Geosynthetics Engineering: In Theory and Practices
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Lecture - 49
Geosynthetics for Ground Improvement

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 49 module 9 geosynthetics for ground improvement. Now, I will focus recap of the previous lecture, that is finite element modelling of encased stone columns.

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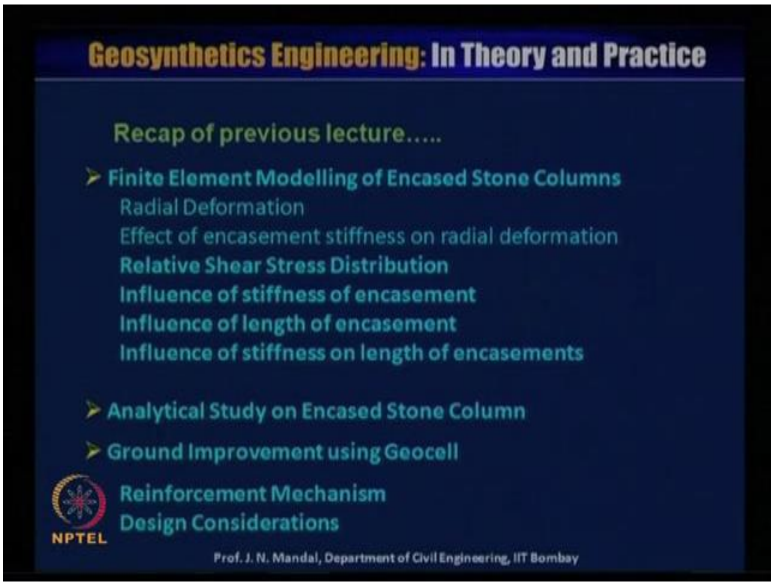

We cover radial deformation, effect of encasement stiffness on radial deformation, relative shear stress distribution, influence of stiffness of encasement, influence of length of encasement, and influence of stiffness on length of encasement. Analytical study of encased stone column. Ground improvement using geocell, reinforcement mechanism and design consideration.

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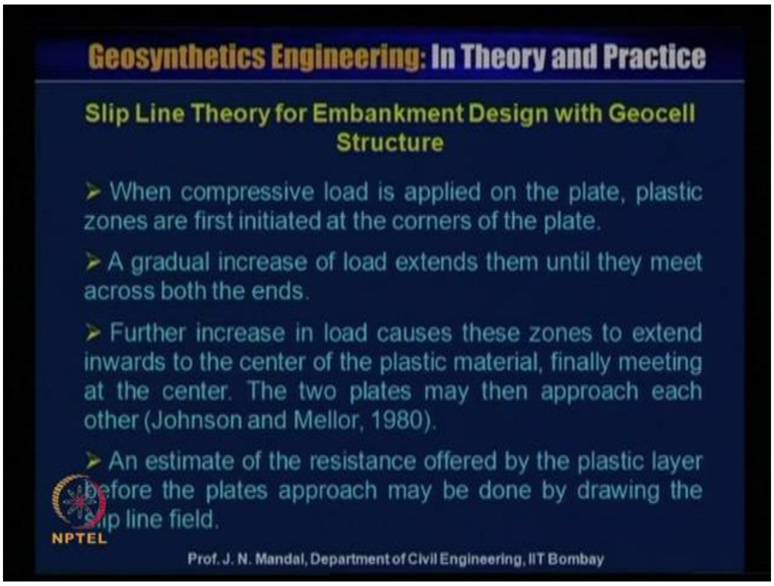

Now, I will focus slip line theory for embankment design with geocell structure. When compressible load is applied on the plate, plastic zone are first initiated at the corner of the plate. A gradual increase of load extend then until they meet across both the end. So, further increase in the load causes this zone to extend inwards to the center of the plastic material and finally, meeting at the center. These two plates may then approach each other, this is Johnson and Mellor 1980. An estimate of the resistance offered by the plastic layer before the plate approach may be done by drawing the slip line method.

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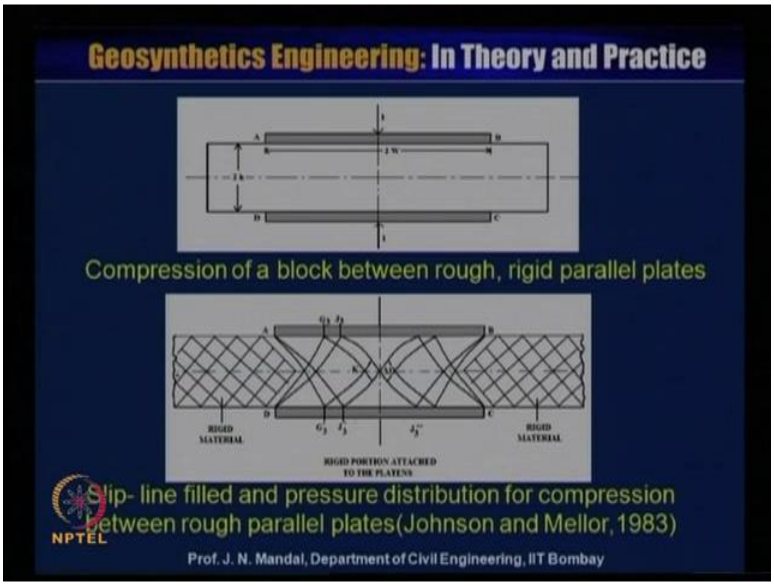

Now, this is like this. Here this is the compressible block between the rough and rigid parallel plates.

So, here is the slip line filled and pressure distribution for compression between the rough parallel plates, this is Johnson and Mellor 1983. So, we are considering like a two plates and one is the embankment and the foundation soil. For example, that foundation soil is rest on the rigid plate and then the foundation, and this embankment also is considering as a rigid plate. And then when you are applying the pressure then there is a deformation. So, you can see the rigid portion of the attach that to the plate and this is the rigid material. This is the rigid material and how the slip line has been form. So, this slip line field was developed by the Johnson and Mellor in 1983 to analysis the compression of a block between the two rough rigid plate of the finite width.

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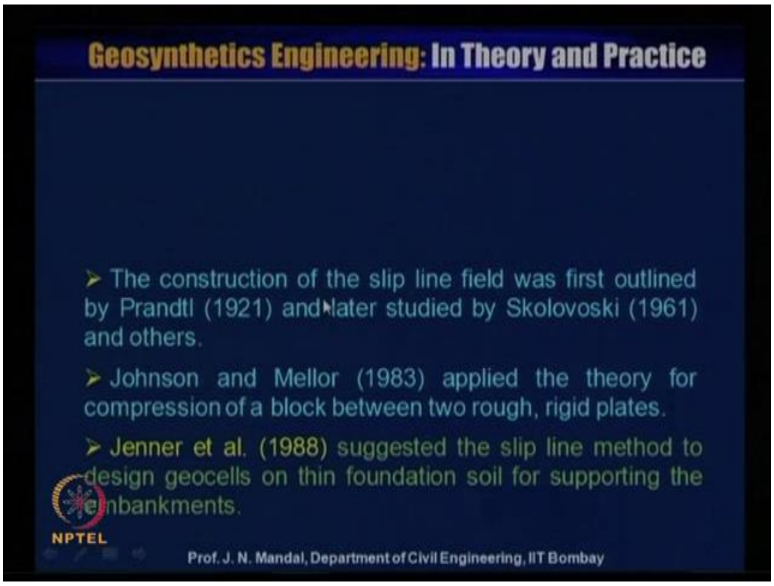

So, this theory also have been adopted by some other authors in geotechnical engineering. The construction of the slip line field was first outlined by Prandtl, 1921 and later studied by Skolovoski 1961 and others. Johnson and Mellor 1983 applied the theory for compression of a block between the two rough, rigid plates. Jenner et al 1988 suggested the slip line method to design the geocell on thin foundation soil for supporting the embankment. Now, we will learn that how we can make that slip line and what is slip line method and from the slip line method how you can calculate the bearing pressure and how we can calculate the factor of safety.

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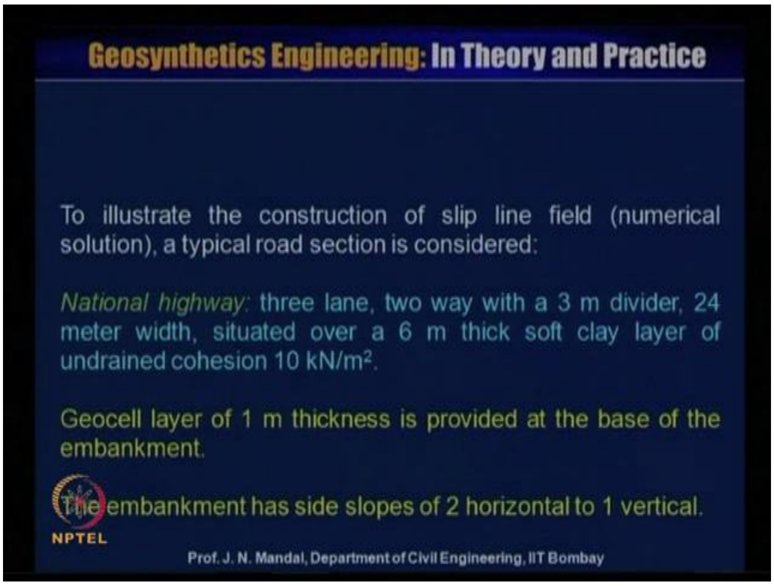

To illustrate the construction of the slip line field numerical solution a typical road section is considered. Let us say we consider national highway and three lane, two way with the 3 meter divider, 24 meter width, situated over a 6 meter thick soft clay layer of undrained cohesion value is 10 kilo Newton per meter. So, geocell layer of 1 meter thickness is provided at the base of the embankment. The embankment has a side slope of two horizontal and one vertical. So, this is the problem which we are considered here for the design.

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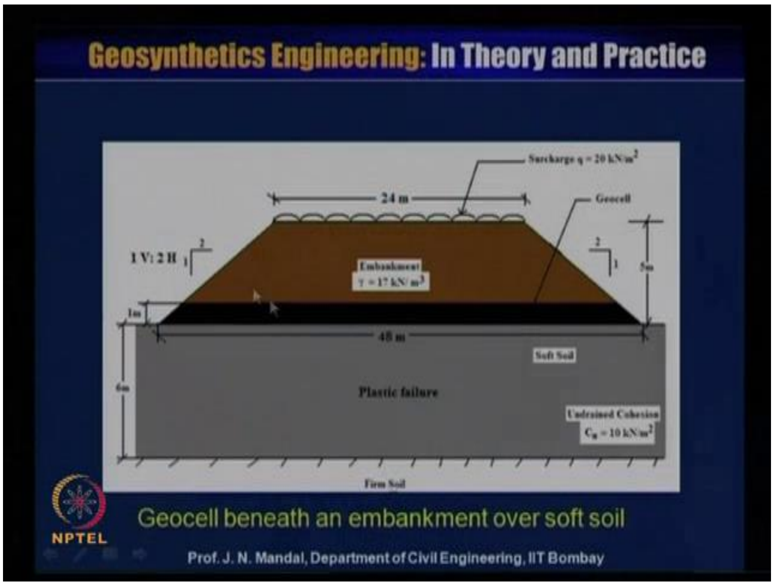

So, let us say this is the embankment and this is the geocell whose height is about 1 meter and top width of the embankment is 24 meter and there is a surcharge load is 20 kilo Newton per meter square. And here slope of the embankment is the one vertical, two horizontal and this height of the embankment is about 5 meter, and depth of the foundation is 6 meter. And this is a here you can see we have consider is a plastic failure because this is also the firm soil. This is soft soil and this is undrained cohesion value c u is 10 kilo Newton per meter square, the very soft soil and also embankment also has a density is about 17 kilo Newton per meter cube.

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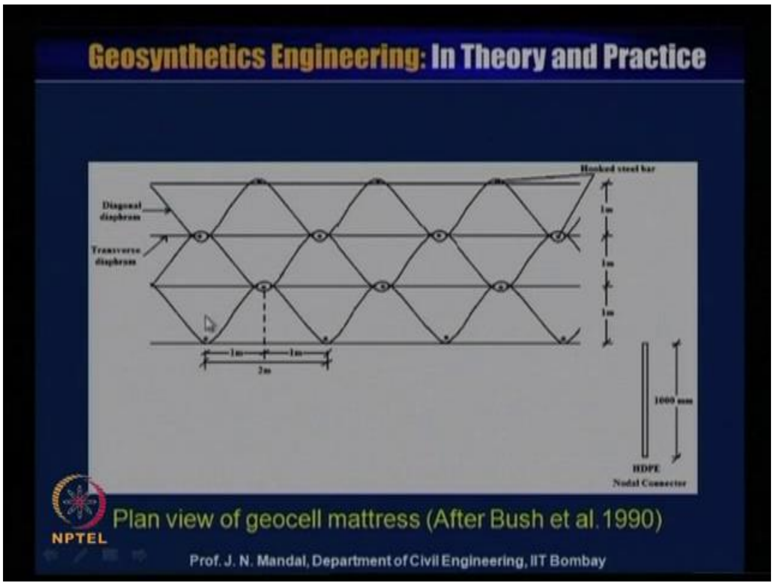

So, here is the plan view of geocell mattresses after Bush et al 1990. So, you can see this is the transverse diagram, this is the diagonal diagram and this is 1 meter 1 meter, this total is the 2 meter. Here it is 1 meter 1 meter and 1 meter and here this geogrid geocell is joined with the hooked steel bar. This hooked steel bar or this is the neural connector also what we call the high density polyethylene material and this is about 1000 millimeter in height. So, this also can be inserted into here into the between the two geogrid and it can be act as a joint. So, this is also you can use that hooked steel bar to be connected one geocell with the other geogrid geocell.

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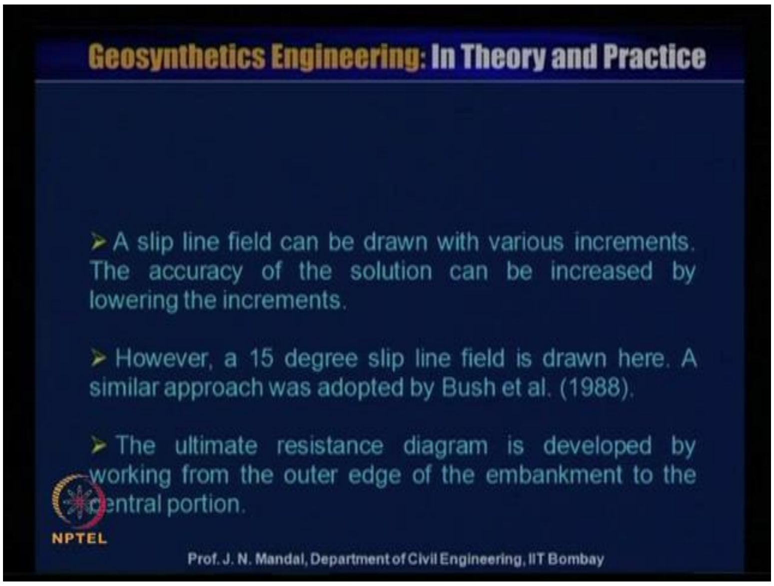

So, a slip line field can be drawn with various increment. The accuracy of the solution can be increased by lowering the increment. However, a 15 degree slip line field is drawn here. A similar approach was adopted by the Bush and et al 1988. The ultimate resistance diagram is developed by working from the outer edge of the embankment to the central portion.

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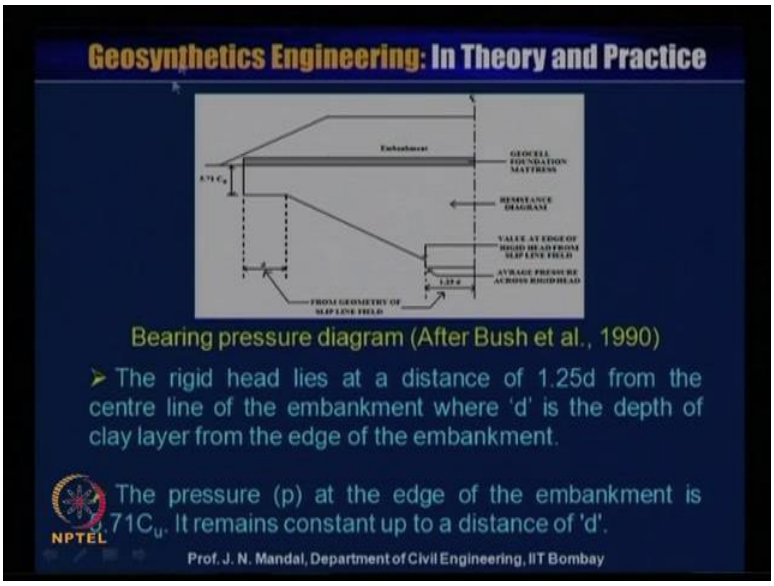

So, here is the bearing pressure diagram. So, this bearing pressure diagram I can show you here. This is the bearing pressure diagram of the Bush et al 1990 and this is the geocell and this is the embankment and this is the center line. So, this geocell foundation mattresses and this is the resisting diagram. So, it goes 5.71 into C u. Then this is the d that means depth of the foundation. This is form of geometry of the slip line field and then this distance from the center line 1.25 of d. This is the average pressure across the rigid head and this value at the edge of the rigid head from the slip line field. So, this is resisting diagram.

So, from this diagram you can calculate what will be the bearing pressure. So, we will come across and we will show you how we can use this design chart from this Bush et al. Now, the rigid head lies at a distance of 1.25d here from the center line of the embankment where I say the d is the depth of the clay layer from the edge of the embankment. The pressure p at the edge of the embankment here is 5.71 C u. So, it remain constant up to a distance d, that means depth of the foundation if the depth of the foundation is 6 meter so it will remain constant.

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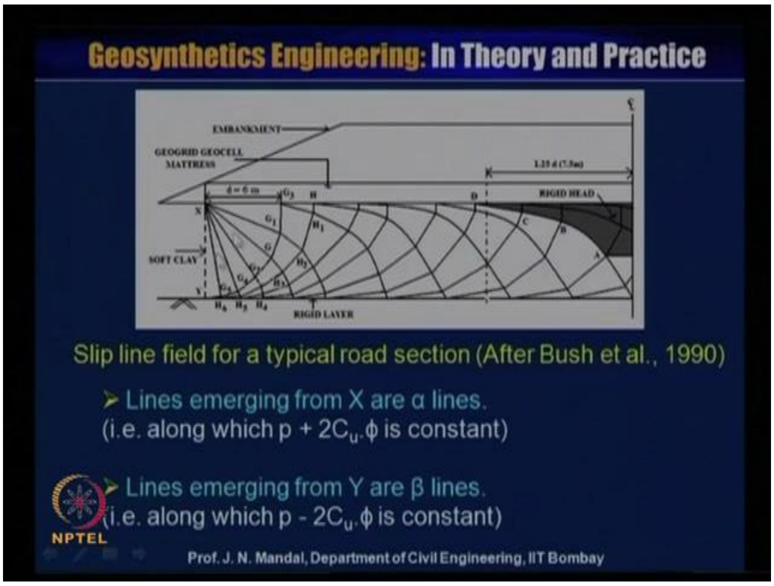

Now, here is the slip line field for a typical road section. So, this you should know and you have to draw this slip line and how to draw this slip line that we will study. So, here you can see this is the embankment and this is the geogrid geocell mattresses. Here geogrid geocell mattresses. So, here is the line emerging from X on a line along with the p plus twice C u phi is constant and line emerging from the Y, here line emerging from y are beta lines.

So, this is along which p minus twice C u phi is constant. So, you remember two lines, one is emerging from the X which are alpha line and along which p plus twice C u phi is constant. On the other end the other line which is emerging from Y are beta line along which p minus twice C u phi is constant. Next that the arc, that is Y of G 3 can be divided into sector. You are dividing this sector 6 in this case 1, 2, 3, 4, 5, 6. So, this is 90 degree. So, if you can divide into the 6 so it will be 15 degree slip line field is drawn. So, here it is a 6 in this case so a 15 degree line field is drawn. If we take a 10 degree each slip line field then number of the sector would be 9 because 10 into 9 is 90 degree, so here 15 degree.

So, 15 degree why that 15 degree is very convenient and it give the appropriate result and that is why 15 degree slip line has been drawn. Now, how to draw this line further the chord Y and G 5 is drawn at an angle 7.5 degree to the horizontal to intersect the line X G 3, X G 5 at the point G 5. Next the line G 5 G 4 is drawn at an angle 22.5 degree to the horizontal.

So similarly, you can draw for G4 G2 and G1 G3 are drawn at an angle 37.5 degree, 52.5 degree, 67.5 degree and 82.5 degree respectively to the horizontal. So, you can draw like this. So, this line can be drawn. Now, line G5 here and the h 6 is drawn at an angle 7.5 degree to the line X of G5. So, thus this slip line field can be completed up to this rigid head. So, like that you can continue and can draw the slip line up to this rigid head. This is a center line.

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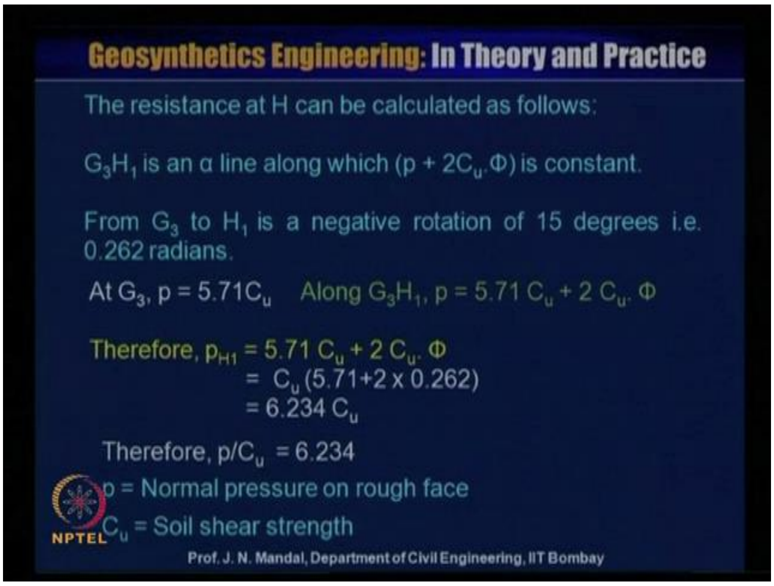

So, now you know that how you can draw this slip line. Now, the resistance at h can be calculated as follows. Suppose G of 3 and the H 1, here is an alpha angle or it is a alpha line along which p plus twice C u phi is constant. Now, from G3 2 H1 is a negative rotation of 15 degree that is 0.262 radian. So, at G3, p will be 5.71 C of u. What C u? It is the undrained shear strength of soil. Now, along G3 and the H1 p will be 5.71 C u plus 2 into C u phi. Therefore, p H1 here will be 5.71 C u plus 2 C u into phi. Now, if you take C u then common then 5.71 plus 2 into phi, phi value is 0.262 radians. So, 2 into 0.262 radians that means you will obtain here that 6.234 into C u, that means p H1 will be equal to 6.234 C u. Therefore, p by C u will be 6.234 where p is equal to normal pressure on rough face and C u is the undrained shear strength of the soil. So, you know what is p by C u?

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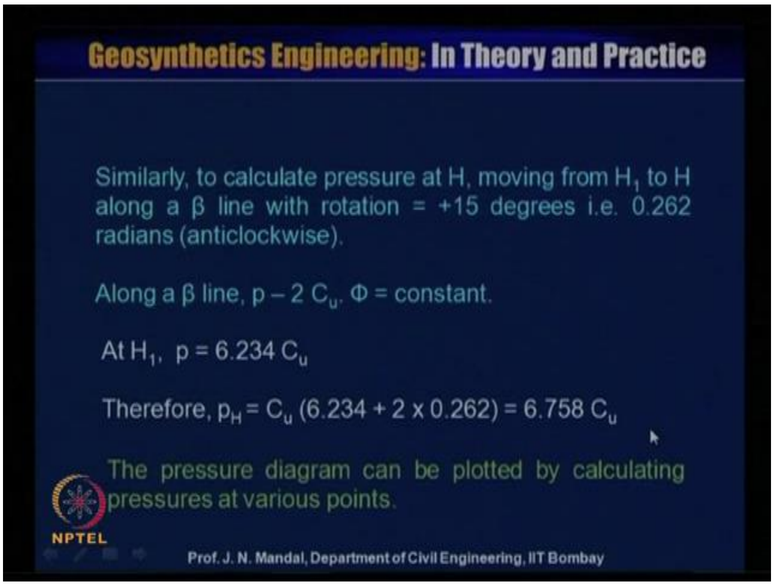

So similarly, you have to calculate the pressure at H, moving from H1 to H. Here H1 to H. So, along a beta line with the rotation plus 15 degree that is 0.262 radians. This is anticlockwise. So, along the beta line you know p minus twice C u into phi is constant. So, at this point H 1 p will be equal to 6.234 into C u. Therefore, p H will be C u into 6.234 plus 2 into that is phi value is 0.262 will be equal to 6.758 C u. So, like this alpha lines and the beta lines you can pressure diagram can be plotted by calculating the pressure at the various points.

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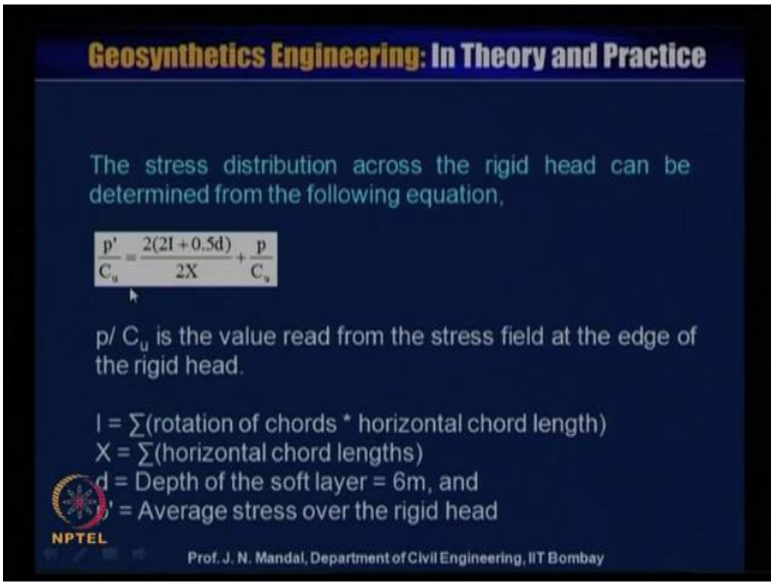

So, now the stress distribution across the rigid head can be determined. Here is the rigid head what the stress distribution across the rigid head can be determined from this equation that is p dash divided by C u is equal to 2 into 2 into I plus 0.5 d divided by 2 X plus p divided by C u, where p by C u is the value read from the stress field at the edge of the rigid head. Where I is the summation of rotation of chord into horizontal chord length and X is the summation of horizontal chord length and d is the depth of the soft clay layer that is 6 meter and p is the average stress over the rigid head. Now, we will see that how we can use this equation.

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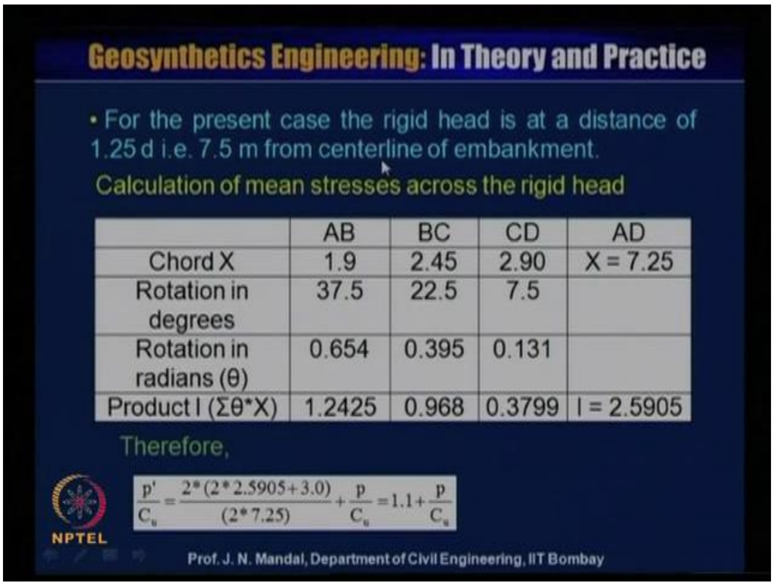

For the present case the rigid head is a distance of 1.25 d that means, this distance 1.25 degree this is the rigid head that means d is the depth of the foundation is 6 meter. So, 1.25 d that means 7.5 meter from the center line of the embankment. Now, here you observe how you can calculate the mean stress across the rigid head. So, here you can see. Here this is the rigid head. This is the chord AB, this is BC, this is CD and the whole is AD.

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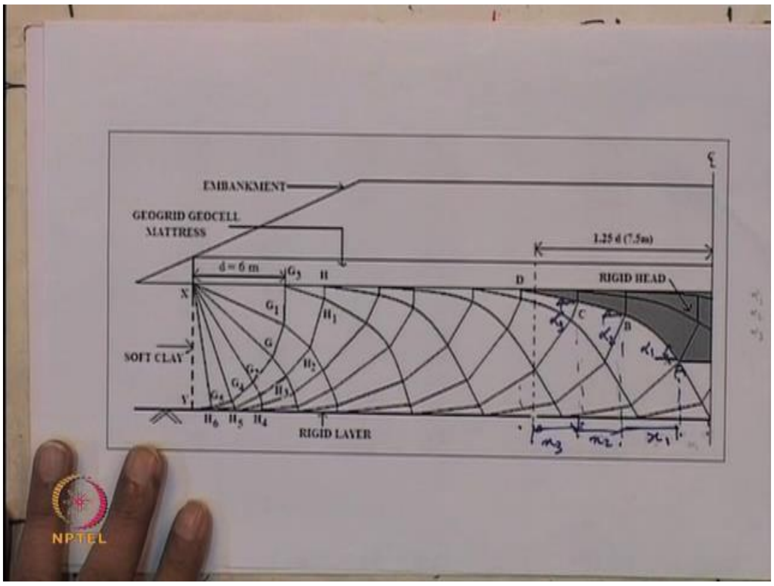

Now, rotation in degree, suppose AB this angle. So, let us say this angle is alpha 1 so that alpha 1 mean rotation in degree is 37.5 degree. So, this alpha 1 is 37.5 degree. Similarly, BC. So, BC let us say this angle is alpha 2. So, this alpha 2 this BC is 22.5 degree. Now, CD mean this here so this angle is let us say alpha 3. So, this CD alpha 3 is 27.5 degree. So, in the rigid head you know that what will be the angle alpha 1, alpha 2, alpha 3 that means you know that what is AB, this is A A B B C C D. You know the angle also you will be knowing what is the chord X. Chord X means suppose this is the A. So, A this is the B from here A B B C and C D.

So, you will be knowing what is the AB. Let us say this is X 1. What will be the BC? Let us say this is X 2 and what is CD? Let us say this is X of 3. So, that means A B X 1 is 1.9. BC is 2.45 mean X 2 and CD is X 3 is 2.90. So, what will be the total X. X will be the summation of AB plus BC plus CD then 1.9 plus 2.45 plus 2.90 is 7.25. So, AD is 7.25. Now, rotation in radian this theta so this in degree you know. You can convert into radian, that means AB will be the 0.654. BC will be the 0.395 radian and CD is 0.13 radian, now you product I. This is the summation of theta into X.

So, you multiply this into X, that means this 0.654 multiplied by 1.9 give 1.2425, then next for BC 0.395 into 2.45. This will give the product I is 0.968. Then for this 0.131 theta into X 2 0.90 give 0.3799. So, then this I product will be equal to summation of 1.2425 plus 0.968 plus 0.3799 is equal to 2.5905. Therefore, we can write p dash by C u will be equal to we are using this equation that 2 into 2I, that means 2 into 2I. I is this 2.5904 plus 0.5 d, d is 6 meter. So, 0.5 d means 0.5 into 6 is 3. So, that is why it is 3.0 this divided by 2 into X 2 into X. X is 7.25. So, this is 2 into 7.25 plus p by C u. So, if you calculate this you can have 1.1 plus p by C.

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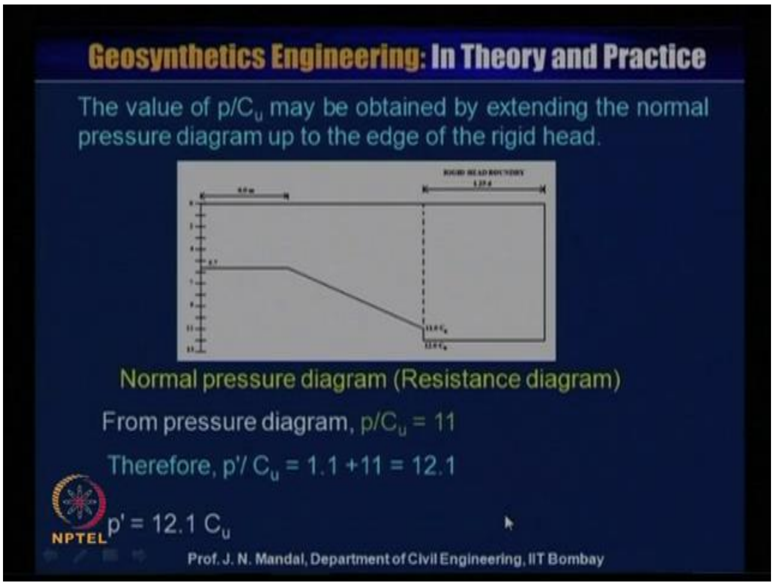

So, now the value of p by C u may be obtained by extending the normal pressure diagram up to the edge of the rigid head. So, here I showed you also this earlier this diagram normal pressure diagram, this one. That is what you call the resistive diagram. So, from the pressure diagram you know that p by C u that means this is 11. So, from this diagram p by C u is 11. Therefore, this p dash by C u is 1.1 plus p by C u that means p dash by C u is 1.1. You are having 1.1 plus p by C u is 11. You are getting here from normal pressure diagram. So, 11 plus 1.1 will give 12.1. So, that means p dash will be equal to 12.1 into C u is here.

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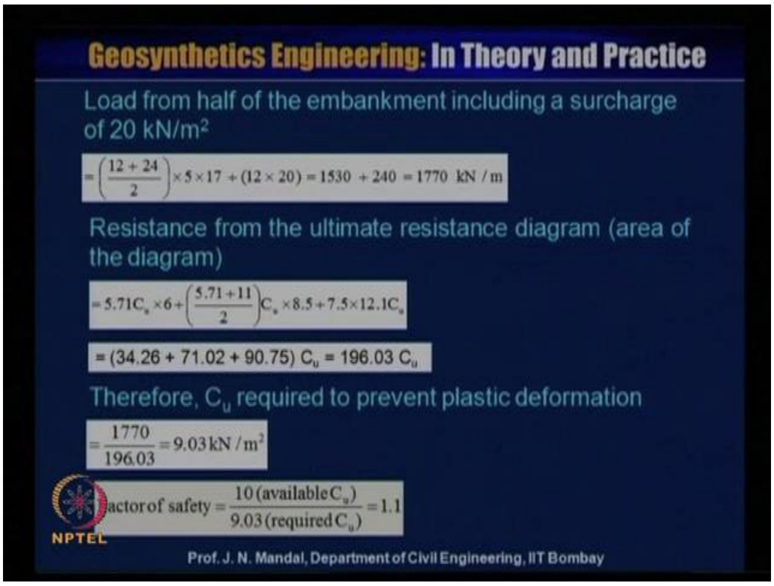

Now, load from the half of the embankment including the surcharge of 20 kilo Newton per meter square. So, we have consider this is the embankment.

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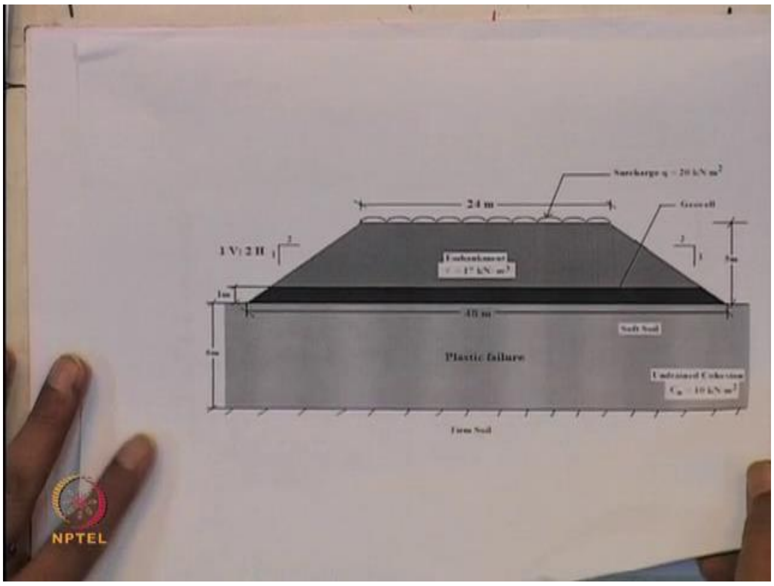

This is the embankment and this width is 24 meter and here surcharge load is 20 kilo Newton per meter square. So, what will be the load is coming here. So, we will use this resisting charge. So, here because we have taken half because from the center line half, that means it will be the 12 meter. So, we are taking 12 meter. So, 12 plus 24 by 2 that means if you take here base is 48.

So, the half of this 48 is 24 and this is top portion of the embankment is 24. So, this half will be equal to 12. So, this area will be equal to half into this is 12 plus 24 into that height of the embankment is 5 meter. Height of the embankment is 5 meter and also unit weight of the embankment is 17 kilo Newton per meter cube. So, that is why here the load from the half of the embankment including surcharge 12 plus 24 by 2 into 5 is the height of the embankment and 7 unit weight of the embankment plus you are taking the surcharge load. That means surcharge is 20. Here the surcharge is 20 and the half mean 12, so 12 into 20.

So, this will give 1530 plus 2401770 kilo Newton per meter. So, resistance from the ultimate resistance diagram that means area of this diagram. So, this diagram will be you know. You look this is 5.71 or 5.71 C u. So, this into this is 6 meter. So, this area will be equal to 5.71 into 6. So, this is 5.71 C u into this is 6 plus this area. This area it is like a trapezoid that means so here is the 11. Here is the 11. So, this is the 11 and this into this is 5.7. You know this is 5.7 and this is 11 up to this area we will take.

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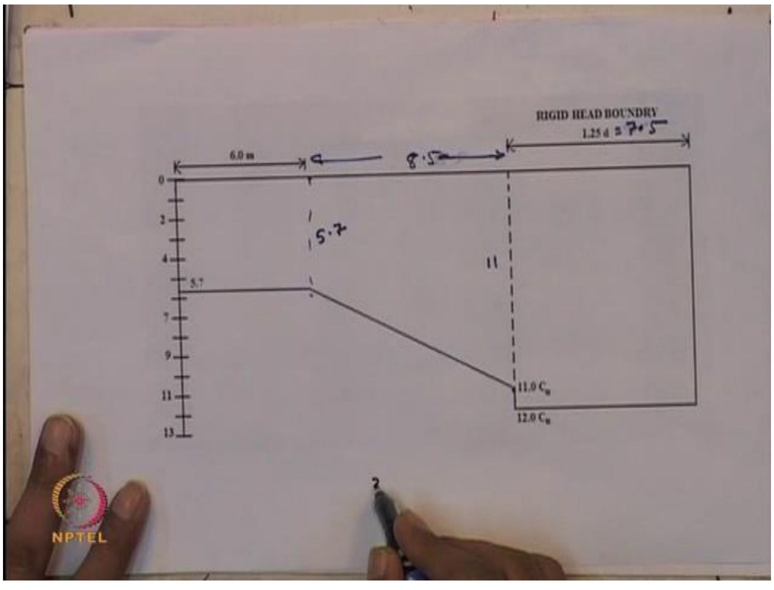

So, 5.7 plus 11 divided by 2 into C u into this length. This length will be 8.5 from here to here because this is 6 meter and this is 1.25 d 1.25 is d is your 5. So, this will be the 7.5 because depth of the foundation is 6. So, 1.25 into d is 7.5. So, if this is 7.5 this is 6. So, total is your will be 20. This is 7.5 plus 6. 13.5 plus 18.8 0.5 that means this will give you 22. That will give you that 22.

So, because why we have taken that 22, you look here. This is the cell and half of this is 24 but here this geocell is 1 meter in height and this is 2 into 1 ratio. So, you neglect this 2 meter. So, we are introducing the cell from here. So, that is why not 24. So, this will be the 22. So, that is why 7.5 plus 6 and so this portion will be the 8.5. So, this will give you that 22 meter. So, this area will be equal to half into 11 plus 5.7 into C u into 8.5 plus this area. So, this area will be again this is 7.5 and this is 12. We have calculated say 12. So, this is about 12.1 or 12.1 into C u. So, this the pressure from the ultimate resistance diagram or area diagram so you can obtain this.

Now, if you can calculate this will give 34.26 plus 71.02 plus 90.75 into C u, this will give 196.03 C u. Therefore, C u required to prevent the plastic deformation that means 1770. This one load from the half of the embankment including surcharge is 1.1770, this divided by what will be the resistance from the ultimate resistance diagram or area diagram that is 196.03. So, this you will obtain the C u required to prevent the plastic deformation is 9.03 kilo Newton per meter square. So, factor of safety will be C u what is available and C u required and C u available is 10 and C u required is 9.03. So, this factor of safety will be equal to 1.1. So, you have determined what will be the factor of safety.

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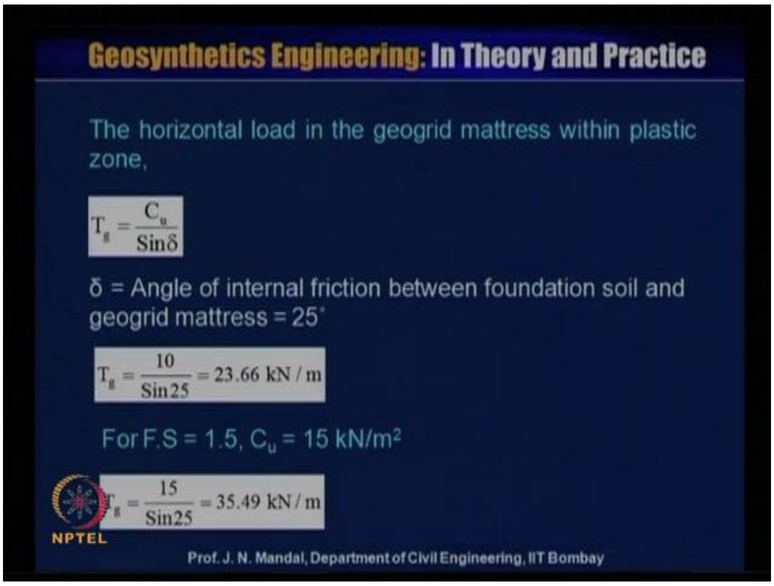

Now, horizontal load in the geogrid mattresses with plastic zone so you can write T g is equal to C u by sin delta. Delta is angle of internal friction between the foundation soil and the geogrid mattresses 25 degree. So, T g will be equal to C you know 10 divided by sin of 25 will be equal to 23.66 kilo Newton per meter for factor of safety is 1.5, C u is 15 kilo Newton per meter square. So, T g will be equal to 15 divided by sin 25 is 35.49 kilo Newton per meter.

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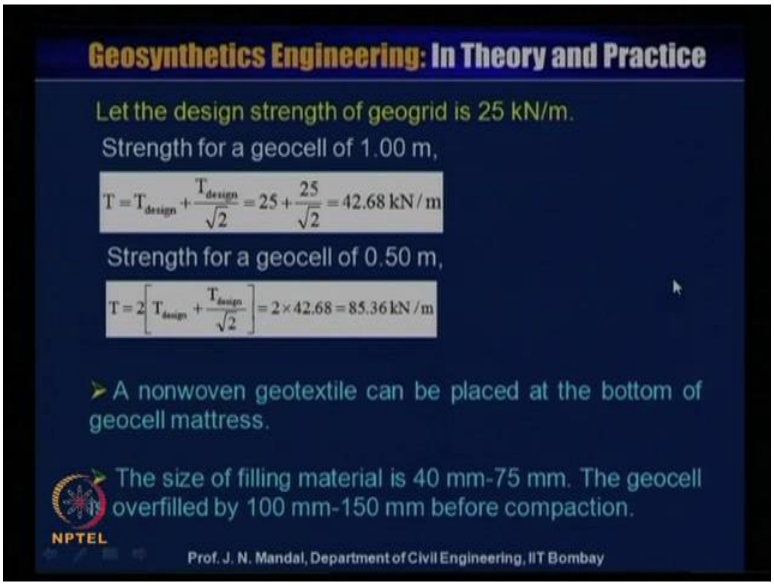

Let the design strength of the geogrid is 25 kilo Newton per meter and strength of a geocell of 1 meter. So, T will be equal to T design plus T design by root 2 that means 25 plus 25 by root 2 is 42.68 kilo Newton per meter. Strength for a geocell is 0.50 meter. So, T will be equal to 2 into T of design plus T design by root 2 is equal to 2 into 42.68 is 85.36 kilo Newton per meter. So, a non woven geotextile can be placed at the bottom of the geocell mattresses.

The size of the fill material is 40 millimeter to 75 millimeter and geocell is overfilled by 100 millimeter to 150 millimeter before the compaction. So, like this using this material that is the settlement also of the geocell mattress beneath the embankment can also reduce and you can save about the 30 percent with respect to the traditional method. And site fabrication and construction of the geocell mattresses is very simple and economical and can provide the contractor also with a working platform. You can make easily the working platform on the soft soil using the geogrid mattresses as a foundation. And what are the performance data for this? So, you can reduce the settlement. You can also reduce the differential settlement and because for the, what you call that load spreading ability on the rigid geocell foundation mattresses.

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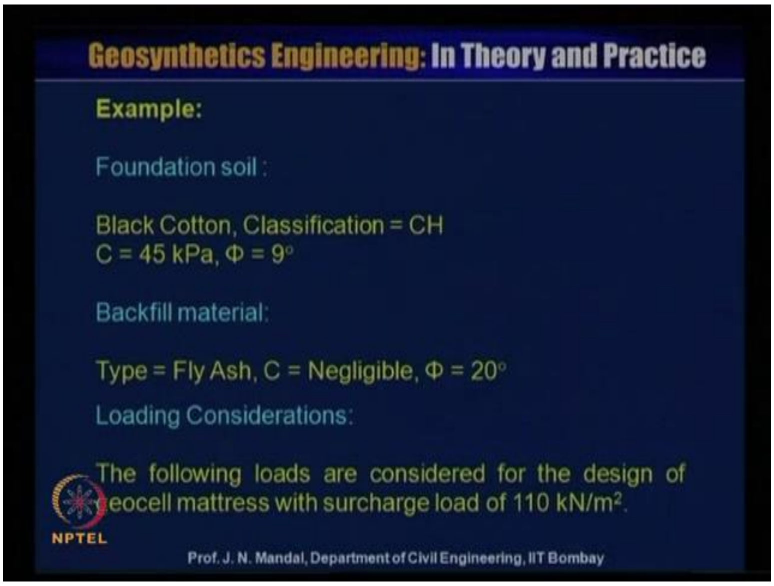

Now, another example for the foundation soil is black cotton classification as CH and C value is 45 kiloPascal, phi is 9 degree. Backfill material type fly ash and C is negligible and phi is 20 degree. Loading consideration, the following loads are considered for the design of geocell mattresses with surcharge load of 110 kilo Newton per meter square.

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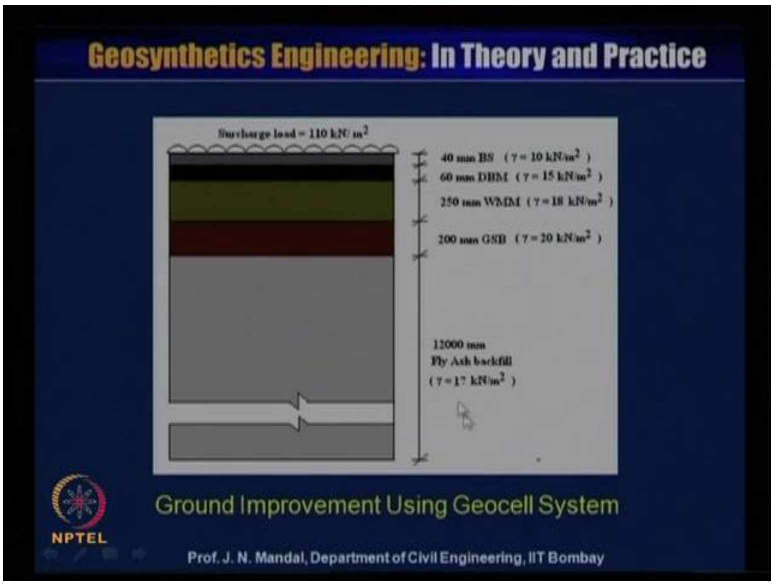

So, this is the ground improvement has been shown using geocell material. Here surcharge load 110 kilo Newton per meter and this is 40 millimeter is BS. That means gamma is 10 kilo Newton per meter square, here 60 millimeter DBM that is gamma is 15 kilo Newton per meter square and this is 250 millimeter WMM, where gamma is 18 kilo Newton per meter square, and here 200 millimeter is GSB. Gamma is 20 kilo Newton per meter square and this is the 1200 millimeter fly ash backfill where gamma is equal to 17 kilo Newton per meter.

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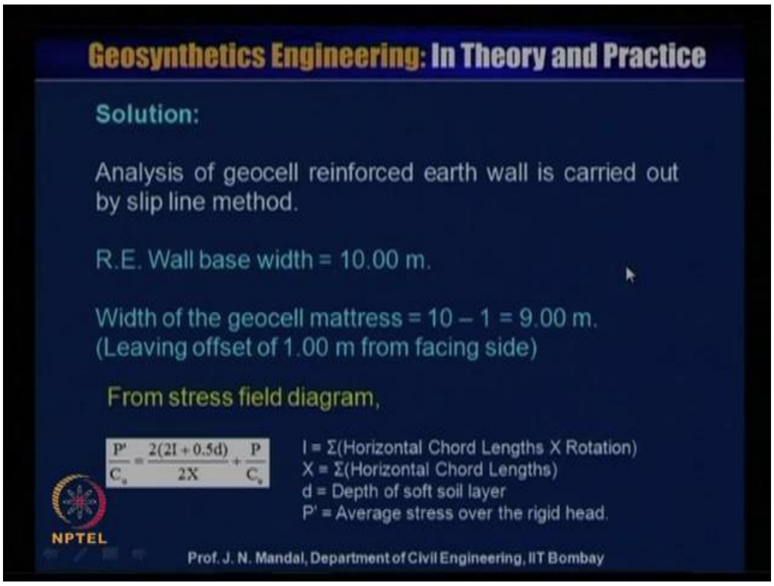

Now, the solution the analysis of geocell reinforced earth wall is carried out by slip line method. Now, you know that how to draw the slip line and how to calculate the bearing pressure. Now, this system you have to construct a reinforced earth wall that base width is 10 meter. So, width of the geocell mattresses is 10 minus 1, say 9 meter. So, living the offset of 1 meter from the facing side. Now, from the stress field diagram you know this equation p dash by C u is equal to 2 into 2I plus 0.5 d divided by 2 X plus p by C u. You know I is equal to summation of horizontal chord length into rotation X is equal to summation of horizontal chord length and d is equal to depth of the soil layer. p dash is average stress over the rigid head.

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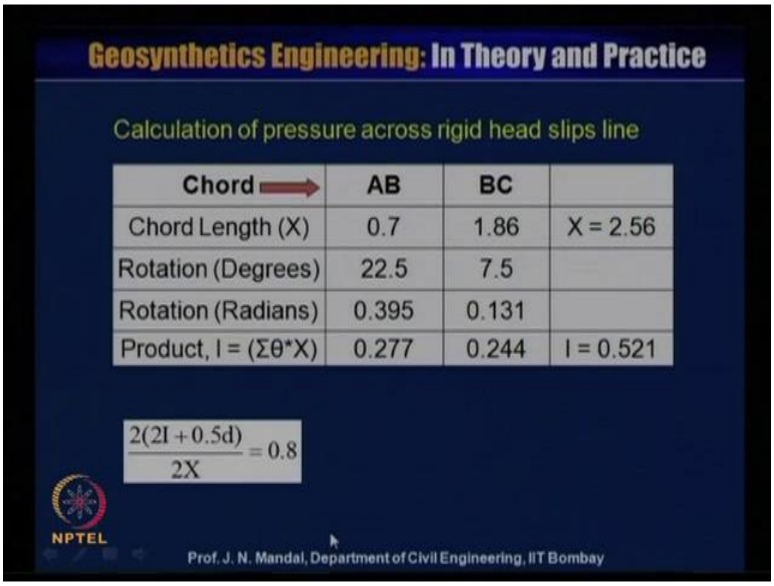

So, from this you can calculate the pressure across the rigid head slip line. So, chord length you can obtain for AB is 0.7, BC is 1.86. So, total X is equal to AB plus BC will be 2.56. Rotation degree 22.5, for BC is 7.5. So, rotation in radian AB will be 0.395, BC is 0.131. So, product I will be summation of theta into X that means 0.277 that means this theta into X and for this BC is 0.244. So, I will be equal to the 0.521. Now, you know this equation 2 into 2 I plus 0.5 d by 2 X is equal to 0.8.

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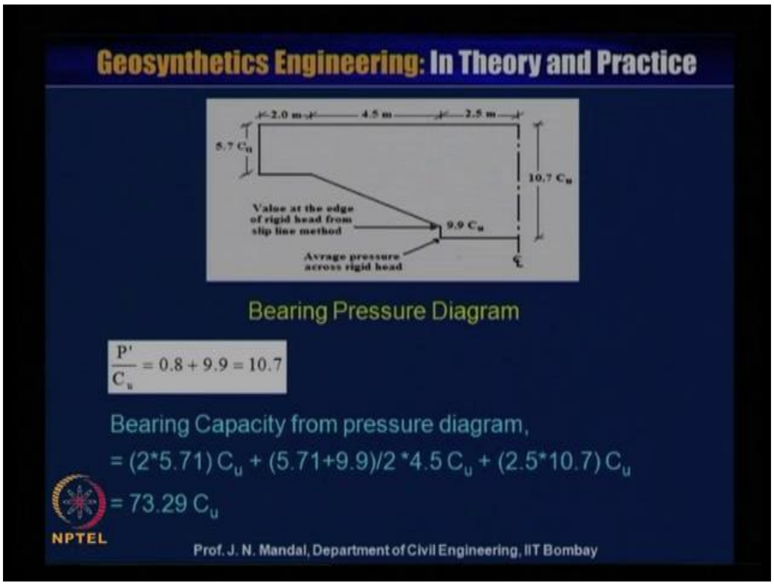

Here you can see that bearing pressure diagram. So, here is 5.7 C u. This is 2 meter, this is 4.5 meter, this is 2.5 meter and this is 10.7 C u. This is the center line and here it is 9.9 C u and here is the average pressure across the rigid head, and here is the value at the edge of rigid head from slip line method.

So, from this bearing pressure diagram so we will calculate what will be the bearing capacity. So, here equation is p dash by C u is equal to 0.8 plus 9.9 is equal to 10.7. Now, bearing capacity from this pressure diagram you can see here this part. This is 2, this is like a rectangle. So, this is 2 and this is 5.71. So, this is 2 into 5.71 into C u plus this part. So, from here to here is 4.5. It is like a trapezoid and here to here is 5.71. So, here to here 5.71 plus here to here is 9.9. So, this is plus 9.9 this divided by 2 into this height. This is 4.5 meter. So, this is 4.5 into C. So, this area this trapezoidal area plus this is the rectangle. So, this is 2.5 and this is 10.7 so 2.5 into 10.7 into C u. So, from this equation you can obtain this is equal bearing capacity from pressure diagram is equal to 73.29 C u.

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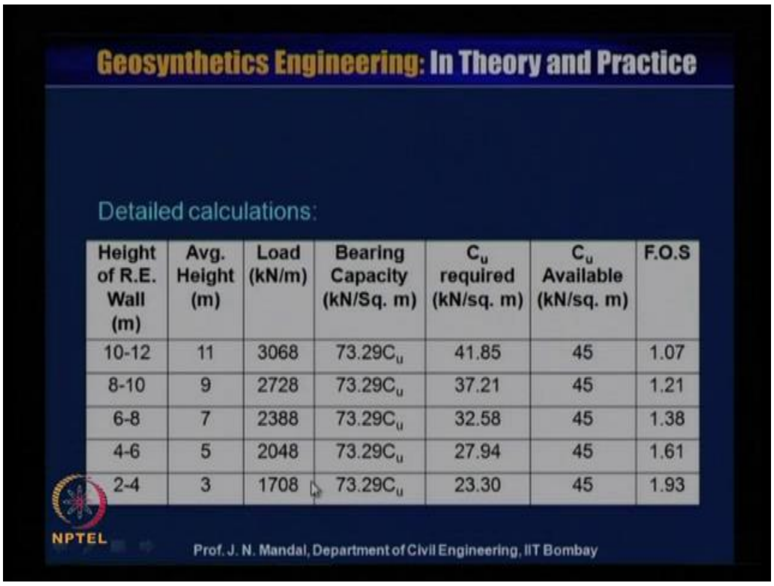

Height of R.E. Wall (m)	Avg. Height (m)	Load (kN/m)	Bearing Capacity (kN/Sq. m)	C_u required (kN/sq. m)	C_u Available (kN/sq. m)	F.O.S
10-12	11	3068	$73.29C_u$	41.85	45	1.07
8-10	9	2728	$73.29C_u$	37.21	45	1.21
6-8	7	2388	$73.29C_u$	32.58	45	1.38
4-6	5	2048	$73.29C_u$	27.94	45	1.61
2-4	3	1708	$73.29C_u$	23.30	45	1.93

Now here the detailed calculation are given. This height of the reinforced earth wall in meter that is 10 to 10. So, average height is equal to 11 meter, load is 3068 kilo Newton per meter and bearing capacity is 73.29 C u. So, here 73.29 C u kilo Newton per square meter and C u is required is 41.85 kilo Newton per square meter and this is C u available 45 kilo Newton per square meter. And then the factor of safety is equal to 1.07 when the height of the wall is 8 to 10 meter and average height is 9 and load is 2728 kilo Newton per meter. So, bearing capacity 73.29 C u kilo Newton per square meter and C u required 37.21 kilo Newton per square meter and C u available is 45 kilo Newton per square meter. So, factor of safety is 1.21 when height of the wall is 6 to 8 meter.

So, average height is 7, load 2388 kilo Newton per meter, bearing capacity 73.29 C u kilo Newton per square meter, C u required is 32.58 kilo Newton per square meter and C u available 45 kilo Newton per square meter. So, factor of safety is 1.38 now when the height of the wall 4 to 6 meter. So, average height is 5 meter, load 2048 kilo Newton per meter, bearing capacity 73.29 C u kilo Newton per square meter and C u required 27.94 kilo Newton per square meter, C u available 45 kilo Newton per square meter and so factor of safety 1.61.

Now, when height of the wall is 2 to 4 that means average height is 3, load 1708 kilo Newton per meter, bearing capacity 73.29 C u kilo Newton per square meter and C u required is 23.30 kilo Newton per square meter, C u available is 45 kilo Newton per square meter. So, factor of safety is 1.93. You can observe from this table that how the load is decreasing with decreasing the height of the wall and here is the factor of safety is increasing.

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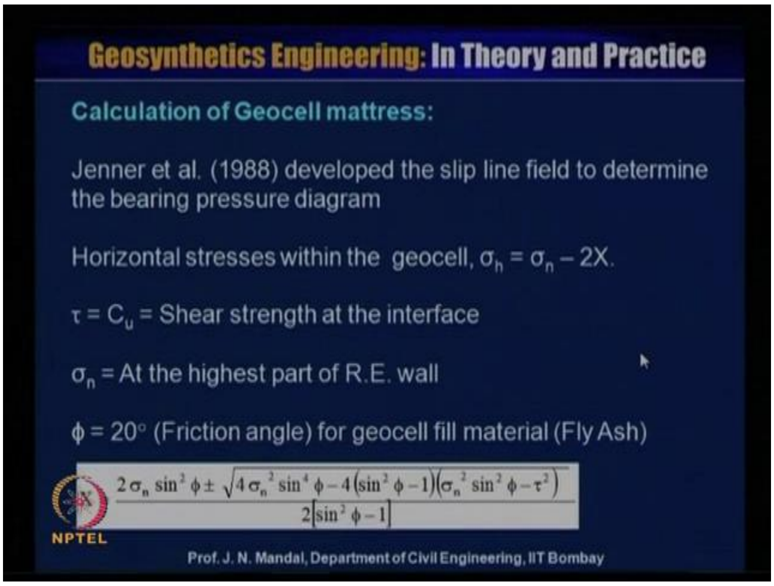

Now, calculation of geocell mattresses, Jenner et al 1988 developed the slip line field to determine the bearing pressure diagram. Horizontal stress within the geocell sigma of h will be equal to sigma n minus 2 X. Tau is equal to C u is shear strength at the interface.

Sigma n is at the highest part of the R E wall and phi is 20 degree friction angle for geocell fill material that is fly ash. So, X will be equal to 2 into sigma n sin square phi plus minus root over of 4 sigma n square sin four phi minus four sin square phi minus 1 then sigma n square into sin square phi minus tau square this divided by 2 into sin square phi minus 1.

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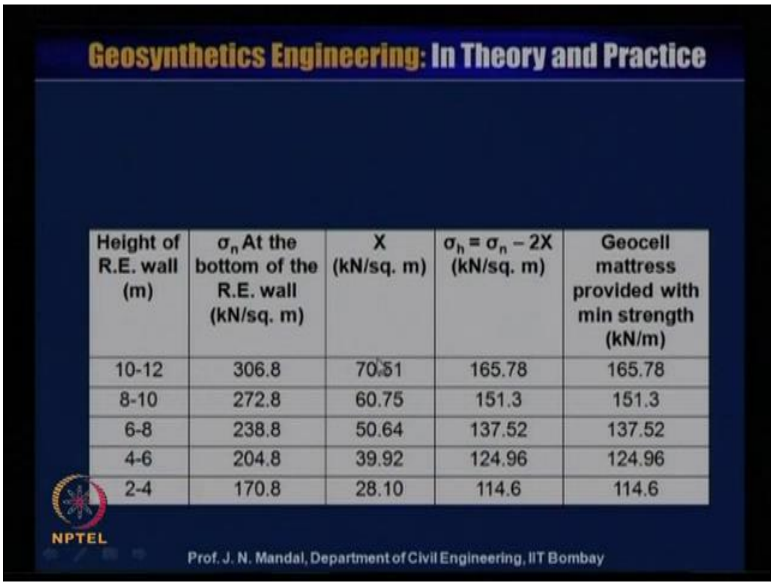

Height of R.E. wall (m)	σ_n At the bottom of the R.E. wall (kN/sq. m)	X (kN/sq. m)	$\sigma_h = \sigma_n - 2X$ (kN/sq. m)	Geocell mattress provided with min strength (kN/m)
10-12	306.8	70.51	165.78	165.78
8-10	272.8	60.75	151.3	151.3
6-8	238.8	50.64	137.52	137.52
4-6	204.8	39.92	124.96	124.96
2-4	170.8	28.10	114.6	114.6

So, from this equation so for the height of the retaining wall different height you can calculate, sigma n at the bottom of the reinforced earth wall in kilo Newton per meter. You can calculate X, you can calculate sigma h is equal to sigma n minus 2 X kilo Newton per square meter and geocell mattress to be provided with the minimum strength this kilo Newton per meter. So, for an example that height 10 to 12 meter this sigma n value we can calculate that is 306.8 kilo Newton per square meter. So, X will be 70.51 kilo Newton per square meter. So, sigma h will be equal to 165.78, so geocell mattress provided with the minimum strength is 165.78. Like that you can calculate for the different height of the wall using this equation.

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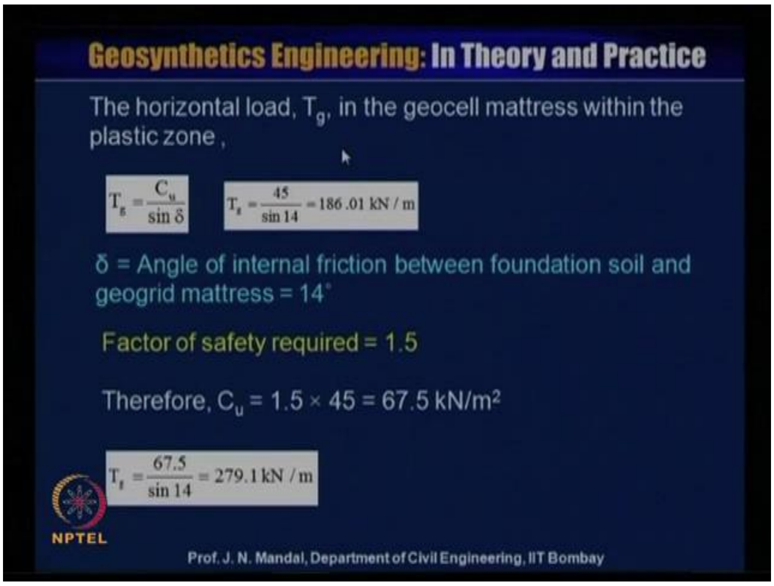

The horizontal load T g in the geocell mattresses with the within the plastic zone that is T g is equal to C u by sin delta. So, T g is 45 by sin 14 is equal to 186.01 kilo Newton per meter. Delta is equal to angle of internal friction between the foundation soil and geogrid mattresses, that is 14 degree. Factor of safety required 1.5. Therefore, C u will be equal to 1.5 into 45 is 67.5 kilo Newton per meter square. So, T g will be 67.5 by sin 14 is 279.1 kilo Newton per meter.

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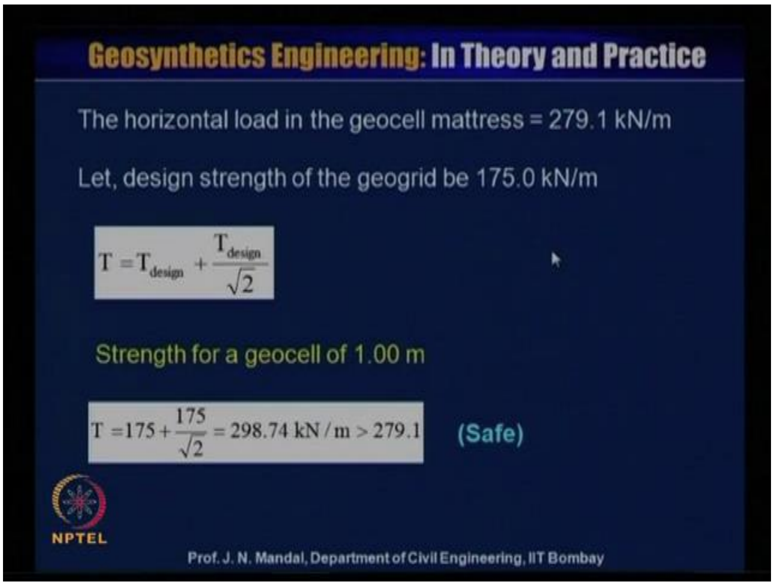

Now, horizontal load in the geocell mattresses 279.1 kilo Newton per meter. Let the design strength of the geogrid be 175 kilo Newton per meter. So, T will be equal to T design plus T design by root 2. So, strength for a geocell of 1 meter length height. T will be equal to 175 plus 175 by root 2 is equal to 298.74 kilo Newton per meter that is greater than 279.1.

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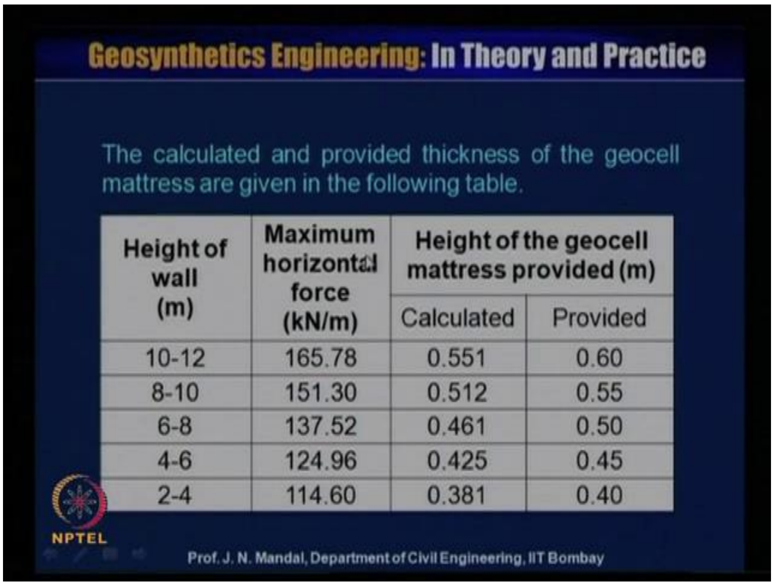

Geosynthetics Engineering: In Theory and Practice

The calculated and provided thickness of the geocell mattress are given in the following table.

Height of wall (m)	Maximum horizontal force (kN/m)	Height of the geocell mattress provided (m)	
		Calculated	Provided
10-12	165.78	0.551	0.60
8-10	151.30	0.512	0.55
6-8	137.52	0.461	0.50
4-6	124.96	0.425	0.45
2-4	114.60	0.381	0.40

So, it is safe to calculate the and provided the thickness of the geocell mattresses given in this following table. So, this is the height of the wall 10 to 12 meter, the maximum horizontal force is 165.78 and height of the geocell mattresses provided calculated is 0.551. So, you have to provide 0.60 for all other height of the wall. So, you calculated this. What will be the height of the geocell? So, accordingly that we have been selected what will be the height of the geocell? So, this is 0.55, 0.50, 0.45 and 0.40. So, different height of the geocell has been also been considered.

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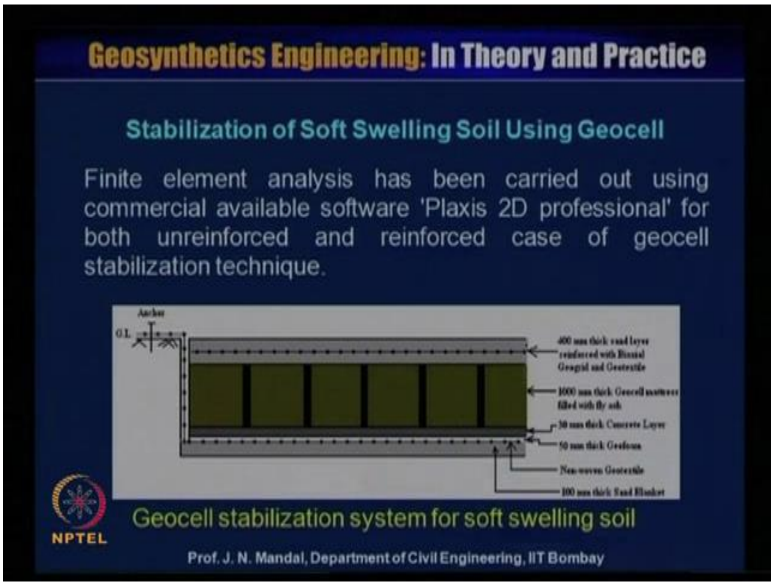

Stabilization of soft swelling soil using geocell. So, finite element analysis has been carried out using the commercial available software Plaxis 2D professional for both unreinforced and reinforced case of geocell stabilization technique. Here when there is the swelling soil it is very difficult to construct this any kind of the structure. Here one of the project where there is a swelling soil and the owner was deciding for the go for the stone column whose length of the stone column about the 8 meter, so alternative to that system that we have a planning for the geocell. How you can geocell stabilization system on the soft swelling soil?

So, in such case you are not go to the deep of the soil. Here in here you can see that you can provide with the 100 millimeter thick of the sand blanket. Then you can place a nonwoven geotextile material and then I am showing you this one. Then you can provide a nonwoven geotextile material, then 15 millimeter thick geofoam which is very super light material. This is 30 millimeter thick concrete layer then 100 millimeter thick geocell mattresses and filled with the fly ash where there is a plenty of fly ash is available.

And then the reinforced with biaxial geogrid and the geotextile material and then 400 millimeter thick sand layer and this geogrid is anchored like this. So, you are not to go so much depth of the foundation. So, it is very easy to construct instead of the stone column even then encased stone column. So, it is much more economical design and it has been also in published in the ASC conference paper.

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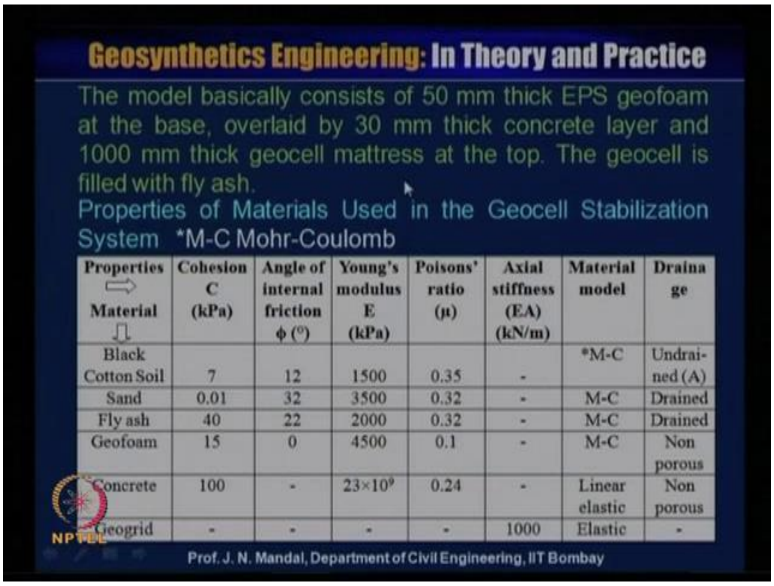

The model basically consist of 50 millimeter thick EPS geofoam at the base overlaid by 30 millimeter thick concrete layer and 1000 millimeter thick geocell mattresses at the top. The geocell is filled with fly ash. Now, this properties of the material used in the geocell stabilization system, this is Mohr-Coulomb. So, property which that is cohesion value angle of internal friction young modulus Poison's ratio axial stiffness material modulus and this is the drainage.

So, black cotton soil whose C value is 7, angle of friction 12 and young modulus 1500 kilopascal, poison ratio 0.35 and this is undrained condition. We have taken now the sand whose cohesion value 0.01, angle of friction 32, young modulus 3500 kilopascal, the poison ratio 0.32. This is Mohr-Coulomb and it is in drain and the sand fly ash that cohesion value 40 kilopascal, angle of friction 22 degree and young modulus 2000 kilopascal and poison ratio 0.32.

This is the Mohr-Coulomb and this drained condition then geo-foam whose cohesion value is 15 kilopascal, angle of internal friction 0, young modulus 4500, poison ratio is 0.1 and this is Mohr-Coulomb and this is non porous concrete cohesion value 100 kilopascal and the young modulus 23 into 10 to the power 9 kilopascal, poison ratio is 0.24 and the material model is linear elastic and the drainage is non porous and then the geogrid whose axial stiffness is 1000 and it is elastic.

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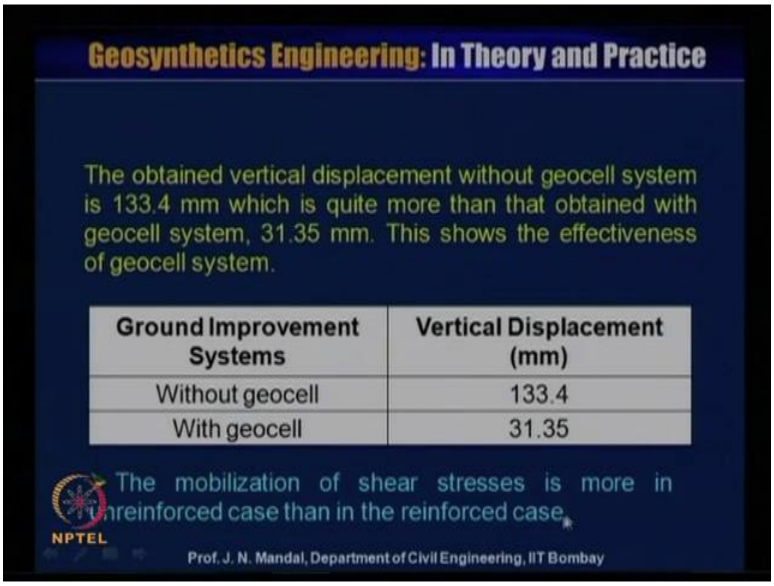

So, to obtain the vertical displacement without geocell system is 133.4 millimeter which is quite more than that obtained with the geocell system is 31.35 millimeter. This shows the effectiveness of the geocell system. So, ground improvement system here you see that without geocell the vertical displacement 133.4 millimeter with geocell 31.35 millimeter. The mobilization of the shear stress is more in unreinforced case than that of the reinforced case.

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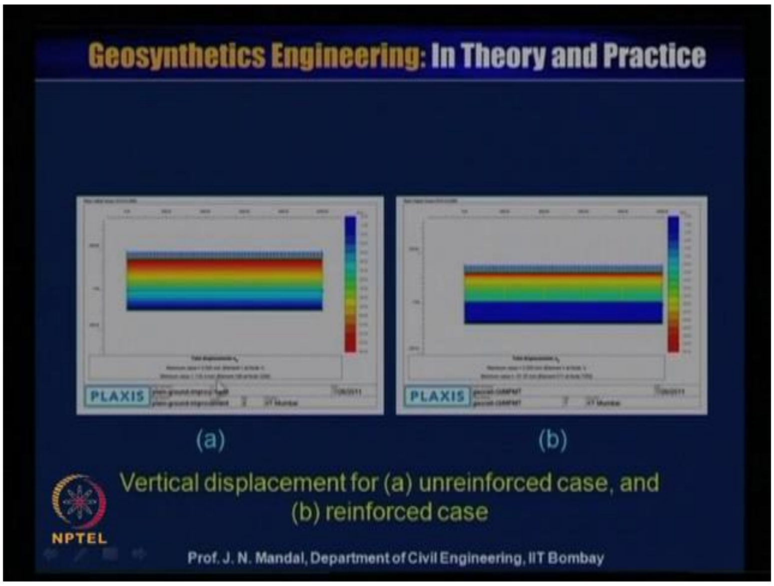

So, here you can see some vertical displacement for unreinforced case and also the reinforced case.

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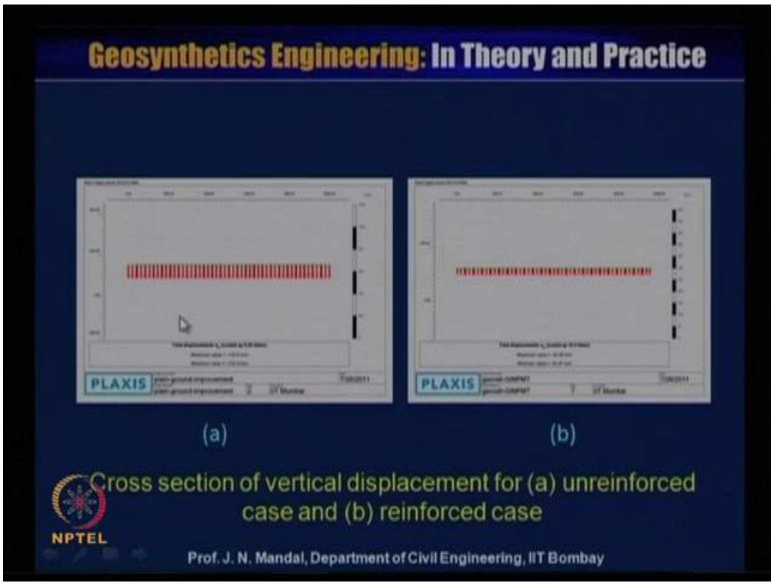

Now, here the cross section of the vertical displacement for this unreinforced case and you can see the reinforced case how it is minimized.

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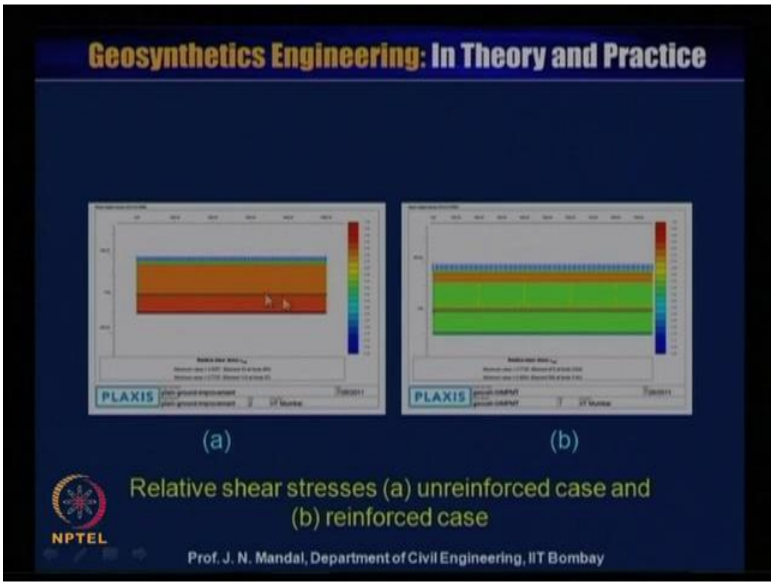

Now, here is the relative shear stresses, this is for unreinforced case and this is for reinforced case the there, how can see that behavior of the relative shear stress with this system.

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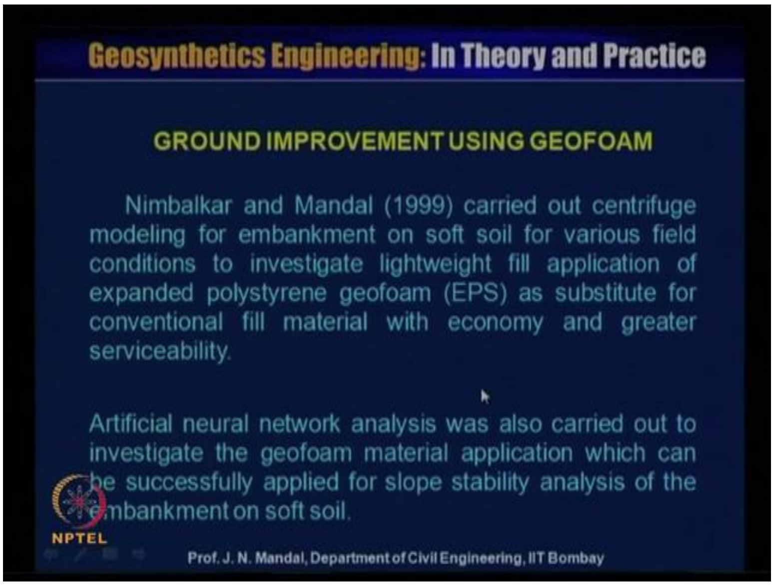

Now, ground improvement using the geofoam, Nimbalkar and Mandal 1999 carried out the centrifuge modeling for embankment on soft soil for various field condition to investigate, the lightweight fill application of expanded polystyrene geofoam EPS as a substitute for conventional fill material with economy and greater serviceability. Artificial neural network analysis was also carried out to investigate the geo-foam material application, which can be successfully applied for slope stability analysis of the embankment on soft soil.

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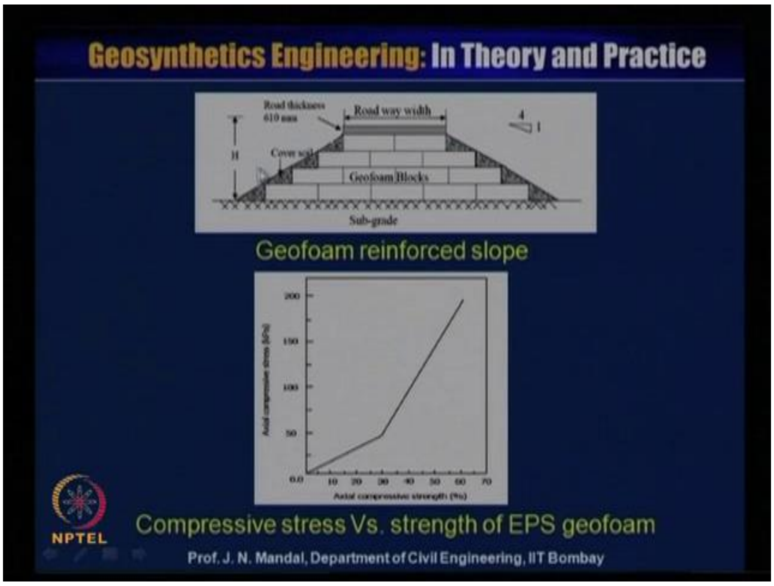

So, this is the embankment which is made of the geofoam block and you can just place on the geofoam block on the subgrade soil, and you can construct this embankment. And then you can cover with the soil and grass can grow and this is the roadway of the width. So, I will give the more detail about this in our geofoam chapter. So, most important that compressive stress versus strength of the EPS geofoam, here you can see that relationship between the axial compressive strength versus the axial strength value. And the nature of the curve, which is increasing and then it is gradually increasing in a linear way. So, this is the stress versus the strength of the EPS geofoam.

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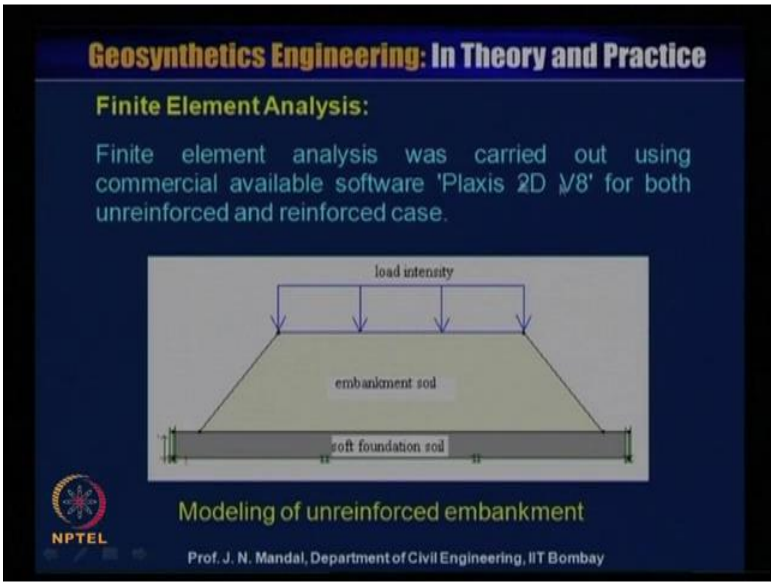

Now, some finite element analysis was carried out using the commercial available software Plaxis 2D V8 for both the unreinforced and the reinforced case. So, this is the soft foundation soil this is the embankment field and here is the load intensity for unreinforced case.

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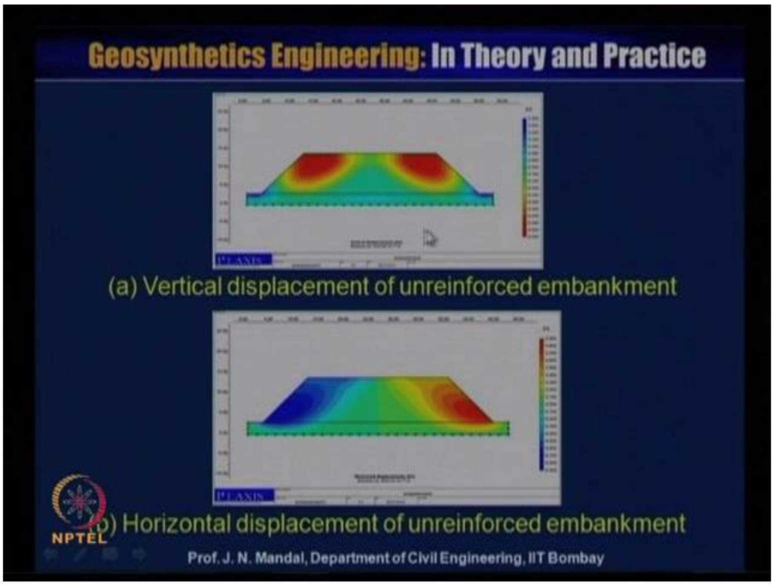

And you can see that vertical displacement for unreinforced embankment here, and also the horizontal displacement for unreinforced embankment here.

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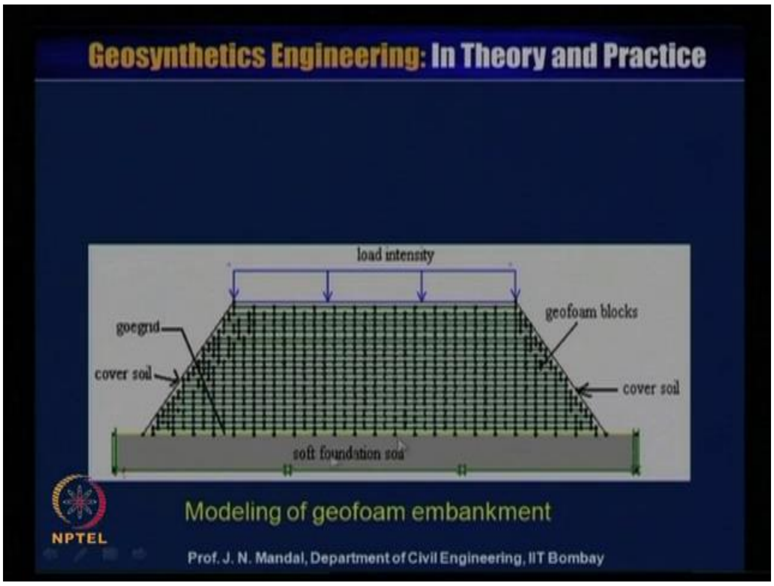

So, now we have modeling with the geofoam as a embankment. Here it is the geofoam, this is the soft foundation soil and this is the cover soil. Surrounding this is the geofoam material and there is a load intensity so this way it has been modeled.

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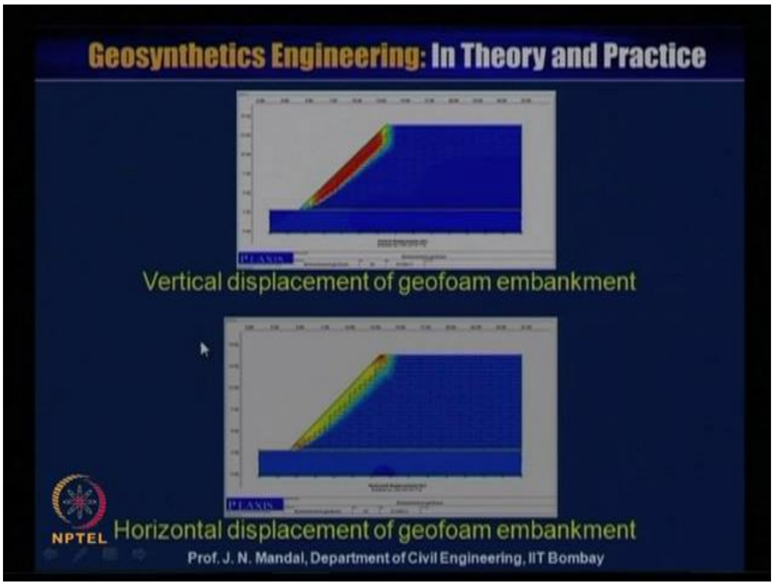

And based on this vertical displacement of the geofoam embankment and the horizontal displacement of the geofoam embankment have been noted.

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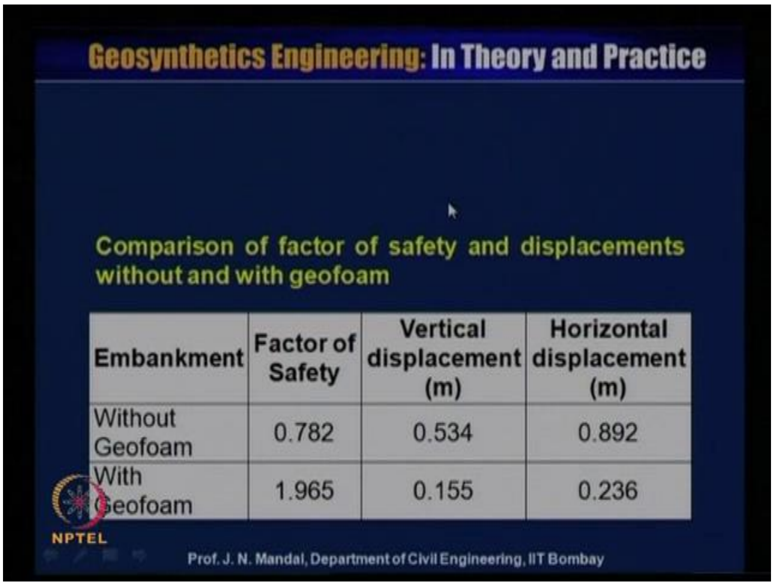

So, when you comparison of the factor of safety and the displacement without and with geofoam the embankment without geofoam, factor of safety 0.782. So, it fell if you do not provide with the geofoam material and the vertical displacement is 0.534 and the horizontal displacement is 0.892 meter. Whereas, with geofoam the factor of safety 1.965, vertical displacement is reduced 0.155 and the horizontal displacement also reduce with respect to without geofoam 0.236. So, you observe that inclusion of the geofoam material for the embankment has reduced the vertical displacement and the horizontal displacement significantly and also there is a substantial improvement in the factor of the safety. That factor of safety is about 1.965.

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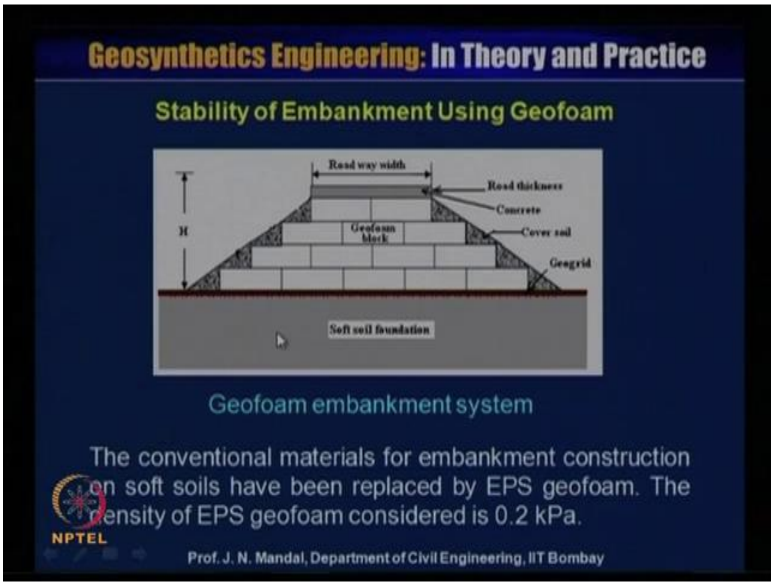

This is geofoam embankment system. The conventional material for embankment construction on the soft soil having been placed by the EPS geofoam. The density of the EPS geofoam is 0.2 kilopascal and this is unit weight is 2 kilopascal and this is the roadway of the width, height of the geofoam is h and here is provided the one layer of the geogrid material.

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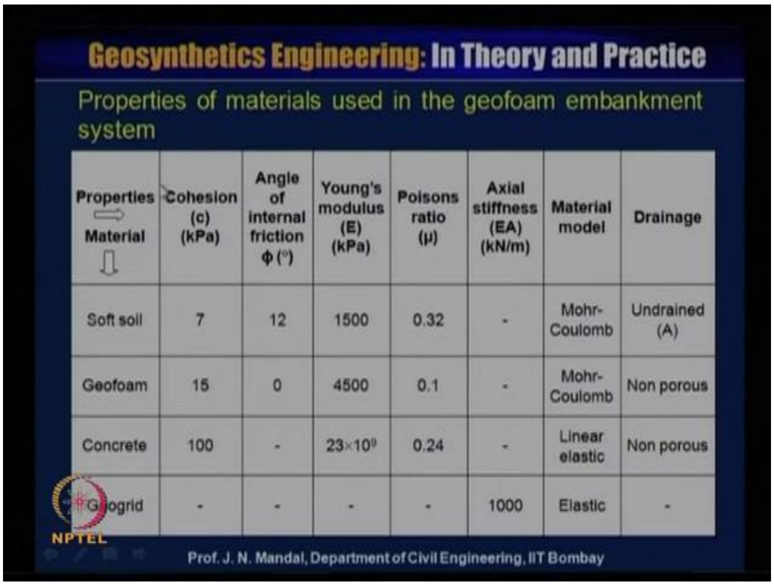

Properties ⇨ Material ⇩	Cohesion (c) (kPa)	Angle of internal friction ϕ (°)	Young's modulus (E) (kPa)	Poisons ratio (μ)	Axial stiffness (EA) (kN/m)	Material model	Drainage
Soft soil	7	12	1500	0.32	-	Mohr-Coulomb	Undrained (A)
Geofoam	15	0	4500	0.1	-	Mohr-Coulomb	Non porous
Concrete	100	-	23×10^9	0.24	-	Linear elastic	Non porous
Geogrid	-	-	-	-	1000	Elastic	-

So, this properties used in the geofoam embankment. This inside this case, this soft soil cohesion value 7, angle of internal friction 12 degree, poison ratio 0.32 that material model Mohr-Coulomb. This is the undrained condition geofoam, cohesion value 15, angle of internal friction 0, young modulus 4500, poison ratio is 0.1 and material model Mohr-Coulomb and drainage is non porous. Concrete that cohesion value 100 kilopascal and young modulus 23 into 10 to the power 9 kilopascal and poison ratio 0.24. This is a material model as a linear elastic and drainage non porous, and geogrid whose axial stiffness 1000 kilo Newton per meter and material model as a elastic.

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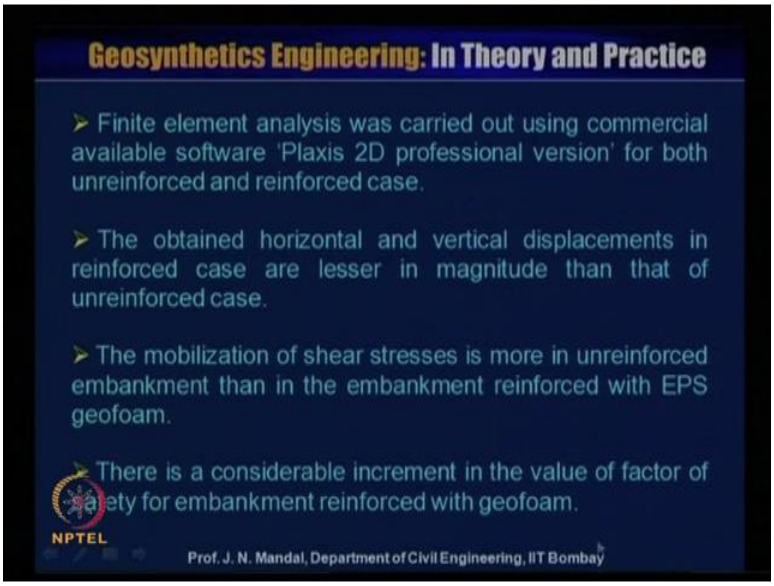

With this property finite element analysis was carried out using commercial available software Plaxis 2D professional version for both unreinforced and reinforced case. The obtained horizontal and the vertical displacement in reinforced case are lesser in magnitude than that of unreinforced case. The mobilization of the shear stresses is more in unreinforced embankment, than in the embankment of reinforced with EPS geofoam. There is a considerable increment in the value of factor of safety of the embankment reinforced with geofoam.

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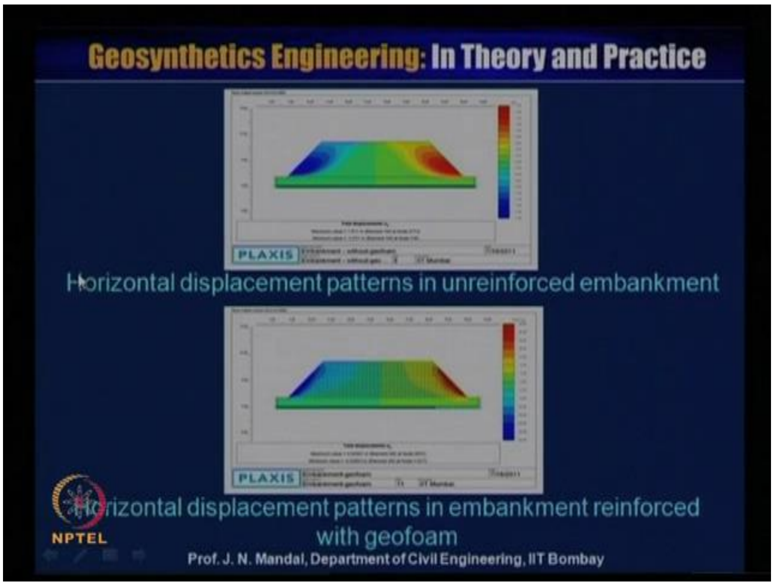

Here we can observe that horizontal displacement pattern in unreinforced embankment. The horizontal displacement pattern in embankment with the reinforcement with geofoam. So, we have provide reinforcement with geofoam.

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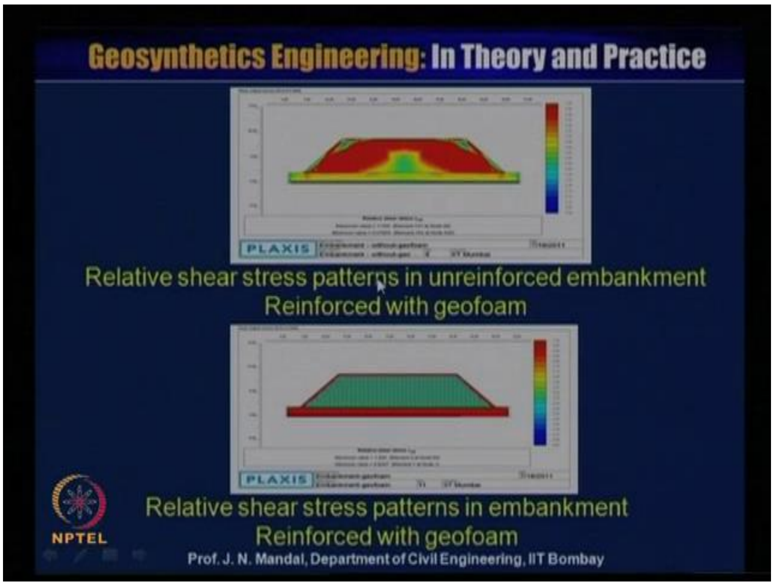

This is relative shear stress pattern in unreinforced embankment reinforced with geofoam. This is relative stress pattern in embankment reinforced with the geofoam.

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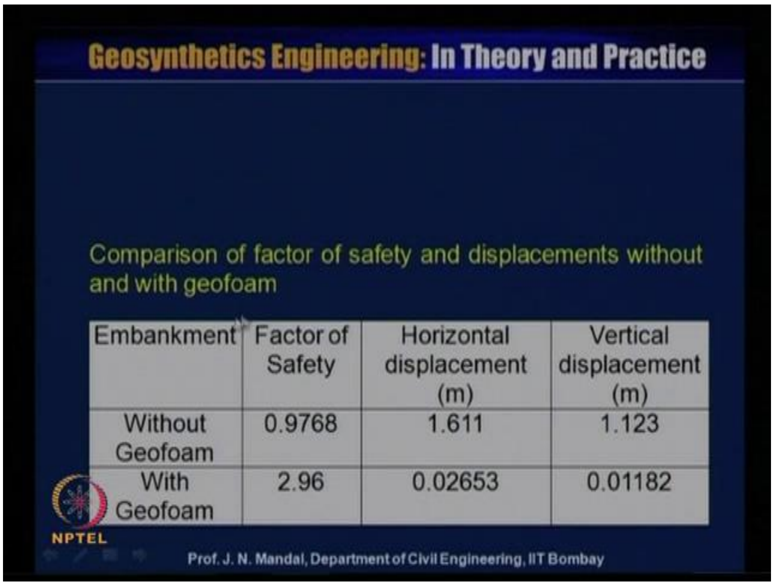

So, comparison factor of safety and the displacement without and with geofoam. For embankment without geofoam the factor of safety 0.9768, horizontal displacement 1.611 and vertical displacement 1.123 meter. Whereas, with the geofoam that factor of safety 2.96, horizontal displacement reduce 0.02653 and vertical displacement 0.01182.

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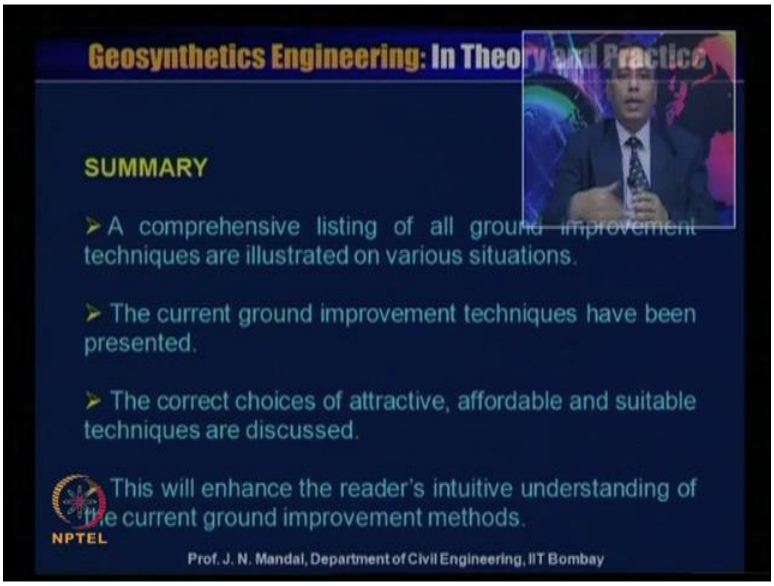

So, this is the summary that a comprehensive listing of all ground improvement technique are illustrated in various situations. The current ground improvement technique have been presented. The correct choice of the attractive, affordable and suitable technique are discussed. So, this will enhance the reader's intuitive understanding of the current ground improvement method.

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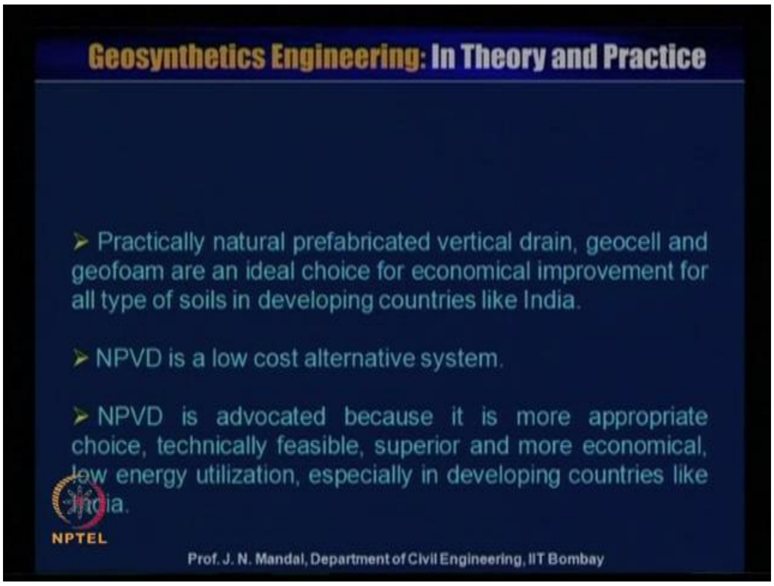

Practically natural prefabricated vertical drain geocell and geofoam are an ideal choice for economical improvement for all type of the soil in developing country like India.

Natural prefabricated vertical drain is low cost alternative system. Natural prefabricated vertical drain advocated because it is more appropriate choice, technically feasible, superior and more economical, low energy utilization, especially in developing country like India.

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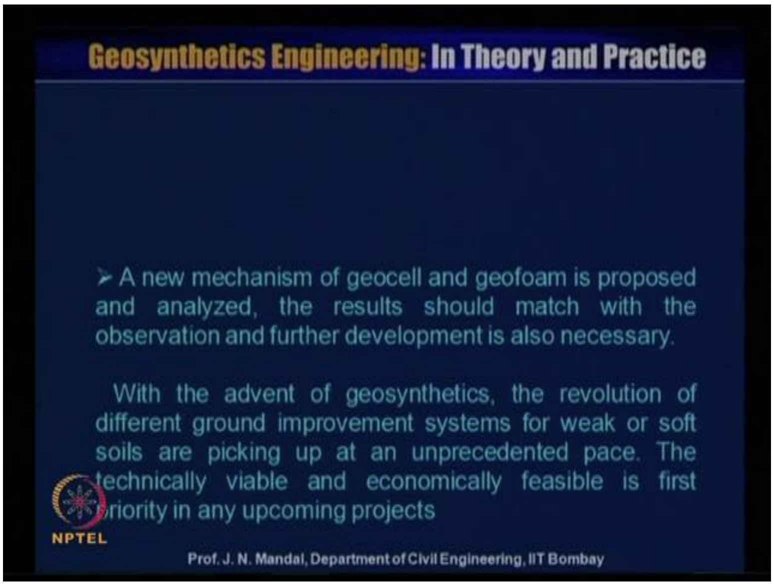

A new mechanics realm of geocell and geofoam is proposed and analyzed, the result should match with the observation and further development is also necessary. With the advent of geosynthetics, the revolution of different ground improvement system for weak or soft soil are picking up at an unprecedented place. The technically viable and economically feasible is the first priority in any upcoming project. With this I finish my lecture today. Please let us hear from you, any question?

Thank you for listening.