Geosynthetics Engineering: In Theory and Practices
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Lecture - 38
Geosynthetics for Steep Slopes

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 38. This module 7, lecture number 38 geosynthetics for steep slope. Now, I will focus the recap of the previous lecture.

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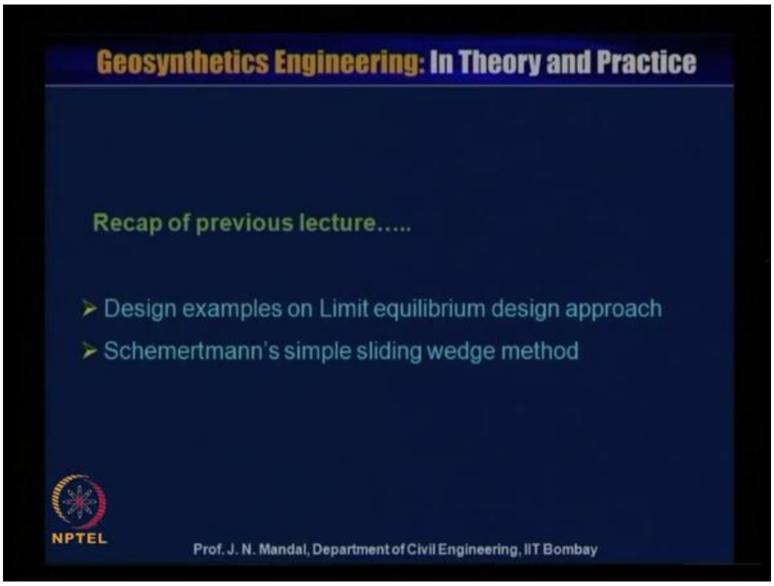

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Recap of previous lecture.....

- Design examples on Limit equilibrium design approach
- Schemertmann's simple sliding wedge method

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The design example on limit equilibrium design approach and Schmertmann's simple sliding wedge method. You have observed in case of Schemertmann et al design approach, and we use the gradually decrease the length of the reinforcement.

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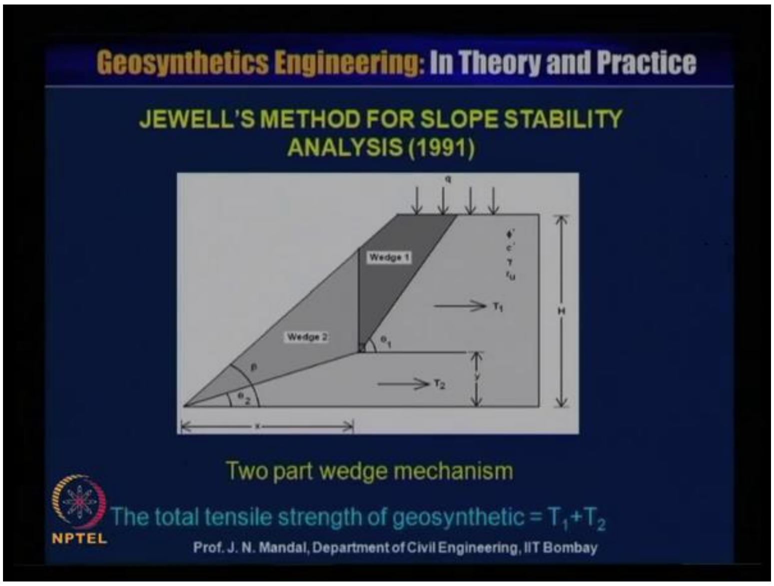
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JEWELL'S METHOD FOR SLOPE STABILITY ANALYSIS (1991)

Two part wedge mechanism

The total tensile strength of geosynthetic = $T_1 + T_2$

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There is a reinforcement at the top, and also there is a reinforcement at the bottom of the reinforced soil slope, and the length of the geogrid material is variable, in case of Schemertmann et al design chart which we have covered. In addition this potential failure surface is curve, that is the logarithmic spiral and this design chart is good and this also more accurate.

But now we will address the design by Jewell's and he has developed the two parts with mechanism. And this method however is suitable for the low and the medium walls. It is more conservative approach and this Jewell method is relatively better. We will had this Jewell's method in this course. Now, then this Jewell method we have considered the limit equilibrium method can be used. So, for an example what will be the definition for the analysis of steep reinforced soil slope.

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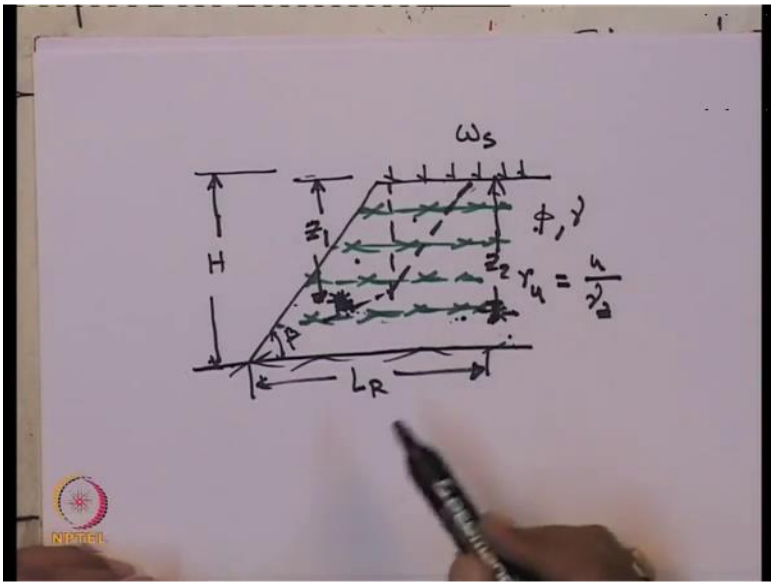

So, if we draw a slope and this is a slope, steep slope and which is making at an angle beta and you can place a number of the layer of the reinforcement. So, this is number of layer of reinforcement and in Jewell method we have considered the two wedge method. So, it has a two wedge. Suppose, this is the wedge 1 and this is the weight 2. So, this is the limit equilibrium method can be used in the form of two parts wedge surface as it is shown and if the height of the slope is equal to this is h. And there is also the surcharge load, and which is designated as w of s and this slope also has a properties of the soil. We know that what will be the gamma, what should be the unit weight of the soil and also what will be the angle of friction that is phi and apart from that there is a pore water pressure which can be designated of r of u. So, r of u is equal to u by gamma z.

For example, that if you want to determine that what should be the pore water pressure at the depth of let us say z of 1. At this point so you can calculated r of u. So, r of u here will be u divided by gamma of z 1. Let us say that it is a u 1. So, you can write r u is equal to u 1 by gamma of z 1. For example, if you want to determine that what will be the pore water pressure in here. So, let us say this is located at a depth of z of 2.

So, r u will be equal to into by gamma of z 2. So, like this you can calculate what will be the pore water pressure and this is the length of the geogrid. Let us say this is L of R. So, this is the definition for the analysis of steep reinforced soil slope which is Jewell is given by 1991. You can use also the primary geogrid uniaxial geogrid material or also you can use the secondary uniaxial geogrid material. Now, here develop the number of the design chart for varying the pore water pressure and also the slope angle and the varying properties of the soil.

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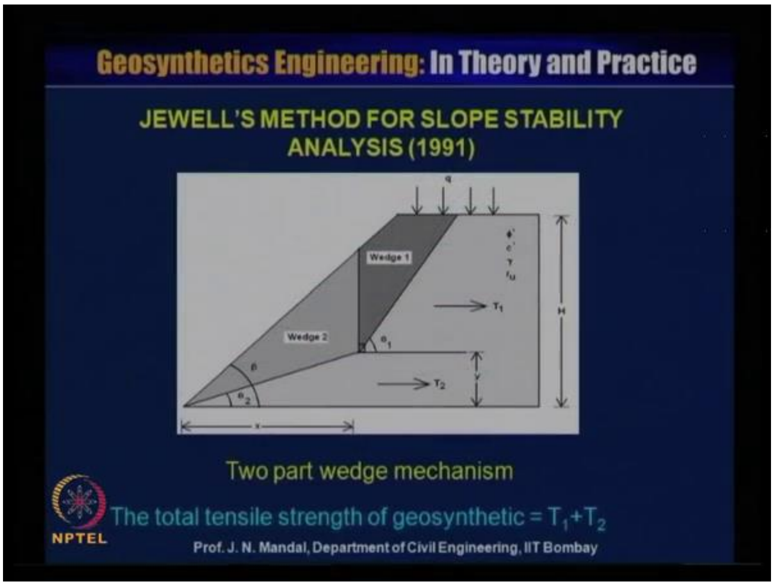
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So, now you can see here Jewell method for slope stability and this is the two parts wedge. This is wedge 1 and this is wedge 2 and the slope angle is beta and this here for wedge 1 this is angle of theta 1 and this for wedge 2 which is making angle of theta 2 and this coordinate is X and Y. So, this is from here to here is X and from here to here is Y and for the wedge 1 this is a tensile strength of the geogrid material T 1 and for the wedge 2, tensile strength of the geogrid material T 2. And this is height of the slope and this is the surcharge q and this is the properties of the soil. That means you know what is angle of friction of the soil. What will be the cohesion value? What will be the unit weight of the soil and also what is r u? What is pore water pressure r u?

Here this is a two parts wedge mechanism. Then in case of the Schmertmann, we adopted that only as a potential failure surface is a curve or the logarithms spiral. But in this case, in the Jewell's analysis we have consider the two wedge mathematics. So, two wedge system and this will be much more applicable for the low and the medium type of the reinforced soil wall. It is also say that more conservative and Jewell chart will be much more suitable. So, here the tensile strength is T 1 and T 2. So, total tensile strength of the geosynthetics will be T 1 and the T of 2.

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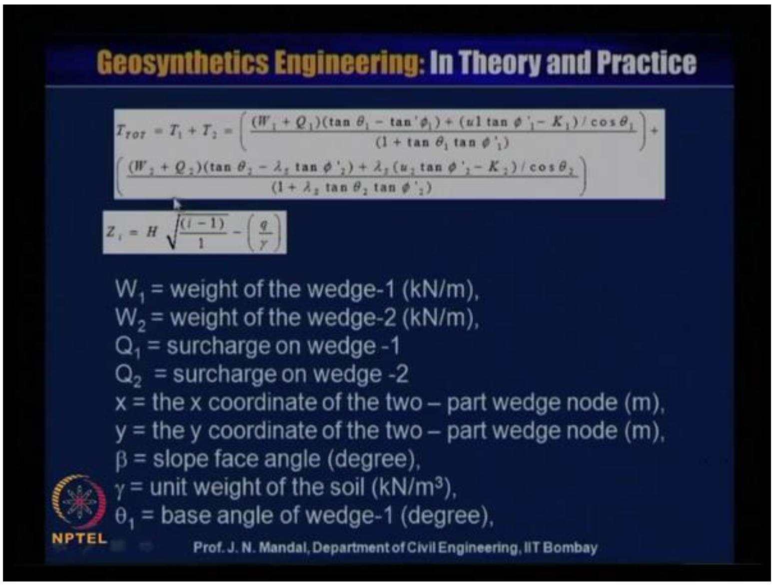

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$$T_{TOT} = T_1 + T_2 = \left(\frac{(W_1 + Q_1)(\tan\theta_1 - \tan'\phi_1) + (u1 \tan\phi'_1 - K_1)/\cos\theta_1}{(1 + \tan\theta_1 \tan\phi'_1)}\right) + \left(\frac{(W_2 + Q_2)(\tan\theta_2 - \lambda_2 \tan\phi'_2) + \lambda_2 (u_2 \tan\phi'_2 - K_2)/\cos\theta_2}{(1 + \lambda_2 \tan\theta_2 \tan\phi'_2)}\right)$$

$$Z_i = H\sqrt{\frac{(i-1)}{1}} - \left(\frac{q}{\gamma}\right)$$

W_1 = weight of the wedge-1 (kN/m),
W_2 = weight of the wedge-2 (kN/m),
Q_1 = surcharge on wedge -1
Q_2 = surcharge on wedge -2
x = the x coordinate of the two – part wedge node (m),
y = the y coordinate of the two – part wedge node (m),
β = slope face angle (degree),
γ = unit weight of the soil (kN/m^3),
θ_1 = base angle of wedge-1 (degree),

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So, this is the equation. Ultimately you will get T total is equal to T 1 plus T 2 is equal to W 1 plus Q 1 into tan theta 1 minus tan phi 1 dash plus u 1 into tan of phi dash minus K 1 divided by cos theta i plus this W 2 plus Q 2 tan theta 2 minus lambda 2 tan theta 2 dash into lambda s into u 2 into tan of theta 2 dash minus K 2 divided by cos theta 2 divided by 1 plus lambda s tan theta 2 into tan theta 2 dash.

This is the Z of i at any depth. This is H is equal to root of i minus 1 by l minus q by gamma. What W 1 is equal to weight of the wedge for 1 that is kilo Newton per meter. W 2 is weight of the wedge 2 that is kilo Newton per meter and Q 1 is the surcharge on the wedge 1. Q 2 is surcharge on which 2 X is equal to the X coordinate of the two parts. Wedge mode that is in meter. The Y coordinate of the two parts wedge node that is in meter. Beta is the slope face angle in degree, aamma unit weight of the soil in kilo Newton per meter cube, theta 1 base angle of wedge 1 in degree.

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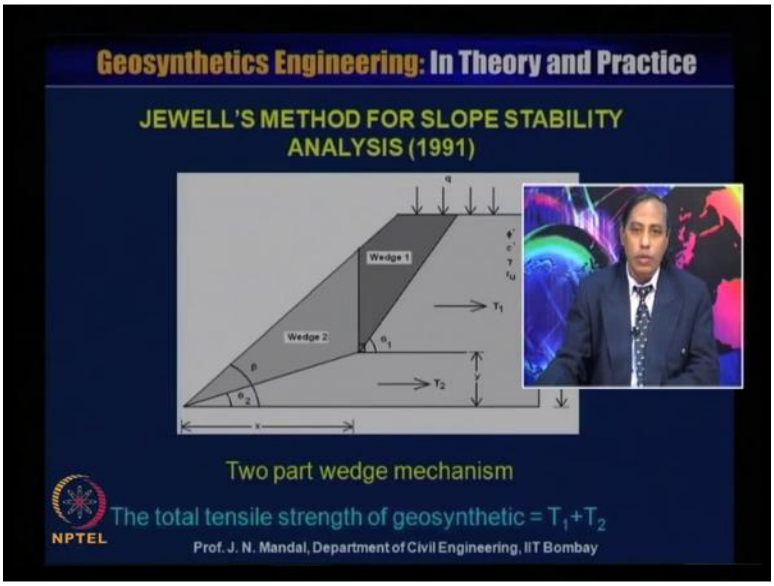

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So, this is what is wedge 1 and wedge degree. This is theta 2, theta 2 this.

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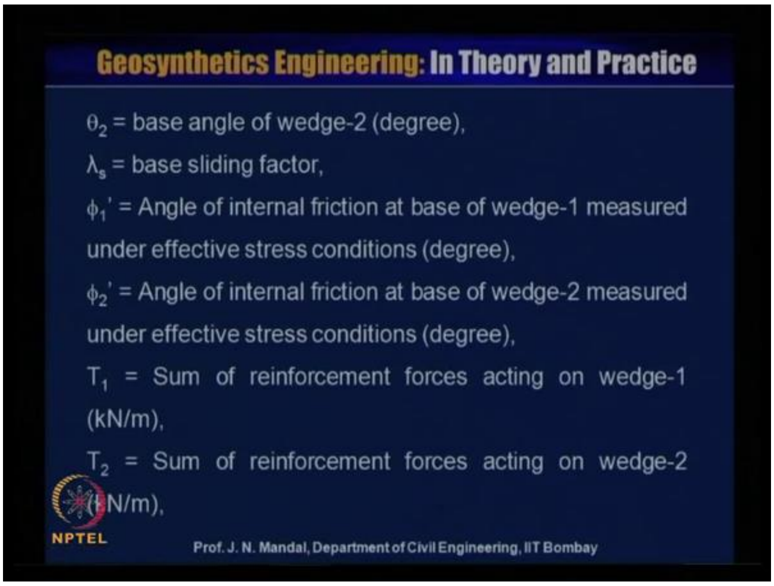

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θ_2 = base angle of wedge-2 (degree),

λ_s = base sliding factor,

ϕ_1' = Angle of internal friction at base of wedge-1 measured under effective stress conditions (degree),

ϕ_2' = Angle of internal friction at base of wedge-2 measured under effective stress conditions (degree),

T_1 = Sum of reinforcement forces acting on wedge-1 (kN/m),

T_2 = Sum of reinforcement forces acting on wedge-2 (kN/m),

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Next theta 2 is equal to base angle of wedge 2 in degree. Lambda s is base sliding factor. Phi 1 dash angle of internal friction at base of wedge 1 measured under effective stress condition in degree. Phi 2 dash angle of internal friction at base of wedge 2 measured under effective stress condition in degree. T 1 sum of the reinforcement forces acting on wedge 1 kilo Newton per meter, T 2 sum of the reinforcement forces acting on wedge 2 kilo Newton per meter based on this theory Jewell has develop some also chart.

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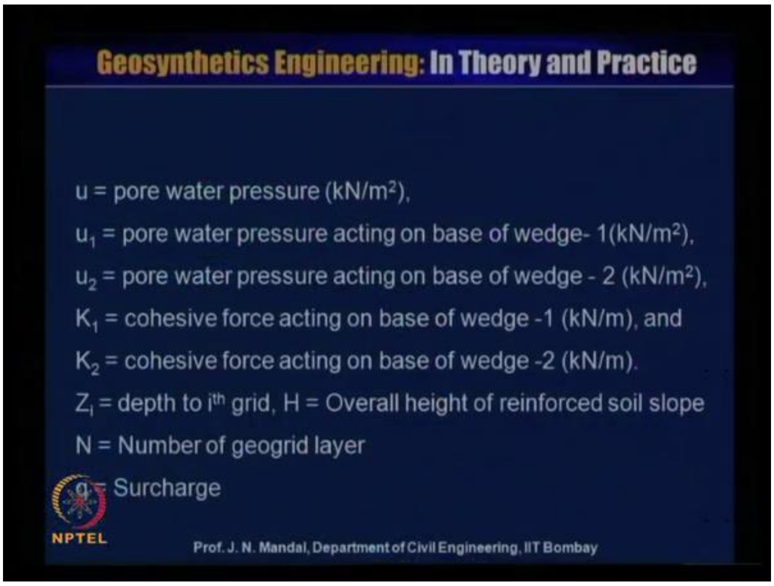

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u = pore water pressure (kN/m^2),

u_1 = pore water pressure acting on base of wedge- 1(kN/m^2),

u_2 = pore water pressure acting on base of wedge - 2 (kN/m^2),

K_1 = cohesive force acting on base of wedge -1 (kN/m), and

K_2 = cohesive force acting on base of wedge -2 (kN/m).

Z_i = depth to ith grid, H = Overall height of reinforced soil slope

N = Number of geogrid layer

q = Surcharge

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And then u is equal to pore water pressure kilo Newton per meter square, u 1 is the pore water pressure acting on the base of the wedge 1 kilo Newton per meter square, u 2 is equal to pore water pressure acting on base of the wedge 2 kilo Newton per meter square. K 1 cohesive force acting on base of the wedge 1 kilo Newton per meter. K 2 cohesive force acting on base of the wedge 2 kilo Newton per meter. Z i is equal to depth ith grid and H is overall height of reinforced soil slope. N is equal to number of geogrid layer and q is equal to surcharge. So, based on this equation Jewell developed the design chart for the steep soil slope in the form of a two parts wedge surface.

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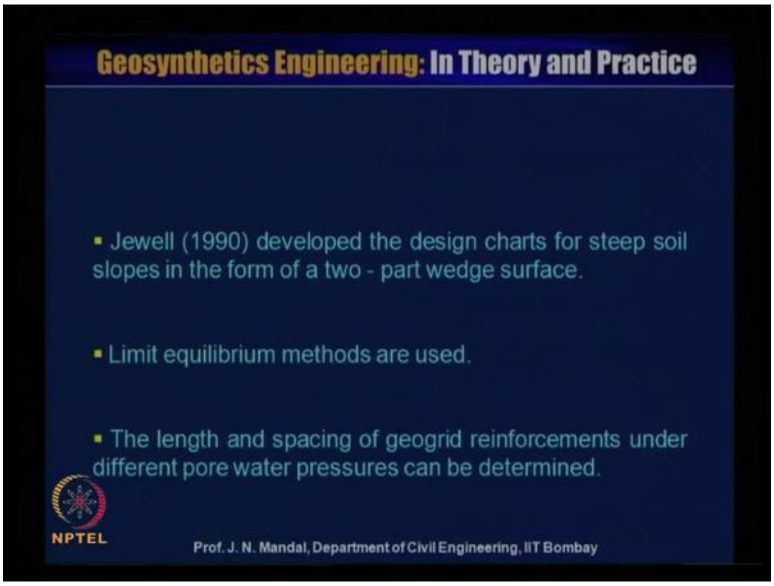

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- Jewell (1990) developed the design charts for steep soil slopes in the form of a two - part wedge surface.
- Limit equilibrium methods are used.
- The length and spacing of geogrid reinforcements under different pore water pressures can be determined.

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I said this is limit equilibrium method have been used and length and the spacing of the geogrid reinforcement under different pore water pressure can be determined. So, this here that Jewell has developed the steep reinforced soil design chart for varying the various pore water pressure ratio. So, that is r u is equal to u by gamma z and this r u value may be 0 or r u value may be 0.25 or r u value may be 0.50. So, in each case of the pore water pressure, let us say when r u is equal to 0 and he has developed a design chart which is related between the K require, the slope angle for the particular, the phi value that means what will be the minimum required forces that is K required.

So, K required you can determine one of the chart knowing the slope angle and the phi value. Then you can determine what will be the minimum required force that is K required and also under the same pore water pressure r u is equal to 0. You can also determine from the another chart which is the correlation between the beta, and the what we called the minimum required length, overall stability that is L r by H overturning. So, knowing the value of the beta you can calculate what will be the L r by H. And similarly, you have to determine what will be the minimum required length of sliding that means L n by H due to direct sliding. So, if you know that what will be the angle beta and the phi then you can calculate that what is L n by H due to sliding?

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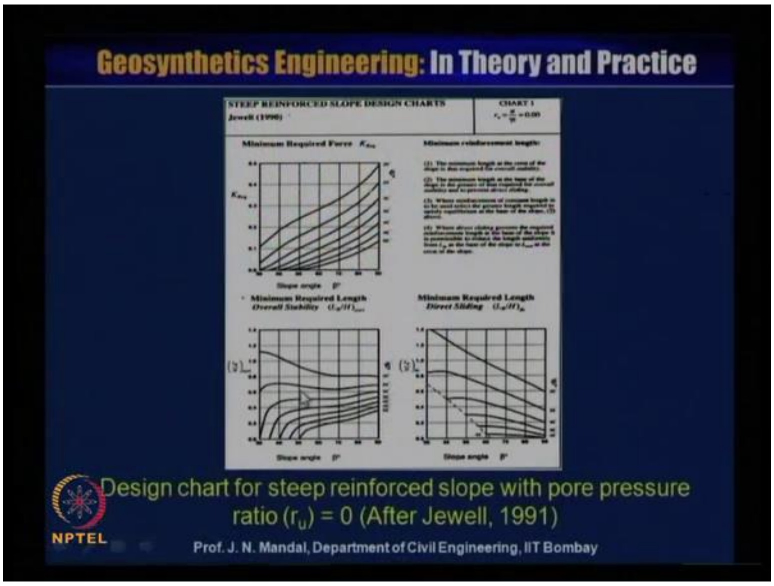

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Design chart for steep reinforced slope with pore pressure ratio (r_u) = 0 (After Jewell, 1991)

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So, I am just representing here. This is the design chart for the steep reinforced slope with the pore water ratio is r u is equal to 0. This is given by Jewell 1991, this is the steep reinforced slope design chart and this chart is the minimum required forces K K r which we have to determine. So, knowing the value of beta and that is fine. Then you can determine K required.

Similarly, from this chart you can determine what will be the minimum required length overturning stability. So, knowing beta and then a phi and then you can determine what is minimum required length over for overturning stability and this also the minimum required length for direct sliding. You know the beta and the phi and then you can calculate the what will be the L r by H due to sliding. Like that he has developed the different chart for various pore water pressure. So, this is the same nature of the curve but the pore water pressure r u is 0.25.

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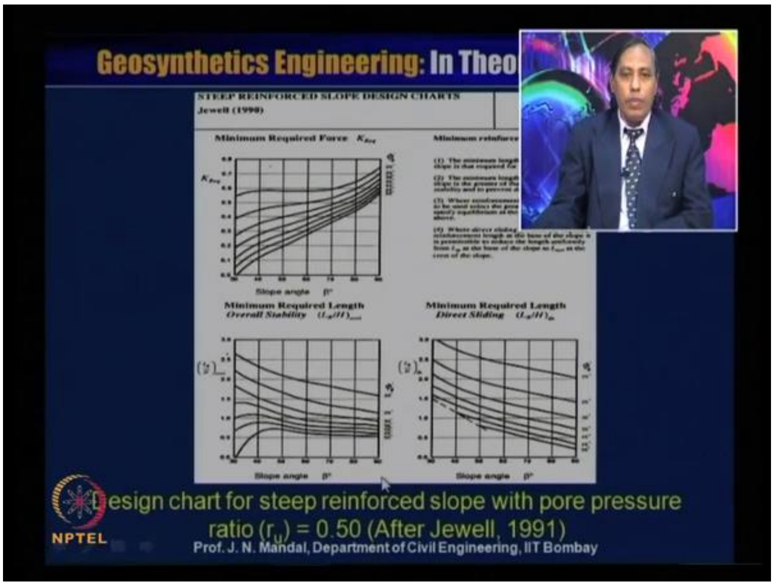
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STEEP REINFORCED SLOPE DESIGN CHARTS
Jewell (1990)

Design chart for steep reinforced slope with pore pressure ratio (r_u) = 0.50 (After Jewell, 1991)

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So, next also this is a design chart for steep reinforced slope with pore water pressure r u is 0.50. So, first of all you can check that what will be the r u and then accordingly you can design for sub stability using the Jewell design chart. So, from the Jewell design chart if you know the pore water pressure ratio, you know the what will be the properties of the soil and the height and the slope. Then you can determine what will be the length of the reinforcement and also you can determine what will be the spacing between the reinforcement. The outline of design procedure is mentioned below.

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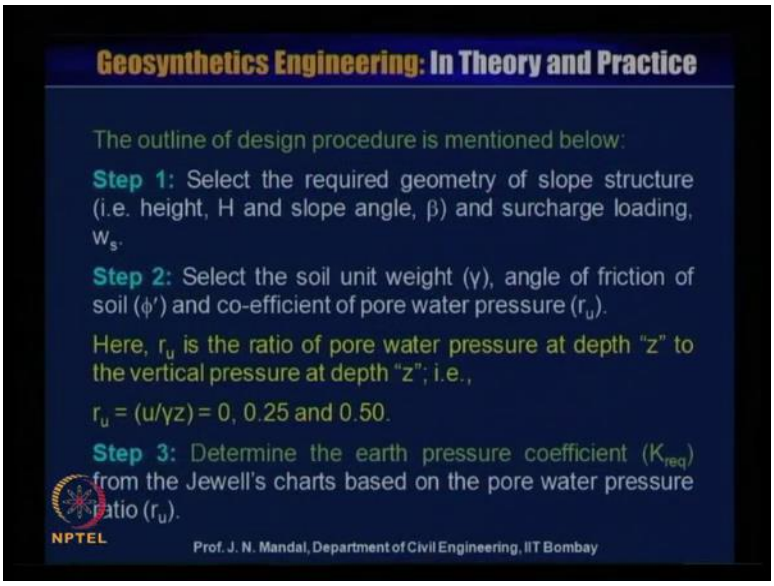

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The outline of design procedure is mentioned below:

Step 1: Select the required geometry of slope structure (i.e. height, H and slope angle, β) and surcharge loading, W_s.

Step 2: Select the soil unit weight (γ), angle of friction of soil (φ′) and co-efficient of pore water pressure (r_u).

Here, r_u is the ratio of pore water pressure at depth "z" to the vertical pressure at depth "z"; i.e.,

$r_u = (u/\gamma z) = 0$, 0.25 and 0.50.

Step 3: Determine the earth pressure coefficient (K_{req}) from the Jewell's charts based on the pore water pressure ratio (r_u).

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Step one, you have to select the required geometry of the slope structure that is what is the height H and the slope angle beta and surcharge loading W s. Step two, select the soil unit weight, angle of friction of the soil phi dash and coefficient of pore water pressure r u. Here r u is the ratio of pore water pressure at depth Z due to the vertical pressure at depth Z that is r u is equal to u by gamma Z that value may be the 0, 0.25 and 0.50. Step three, determine the earth pressure coefficient K required from the Jewell chart based on the pore water pressure ratio, that means r u.

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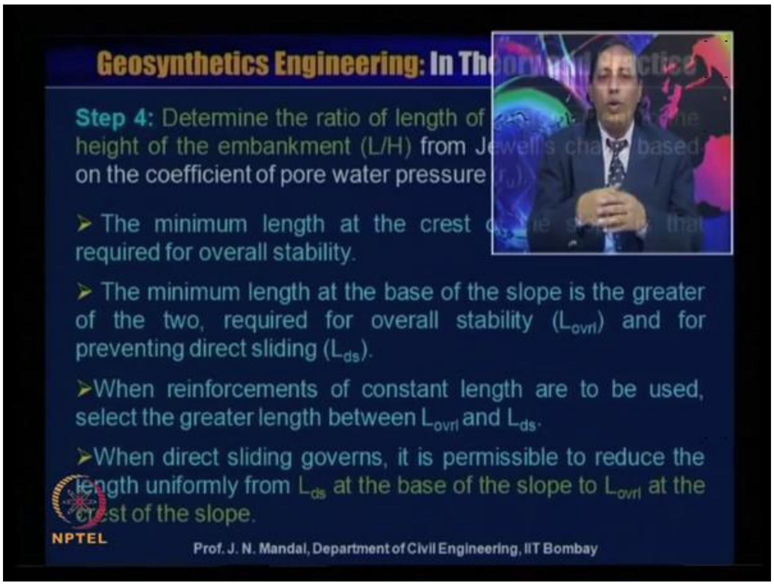

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Step 4: Determine the ratio of length of [illegible] the height of the embankment (L/H) from Jewell's charts based on the coefficient of pore water pressure (r_u).

- ➢ The minimum length at the crest of the [illegible] that required for overall stability.
- ➢ The minimum length at the base of the slope is the greater of the two, required for overall stability (L_{ovrl}) and for preventing direct sliding (L_{ds}).
- ➢ When reinforcements of constant length are to be used, select the greater length between L_{ovrl} and L_{ds}.
- ➢ When direct sliding governs, it is permissible to reduce the length uniformly from L_{ds} at the base of the slope to L_{ovrl} at the crest of the slope.

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Step four, determine the ratio of length of the reinforcement to the height of the embankment that means L by H from the Jewell chart based on the coefficient of pore water pressure that is r u. So, if that r u value is 0 then you can select what will be the length to the height ratio or if the r u value is 0.25 or r u value 0.50 then accordingly from the design chart you can calculate what will be the length to height ratio of the embankment.

So, minimum length at the crest of the slope is that required for the overall stability and minimum length at the base of the slope is greater of the two, required for overall stability, L overall and for preventing the direct sliding L d s. When the reinforcement of constant length are to be used, select the greater length between the L overturning and the L direct sliding.

When the direct sliding govern it is permissible to reduce the length uniformly from length due to direct sliding L d s at the base of the slope to L overturning L ovrl at the crest of the slope. So, this is the from point has been given by the Jewell and this will be much more clear when while give one example related on the steep reinforced soil slope. We will see that how, we can make use of the design chart given by the Jewell and how that length it can be selected based on the direct sliding and overall stability.

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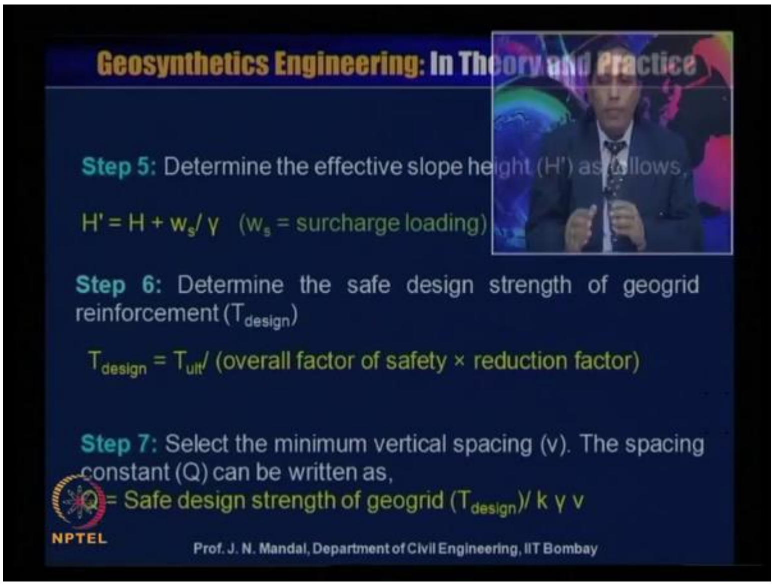

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Step 5: Determine the effective slope height (H') as follows,

$H' = H + w_s/\gamma$ (w_s = surcharge loading)

Step 6: Determine the safe design strength of geogrid reinforcement (T_{design})

$T_{design} = T_{ult}/$ (overall factor of safety × reduction factor)

Step 7: Select the minimum vertical spacing (v). The spacing constant (Q) can be written as,

Q = Safe design strength of geogrid (T_{design})/ $k \gamma v$

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Step five, determine the effective slope height H dash as follow. So, H dash is equal to H plus W s by gamma. You know W s is equal to surcharge loading. So, you can calculate that what will be the height of the slope due to the surcharge. Step six, determine the safe design strength of geogrid reinforcement that means T design. So, T design will be equal to T ultimate divided by overall factor of safety into reduction factor.

Step seven, select the minimum vertical spacing, that v. The spacing constant Q can be written as Q is equal to safe design strength of geogrid that is T design divided by K into gamma into v. So, you should remember what is Q that is spacing constant that means, Q is equal to T design by K into gamma into v. So, we will use this equation when we will design the reinforced steep slope using the Jewell chart.

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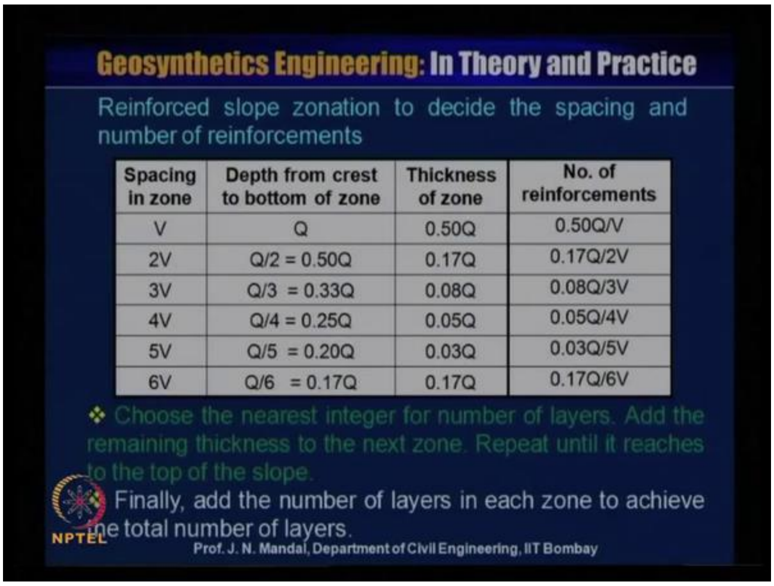

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Reinforced slope zonation to decide the spacing and number of reinforcements

Spacing in zone	Depth from crest to bottom of zone	Thickness of zone	No. of reinforcements
V	Q	0.50Q	0.50Q/V
2V	Q/2 = 0.50Q	0.17Q	0.17Q/2V
3V	Q/3 = 0.33Q	0.08Q	0.08Q/3V
4V	Q/4 = 0.25Q	0.05Q	0.05Q/4V
5V	Q/5 = 0.20Q	0.03Q	0.03Q/5V
6V	Q/6 = 0.17Q	0.17Q	0.17Q/6V

❖ Choose the nearest integer for number of layers. Add the remaining thickness to the next zone. Repeat until it reaches to the top of the slope.

❖ Finally, add the number of layers in each zone to achieve the total number of layers.

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Now, reinforced slope zonation to decide the spacing and the number of the reinforcement. So, you can provide the spacing in zone. Let us say V, 2V, 3V, 4V, 5V and 6V. So, what will be the depth from the crest to the bottom of the zone? Let us say Q then it will be Q by 2 that mean 0.5 Q, Q by 0.33 Q, Q by 4.25 Q, Q by 5.20 Q and Q by 6.17 Q. Then what will be the thickness of the zone that means it will be the 0.5 Q and then this will be 0.17 Q. That means 0.50 minus 0.33Q, 0.17Q. Similarly, 0.33 minus 2.5Q is give 0.08Q, 0.25Q divided by minus 0.20Q which will give 0.05Q 0.20Q minus 0.17Q will give 0.03Q and this is 0.17Q. This is the thickness of zone.

Now, how many number of the reinforcement. So, number of the reinforcement will be 0.50Q by V, 0.17Q by 2V, 0.08Q by 3V, 0.05Q by 4V, 0.03Q by 5V and point 0.17Q by 6V. So, you have to choose the nearest integer of the number of layer and add the remaining thickness to the next zone and repeat until it reaches to the top of the slope. And finally, add the number of the layer in each zone to achieve the total number of the layer. It will be more clear when I will give one example.

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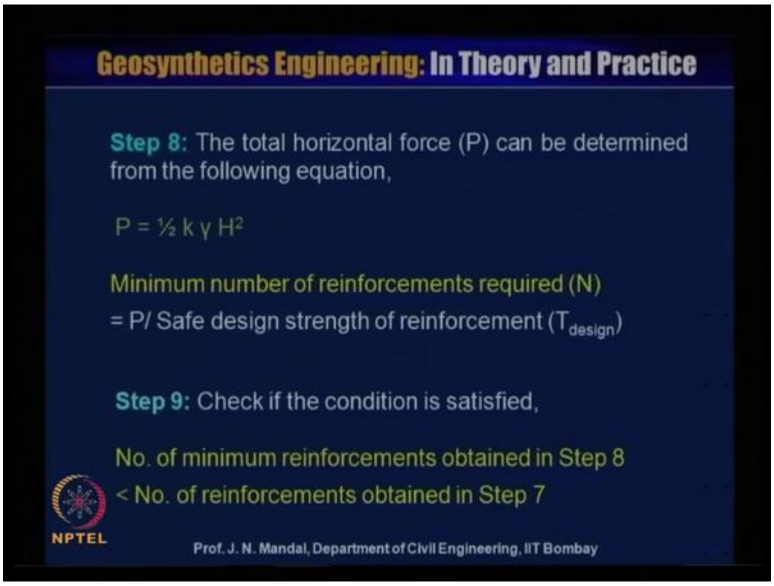

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Step 8: The total horizontal force (P) can be determined from the following equation,

$P = \frac{1}{2} k \gamma H^2$

Minimum number of reinforcements required (N)
= P/ Safe design strength of reinforcement (T_{design})

Step 9: Check if the condition is satisfied,

No. of minimum reinforcements obtained in Step 8
< No. of reinforcements obtained in Step 7

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Now, step eight total horizontal force P can be determined from the following equation that is P is equal to half into K into gamma H square, where minimum number of the reinforcement required N is equal to P divided by safe design strength of reinforcement that means T design. Step nine, check if the condition is satisfied, that is number of minimum reinforcement obtained in step eight should be less than number of the reinforcement obtained in step seven, then if it is satisfy then your design is correct.

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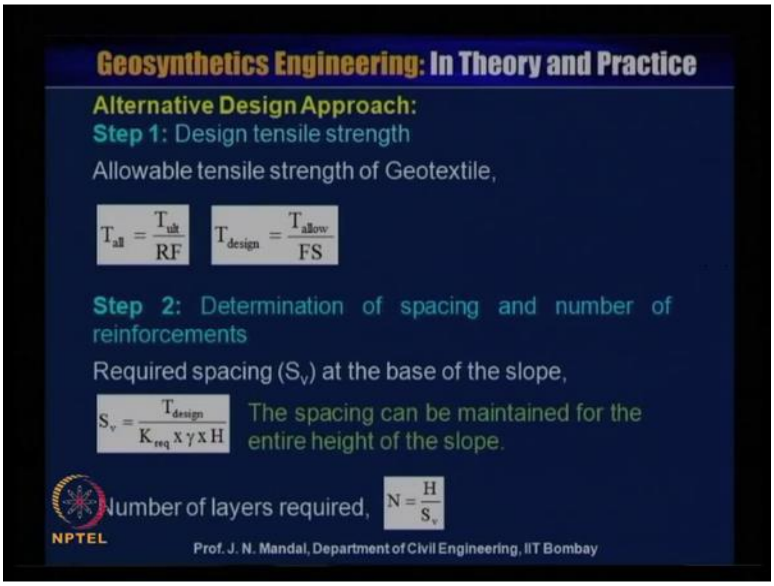

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Alternative Design Approach:

Step 1: Design tensile strength

Allowable tensile strength of Geotextile,

$$T_{all} = \frac{T_{ult}}{RF} \qquad T_{design} = \frac{T_{allow}}{FS}$$

Step 2: Determination of spacing and number of reinforcements

Required spacing (S_v) at the base of the slope,

$$S_v = \frac{T_{design}}{K_{req} \times \gamma \times H}$$

The spacing can be maintained for the entire height of the slope.

Number of layers required, $N = \frac{H}{S_v}$

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Now, alternative design approach. Step one, design the tensile strength. So, allowable tensile strength of the geotextile T allowable is equal to T ultimate by reduction factor. So, T design will be T allowable by factor of safety FS. Step two, determine sum of spacing and the number of the reinforcement. So, required spacing S v at the base of the slope. S v is equal to T design by K required into gamma into H. This spacing can be maintained for the entire height of the slope. So, number of the layer required N is equal to H by S v. H is equal to height of the slope and S v is the spacing between the two reinforcement. So, you can determine that number of layer of the reinforcement required.

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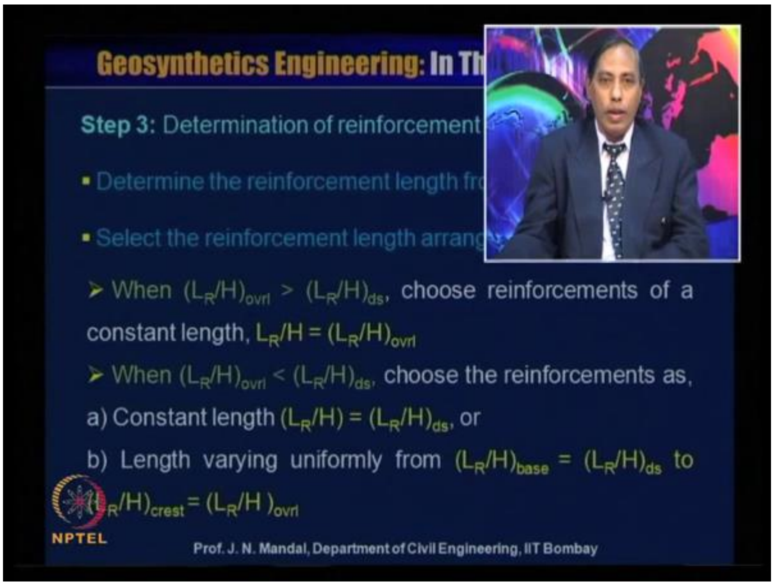

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Step 3: Determination of reinforcement

- Determine the reinforcement length fr
- Select the reinforcement length arrang

➢ When $(L_R/H)_{ovrl} > (L_R/H)_{ds}$, choose reinforcements of a constant length, $L_R/H = (L_R/H)_{ovrl}$

➢ When $(L_R/H)_{ovrl} < (L_R/H)_{ds}$, choose the reinforcements as,

a) Constant length $(L_R/H) = (L_R/H)_{ds}$, or

b) Length varying uniformly from $(L_R/H)_{base} = (L_R/H)_{ds}$ to $(L_R/H)_{crest} = (L_R/H)_{ovrl}$

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Step 3, determination of reinforcement length. So, we require the reinforcement length, the reinforcement length from the Jewell chart. Select the reinforcement length arrangement as follow when L R by H overturning. Due to overturning it should be greater than L R by H direct sliding. Then choose the reinforcement of a constant length that means L R by H is equal to L R by H overturning, but when the L R by H overturning is less than L R by H direct sliding, choose the reinforcement as a constant length that means L R by H is equal to L R by H direct sliding or b length varying uniformly from L R by H base is equal to L R by H direct sliding to L R by H crest is equal to L R by H overturning.

So, you can then based on the L R by H value due to the direct sliding or L R by H value due to the overturning value. So, you can determine what should be the length of the geogrid you know if it is a L R by H greater than L R by H direct sliding. Then L R by H will be L R by H overall and if it is not then you can think about the constant length, or you can think that how the length varying can be done in this method.

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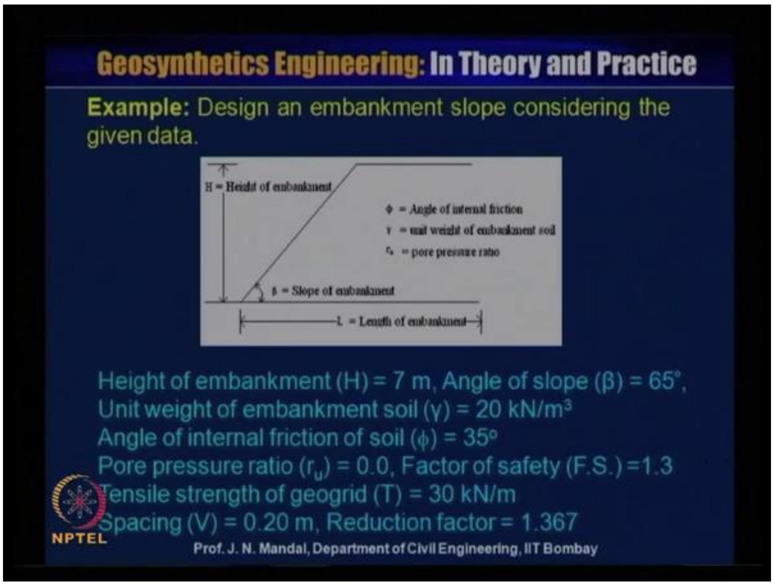

Geosynthetics Engineering: In Theory and Practice

Example: Design an embankment slope considering the given data.

Height of embankment (H) = 7 m, Angle of slope (β) = 65°,
Unit weight of embankment soil (γ) = 20 kN/m^3
Angle of internal friction of soil (ϕ) = 35°
Pore pressure ratio (r_u) = 0.0, Factor of safety (F.S.) =1.3
Tensile strength of geogrid (T) = 30 kN/m
Spacing (V) = 0.20 m, Reduction factor = 1.367

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So, this is one example design and embankment slope considering the given data. So, this is the embankment and this is the height of the embankment. This is the slope of the embankment, this is the length of the embankment and this properties of the soil. Phi angle of internal friction, gamma unit weight of embankment soil and r u is pore pressure ratio.

When this problem it is given the height of the embankment H is equal to 7 meter, angle of slope beta is 65 degree, unit weight of embankment soil gamma is equal to 20 kilo Newton per meter cube, angle of internal friction of the soil phi is 35 degree. And we are considering here pore pressure ratio that is r u is equal to 0 and factor of safety FS is equal to 1.3, tensile strength of the geogrid T is 30 kilo Newton per meter and spacing between the two geogrid material is 0.20 meter and reduction factor is equal to 1.367.

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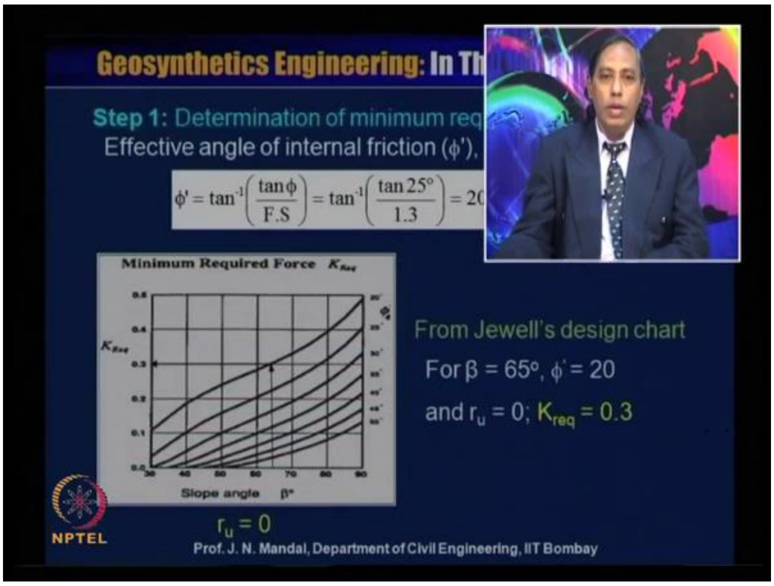

Geosynthetics Engineering: In Th

Step 1: Determination of minimum req

Effective angle of internal friction (ϕ'),

$$\phi' = \tan^{-1}\left(\frac{\tan\phi}{F.S}\right) = \tan^{-1}\left(\frac{\tan 25^\circ}{1.3}\right) = 2$$

From Jewell's design chart

For β = 65°, ϕ' = 20

and $r_u = 0$; $K_{req} = 0.3$

$r_u = 0$

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So, this is the example and now we will adopt the Jewell chart. So, this is the Jewell chart is given. So, step 1, you have to determination of minimum required forces that is K required. So, effective angle of internal friction phi dash you have to determine. So, phi dash is equal to tan inverse tan phi by factor of safety that means, tan inverse tan of 25 degree divided by factor of safety 1.3 depending upon the type of the material you are using. So, this will give you that phi dash value is equal to 20 degree. So, this is the design chart which for r u is equal to 0 that is pore water pressure ratio is equal to 0 and this is the slope angle is here base beta and this is the minimum required force, K required.

So, we have to calculate what will be the minimum required force, K required from this Jewell design chart. Now, we know that beta is 65 degree and phi dash is 20 degree. So, we know beta here 65 degree and phi dash is 20 degree. So, you move up and when phi is equal to 20 degree then you move horizontally and which will give you the value of the minimum required force, that is K required. So, K required will be equal to 0.3. This is K required is equal to 0.3 for r u is equal to 0. So, we calculate what is K required from this chart.

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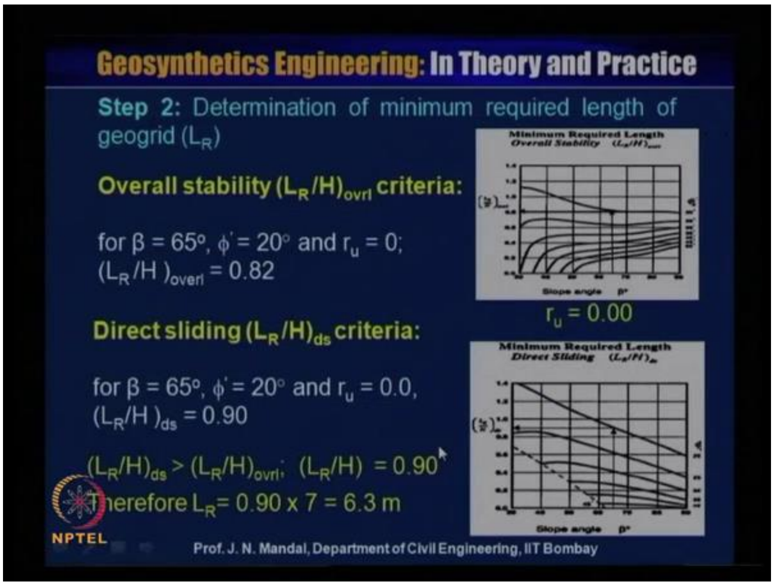

Geosynthetics Engineering: In Theory and Practice

Step 2: Determination of minimum required length of geogrid (L_R)

Overall stability $(L_R/H)_{ovrl}$ criteria:

for $\beta = 65^\circ$, $\phi' = 20^\circ$ and $r_u = 0$;
$(L_R/H)_{overl} = 0.82$

Direct sliding $(L_R/H)_{ds}$ criteria:

for $\beta = 65^\circ$, $\phi' = 20^\circ$ and $r_u = 0.0$,
$(L_R/H)_{ds} = 0.90$

$(L_R/H)_{ds} > (L_R/H)_{ovrl}$; $(L_R/H) = 0.90$
Therefore $L_R = 0.90 \times 7 = 6.3$ m

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Next, step two determination of minimum required length of the geogrid L R that is due to overall stability, that is L R by H overall stability criteria. So, this is the Jewell design chart in which we can calculate what will be the minimum required length or overall stability. That means L R by H overall and this is the slope angle and this is the L R by H overall and this is the phi value. So, here beta is equal to 65 degree and you move up this is phi is equal to 20 degree and then we move horizontally. You can have L R by H ovrl is 0.85. So, L R by H that is minimum length, you can calculate for overall stability is equal to 0.82. So, we calculate the L R by H for overall stability is 0.82 from this design chart when r u is equal to 0.

Now, next we have to calculate what will be the direct sliding that means L R by H direct sliding criteria. Again from this design chart this is for minimum required length for direct sliding that means L R by H s and this is a slope angle beta and this is the phi value. So, you know that slope angle beta is 65 degree. You move up and check that where is phi dash is equal to 20 degree.

Then you move horizontal and then you can calculate that what will be the L R by H that for direct sliding. That means minimum required length for direct sliding. So, L R by H direct sliding you can have 90.90. So, we check that what will be the K required. We also check what will be the L R by H for overall stability that is 0.82. We know also what is L R by H due to direct sliding that is 0.90.

Now, you check that whether L R by H, the direct sliding greater than L R by H overall stability or not. Here you can see that L R by H direct sliding is 0.90. So, this is greater than the L R by H overall stability. So, if it is slope so you can say that L R by H is equal to 0.90. If it is greater than this then you can adopt L R by H 0.90. Therefore, L R will be equal to 0.90 into height of the slope is 7. So, this will give 6.3 meter. So, you know the length of the geogrid material is 6.3 meter. So, you can calculate this.

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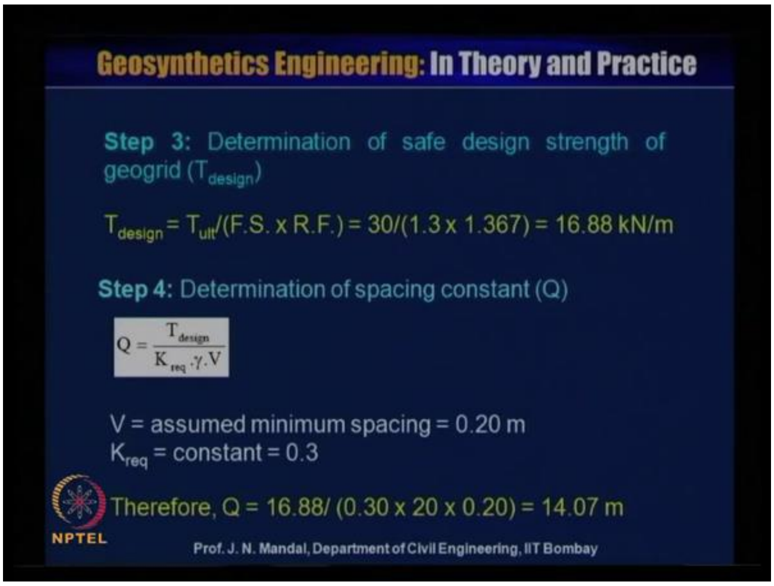

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Step 3: Determination of safe design strength of geogrid (T_{design})

$T_{design} = T_{ult}/(F.S. \times R.F.) = 30/(1.3 \times 1.367) = 16.88$ kN/m

Step 4: Determination of spacing constant (Q)

$$Q = \frac{T_{design}}{K_{req} \cdot \gamma \cdot V}$$

V = assumed minimum spacing = 0.20 m
K_{req} = constant = 0.3

Therefore, Q = 16.88/ (0.30 x 20 x 0.20) = 14.07 m

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Now, step three determination of safe design strength of geogrid that is T design will be equal to T ultimate divided by factor of safety into reduction factor and T ultimate is given is 30, geogrid factor of safety 1.3 into reduction factor is given 1.367. So, this will give the T design value 16.88 kilo Newton per meter. Step four, determination of spacing constant that is Q. So, Q is equal to T design by K required into gamma into V. This I talk about that what will be the spacing constant. So, where V you can assume this minimum spacing is 0.20 and K required is 0.3 is constant. Therefore, you can calculate what will be the Q, that means what will be the spacing constant. So, this Q will be equal to this T is 16.88. This is 16.88, this divided by what is K required? K required is 0.3. What is gamma? Gamma you know 20 and what is V, that minimum spacing we consider

0.20 meter. So, 0.20 meter. So, this way you can calculate that Q or spacing constant is 14.07 meter.

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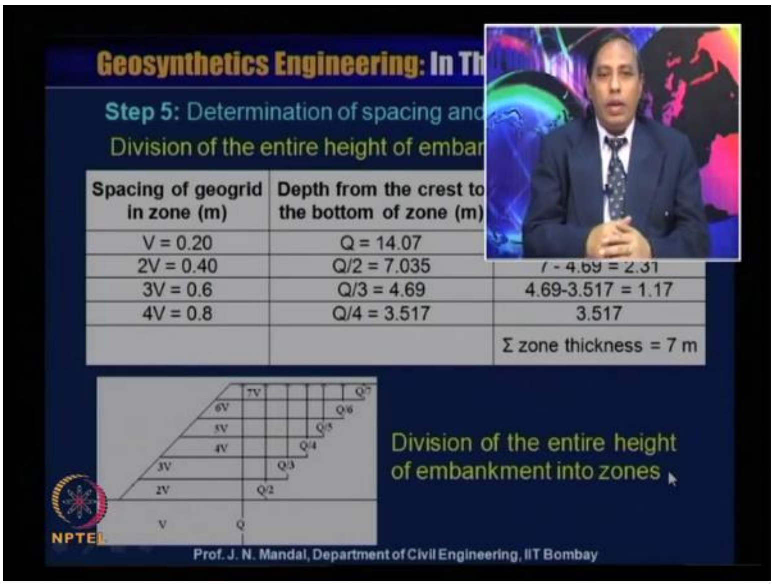

Geosynthetics Engineering: In Th

Step 5: Determination of spacing and

Division of the entire height of embar

Spacing of geogrid in zone (m)	Depth from the crest to the bottom of zone (m)	
V = 0.20	Q = 14.07	
2V = 0.40	Q/2 = 7.035	7 - 4.69 = 2.31
3V = 0.6	Q/3 = 4.69	4.69-3.517 = 1.17
4V = 0.8	Q/4 = 3.517	3.517
		Σ zone thickness = 7 m

Division of the entire height of embankment into zones

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Now, step 5 determination of spacing and the number of the layer. So, division of the entire length of the embankment into zone. So, this is the spacing of geogrid in zone in meter. It has say V spacing. We have consider 0.20 or 2V will be the 0.40 meter 3V will be the 0.6 meter and 4V is equal to 0.8 meter and next that what will be the depth from the crest to the bottom of the zone. So, this is spacing constant Q. So, Q will be equal to 14.07 which we are calculated. Q is equal to 14.07. So, Q is equal to 14.07. Next Q by 2 will be half of this. That means 7.035, again Q by 3 will be 4.69 and Q by 4 will be 3.517.

So, here you can see that division of the entire height of the embankment into zone. So, when a Q spacing constant here the spacing is V. Next this term Q by 2 when spacing is 2V. When this is Q by 3, this spacing is 3V. When this is Q by 4, your spacing is 4V, when Q by 5, the spacing is 5V, when Q by 6, this spacing is 6V. When Q by 7, spacing is 7V. So, this is the division of the entire height of the embankment into zone.

Now, you seen here that we have considered only up to 4V. Only up to 4V here because you see that our height of the embankment is 7 meter, our height of the slope is 7 meter. So, that means this we can consider 7 minus 4.69 will give you that. What will be the thickness of that zone. That mean this will give 2.31 meter again 4.69 minus 3.571 will give 1.17, that means this is the thickness of that zone that is in meter and then remaining 3.517.

So, now if we add this 2.31, 1.17 plus 3.517 which will give you the summation of the zone of the thickness 7 meter. So, you are having the 7 meter so that is why that slope. This is the height of the slope is 7 meter. So, you can see it satisfy the zone thickness is 7 meter, so that is how you are considering up to the 4 of V because we are not going beyond that because the height of the slope is only 7 meter. See if it is a more you can go ahead with the different value, you can go ahead with the Q by 5 Q by 6 Q by 7 etcetera.

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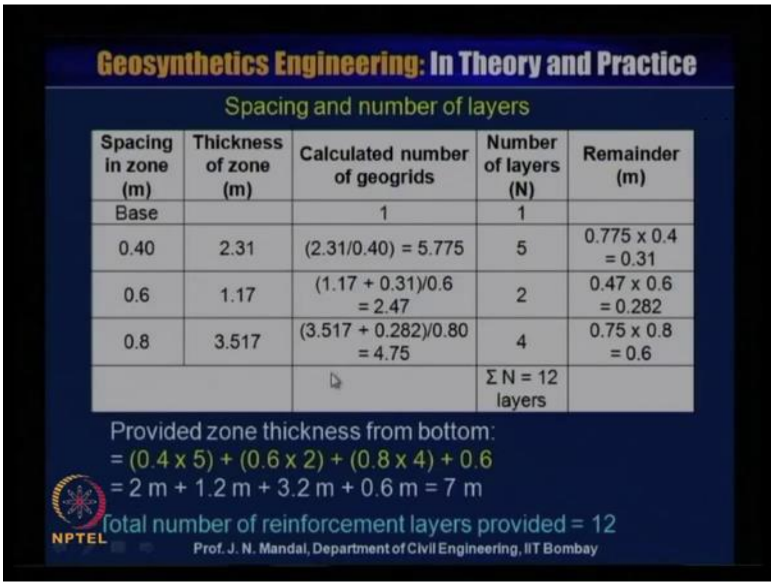

Geosynthetics Engineering: In Theory and Practice

Spacing and number of layers

Spacing in zone (m)	Thickness of zone (m)	Calculated number of geogrids	Number of layers (N)	Remainder (m)
Base		1	1	
0.40	2.31	(2.31/0.40) = 5.775	5	0.775 x 0.4 = 0.31
0.6	1.17	(1.17 + 0.31)/0.6 = 2.47	2	0.47 x 0.6 = 0.282
0.8	3.517	(3.517 + 0.282)/0.80 = 4.75	4	0.75 x 0.8 = 0.6
			ΣN = 12 layers	

Provided zone thickness from bottom:
= (0.4 x 5) + (0.6 x 2) + (0.8 x 4) + 0.6
= 2 m + 1.2 m + 3.2 m + 0.6 m = 7 m
Total number of reinforcement layers provided = 12

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So, now spacing and the number of the layer. Now, spacing in the zone that is meter and this is the thickness of the zone meter. This is calculated number of geogrid and this is number of layer N and this is the remainder in meter. So, in general that at the base of the steep slope you have to provide one layer of the geogrid. So, this we can say that calculated number of geogrid 1. So, we take one layer of the geogrid at the base or in between the foundation and the embankment.

So, you can provide one layer. Now, base spacing zone, base is 0.40, 0.6, 0.8. So, you know here that spacing zone because from here so 0.40, 0.6 and 0.8. So, that is why the spacing in zone meter 0.40, 0.6 and 0.8 and thickness of the zone. This is thickness of the zone 2.31, 1.17 and 3.517. So, here thickness of the zone is 2.31, 1.17 and 3.517. So, next you calculate the number of the geogrid, I say at the base you should provide one.

Now, here the 2.31 by spacing of the 0.40 will give you 5.775.

So, you take the number of the layer 5. So, remainder is 0.775 into spacing zone 0.4. This will be the 0.31. So, this is the remainder in meter, my next spacing in zone 0.6, thickness of the zone 1.17. So, calculated number of geogrid 1.17 plus the remainder that is 0.31 divided by the spacing zone is 0.6. So, it will give 2.47. So, we are considering number of layer 2 and remainder is 0.47 into spacing in zone 0.6. This will give you 0.282. Now, next spacing of the zone 0.8, thickness of the zone 3.517, so 3.517 plus that remainder is 0.282 divided by this spacing zone 0.8 will give 4.75. So, you take 4. So, then remainder is 0.75 into 0.8 is equal to 0.6.

So, here you can see that what will be the number of the layer. So, if you add 1 plus 5, 6 plus 2, 8 plus 4, 12. So, total number of layer will be the 12. So, you have to place the total number of the geogrid in this slope above 12 layer. So, provided the zone thickness from the bottom you can see that 0.4 into 5 plus 0.6 into 2 plus 0.8 into 4 plus reminder is 0.6. So, that means this will give 2 meter, this will give 1.2 meter. This will give 3.2 meter and 0.6 meter. So, this will be the 7 meter. So, you can see that zone thickness from the bottom is about 7 meter and total number of the reinforcement layer provided is 12 meter.

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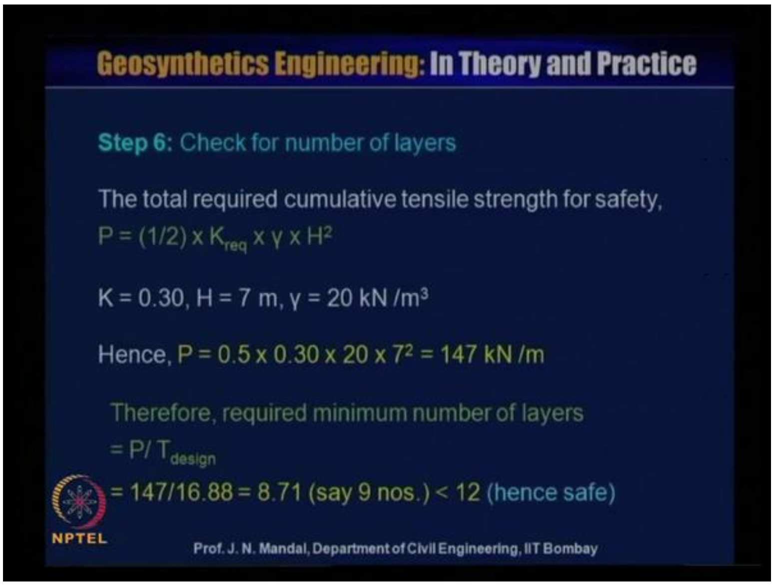

Geosynthetics Engineering: In Theory and Practice

Step 6: Check for number of layers

The total required cumulative tensile strength for safety,

$P = (1/2) \times K_{req} \times \gamma \times H^2$

$K = 0.30$, $H = 7$ m, $\gamma = 20$ kN/m^3

Hence, $P = 0.5 \times 0.30 \times 20 \times 7^2 = 147$ kN/m

Therefore, required minimum number of layers

$= P/T_{design}$

$= 147/16.88 = 8.71$ (say 9 nos.) < 12 (hence safe)

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Now, step 6 you have to check for the number of the layer. Total required cumulative tensile strength for safety P is equal to half into K required into gamma into H square. K value is known 0.30 which we have determined from the Jewell chart. H is 7 meter and gamma is 20 kilo Newton per meter cube given. So, P will be equal to half 0.5 into K required is 0.30 into gamma 20 and H is 7 square. So, it will give P is equal to 147 kilo Newton per meter.

Therefore, required minimum number of the layer will be equal to P divided by T design. So, what is P? We have calculated now 147 divided by T design. We know 16.88. So, this will give 8.71 that number of the geogrid layer. So, 8.71 say this is 9 number, where as per our design method what we have adopted and it is coming 12. So, it is less than the 12. So, we require about 9 but we have providing the 12 then it is the safe. So, design is safe.

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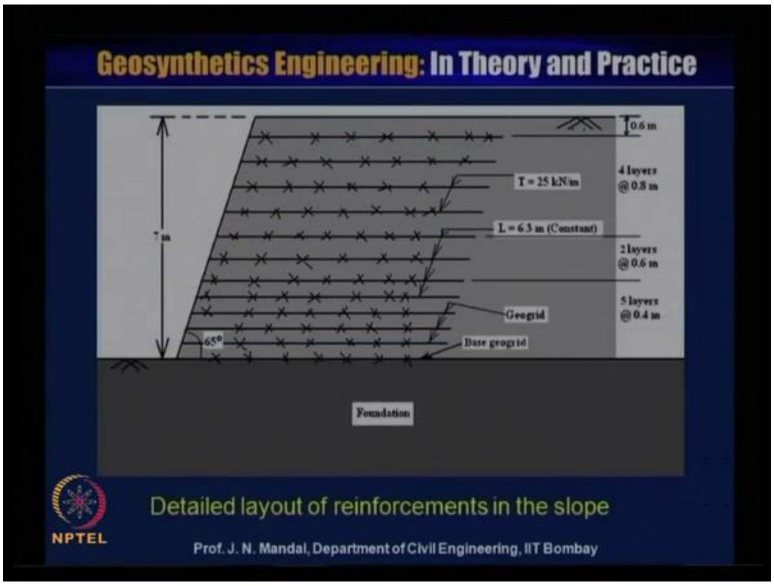

Geosynthetics Engineering: In Theory and Practice

Detailed layout of reinforcements in the slope

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So, this is the layout of the geogrid reinforced slope is given in this figure. So, this angle of the slope is 65 degree you know and height of the slope is 7 meter and as I say at the base you have to provide one layer of the geogrid material. Then we are giving 5 layer, 5 layer of geogrid, 5 layer 2 and 4 like this. So, we are giving five layer at a spacing of 0.4 meter. And then the here is two layer at a spacing of 0.6 meter and then here four layer at a spacing of 0.8 meter and then remaining you can provide with the 0.6 meter and tensile strength of the geogrid we consider about 25 kilo Newton per meter. So, you know what will be the tensile strength of the geogrid material. You know what will be the spacing at the different height of the reinforced soil slope. So, then you can design like this.

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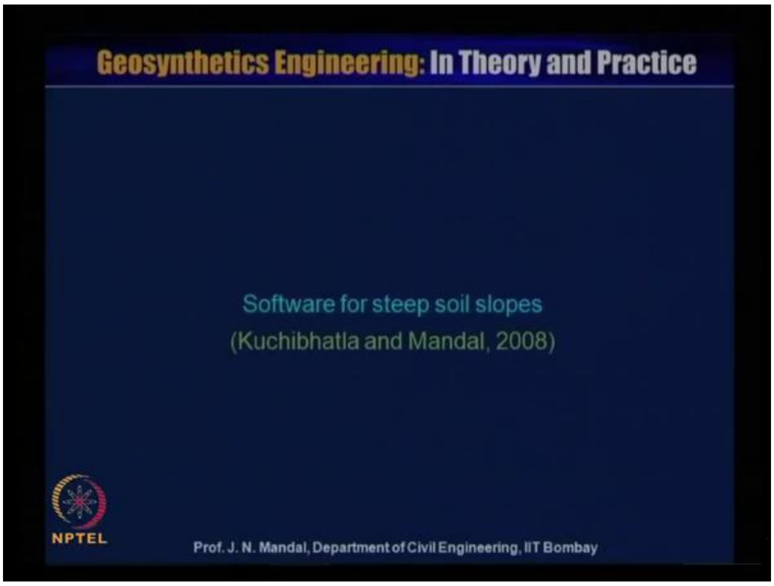

Geosynthetics Engineering: In Theory and Practice

Software for steep soil slopes

(Kuchibhatla and Mandal, 2008)

Now, I will show you that software for steep soil slope. This is Kuchibhatla has developed this software and here in this software, it is very interesting. With the same software you can design the slope at any angle as you like it.

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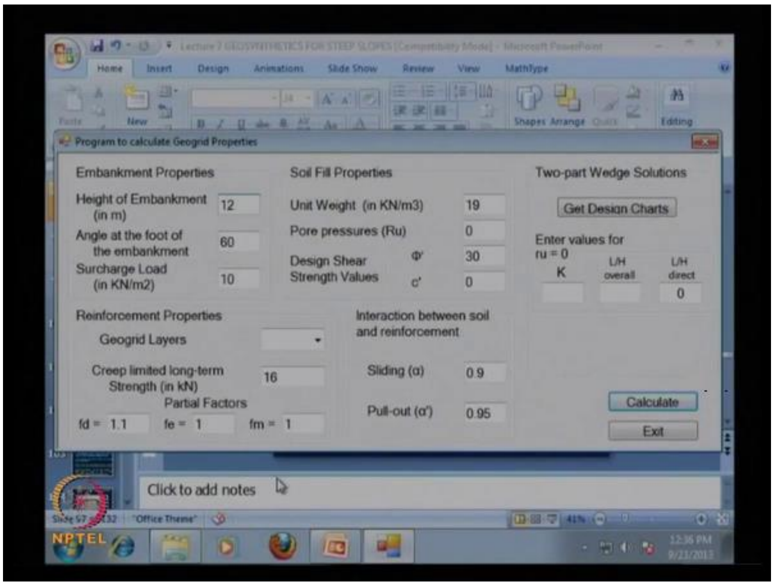

Program to calculate Geogrid Properties

Embankment Properties

Height of Embankment (in m): 12

Angle at the foot of the embankment: 60

Surcharge Load (in KN/m2): 10

Soil Fill Properties

Unit Weight (in KN/m3): 19

Pore pressures (Ru): 0

Design Shear Strength Values: Φ' 30; c' 0

Two-part Wedge Solutions

Enter values for ru = 0

K:

L/H overall:

L/H direct: 0

Reinforcement Properties

Geogrid Layers:

Creep limited long-term Strength (in kN): 16

Partial Factors: fd = 1.1 fe = 1 fm = 1

Interaction between soil and reinforcement

Sliding (α): 0.9

Pull-out (α'): 0.95

And also you can design the mechanically stabilize reinforced soil slope. Now, let us say this is the embankment property, height of the embankment is 12 and angle of foot for the embankment is 60 degree and surcharge load is 10 degree. Reinforcement properties and the creep limited long term strength is 16 and here we are providing the some partial factor of the safety.

Now, this partial factor of safety is what is called F of D, F of E and also F of M. Now, this partial factor of safety has been taken from the BS code specification. British Standard code specification where that F of D here which is 1.1, this is partial factor for mechanical damage and this is F of E is equal to 1. This is for the environmental damage and this is F of M is equal to 1. This is the partial factor for the manufacturer or the data interpretation.

So, these are the factor you have to take into consideration for the design and also you have to check that what should be the creep limited long term strength, and this is the limit equilibrium method has been adopted and soil fill property. Let us say unit weight is 19 kilo Newton per meter cube, pore pressure r u is 0, it can also vary and the design shear phi dash is 30 degree. Strength value is equal to this 0 and here also the check that interaction between the soil, and the reinforcement that is due to the sliding and due to the pullout value. So, before you use this we have to check that what should be the data we have to consider for this design of a 12 meter height of embankment.

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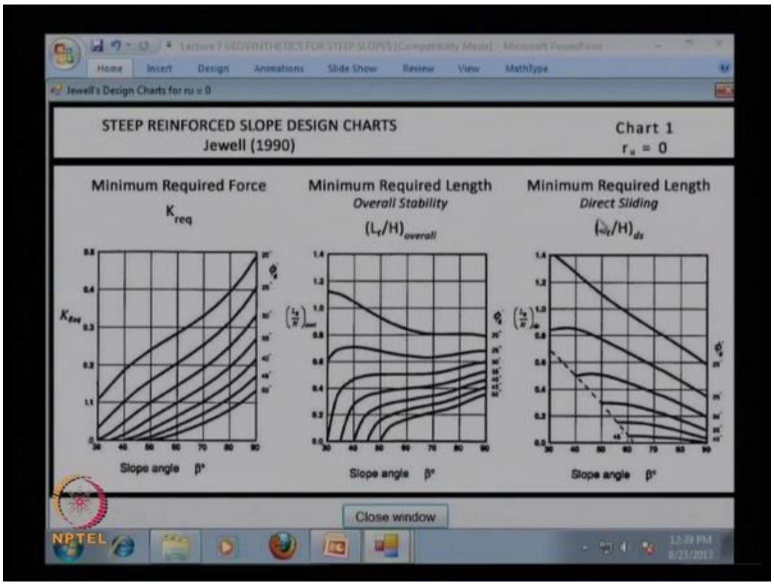

So, you can use this two parts wedge solution by the Jewell given by 1990. This is the steep reinforced slope design chart for r u is equal to 1, pore water pressure is equal to 1. Let us say that we are considering here a height of the wall 12 meter and beta is equal to 60 degree. If beta is equal to 60 degree we first of all determine what will be the minimum required force K required and when phi value is equal to 30 degree. So, let us say phi value here equal to 30 degree and for 60, if we go up and for phi 30 and then you can calculate K required and let us say this is K required value is 0.15.

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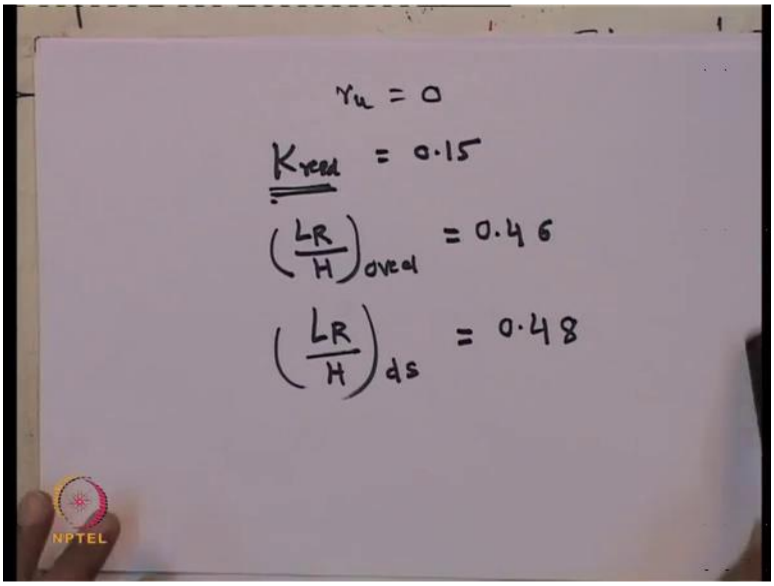

$$r_u = 0$$

$$\underline{\underline{K_{reqd}}} = 0.15$$

$$\left(\frac{L_R}{H}\right)_{overal} = 0.46$$

$$\left(\frac{L_R}{H}\right)_{ds} = 0.48$$

I am just noting here from this chart that what you obtain, that is what is K required you obtain 0.15 from this chart. This is the minimum required force, this is the minimum required force or 0.15 and r u value I say it is equal to 0. Next for minimum required length for overall stability that means L R by H overall will determine from this chart. So, we know the slope angle that is beta is equal to 6 degree and you move up when phi value is equal to 30 degree and then you can calculate this. What should be the L R by H for overall stability. So, L R by H for overall stability will be about 0.46. So, from this chart we can calculate that L R by H and this is due to the overall stability.

So, this will be about 0.46 and next that you have to calculate the minimum required length for direct sliding L R by H direct. So, we know that slope beta angle is equal to 60 degree and that phi value is equal to the 30 degree. So, then it can move in the horizontally then you can have L R by H direct sliding is about 0.48. So, this you can have L R by H for the direct sliding will equal to 0.48. So, we know all this data, then we know all the data, then we will substitute.

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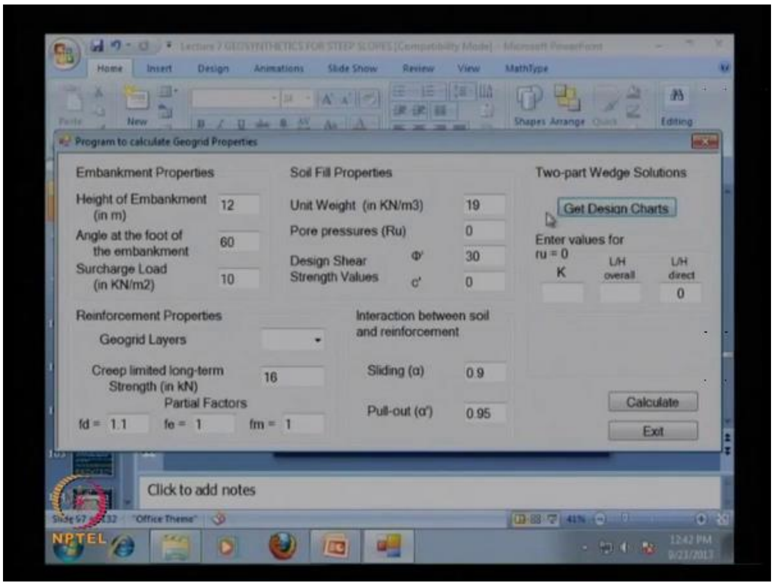

Height of Embankment (in m) 12
Angle at the foot of the embankment 60
Surcharge Load (in KN/m2) 10
Unit Weight (in KN/m3) 19
Pore pressures (Ru) 0
Design Shear Strength Values Φ' 30
c' 0
Enter values for ru = 0
K
L/H overall
L/H direct 0
Geogrid Layers
Creep limited long-term Strength (in kN) 16
fd = 1.1 fe = 1 fm = 1
Sliding (α) 0.9
Pull-out (α') 0.95

We will substitute this value here. Here you can see for the design chart r u and K value. As I said this is K required 0.15. So, we substitute this value is that is 0.1 and 5 and then L R by H overturning 0.46. So, this is 0.46 and then L R by H direct sliding 0.48, so 0.48 so we substitute this value so we can calculate we can see. We can calculate, you will obtain the depth of the geogrid layer that is depth of the layer here you can obtain it. This is the reinforcement length, you can have it and we can have also the anchorage length here. So, we can calculate what will be the total length of the reinforcement. So, this is the total length of the reinforcement. Now, you can see the figure.

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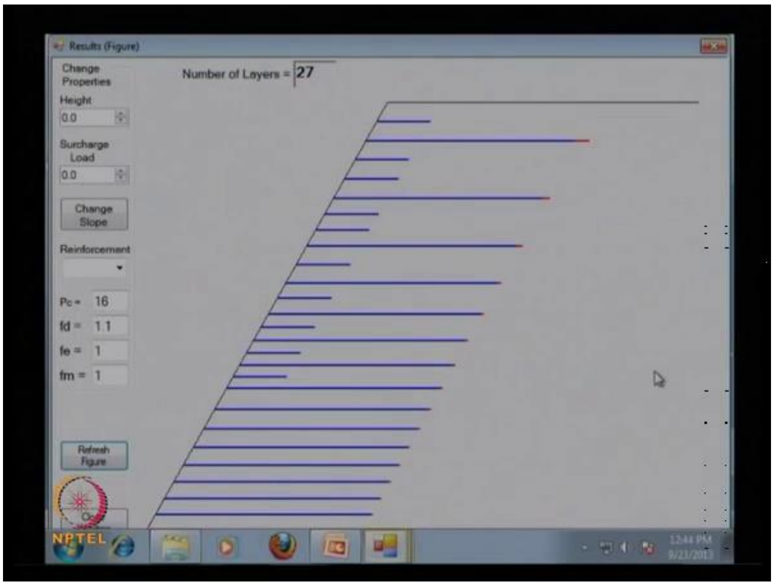

Number of Layers = 27
Height 0.0
Surcharge Load 0.0
Reinforcement
Pc = 16
fd = 1.1
fe = 1
fm = 1

Here this is total number of the layer is 27 and if the spacing is more so you are provide you the secondary uniaxial geogrid material. So, you know that what is the red and this red color which will give the embankment length. So, for this reinforcement where here is the Pc is equal to 16, that is the creep limit long term stability and f d 1.1. I say that partial factor of mechanical damage this is f e for environmental damage and this is f m is the manufacturer and data exploration.

So, you can use this design chart. So, you can also base at any height. You can you can make it at any height. You can see, you can make any height. You can see how it is changing, how the design chart is changing, how K is changing. So, you can make it. You can also push the define the surcharge load also due to the surcharge load how it is the changing of the curve.

So, this is very useful and you can use this kind of the software from in your problem. Also that you can use the same for you can change the angle. You can change this angle. For example, if you wanted to make a 90 degree. Let us say you wanted to make 90 degree. So, if it is a 90 degree then you also keeping all other same. You can change it and then you can calculate it. You can have and then you can show the figure.

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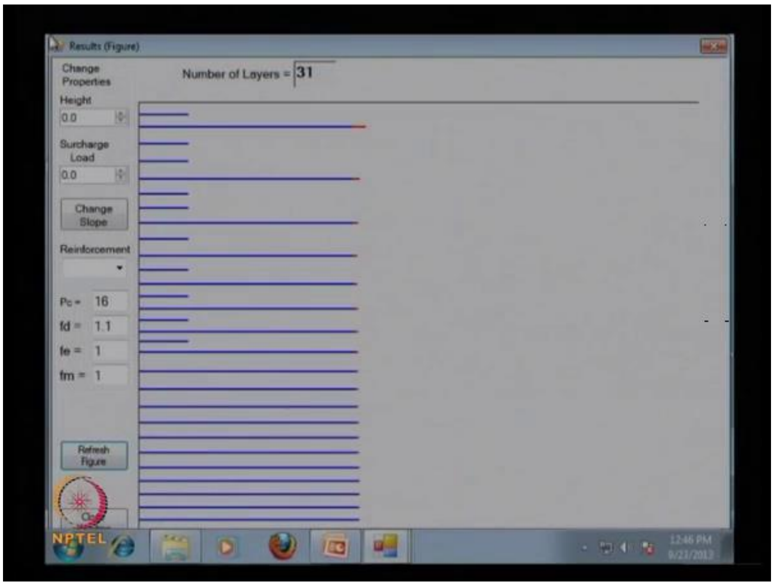

Number of Layers = 31

Height 0.0

Surcharge Load 0.0

Pc = 16

fd = 1.1

fe = 1

fm = 1

You can see this is 90 degree. So, this is the number of the layer of the reinforcement. This is the embankment length and total number of the reinforcement length about 31. So, you can make use of this software for the mechanically stabilized reinforced soil wall and as well as for any steep slope as you like it. Apart from that you can also determine, apart from that you can also change this reinforcement strength. Suppose this is 40 r e. So, I am just putting some of the value here. Let us say 0.3 K value L by H value. Let us say 0.5 and L by H direct sliding. Let us say 0.6.

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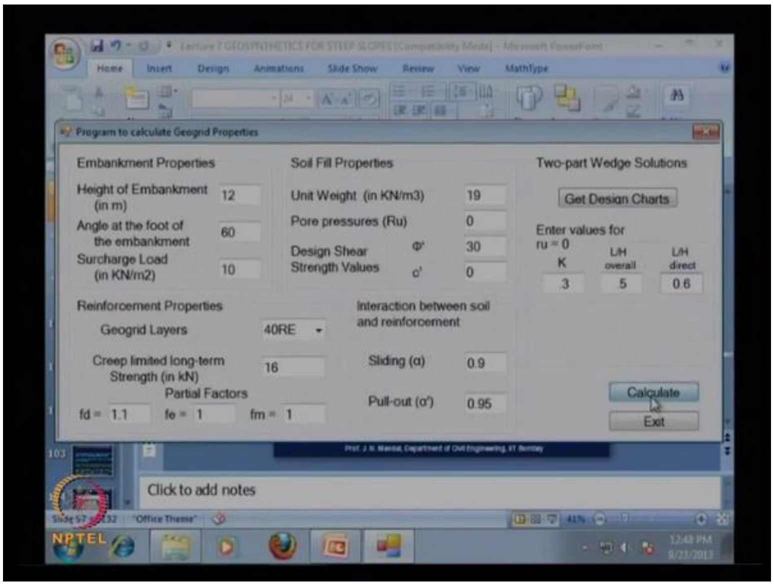

Program to calculate Geogrid Properties

Embankment Properties

Height of Embankment (in m): 12
Angle at the foot of the embankment: 60
Surcharge Load (in KN/m2): 10

Soil Fill Properties

Unit Weight (in KN/m3): 19
Pore pressures (Ru): 0
Design Shear Strength Values Φ': 30
Design Shear Strength Values c': 0

Two-part Wedge Solutions

Enter values for ru = 0
K: 3
L/H overall: 5
L/H direct: 0.6

Reinforcement Properties

Geogrid Layers: 40RE
Creep limited long-term Strength (in kN): 16

Partial Factors

fd = 1.1
fe = 1
fm = 1

Interaction between soil and reinforcement

Sliding (α): 0.9
Pull-out (α'): 0.95

So, you can calculate this and you can show the figure.

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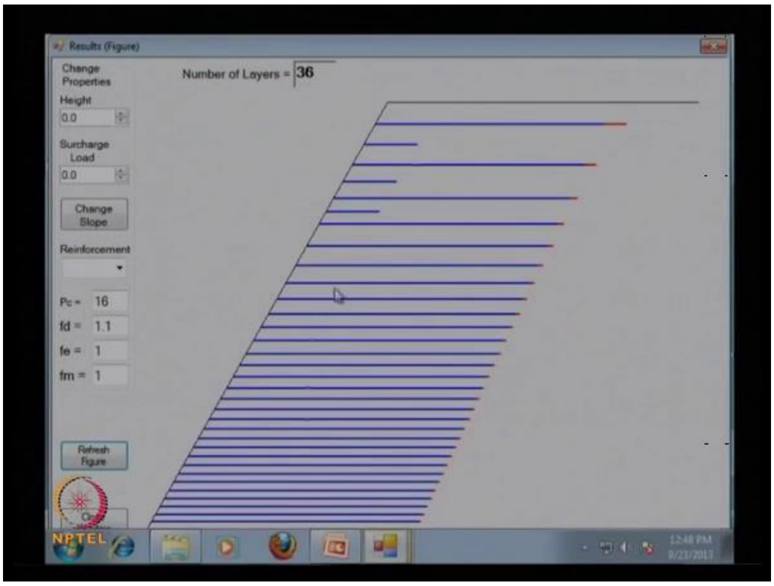

Results (Figure)

Number of Layers = 36

Change Properties

Height: 0.0
Surcharge Load: 0.0
Pc = 16
fd = 1.1
fe = 1
fm = 1

For this 40 r e, you can also change this the reinforcement property. Suppose 80 r e, you can do the 80 r e then we can calculate and you can see the property say you can see that.

Now, for the seismic aspect also it can be so seismic, also you have to take into account. Now, you can say the seismic stability, also you can want to calculate. So, you can give that some value of the basic horizontal seismic coefficient in that zone, whether it is zone 1, 2, 3, 4 as far as classified by I s. So, let us say that seismic zone factor is 0.3. So, then you can directly calculate. You can see what is the seismic thrust, that is kilo Newton per meter. What will be the horizontal inertia force 591.52, total dynamic force 649.73 and dynamic force act at a height of 7.2.

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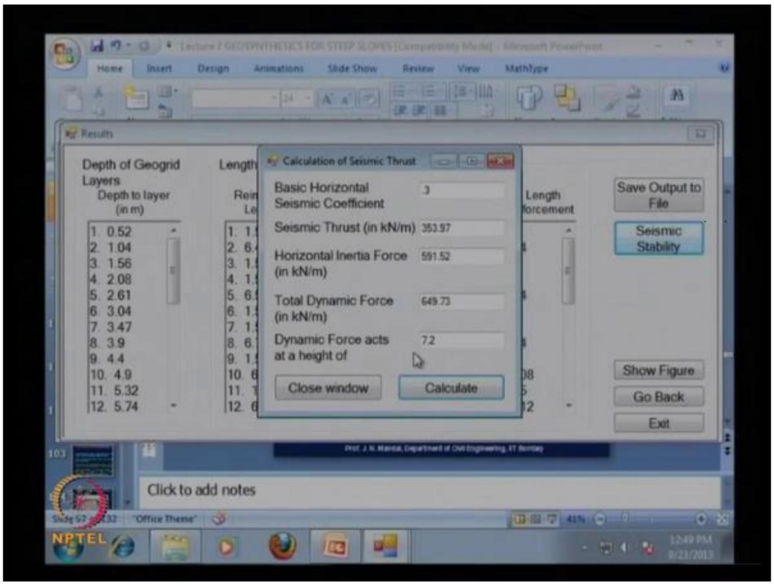
Results

Calculation of Seismic Thrust

Basic Horizontal Seismic Coefficient: .3
Seismic Thrust (in kN/m): 353.97
Horizontal Inertia Force (in kN/m): 591.52
Total Dynamic Force (in kN/m): 649.73
Dynamic Force acts at a height of: 7.2

Depth of Geogrid Layers
Depth to layer (in m)
1. 0.52
2. 1.04
3. 1.56
4. 2.08
5. 2.61
6. 3.04
7. 3.47
8. 3.9
9. 4.4
10. 4.9
11. 5.32
12. 5.74

So, you can also use this and also determine what will be the other forces. So, this way you can make use of this software and this software is very easy to calculate for any angle of the slope. Even then if it is a 90 degree you can do. You can use also the seismic aspect and it is very user friendly. So, with this I finish my lecture today. Any question let me hear from you.

Thank you for listening.