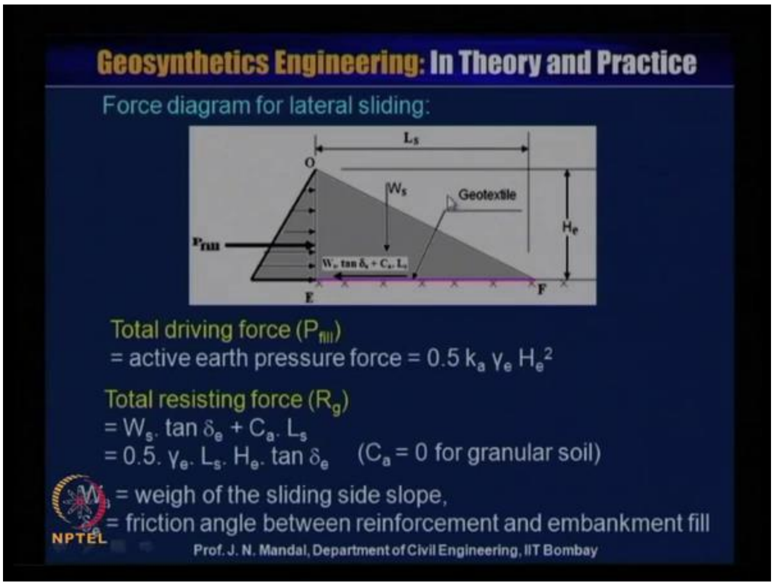

So, you can see here what will be the force diagram for lateral sliding, so here is a total driving force that is P fill that is active earth pressure that is half into K into gamma e into H square H e square you know, and total resisting force let us say R of g. So, R g will be equal to this is due to the weight of this part W s into tan delta e plus this is C a into L of s, but because where the granular soil the C a is 0.

So, this C a will be the 0. So, W s will be this triangle that means half into gamma e is unit weight of the embankment into L of s. So, half into gamma e into L of s into H e tan of delta e, so this part so what W s is the weight of the sliding side slope and delta e is the friction angle between the reinforcement and the embankment. So, then you can calculate what will be the total driving force as well as what will be the total resisting force, but you remember here that here embankment slides on the reinforcement.

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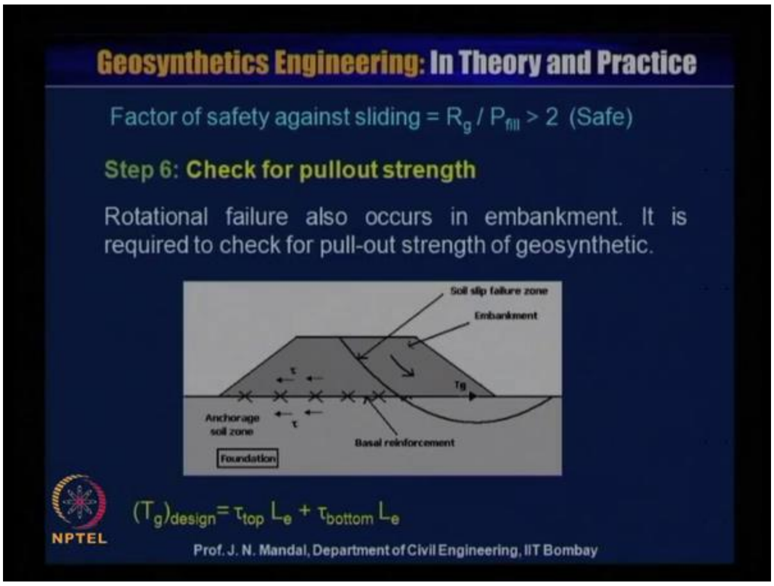

Now, you have to calculate what will be the factor of safety against sliding that means that equal to R g by P of fill, it should be greater than 2 that means it is safe. Now, step six check for pullout strength, now rotational failure also occur in the embankment it is required to check for pullout strength of geosynthetics material. Here you can see this is the foundation soil and this is the soil slip failure zone, here this is the embankment and this is basal reinforcement.

So, this is the anchorage soil zone and you can see that due to this slip failure, this is the reinforcement with tensile strength of the basal reinforcement, this T g and due to the soil surface failure zone and there is a development of the shear stresses between the embankment and the foundation soil. So, this T of g for the design it should be the tau of top, it is a tau of top into the embankment layer L e plus tau of bottom into L of e, because sometimes you can observe that characteristics of the foundation soil is different from the characteristics of the embankment soil. So, whatever the mobilization of the shearing strengths between the basal reinforcement and foundation soil is not the same, the mobilization of the friction between the soil and the embankment soil.

So therefore, you have to consider in the design that what is tau top that means that is the embankment fill soil with the geogrid reinforcement. And similarly, you have to think about that what should be the shearing resistance between the foundation soil and the basal reinforcement. So, you should consider the both the characteristics of the soil because embankment fill is not the same, it is the foundation fill, but most of the cases we consider it is the same now tau top is the shear stress.

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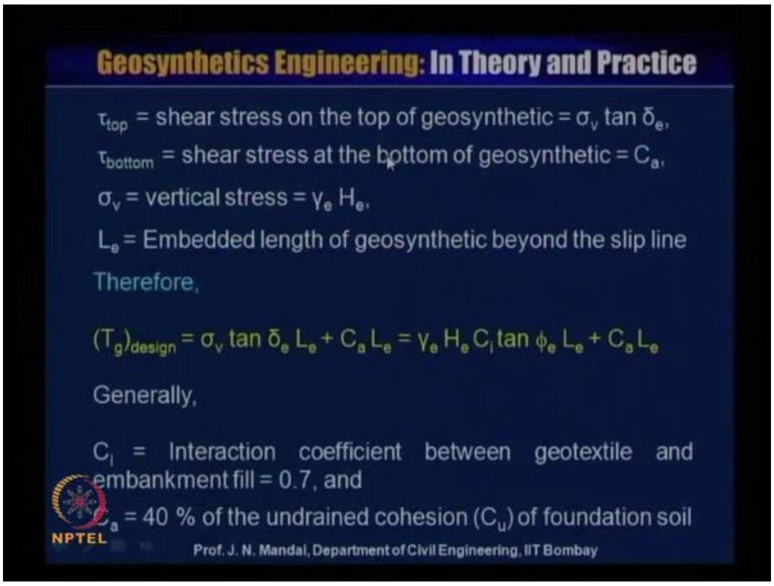

On the top of the geosynthetics that means that is sigma v into tan of delta e and why it is sigma v, sigma v I get the vertical stress, that means what is gamma e into H of e and tau bottom is the shear stress at the bottom of the geosynthetics, that is C of a. Here C of a, now L e that is the embedment length of the geosynthetics beyond the slip line.

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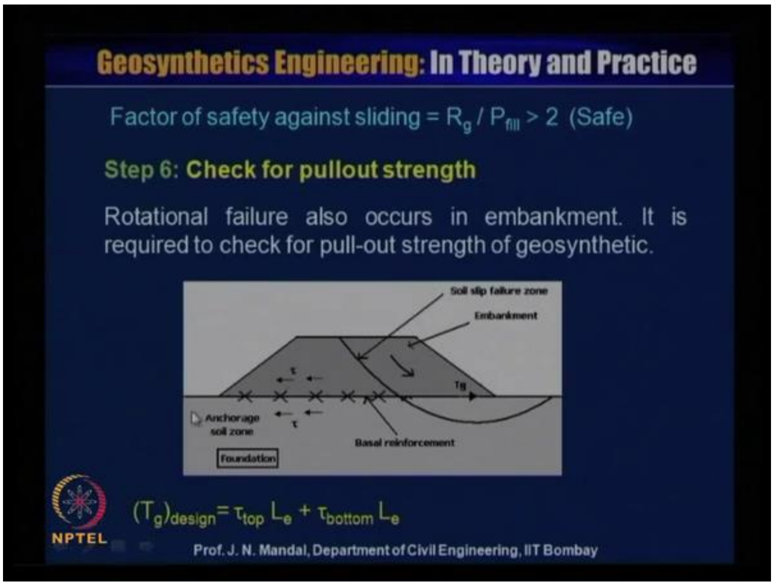

This is L e, this is the slip line beyond the slip line this is L of e.

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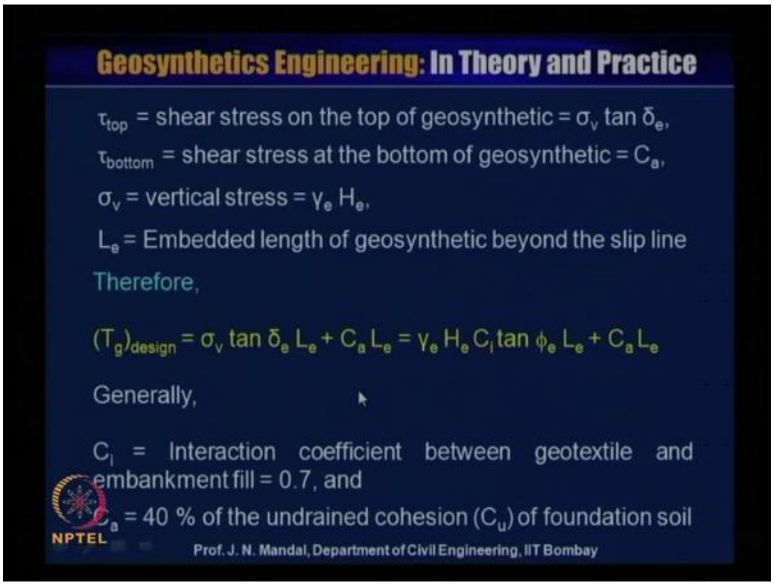

So, we can write T g design, if this is tau top that is sigma v tan delta into L e plus C of a into L e is equal to gamma e into H e that is due to the sigma v into tan delta, you can write C i tan phi e tan delta, you can write C i into, where C i is the interaction coefficient between the geotextile and the embankment and that value, let us say 0.7. So, you can write and this is the friction angle of the embankment, so tan phi e into L of e plus C a into L of e. So, we can write this equation T g design, but this C a value we can take about 40 percent of the undrained cohesion of the foundation soil. So, C a is 40 percent of the undrained cohesion value of the foundation soil.

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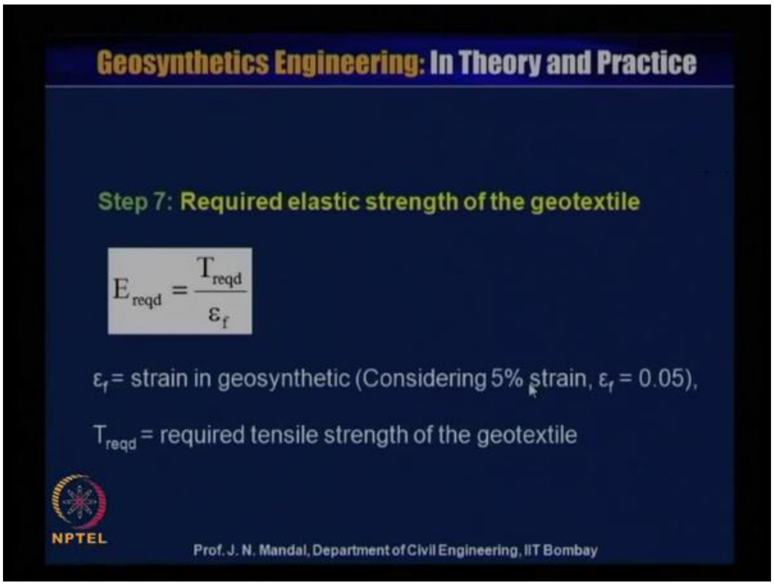

Step seven, you require elastic strength of the geotextile. So, you require is elastic strength is equal to T required divided by epsilon f, where epsilon f is the strain in geosynthetics considering 5 percent strength and the epsilon f will be equal to 0.05. So, T required will be the required tensile strength of the geotextile.

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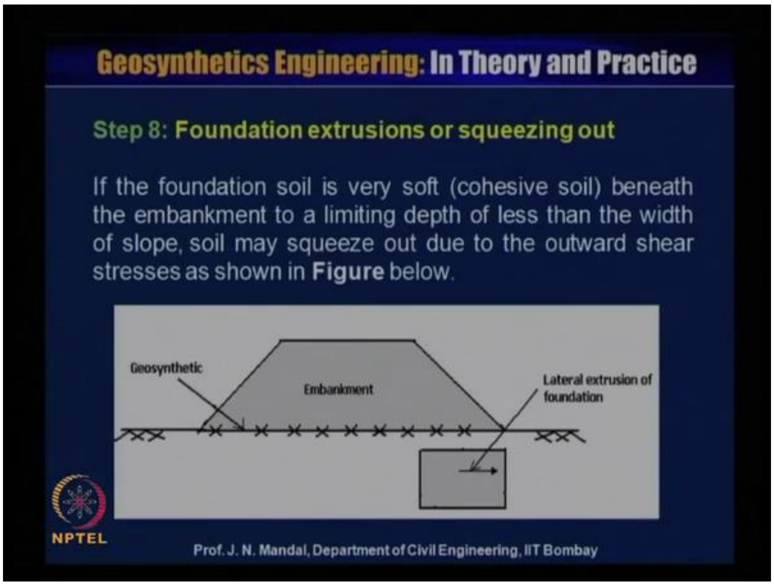

Step eight, formation extrusion or squeezing out, this is also very important if the foundation soil is very soft that is cohesive soil. Here the foundation soil is very soft cohesive soil beneath the embankment to a limiting depth of less than the width of the slope, this soil may squeezed out, this soil may squeezed out due to the outward shear stresses. So, this is the lateral extrusion of the foundation, it will squeeze it out here.

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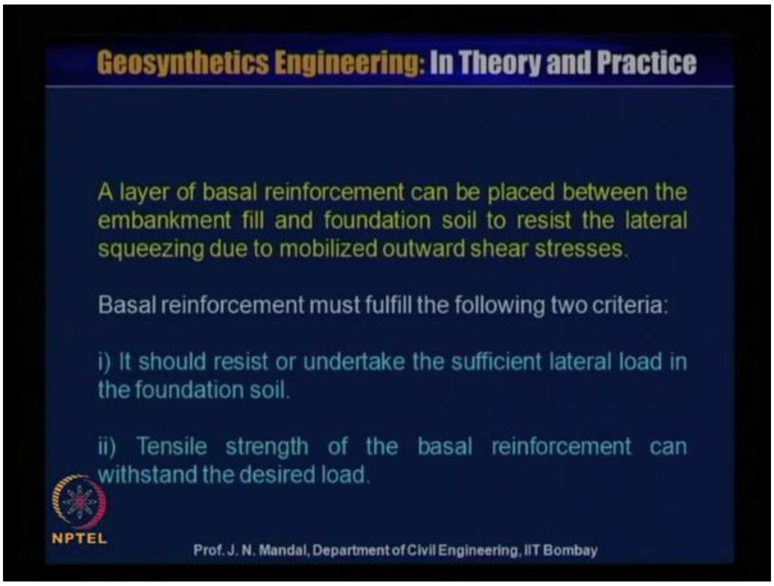

So, a layer of basal reinforcement can be placed between the embankment fill and foundation soil to resist the lateral squeezing due to mobilized outward shear stresses. So, basal reinforcement must fulfil the following two criteria, one it should resist, or undertake the sufficient lateral load in the foundation soil. And second tensile strength of the basal reinforcement can withstand the desired load.

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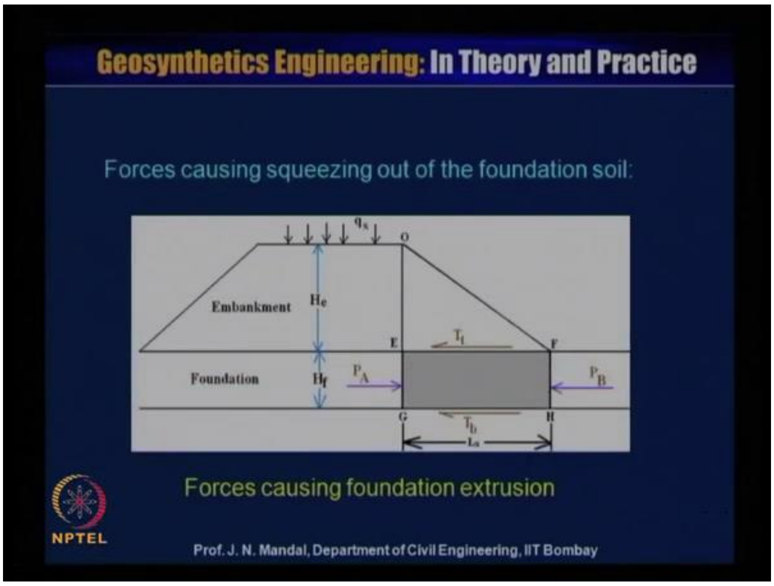

So, what are the forces causing the squeezing out of the foundation soil, you can see here this is the embankment, this height of the embankment is H e and this is the surcharge load q s and this is the foundation soil and here the force is causing the foundation extrusion. So, here you can see that how the shear stresses acting at the top here how the shear stresses acting at the bottom, so as the foundation soil is saturated here.

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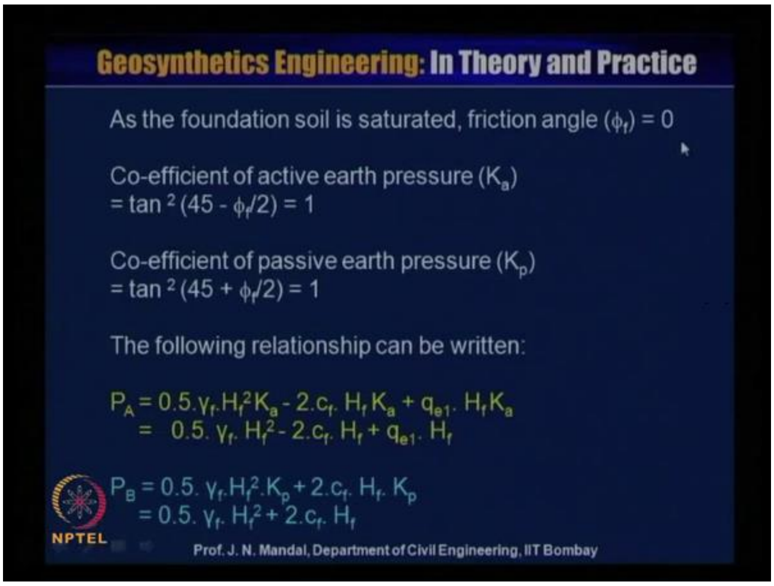

So, this phi f value is equal to 0 and coefficient of active earth pressure K a will be equal to tan square 45 degree minus phi by 2, that will be equal to 1, the coefficient of passive earth pressure K p will be equal to tan square 45 degree plus phi by 2 is equal to 1. So, this following relation can be written that is P A will be equal to half gamma f, H f square into K a.

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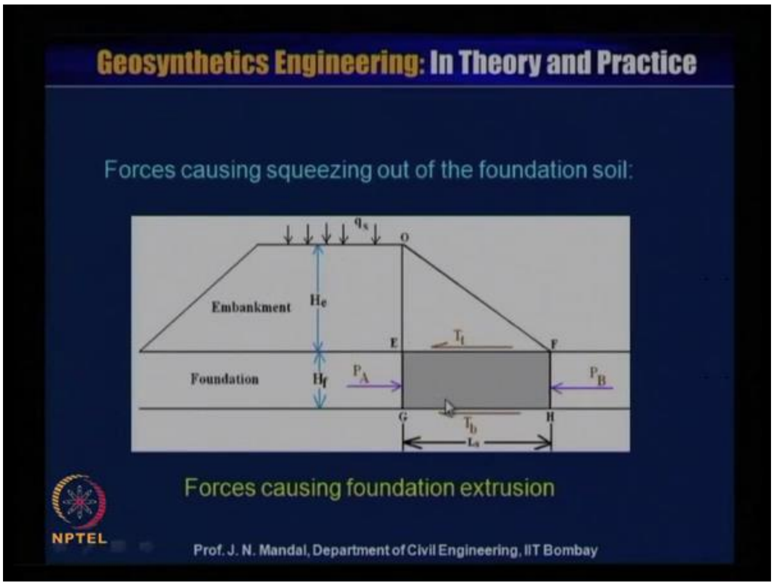

That is due to this P of A this is half gamma f, H f square, this is H f square into K a minus this, that is 2 into C f into H f into K a 2 into C f into H f into K a plus due to the surcharge, that is q. Let us say q of e, this is q e 1 into H f into K a. So, this is for P of A because P A is acting in this direction and this is acting on this direction shear stress is acting on this direction.

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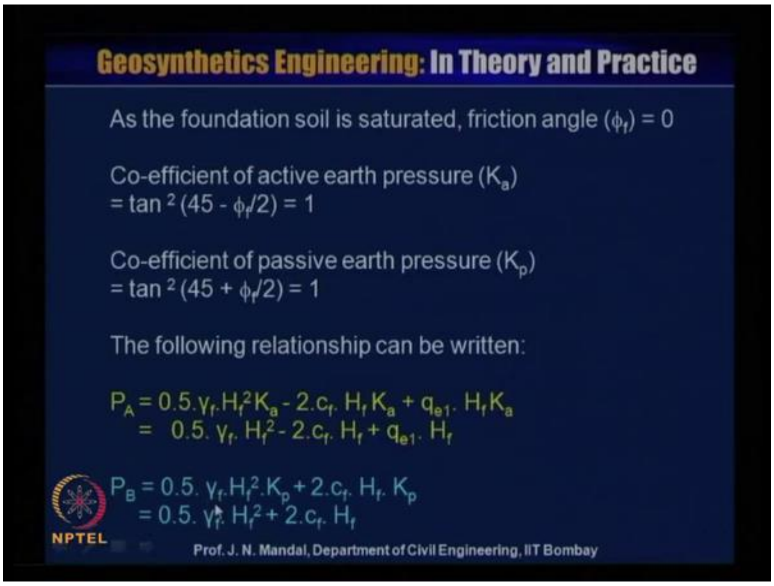

So, this is 0.5 gamma f, H f square minus 2 C f H f plus q e 1 into H f. Similarly, P of B this P B is equal to half gamma f H f square plus into K p, here plus 2 C f H f into K p.

So, this is plus this direction is the same. So, this will be equal to 0.5 gamma f H f square plus 2 C f into H of f. So, you know that what will be the relationship for the P A and what will be the relationship for P B, I have already that covered for the embankment on the soft soil and how you can make this different design step for the local stability also for the global stability. And how there is a possibility for the failure different types of the failure, or the squeezing out of the failure of the embankment slope and how you can determine all the factor of safety. Next, also we will go some more theory and also some example for the embankment design, which is based on the soft soil and the how you can use the basal reinforcement for the stability of the embankment. With this I finish my lecture today. Let us hear from you, any question?

Thank you for listening.