Geosynthetics Engineering: In Theory and Practices
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Lecture - 47
Geosynthetics for Ground Improvement

Dear students warm welcome to NPTEL phase two 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. Lecture number 47 module 9 geosynthetics for ground improvement.

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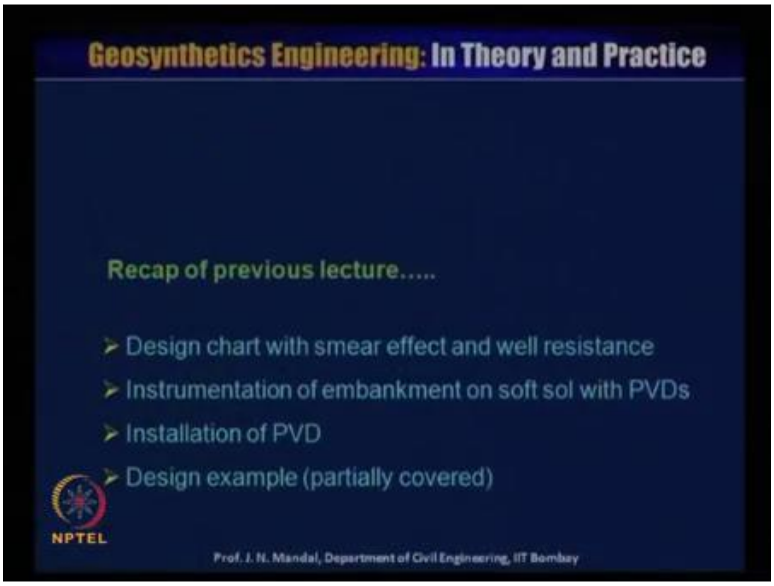

Now, I focus recap our previous lecture design chart with smear effect and well resistance, instrumentation of embankment on soft soil with prefabricated vertical drain, installation of prefabricated vertical drain. And now I have complete design example partly covered.

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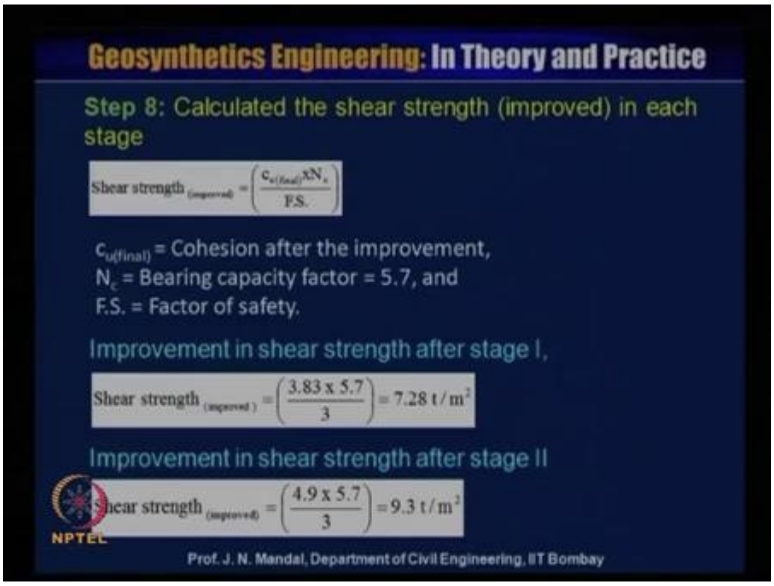

Now this design example now I will continue in step 8, calculate the shear strength that is improved in each stage. So, shear strength improved is equal to Cu final into Nc by FS, for Cu final is the cohesion after the improvement and Nc bearing capacity factor is equal to 5.7 and FS factor of safety. Improvement in shear strength after stage 1, that means shear strength improved is equal to you know Cu value is 3.83, Nc value is 5.7 this divided by 3, factor of safety is 7.28 ton per meter square. Now, improvement in shear strength after stage 2, that is shear strength improved that is 4.9 that is Cu into 5.7 Nc divided by factor of safety 3 that is 9.3 ton per meter square. So you can see by stage wise how this improvement in the shear strength value.

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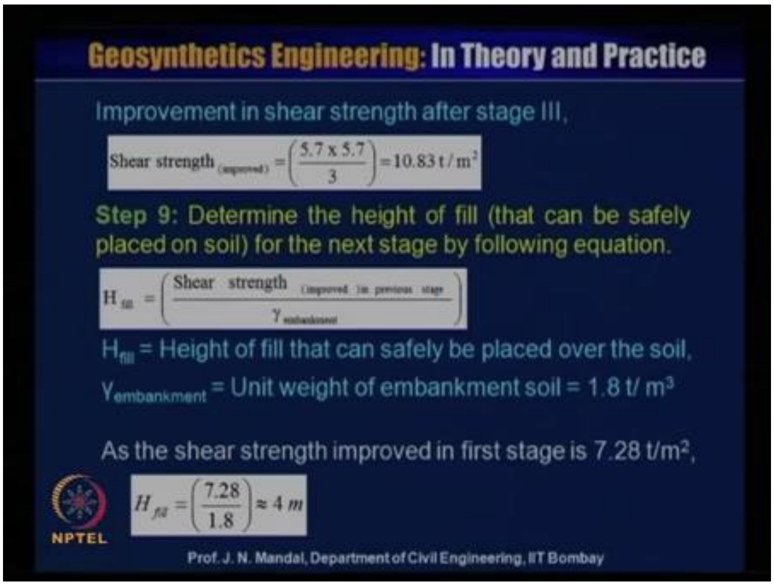

Improvement in shear strength after stage 3, shear strength improved is equal to 5.7 into 5.7 divided by 3 is equal to 10.83 ton per meter square. Step 9, determine the height of fill that can be safely placed on soil, for the next stage by following equation. H fill is equal to shear strength improved in previous stage, divided by gamma of embankment or H fill is equal to height of fill, that can safely be placed over the soil. And gamma embankment is equal to unit weight of embankment soil 1.8 ton per meter cube, as the shear strength improved in the first stage is 7.28 ton per meter square. So, H of fill is equal to 7.28 divided by 1.8 is approximately 4 meter.

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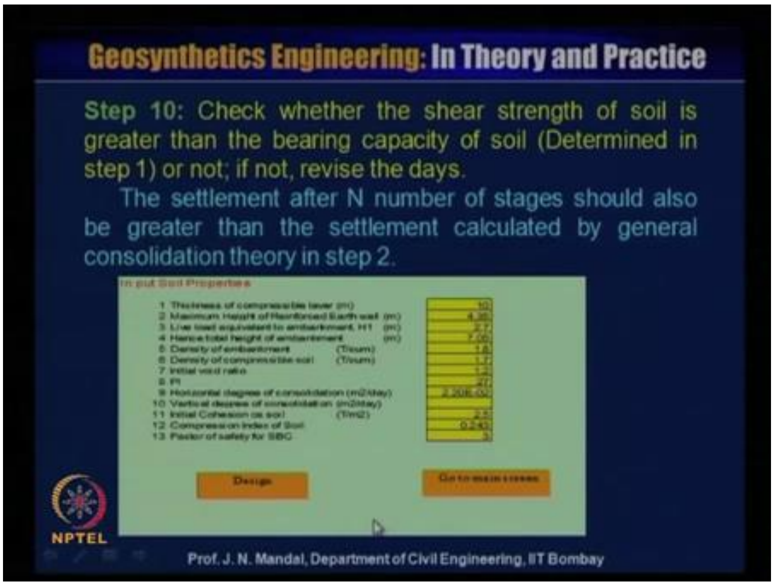

Now step 10 check whether the shear strength of the soil is greater than the bearing capacity of the soil, which determined in step one or not, if not revise the days. The settlement after n number of stages, should also be greater than the settlement calculated by the general consolidation theory in step 2. Here input soil properties all given, that is, this is the thickness of the compressible soil layer that is 10 meter, that is maximum height of the reinforced earth wall is 4.35 meter. Live load equivalent to embankment is 2.7 meter, then height of total of the embankment 7.04, density of the embankment 1.8 ton per meter cube and the density of the compressible soil is 1.2 ton per meter cube. And initial void ratio 1.2 and plasticity index 27, horizontal degree of consolidation is 2.2 into 10 to the power minus 2 meter square per day and vertical degree of consolidation is 2.5 meter square per day. So, initial cohesion of the soil is 2.5 ton per meter square and factor of safety is 3 and compression index of the soil 0.243.

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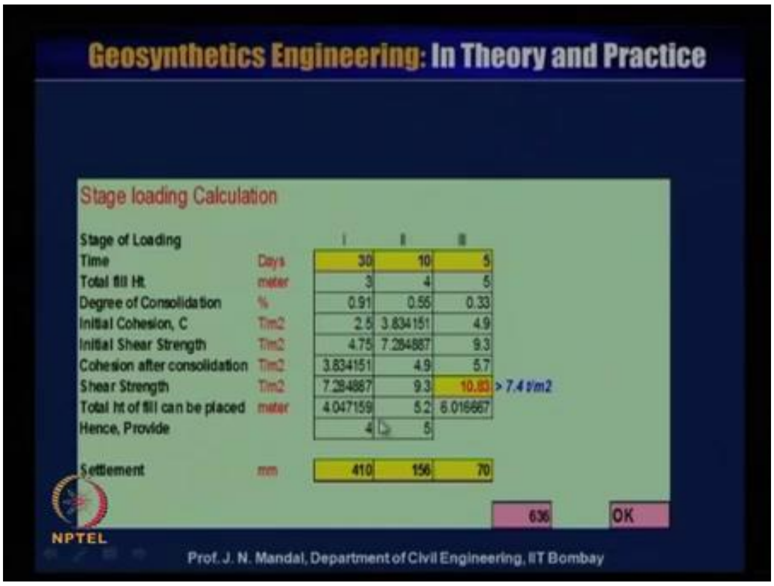

So we can see that, what is the result or stage loading calculation? So, stage loading or the time that is day, this is the first stage loading for 30 days, second stage loading for 10 days and third stage loading for 5. And this is the total fill height meter so initial stage you calculated 3 meter then second stage is 4 meter and third stage is 5 meter. So, degree of consolidation you have achieved 0.91, 91 percentage in the first stage, second stage is 55 percentage and third stage is 33 percentage.

Now, initial cohesion C in ton per meter square in the first stage 2.5 ton per meter square then increased to t 3.83, then third stage is increased to 4.9 ton per meter square. Initial shear strength is first stage 4.75, then increased to second stage 7.28 and third stage is 9.3 ton per meter square. Cohesion after consolidation is 3.83 in the first stage, 4.9 in the second stage and 5.7 in the third stage.

And shear strength value, which is important to us that is in the first stage 7.28 ton per meter square, second stage 9.3 ton per meter square and the third stage 10.83 ton per meter square, which is greater than 7.4 ton per meter square. So, total height of the fill can be placed initial about 4 meter, then 5.2 meter and the third stage is 6 meter. Hence provide that 4 and the 5, you have also calculate the settlement in the first stage more 10 millimeter, second stage is settlement is 156 millimeter and the third stage is 70 meter. So, you can add so you can have the total settlement about 636 millimeter.

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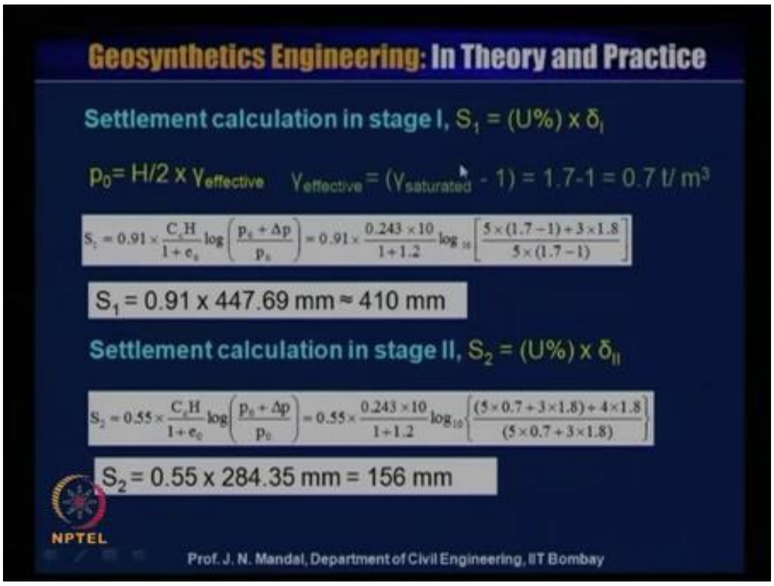

Now settlement calculation in each stage S1 is equal to U percentage into delta 1, P0 is equal to H by 2 gamma of effective, gamma effective is equal to gamma saturated minus 1. And gamma saturated value given 1.7 minus 1, 0.7 ton per meter cube so settlement S1 is equal to 0.91 here. And then Cc 0.243, H is equal to 10, 1 upon 1 plus Cc is 1.2, plus log 10 and this P0 is equal to 5 into 1.7 minus 1 plus, delta p is 3 into 1.8. This divided by P0 so P0 is equal to 5 into 1.7 minus 1 so you can calculate the S1 will be 0.91 into 447.69 millimeter is approximately 410 millimeter.

Settlement calculation in stage 2, that is S2 is U percentage into delta of 2, that means S2 will be equal to 0.55, because U is 055. So, Cc into H by 1 plus e0 log P0 plus delta p by P0, this is 0.55 U into that Cc 0.243 into height is 10 divided by, 1 plus e0 is 1.2 log 10 into P0, 5 into 0.7 plus 3 into 1.8 plus that is P0, that is 4 into 1.8. This divided by what is, P0 so this is P0 again 5 into 0.7 plus 3 into 1.8 so this is P0 plus delta p by P0. So, S2 will be equal to 0.55 into 284.35 millimeter is, 156 millimeter, this is the settlement calculation in stage 2, S2.

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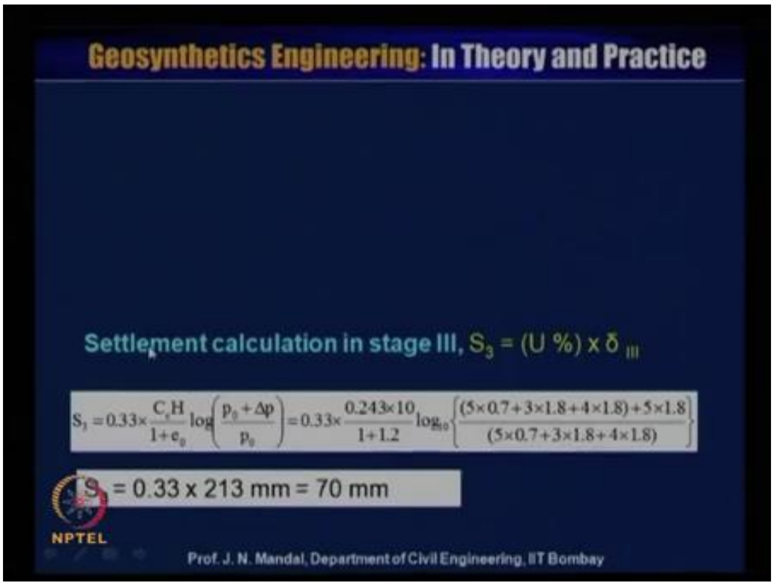

Now similarly, you can calculate settlement calculation in stage 3, that is S3 will be equal to U percentage into delta of 3. That means S3 is equal to U is 33 percentage 0.33 into Cc into H divided by 1 plus e0 log P0 delta p divided by P0., that means 0.3 into 0.243 into height 10 divided by 1 plus e 0, 1.2 log 10. And this is P0, is 5 into 7 plus, 3 into 1.8 plus, 4 into 1.8 plus, delta p 5 into 1.8, this divided by P0 is 5 into 0.7 plus, 3 into 1.8 plus, 4 into 1.8. So, if you calculate you can obtain the settlement in stage 3, S3 will be equal to 0.33 into 213 millimeter that is 70 millimeter.

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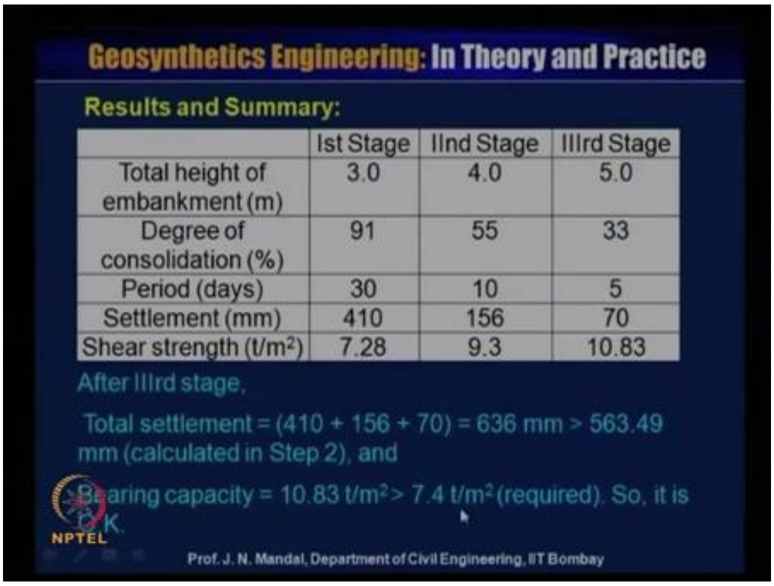

So, now we can result and summary it can be said that, total height of the embankment in the first stage it is 3 meter, second stage 4 meter and third stage 5 meter. And degree of consolidation in the first stage 91 percentage, second stage 55 percentage and third stage 33 percentage. And period of days is required first stage 30 days, second stage 10 days and third stage is 5 days.

Most of the consolidation takes place in the first stage that means within 30 days, you have achieved the major degree of consolidation. And then gradually you can see that degree of consolidation is decreasing with the minimum time or days. Settlement initially first stage 410 millimeter, then second stage 156 millimeter and third stage is 70 millimeter. Shear strength is ton per meter square, in the first stage 7.28, then second stage 9.3 ton per meter square and the third stage 10.83 ton per meter square.

So, after this third stage so total settlement we find 410 plus 156 plus 70, that means 636 millimeter and you know that, earlier we checked this settlement 563.49 millimeter, which we calculated in step 2 so this settlement is greater than the 563.49 then it is so in terms of the settlement. And in terms of the bearing capacity this is 10.83 ton per meter square, which is greater than 7.4 ton per meter square what is required. So, it is also so we checked in terms of the total settlement and in terms of the bearing capacity. So, it satisfy the criteria so design is safe. I will show you that, excel program for this design of the PVD.

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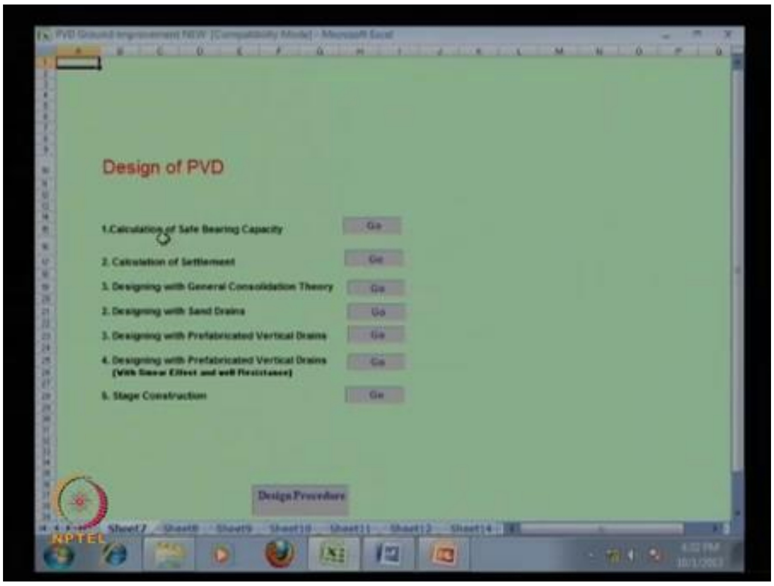

So, first the calculation of safe bearing capacity.

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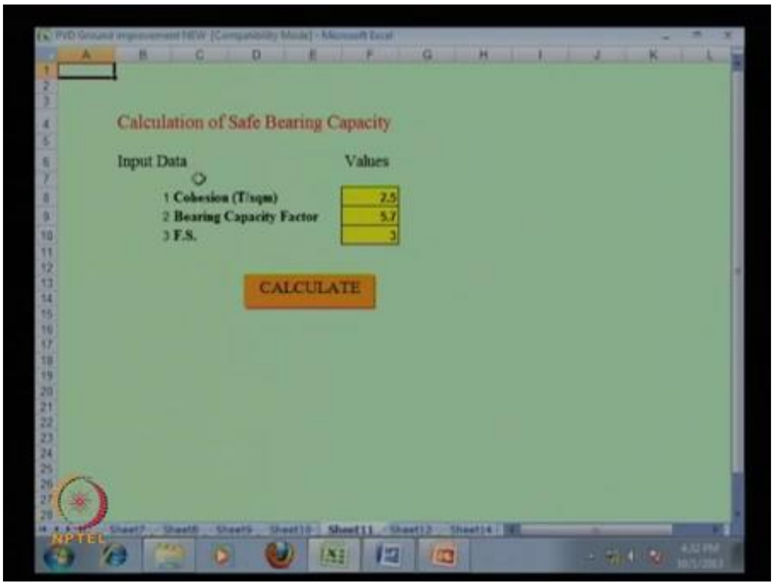

So, you can put the input data cohesion 2.5 ton per square meter bearing capacity factor 5.7 factor of safety 3, so you can calculate.

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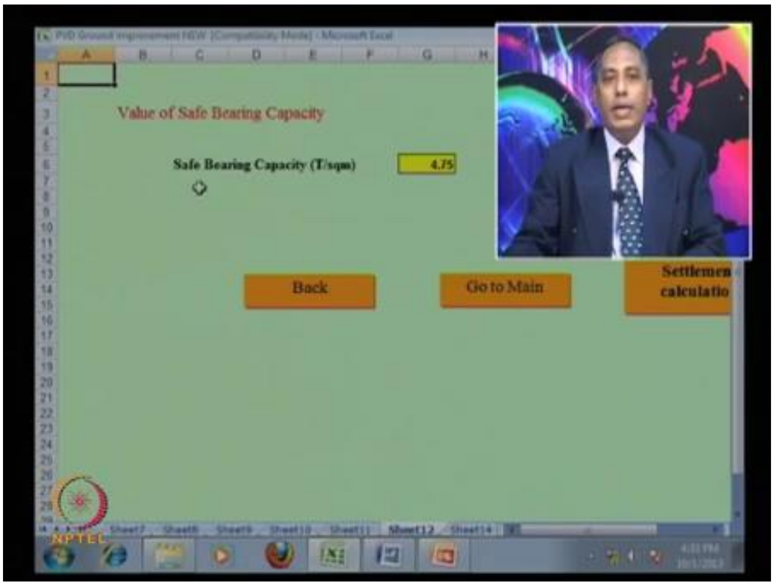

So, you find the safe bearing capacity is 4.75 ton per square meter.

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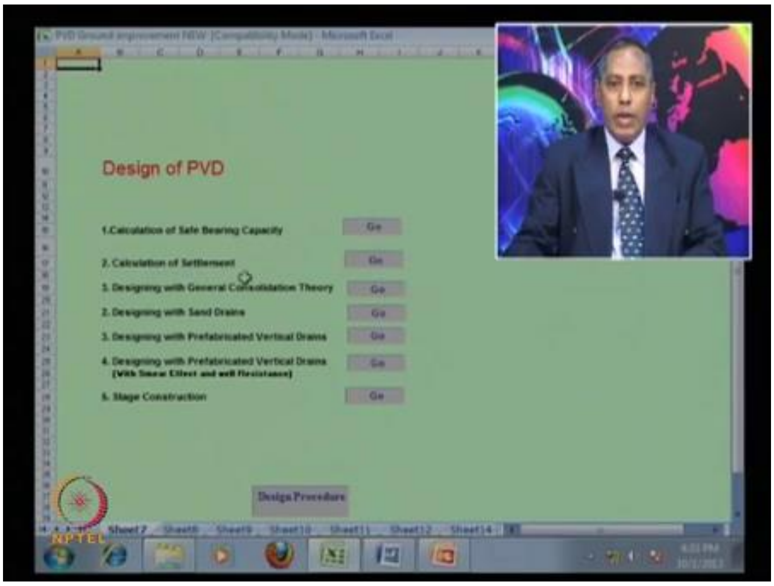

Next, you calculate the settlement, you calculate the settlement.

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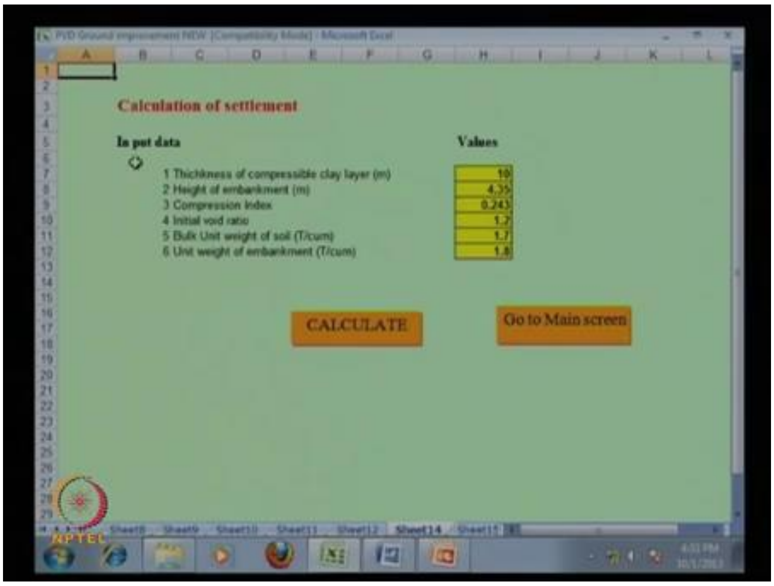

So, for the settlement is input data thickness of the compressible clay layer is 10 meter height of the embankment is 4.35 meter compression index is 0.243. Initial void ratio 1.2, bulk unit weight of soil 1.7 ton per cubic meter, unit weight of embankment is 1.8 ton per cubic meter. Now, you calculate.

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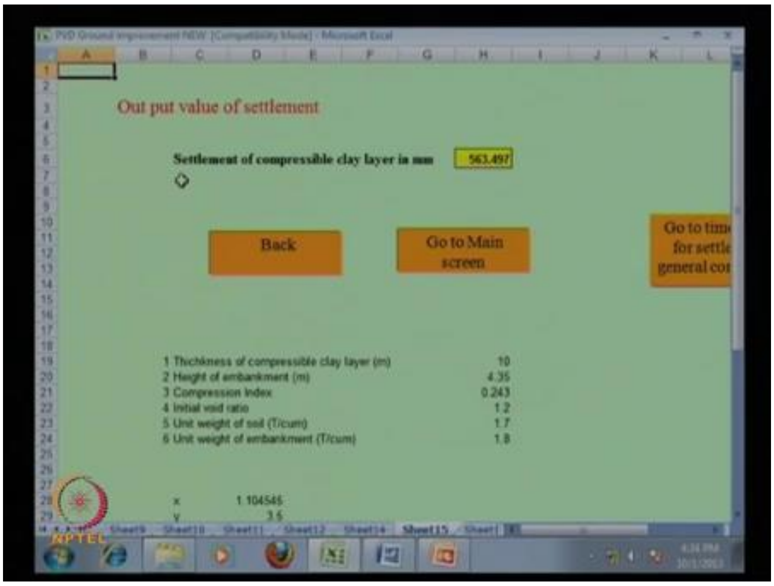

So, you can obtain the output value of the settlement, that is settlement of compressible clay layer is 563.497 millimeter. So, you calculate initially what is the bearing capacity and then you calculate what will be the settlement.

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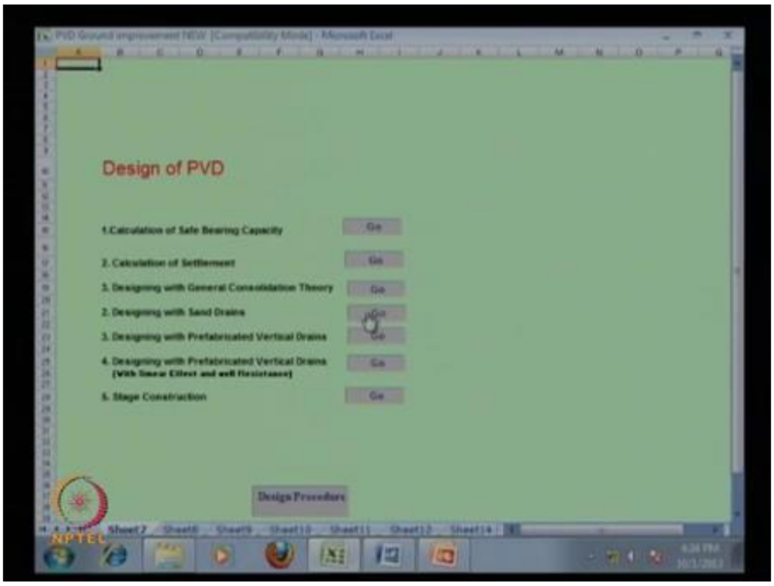

Now, we can design with the general consolidation theory.

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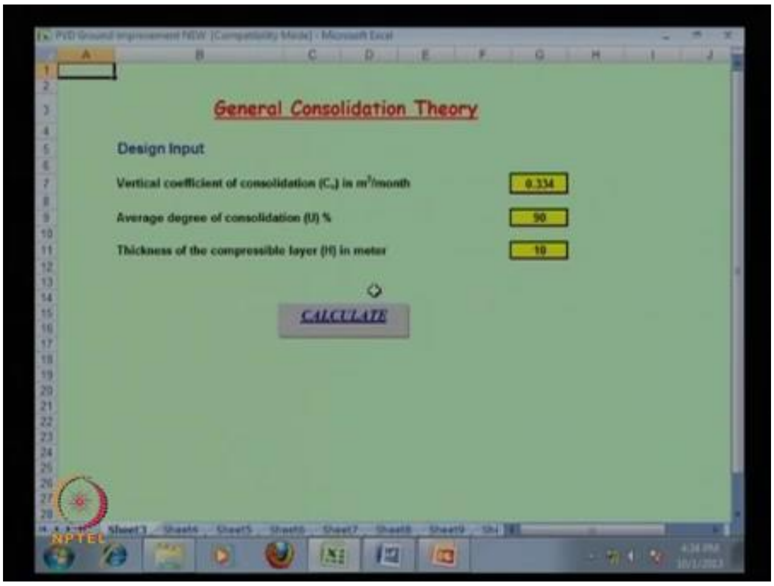

So, we will first design with the general consolidation theory. So, here design input vertical coefficient of consolidation, that is C v in meter square for month is 0.334, average degree of consolidation U is 90 percentage, thickness of the compressible layer H in meter 10.

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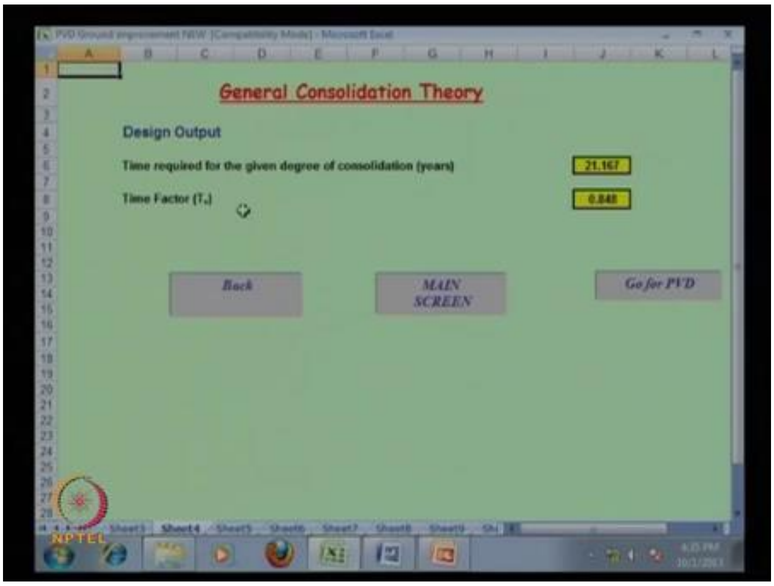

So, you can calculate and this is the design output time required for the given degree of consolidation in years 21.167. And time factor Tb is 0.848 so you see that how many years you have to wait to calculate.

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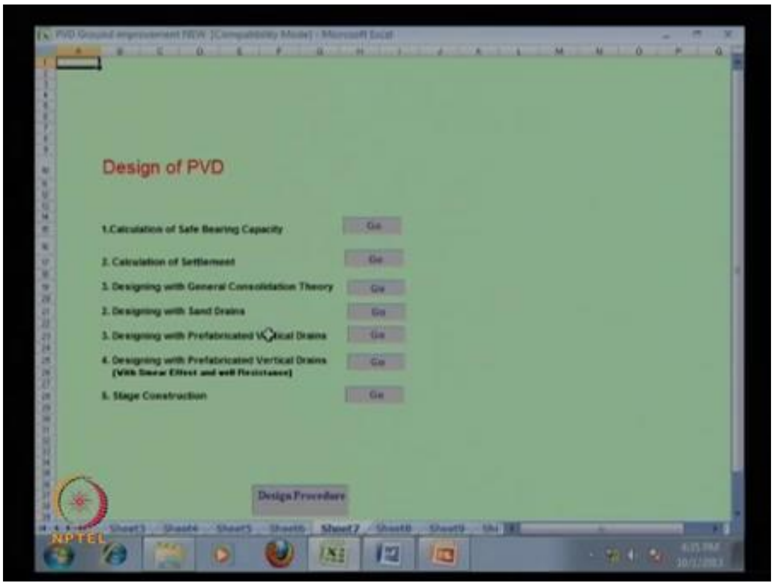

Now and that is why, we want to go for the design with the sand drain so you use the sand drain.

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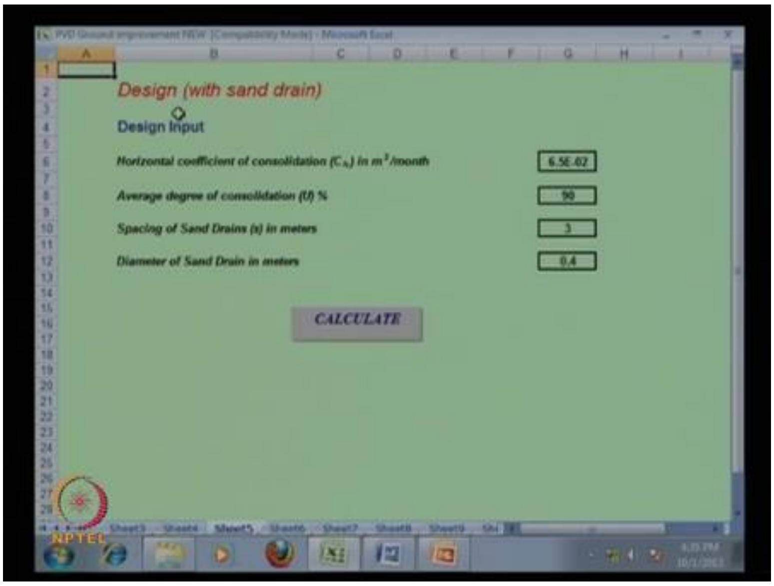

So, here design input horizontal coefficient of consolidation Ch in meter square per month is 6.5 into 10 to the power minus 2, average degree of consolidation U percentage 90. Spacing of the sand drain in meter is 3 and diameter of the sand drain in meter 0.4 meter so you can calculate using sand drain.

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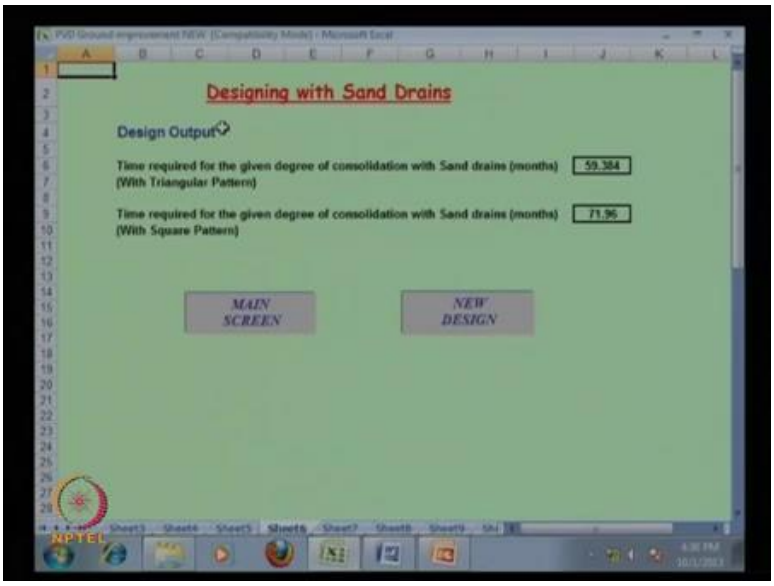

So, this is the design output, the time required for the given degree of consolidation, with sand drain in month with triangular pattern 59.384 month. And time required for the given degree of consolidation, with sand drain in month with square pattern is 71.96

month. So, you see that even then if you introduce the sand drain it takes about 59 month or 71 month.

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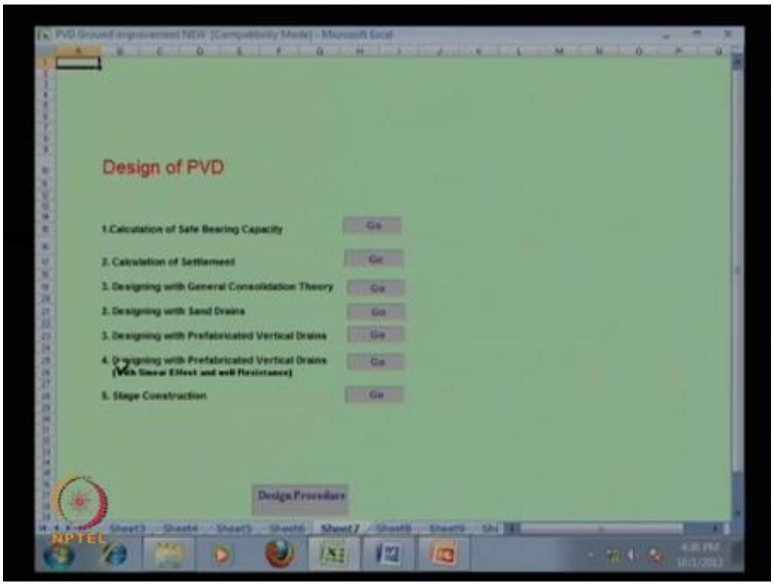

Now, we will adopt the prefabricated vertical drain, designing with prefabricated vertical drain. So, let us see what will happen if we use the prefabricated vertical drain.

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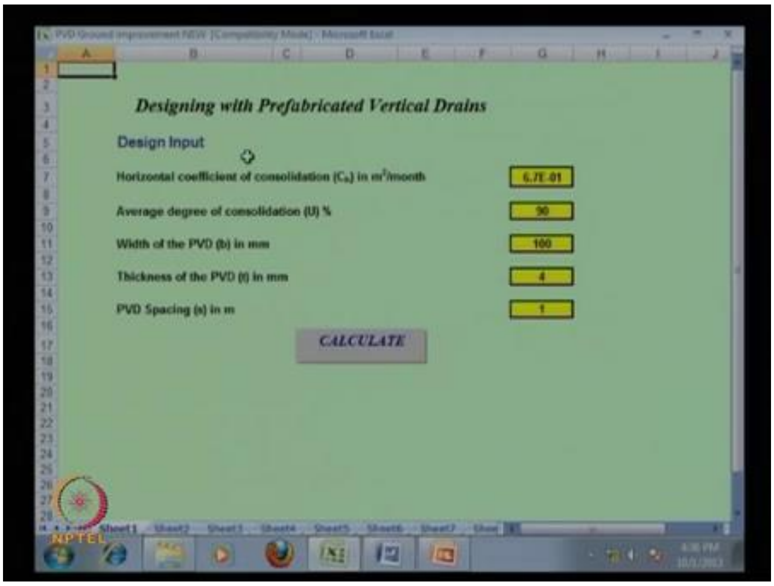

So, here design input horizontal coefficient of consolidation Ch in meter square per month, that is 6.7 into 10 to the power minus 1. Average degree of consolidation U percentage, 9 percentage and width of the prefabricated vertical drain is 100 millimeter and thickness of the prefabricated vertical drain is 4 millimeter and PVD spacing is 1 meter.

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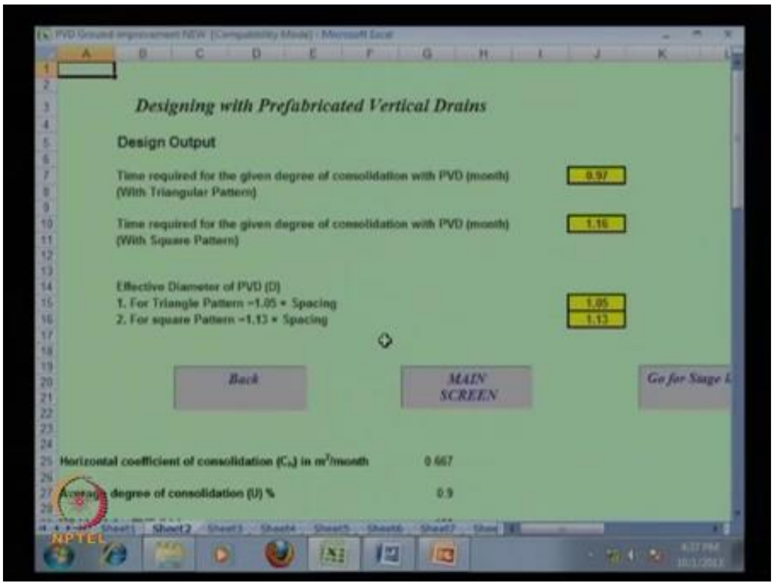

And now, you can calculate and you can have the design output. So, time required for the given degree of consolidation with PVD, in month triangular spacing is 0.97 month. And time required for the given degree of consolidation with PVD in month with square pattern 1.16 month. So, effective diameter of PVD for triangular pattern, you know 1.05 into spacing that means 1.05 and for square pattern 1.13 into spacing this is 1.13. So, you can see that how drastically you can reduce the time when, you use this prefabricated vertical drain. This is only 0.97 month for triangular pattern and 1.16 month for the square pattern.

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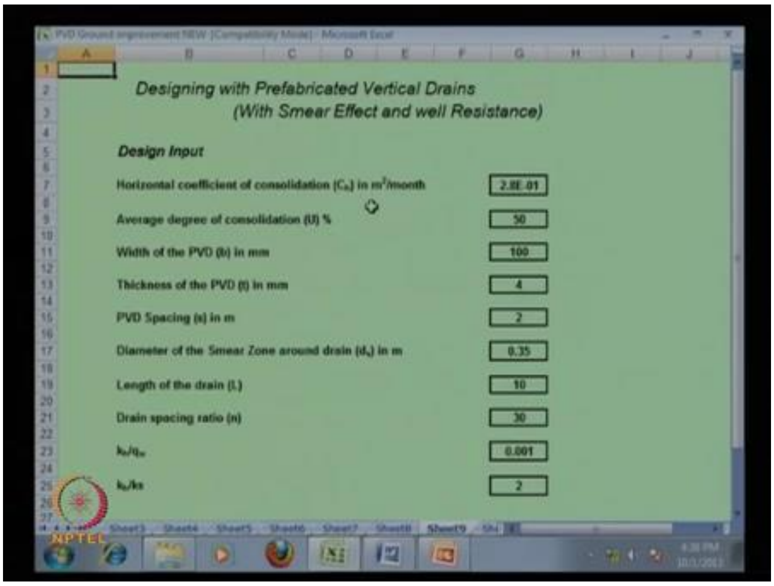

Now, design with prefabricated drain with smear effect and well resistance, most of the time we do not consider, but if you consider then horizontal coefficient of consolidation design input, Ch in meter square per month is 2.8 10 to the power minus 1. Average degree of consolidation U percentage 50, width of the PVD is 100 millimeter thickness of the PVD is 4 millimeter. PVD spacing is 2 meter, diameter of the smear zone along the drain is 0.35, length of the drain is 10, drain spacing ratio is 30 Kh by qw is equal to 0.001 and Kh by ks is equal to 2. Now, if you calculate.

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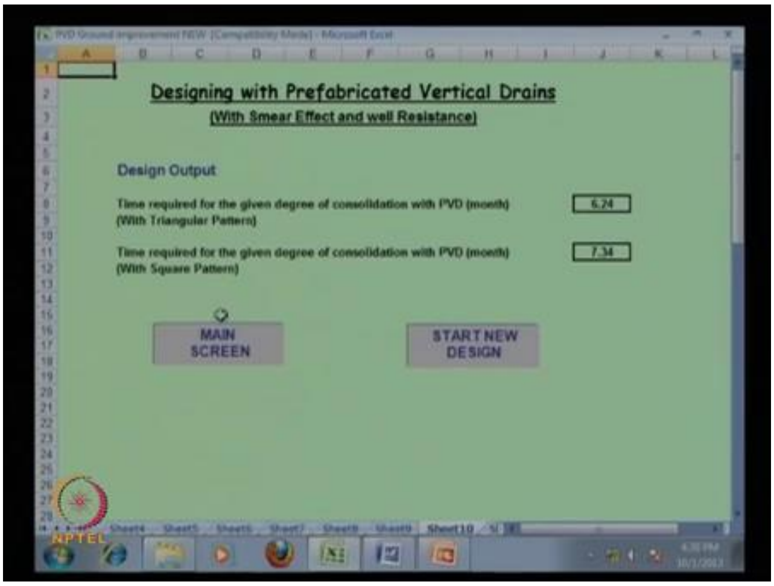

So, you can obtain the design output time required for the given degree of the consolidation with PVD in month, with triangular spacing is 6.24. So, if you consider the smear zone now, time required for the given degree of consolidation with PVD month, with square pattern is 7.34 month. So, you can see that when are using this smear zone is taken into consideration, you require more time.

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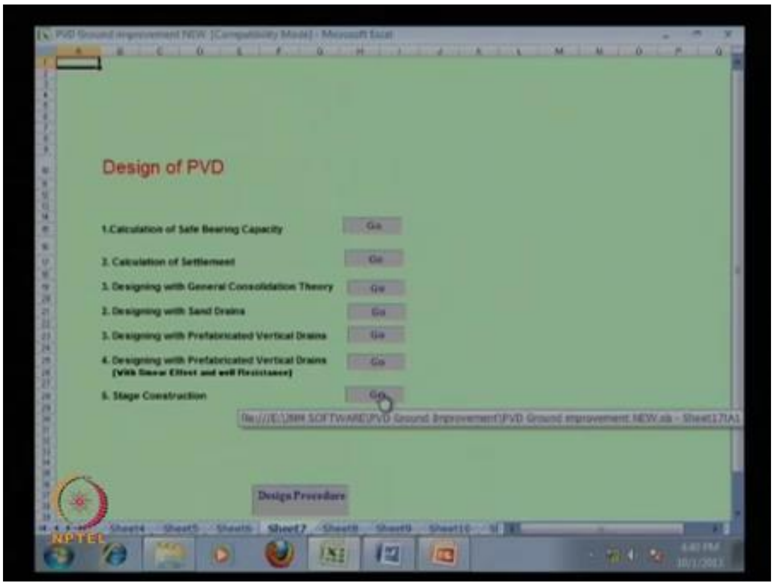

Now, the stress construction this is important, that input soil property.

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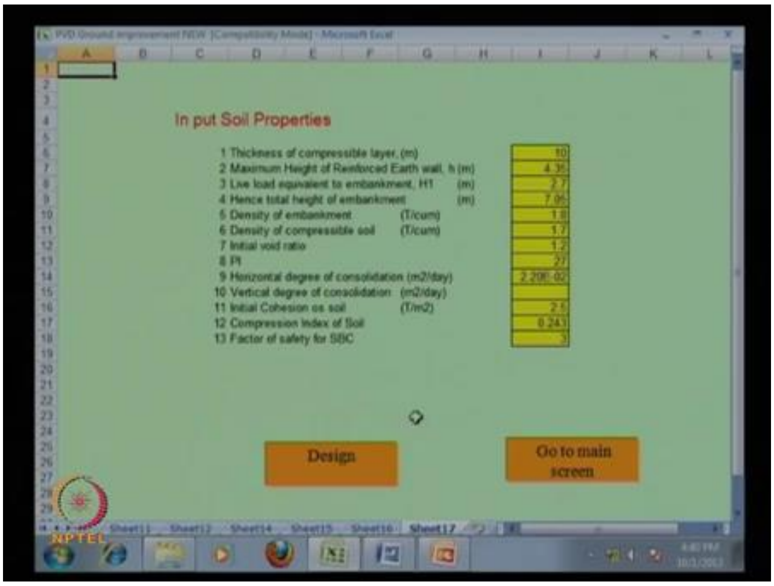

So, thickness of the compressible layer is 10 meter maximum, height of the reinforced earth wall h is 4.36 meter, live load of equivalent to embankment H1 is 2.7 meter and then hence the total height of the embankment is 7.05 meter. Density of the embankment 1.8 ton per cubic meter, density of the compressible soil 1.7 ton per cubic meter, initial void ratio 1.2, plasticity index 27. Horizontal degree of consolidation is 2.2 into 10 to the power minus 2 meter square per day, vertical degree of consolidation and initial cohesionless soil is 2.4 ton per meter square. Compression index of the soil is 0.243 and factor of safety for safe bearing capacity is equal to 3. Now, this is the input soil property and now, if you design.

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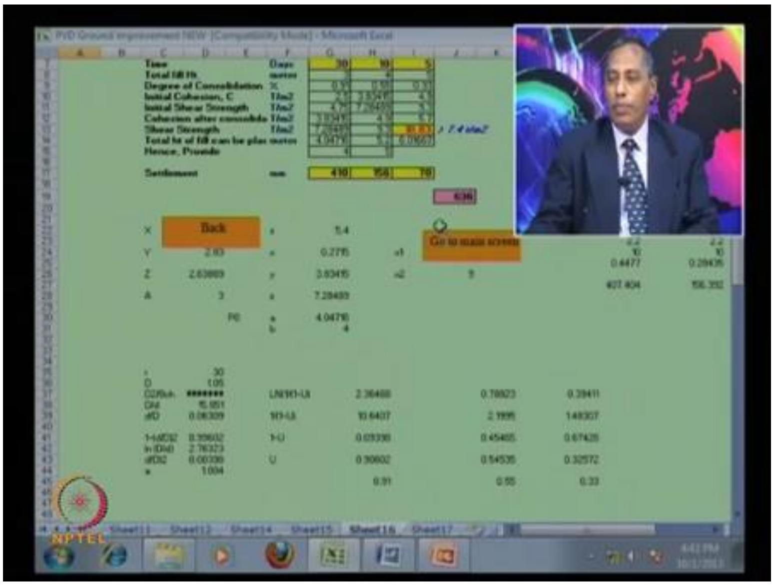

So, you can obtain the stage loading calculation, which means this is first stage, second stage and the third stage. And time required 30, second stage 10 and third stage 5 and total fill height is, the first stage 3 meter, second stage 4 meter and then 5 meter. Then degree of consolidation 0.91 first stage, 0.55 second stage and 0.33 third stage and initial cohesion value in the first stage 2.5, second stage 3.8 and third stage 4.9 ton per meter square. Then initial shear strength 4.75 first stage, 7.28 second stage and 3.3 is the third stage then cohesion of the shear strength 3.8 in the first stage, 4.5 in the second stage and 5.7 in the third stage. And shear strength in the first stage 7.28, in the second stage 9.3 and third stage 10.83, which is greater than 7.4 ton per meter square so this is in terms of the bearing capacity of the soil or improvement of the soil. So, total height of the fill can be placed that is 4 and 5 meter and also it has calculated the settlement.

So, settlement in the first stage 410, second stage 156 millimeter and third stage 70 millimeter. So, total settlement 636 meter so you can see that is 636 meter, which is less than the, may be you got in the second stage about 536 or like that millimeter, so this also satisfy this criteria. So, we completed this excel program for the prefabricated vertical drain and also prefabricated vertical drain with the smear effect and also the sand drain and without the sand drain. So, you find that there is a substantially reducing time for consolidation, if you use the prefabricated vertical drain. Next, I will study geosynthetics encased stone column.

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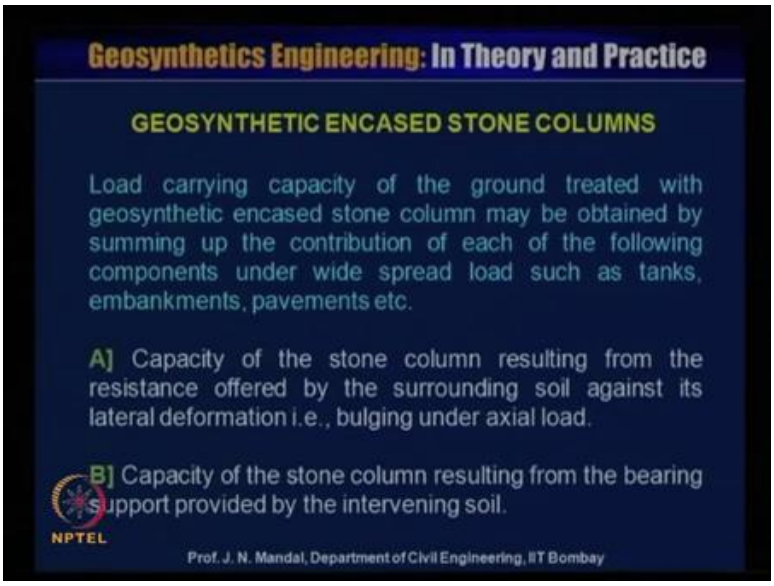

Now, load carrying capacity of the ground treated with geosynthetics encased stone column, may be obtained by summing up the contribution of each of the following component, under wide spread of load such as tank, embankment and pavement etcetera. A - capacity of the stone column resulting from the resistance offered by the surrounding soil, against its lateral deformation that is bulging under axial load, B - capacity of the stone column resulting, from the bearing support provided by the intervening soil.

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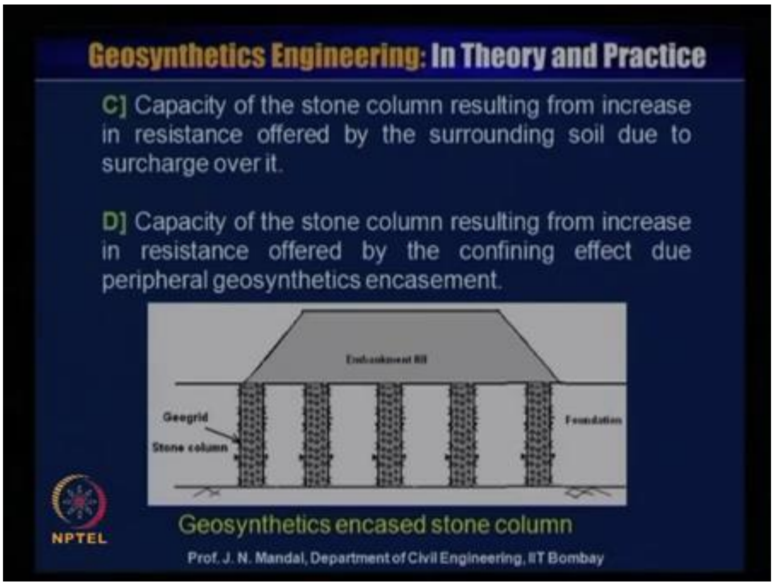

And C - capacity of the stone column resulting from increase in resistance offered by surrounding soil, due to the surcharge over it. And D- capacity of the stone column resulting from increase in resistance, offered by confinement effect due to the peripheral geosynthetic encased stone column. Here you can see this diagram, this is geosynthetic encased stone column and this is the stone and this is the geogrid so you have geogrid encased stone column. And it has placed at a particular spacing, the number of research work also have been carried out in IIT Bombay in the encased stone column. I will just specifically focus only the one result, using that encased stone column and this is the embankment.

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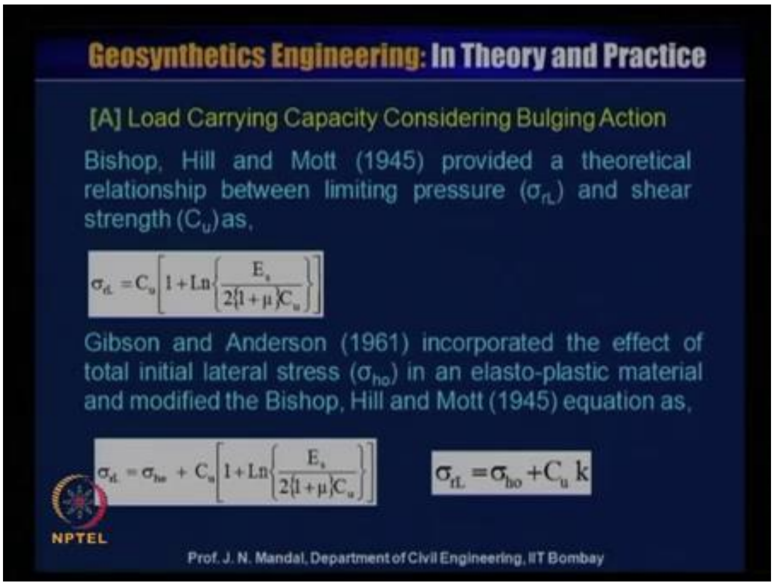

A so what are the theory have been adopted for this. A load carrying capacity considering the bulging action. Bishop, Hill, Mott 1945 provided a theoretical relationship between the limiting pressure sigma r L and the shear strength Cu. So, this is the sigma r L is equal to C u into 1 plus L n Es divided by 2 into 1 plus mu into Cu. Now Gibson and Anderson 1961, incorporated the effect of total initial lateral stress, that is sigma h0 in an elasto-plastic material. And modified the Bishop, Hill and Mott 1945 and equation is sigma r L is sigma h0 plus Cu into L n Es divided by 2 into 1 plus mu into Cu. So, sigma of r L will be equal to sigma h0 plus Cu into K.

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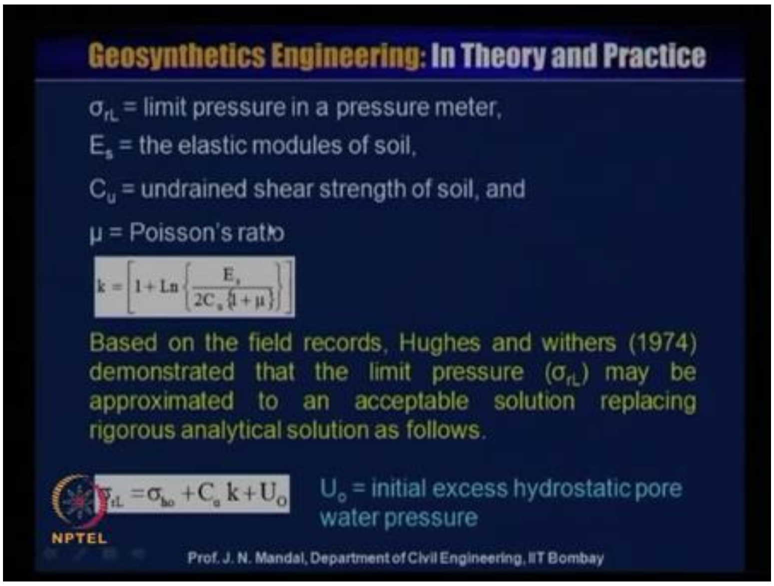

Now where sigma r L is limit pressure in a pressure meter and Es is elastic modulus of soil and C u undrained shear strength of the soil and mu is Poisson's ratio. And K is equal to 1 plus L n into Es, divided by 2 into C u into 1 plus mu. So, based on the field record Hughes and withers 1974, demonstrated that limit pressure sigma r L may be approximated to an acceptable solution, replacing rigorous analytical solution as follow. That means sigma r L is equal to sigma h 0 plus Cu into K plus U0, where U0 is equal to initial excess hydrostatic pore water pressure.

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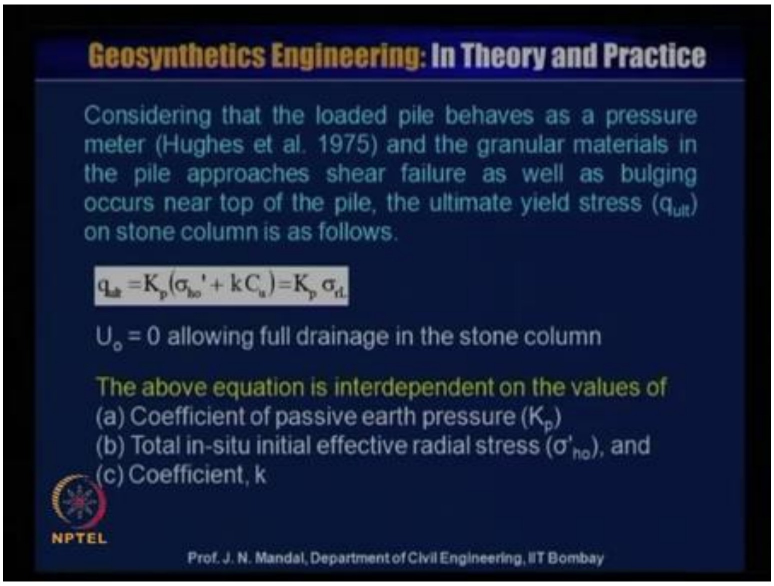

Now considering that the, loaded pile behave as a pressure meter Hughes et al 1975 and the granular material in the pile, approaches shear failure as well as bulging occur near top of the pile. The ultimate yield stress q ultimate on stone column is as follows, that is q ultimate is equal to K p into sigma h0 dash plus K into Cu is equal to K p into sigma r L where U0 is equal to 0, allowing full drainage in the stone column. The above equation is interdependent, on the value of a, coefficient of passive earth pressure K p b, total in situ initial effective radial stress sigma dash h0 and c, that coefficient k.

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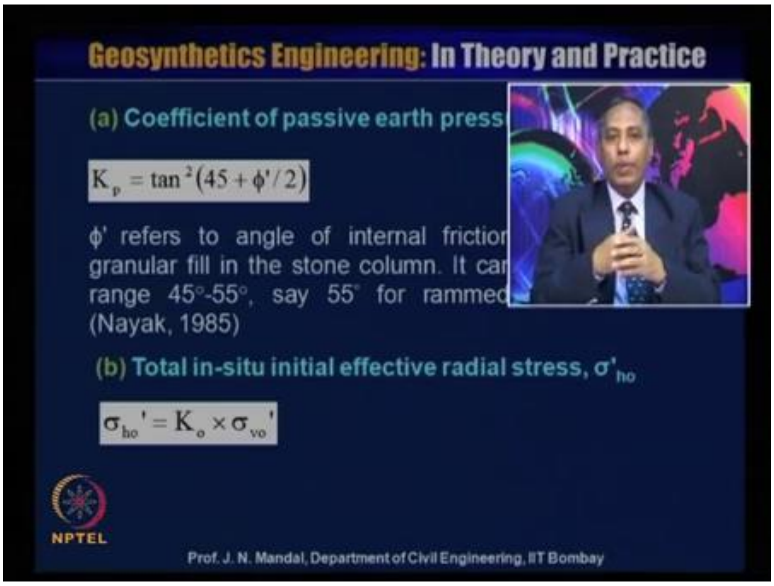

A, coefficient of passive earth pressure Kp so Kp is equal to tan square 45 degree plus phi dash divided by 2. Where, phi dash refer to, angle of internal friction for compacted granular fill in the stone column. It can be taken in the range of 45 degree to 55 degree say 55 degree for rammed stone column, that is Nayak 1985. B, Total in situ initial effective radial stress sigma h0 dash so sigma h0 dash is equal to K0 into sigma of v0 dash.

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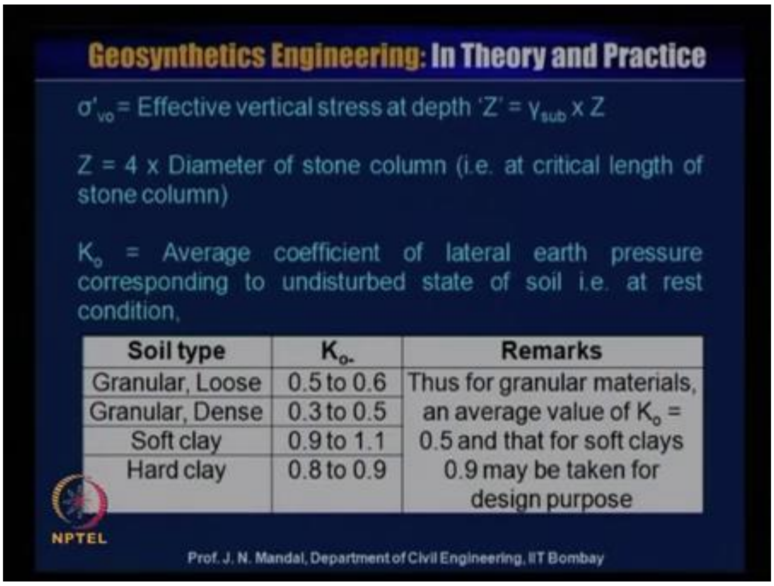

Soil type	K_o	Remarks
Granular, Loose	0.5 to 0.6	Thus for granular materials, an average value of K_o = 0.5 and that for soft clays 0.9 may be taken for design purpose
Granular, Dense	0.3 to 0.5	
Soft clay	0.9 to 1.1	
Hard clay	0.8 to 0.9	

Sigma v 0 dash is equal to effective vertical stress, at depth Z that is equal to gamma submerged into Z. Where z is equal to 4 into diameter of the stone column, that is at critical length of the stone column, K 0 is equal to average coefficient of lateral earth pressure corresponding to undisturbed state of soil, that is at rest condition. So, most of the time that critical length of the stone column is occurred within the 4 times the diameter of the stone column.

There is a possibility for any bulging, at that zone so that is why this Z value has been considered 4 into diameter of the stone column. Now, here that depend upon the soil type you can select the K0 so over granular loose then 0.5 to 0.6 granular and dense K0 value lies between 0.3 to 0.5. It is soft clay K0, 0.9 to 0.1, hard clay K0, 0.8 to 0.9 and here is the remark, thus for the granular material an average value of K0 is equal to 0.5 and that for the soft clay 0.9 may be taken for the design purpose.

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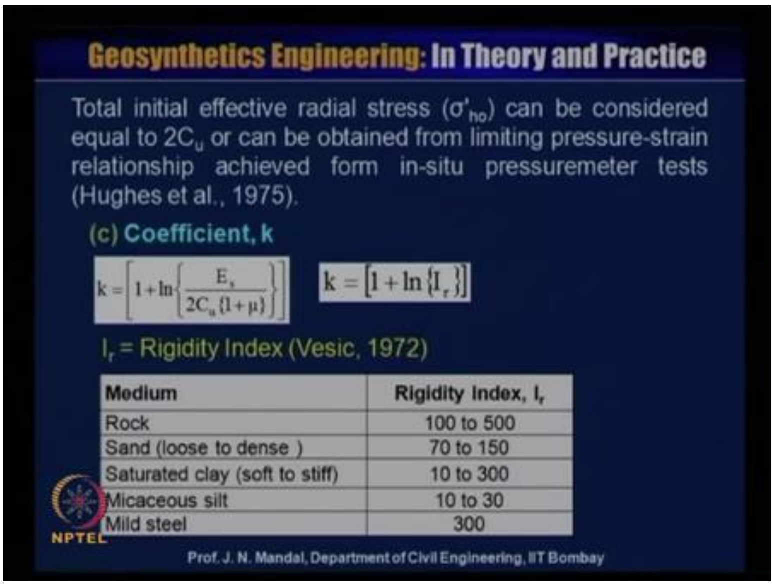

So, total initial effective radial stress sigma h0 dash can be considered equal to 2 into Cu or can be obtained from limiting pressure strain relationship, achieved from in situ pressure meter test Hughes et al 1975. Now c, the coefficient k so you know k is equal to 1 plus L n Es divided by 2 into C u into 1 plus mu or k is equal to 1 plus Ln into I of r. Now, I r is the rigidity index that is Vesic 1972 now, whether it is a medium what should be the rigidity index.

So, if it is a rock rigidity index is 100 to 500, it is sand loose to dense 70 to 150, saturated clay soft to stiff 10 to 300, miscellaneous silt is 10 to 30 and mild steel it is 300. So, you can obtain this rigidity index by Vesic given by Vesic 1972 depend upon the medium so whether it is a rock, sand, clay, steel. So, you can select this rigidity index value from this chart.

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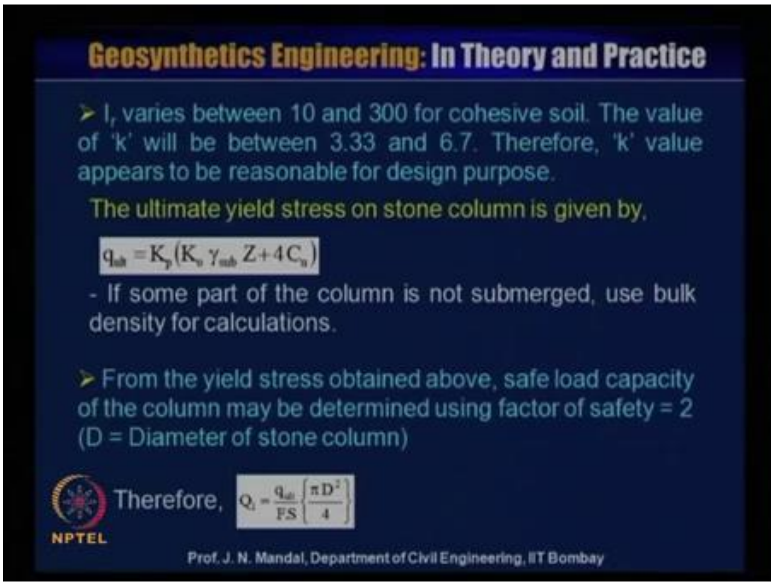

Now, this I r varies between 10 and 300 for cohesive soil, the value of k will be between 3.33 and 6.7. Therefore, k value appear to be reasonable for design purpose, the ultimate yield stress on stone column is given by, q ultimate is equal to Kp into K0 into gamma of sub into Z plus 4 into Cu. If some part of the column is not submerged, use bulk density for calculation, from the yield stress obtained above, safe load capacity of the column may be determined using the factor of safety is equal to 2. Or D is diameter of the stone column therefore Q1 is equal to q of ultimate by factor of safety into pi by 4 into D square, where D is the diameter of the stone column. So, you can calculate the Q1 from this equation.

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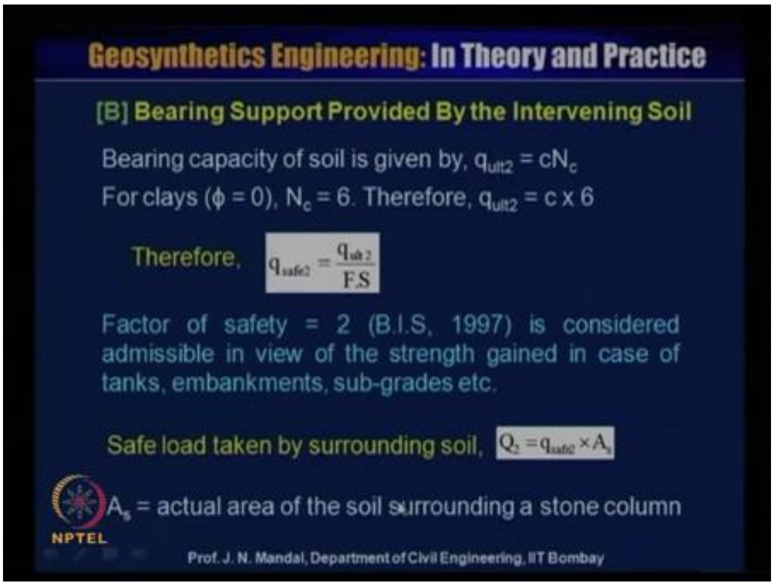

Now, B bearing support provided by the intervening soil, that is bearing capacity of the soil is given by q ultimate is equal to c into N c. For the clay, phi is equal to 0, N c is equal to 6 therefore, q ultimate is equal to c into 6. Therefore, q safe will be q ultimate 2 divided by factor of safety, as factor of safety is equal to 2 as per B.I.S 1997, is considered admissible in view of the strength gained in case of tank, embankment and sub grade etcetera. So, safe load taken by the surrounding soil, that is Q2 is q safe into As, where As is equal to actual area of the soil surrounding a stone column.

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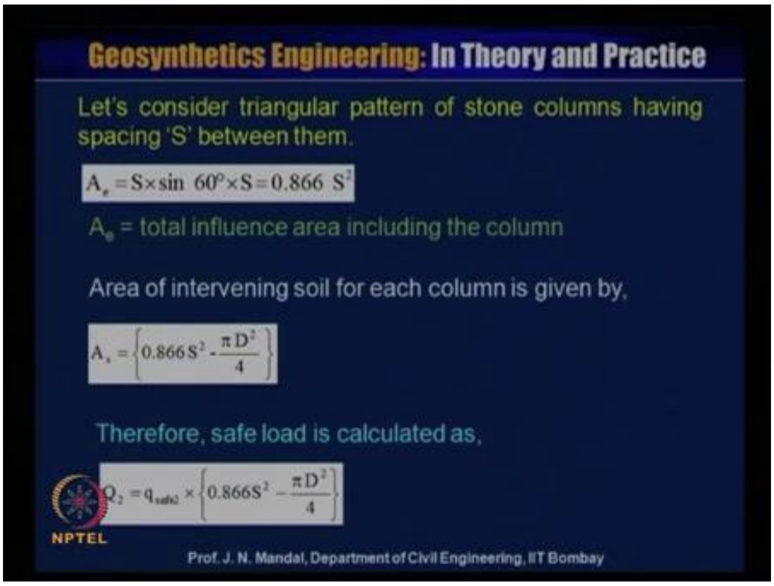

So, let us consider the triangular pattern of the stone column having a spacing S between them. So, Ae is total influence area including the column, is equal to S into sin of 60 degree into S. That means 0.866 S square. Area of intervening soil for each column is given by A s will be equal to 0.866 S square, minus pi D square by 4. Therefore, safe load is calculated as Q2 is equal to q safe 2 into 0.866 S square minus pi by 4 into D square.

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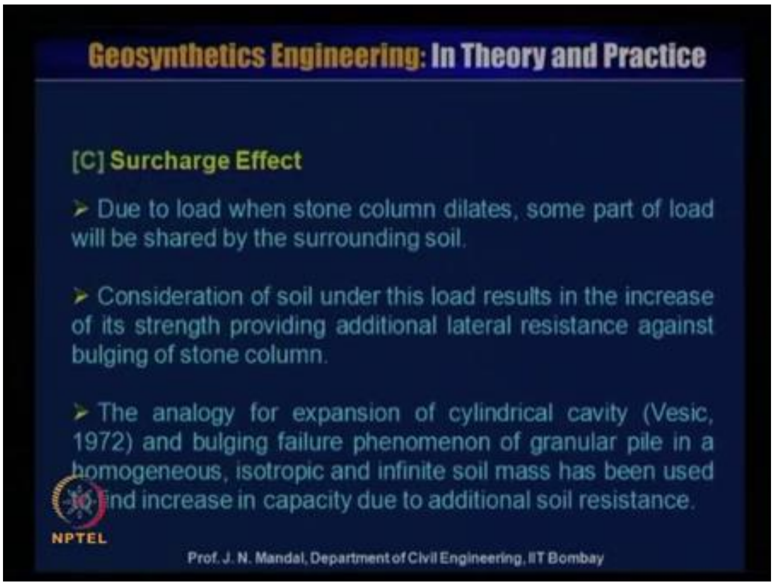

Next surcharge effect, due to load when the stone column dilate, some parts of the load will be shared by the surrounding soil. Consideration of soil under this load, result in the increase of its strength providing additional lateral resistance against the bulging of stone column. The analogy for expansion of the cylindrical cavity, that is Vesic 1972 and bulging failure phenomenon of granular pile in a homogeneous isotropic and infinite soil mass, has been used to find increase in capacity due to the additional soil resistance.

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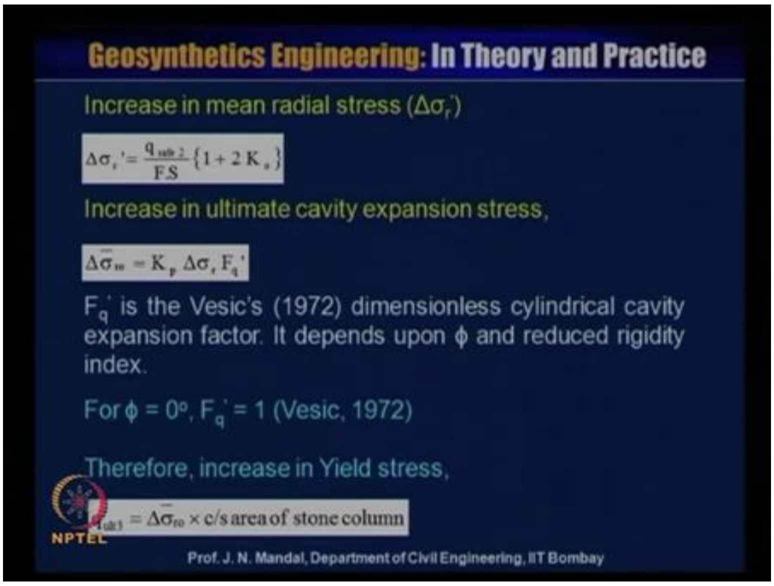

Now increase in the, means radial stress that is del sigma r dash so del sigma r dash is equal to q safe 2 divided by factor of safety into 1 plus 2 K0. So, increase in the ultimate cavity expansion stress, that is delta sigma r0 is equal to K p into delta sigma r into F q dash. Where, F q dash is the Vesic's 1972, dimensionless cylindrical cavity expansion factor and it depend upon the phi and the reduced rigidity index. For when phi is equal to 0, F dash q value is equal to 1 that is mentioned Vesic 1972. Therefore increase in the yield stress, will be equal to q ultimate 3, will be equal to sigma del sigma r0 into central cross sectional area of the stone column.

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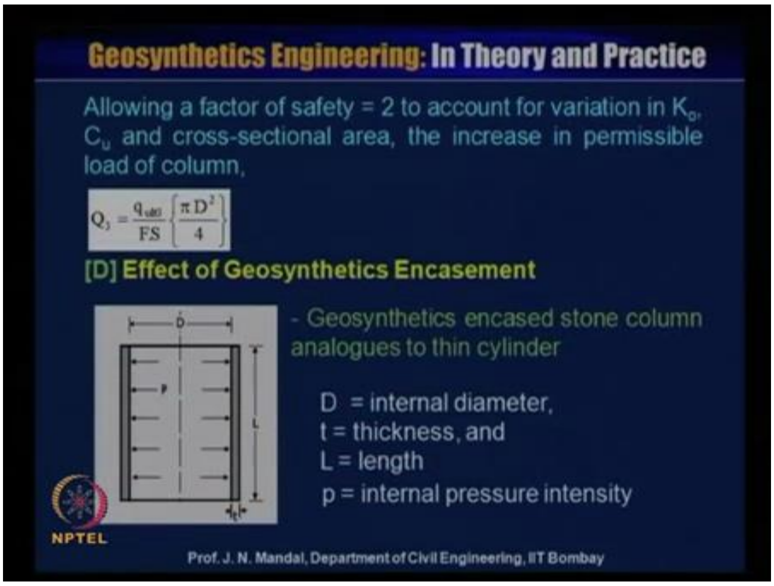

So, allowing a factor of safety is equal to 2, to account for various in k0, Cu and cross sectional area, the increase in permissible load of column that is Q 3, will be equal to q ultimate divided by factor of safety into pi by 4 into D square. Now, D what will be the effect of geosynthetics encasement now, we will study what is the role of the geosynthetics encasement. Now, geosynthetics encased stone column analogue to the thin cylinder so you are considering a thin cylinder, where D is the internal diameter and t is the thickness and L is the length and p is the internal pressure intensity. So, we are considering as a thin cylinder, it is analogue like a thin cylinder, also thin cylinder, also flexible and geotextile material also flexible.

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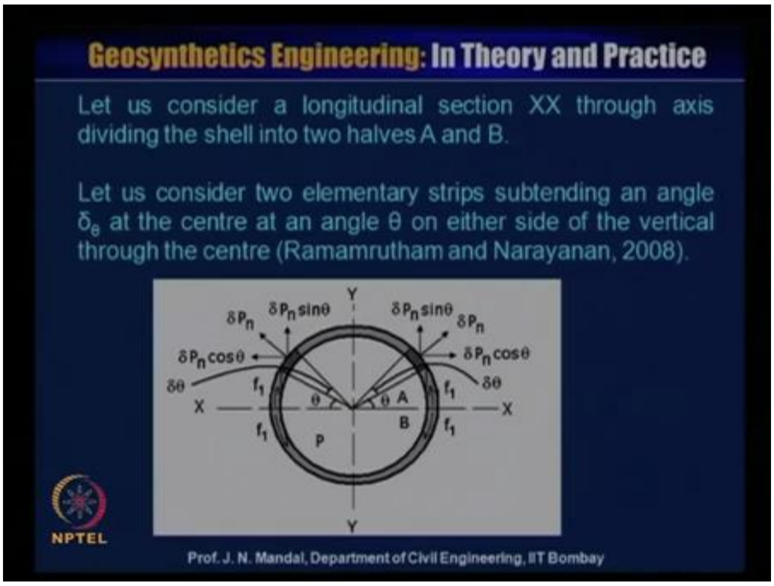

Let us consider a longitudinal section XX, through axis dividing the shell into two halves A and this A and this B. Now, let us consider two elementary strips and subtending at an angle of delta of theta, at the centre, at an angle theta either side of the vertical through the centre. This is Ramamrutham and Narayanan in 2008.

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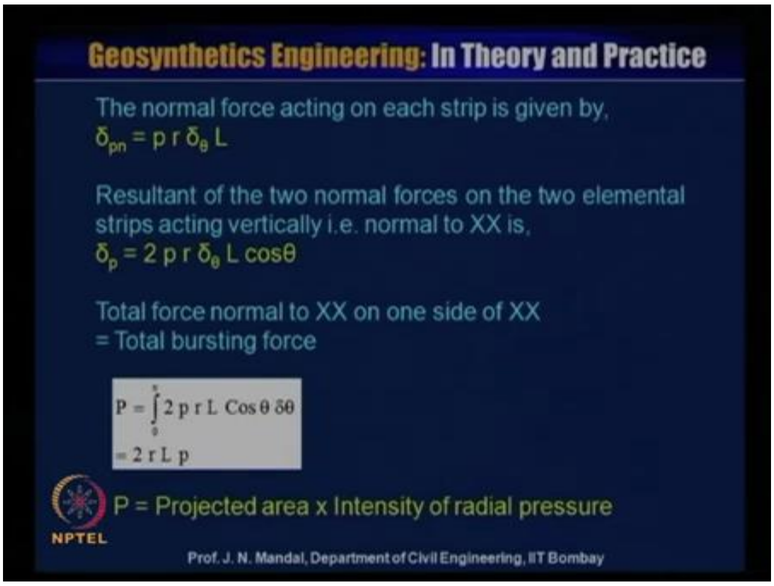

So, we can have the normal force acting on each strip is given by, delta p n is equal to p into r into delta theta into L. And resultant of the two normal forces on the two elemental strip acting vertically that is normal to XX is, delta p is equal to 2 p r delta theta into L into cos theta. So, total force normal to the XX, on one side of the XX is equal to total bursting force that is P is equal to integration 0 to pi into 2 pi r L cos theta into del theta. So, which we are having from here, so you can have p is equal to 2 into r into L into p where, p is the projected area into intensity of radial pressure.

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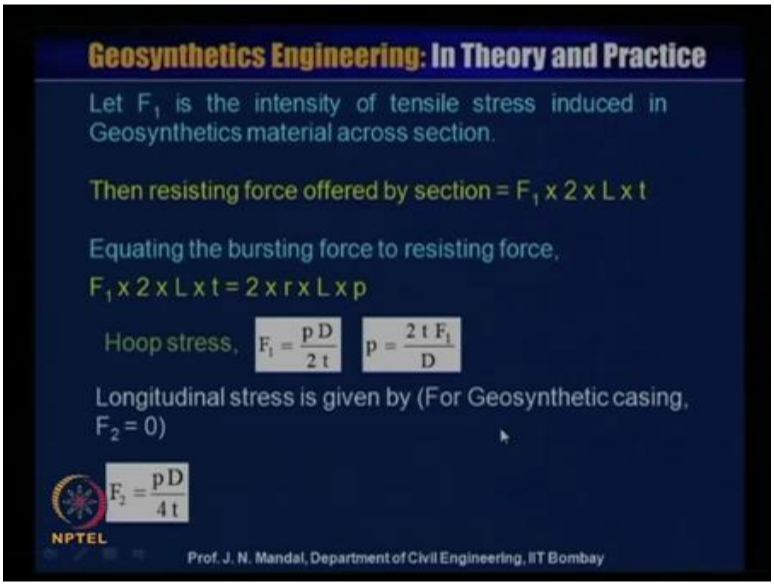

Let F1 is the intensity of tensile stress, induced in geosynthetics material across section. The resisting force offered by the section is equal to, F1 into 2 into L into t equating the bursting force to resisting force. That means F1 into 2 into L into t will be equal to 2 into r into L into p so Hoop stress that is F1 will be p D by 2 t or p is equal to 2 into t into F1 divided by D. Now, longitudinal stress is given by for geosynthetic casing F2 is equal to 0 so F2 will be equal to p into D divided by 4 of t.

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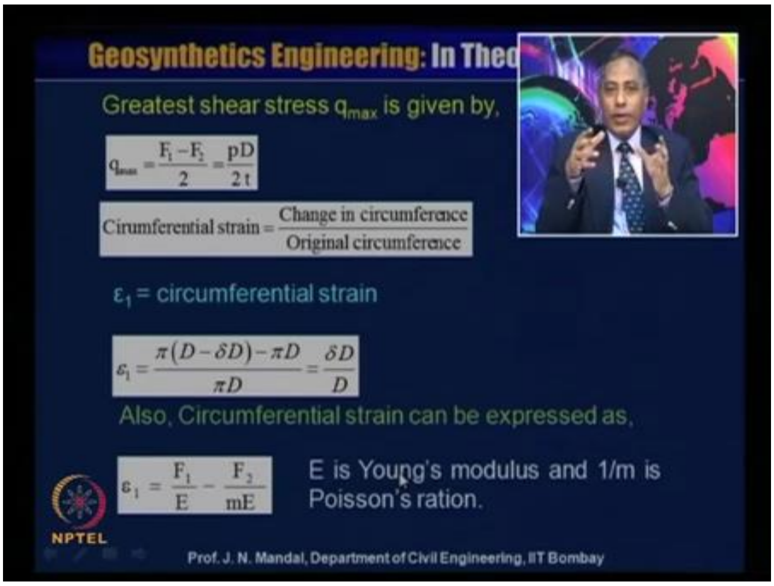

Now greatest shear stress, q maximum is given by q maximum is equal to, F1 minus F2 by 2, that means equal to p into D divided by 2 t. Now, you know what is circumferential strain? That is the ratio of change in circumference to original circumferences where, epsilon 1 is circumferential strain. So, epsilon 1 can be written pi into D minus delta into D minus, pi D that is change in the circumference this divided by original circumference is pi D. So, this will give delta D by D also circumferential strain can be expressed as, epsilon 1 is equal to F1 by E minus F2 by m into E, where E is the young modulus and L by this m is the Poisson's ratio.

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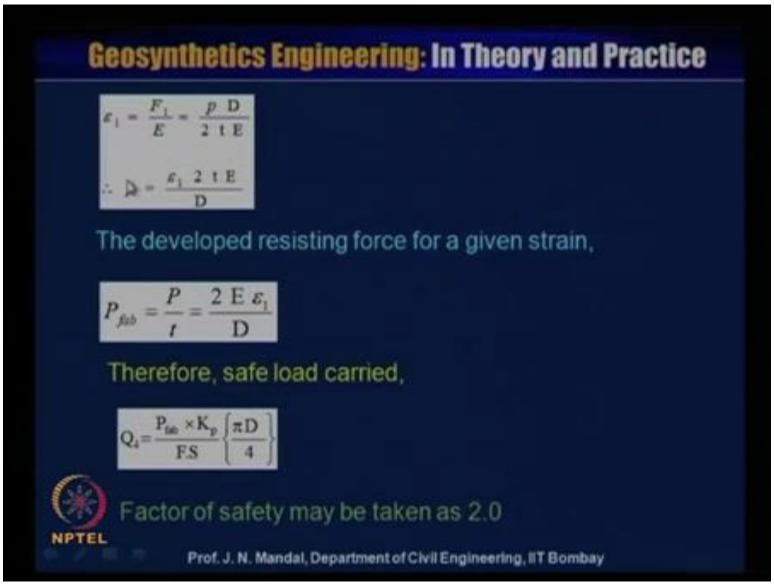

So, epsilon 1 is equal to F1 by E is equal to p by 2 into D divided by t into E where, p will be equal to epsilon into 2 into t into E divided by D. So, the developed resisting force for a given strain so p of fabric is equal to p by t that means p 2 into E into epsilon 1 by D. Therefore, safe load carried Q4 will be equal to P fab into K p divided by FS into pi D by 4 where, factor of safety may be taken as 2.

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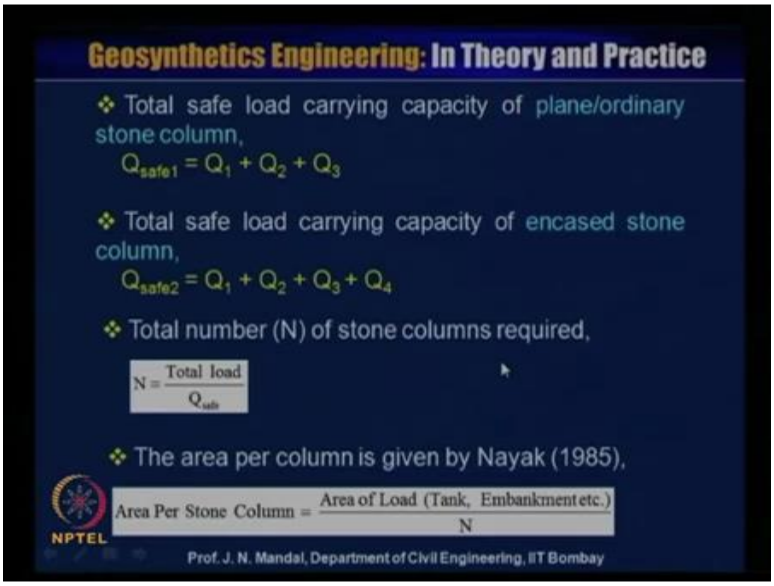

So, what is the total safe load carrying capacity of plane and ordinary stone column that is Q safe will be equal to Q1 plus Q2 plus Q3. Now, total safe load carrying capacity of encased stone column that means when, you are using this geosynthetic material so Q safe 2 will be equal to Q1 plus Q2 plus Q3 plus Q4. So, you know that how you have to calculate that Q1, how to calculate Q2, how to calculate Q3. And then also you know how to calculate the load carrying capacity for the geosynthetics material that is q of 4. So, q safe 2 will be equal to Q1 plus Q2 plus Q3 plus Q4 so total number N of stone column required, N will be equal to total load divided by q safe. So, area per column is given by Nayak 1985, that area per stone column is equal to area of the load divided by N. So, area of the load it may be the tank or embankment, etcetera; that divided by N.

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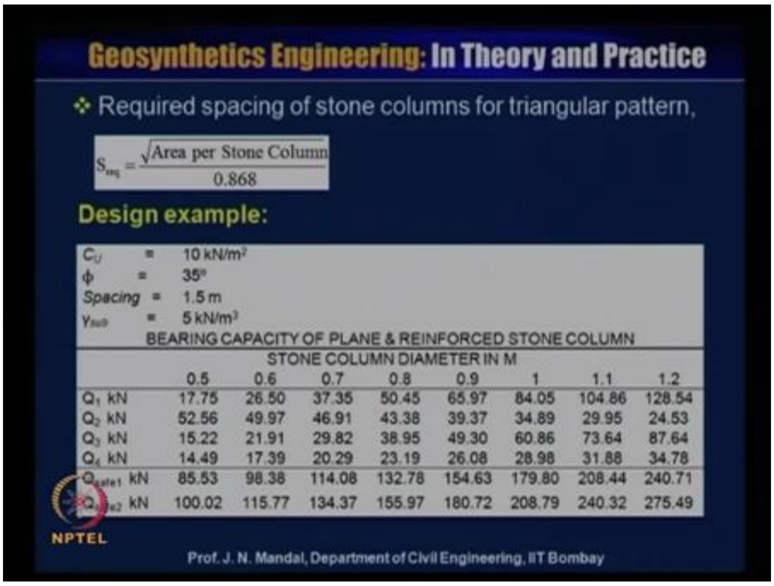

	STONE COLUMN DIAMETER IN M							
	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2
Q_1 kN	17.75	26.50	37.35	50.45	65.97	84.05	104.86	128.54
Q_2 kN	52.56	49.97	46.91	43.38	39.37	34.89	29.95	24.53
Q_3 kN	15.22	21.91	29.82	38.95	49.30	60.86	73.64	87.64
Q_4 kN	14.49	17.39	20.29	23.19	26.08	28.98	31.88	34.78
Q_{safe1} kN	85.53	98.38	114.08	132.78	154.63	179.80	208.44	240.71
Q_{safe2} kN	100.02	115.77	134.37	155.97	180.72	208.79	240.32	275.49

So, required spacing of the stone column for triangular pattern, that is S required will be equal to, root of area per stone column divided by 0868. We have made a several design chart for the encased stone column, only in this course one of the design chart is given here. So, here Cu value considering 10 kilo Newton per meter square, phi value 35 degree spacing 1.5 meter gamma surcharge 5 kilo Newton per meter cube and then bearing capacity of the plane and the reinforced stone column is given.

This is the stone column diameter, it may be 0.5, 0.6, 0.7, 0.8, 0.9, 1, 1.1 and 1.2 meter and this you know that Q1, Q2, Q3 and Q4. So, you can see that for a particular, the stone diameter let us say that when the diameter is 1.2. So, Q1 you are having that bearing capacity 128.54 for Q1, Q2 24.53 and Q3 is 87.64 kilo Newton and Q4 that is due to the geosynthetics material the 34.78. So, total q safe 1 is 240.71 and q safe 2 this is for this geosynthetics material it is coming for 275.49.

So, you can have some idea of that what will be the, how you can increase the load carrying capacity of the encased stone column. So, if you introduce that geogrid or geotextile, which is may be made of the polyester or the bamboo geogrid then the load carrying capacity can be increased. And there are many, many design chart for the different value of Cu phi at different spacing and here as I mentioned that, only one chart has been given. So, you have some idea that how you have to calculate, that load bearing capacity in a encased stone column and what are the, theory also have been adopted, what are the structure theory, how it can be incorporate at a analogue in the geotechnical engineering.

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So, from the encasement, different types of the encasement can be prepared using geosynthetic reinforcement. Bamboo is easily available and cheaper in India, with respect to polyester geogrid and also environmental friendly. Natural bamboo geogrid encasement, can be prepared to encapsulated the stone column. Narrow bamboo stick of 10 millimeter width with proper finishing, were collected to prepare the bamboo encasement. This is given by Dutta and Mandal 2012.

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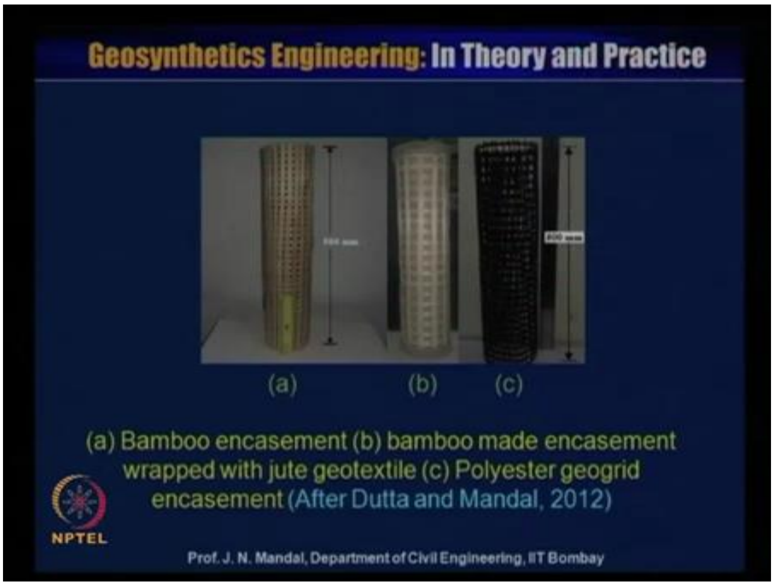

And plenty of the bamboos are also available and here, you can see that some of the bamboo encasement, which is made of the encasement wrapped with the jute geotextile material. Also you have made with the, geogrid with the polyester geogrid encasement material so this is one of the bamboo that, they are geogrid.

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This is the, this is the geotextile material and this is the bamboo. So, you can make a bamboo encasement that is wrapped with the jute geotextile material and number of the test also has been, also carried out on this, with this material. And because this is one of the bamboo material, which is plenty is available and also its growth is very, very fast.

So, you can say that environmental safety, in terms of environmental safety this is no problem, because this is one of the, that plant which grows fast, very fast in the world with respect to any other plant. So, growth wise, production wise there is no problem and it is also the ecofriendly. So, one can make use of the bamboo as a geogrid material and we will observe here that, what are the properties of the bamboo, how you can introduce a bamboo as a geogrid bamboo, also as a form of the mat form.

So, we have also number of tests also have been carried out, using this in the form of the mat so you can use as a mat form. So, it can be come indeed, it can be, it can be come and contact with the soil and it is very good tensile strength material. So, lot of research work have also been carried out in IIT Bombay, using the bamboo material in different shape and the size including the plastic waste plastic material.

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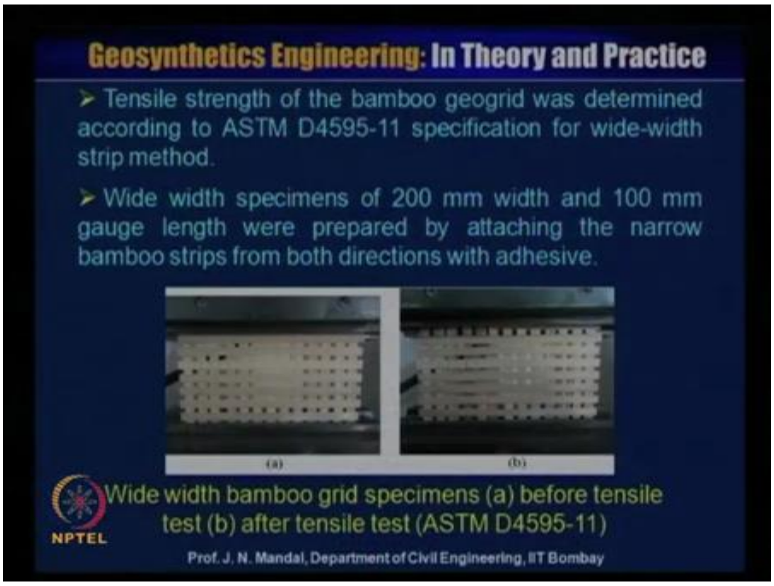

Now, we will study that some tensile strength of the bamboo geogrid was determined according to the ASTM D4595-11 specification for wide width strip method. Because wide width specimens of 200 millimeter, this is the width, the width is 200 millimeter and 100 millimeter is the gauge length, were prepared. By attaching the narrow bamboo strip from both direction with adhesive. Now, this is the test have been performed, this is what is the bamboo geogrid specimen, this is the before the tensile stress and this is the after tensile stress. You can see that, what is the behavior of the bamboo grid, bamboo geogrid before and the after and how it also fail.

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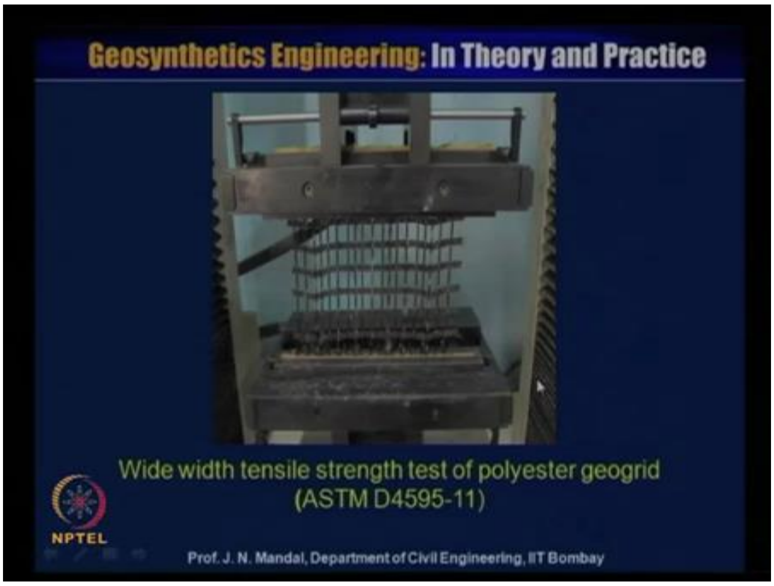

So, because we are also equally comparing with the polyester geogrid, this is wide width tensile strength of the polyester geogrid, with the same specification.

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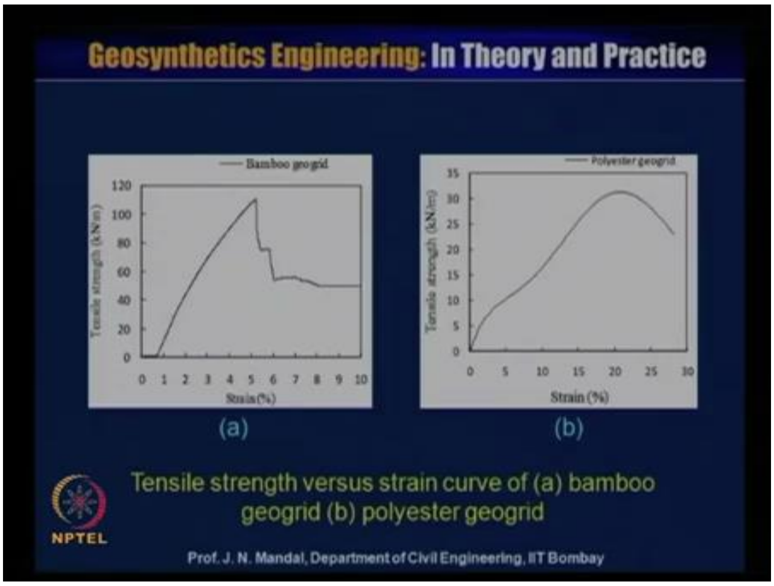

And you can see some, also the result that tensile strength versus the strain curve, for a is the bamboo geogrid and this is the polyester geogrid. So, there is a substantial improvement of the tensile strength of the bamboo geogrid, you can see it gives about the 100 kilo newton per meter. And in case of the polyester geogrid, it is about 30 kilo newton per meter, but you cannot compare with this geogrid with the bamboo grid, at this present stage. Because the configuration size and shape is the different, but overall you can have some idea that, there is an improvement of the tensile strength of the bamboo grid.

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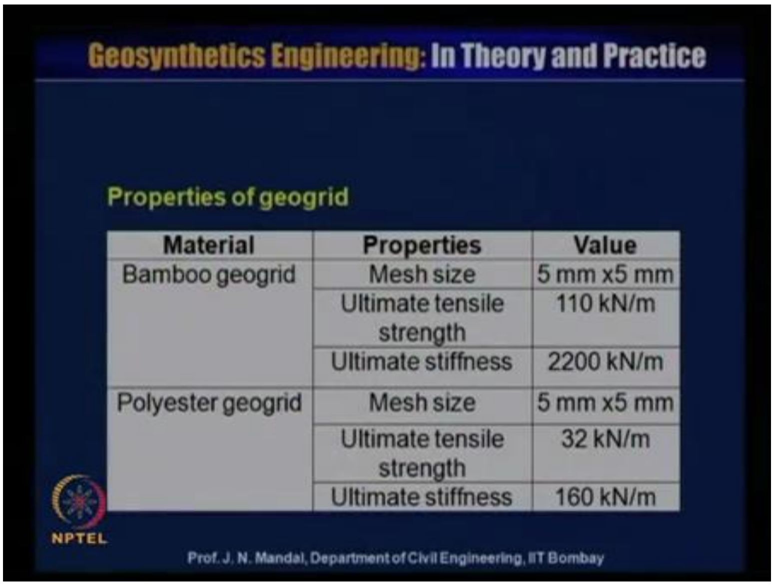

So, properties of the geogrid here shown that bamboo geogrid that mesh size is 5 millimeter into 5 millimeter, ultimate tensile strength is 110 kilo Newton per meter and ultimate stiffness is 2200 kilo Newton per meter. Polyester geogrid the mesh size is 5 millimeter into 5 millimeter and ultimate tensile strength is 32 kilo Newton per meter and ultimate stiffness is 160 kilo Newton per meter.

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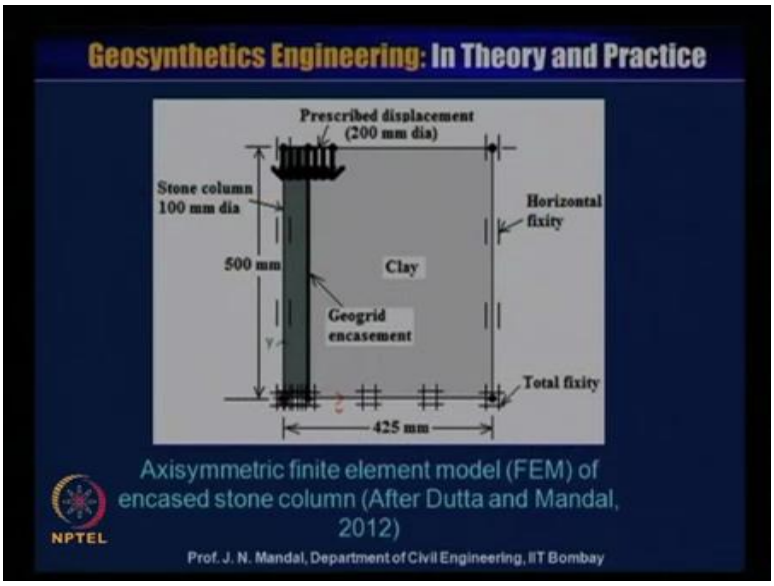

Now, this is the axi-symmetric finite element model of encased stone column after Dutta Mandal, 2012. So, this is the stone column it is about 100 millimeter in diameter and the length of the stone column about 500 millimeter, this is geogrid as an encasement. And this is prescribed as a displacement that is 200 millimeter of diameter, this is the horizontal fixity and this is the total fixity and this is about 425 millimeter and this on the clay soil sample.

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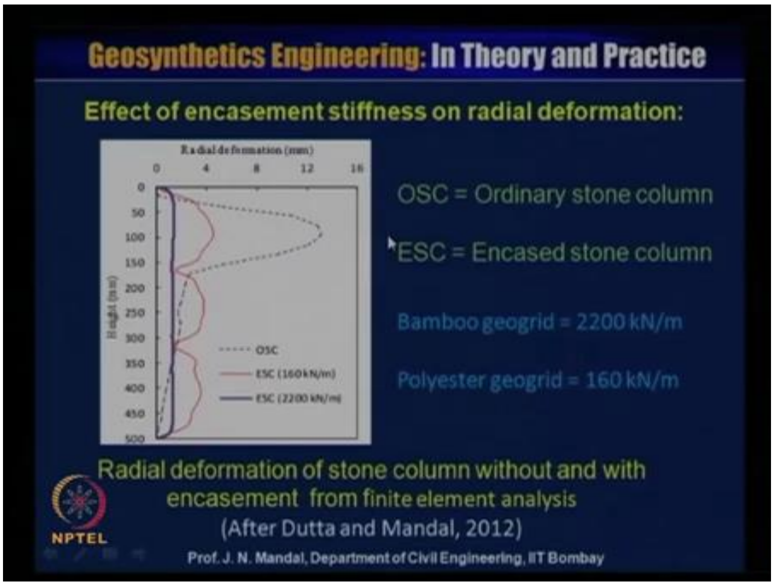

Now let us see that, what is happening effect of the encasement stiffness on radial deformation. So, this is the radial deformation with respect to height so you have used ordinary stone column this is dot is the ordinary stone column and ESC is the encased stone column, which is 160 kilo Newton per meter and also the encased stone column is 2200 kilo Newton per meter. So, here you have used the bamboo geogrid stiffness is 2200 kilo Newton per meter, polyester geogrid 160 kilo Newton per meter.

So, what is the radial deformation of stone column without and with the encasement from the finite element method. You can see that here, that in case of the ordinary stone column, you can see the deformation is much higher with respect to the encased stone column. So, this encased stone column also depend upon that, what will be the tensile strength of the encasement or material or reinforcement material. You can see that, how this is substantially, its deformation is decreasing with the height for the inclusion of the reinforcement. And then depend upon the, what will be the modulus of the elasticity of the material, what will be the tensile strength of the material.

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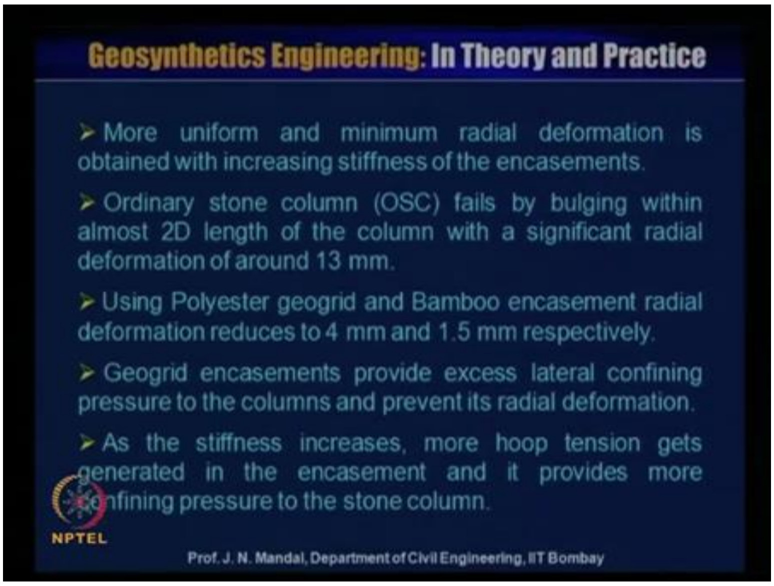

So, more uniform and minimum radial deformation is obtained, with increasing the stiffness of the encasement. Ordinary stone column OSC, fail by bulging within almost 2D length of the column, with a significant radial deformation of around 13 millimeter. Whereas, using polyester geogrid and bamboo encasement radial deformation reduces to 4 millimeter and 1.5 millimeter respectively.

So, you can see that compared to the ordinary stone column where, deformation is 13 millimeter, but in case of the polyester geogrid is 4 millimeter, in case of the bamboo geogrid it is 1.5 millimeter only. So, you can observe that, how the radial deformation is drastically reduced for the inclusion of the polyester or bamboo as a geogrid reinforcement material. Of course, it is depend upon what should be the stiffness of the material.

Now geogrid encasement provide, excess lateral confining pressure to the column and prevent, its radial deformation. As the stiffness increases more hoop tension gets generated in the encasement and it provides more confining pressure to the stone column. So, here so far we have studied it that, in case of the encased, that stone column how you can design and what are the design step has been taken into consideration. And how the structural plate thin stage theory, has be analogue with this encased stone column problem.

And also that natural material like a bamboo geogrid material, how it can be incorporated and we find that, how it is that stiffness also has increased. And the deformation or radial deformation has been reduced, with respect to the ordinary stone. So, there is a potential use of the bamboo geogrid as reinforcement in India and some other parts of the world. So, with this I finished my lecture today. Let us hear from you, any questions?

Thanks for listening.