Geosynthetics Engineering: In Theory and Practices
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Lecture - 48
Geosynthetics for Ground Improvement

Dear student, 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. Now, this module 9 lecture 42 Geosynthetics for ground improvement.

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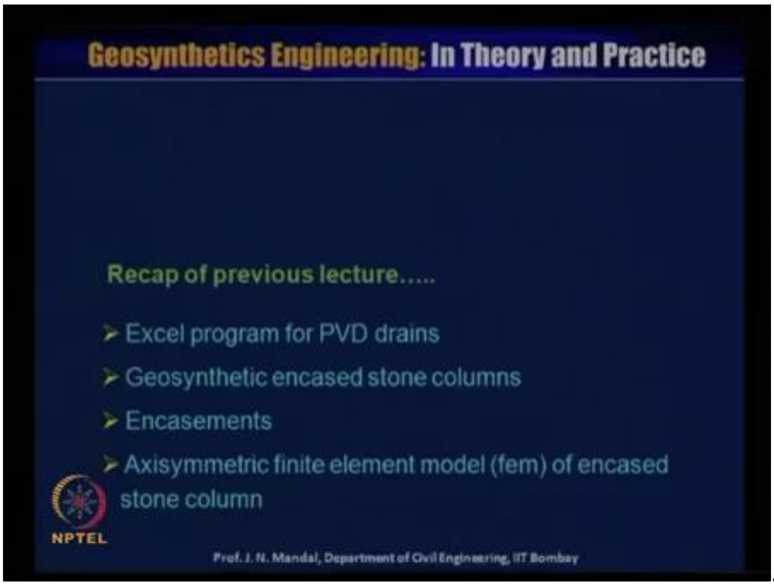

I will now address recap of previous lecture is Excel program for prefabricated vertical drain, geosynthetics encased stone columns, encasements, and Axisymmetric finite element model F E M of encased stone column.

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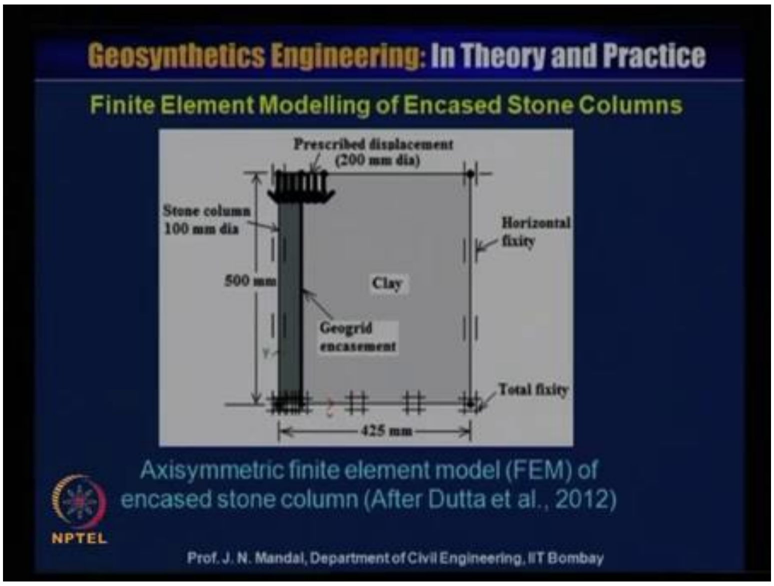

Now, here one axisymmetric finite element model of the encased stone column. This is the encased stone column, this is height of the stone column is about 500 millimeter and diameter of the stone column is 100 millimeter. Here, prescribed this displacement because this total diameter will be equal to 200 millimeter and the surrounding of this stone column is the clay and this is the geogrid encasement, this is axisymmetric case and here is the horizontal fixity and this is total fixity and this is around 425 millimeter. So, we want to check the behavior of the encased stone column by finite element method this is after Dutta et al 2012.

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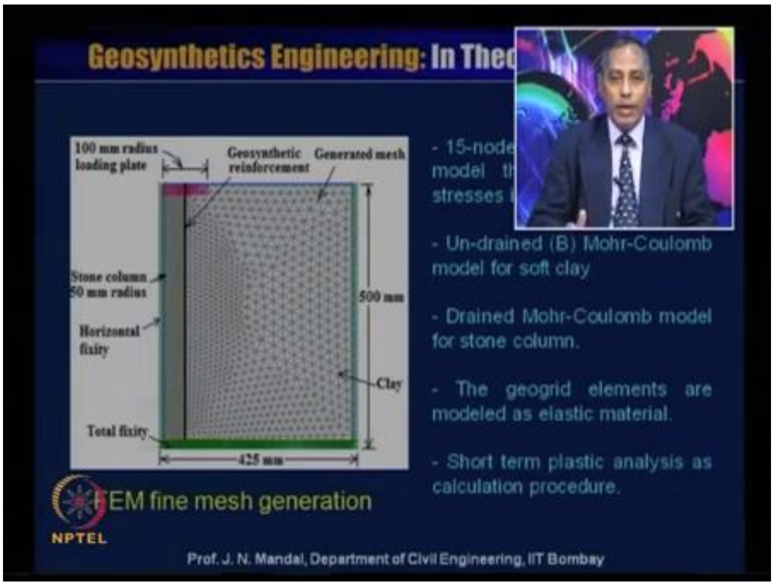

Now, this is the finite element mesh generation this is the reinforcement, this is the generated mesh and here is the stone column is 50 millimeter radius and this is the horizontal fixity, this is 100 millimeter radius loading plate and this is the clay. So, this is how the finite element method fine mesh generated, this is 15 node triangular element to model the deformation and stresses in the soil then undrained b Mohr Coulomb model for the soft clay. This is from flat sheets has been taken drained Mohr Coulomb model for the stone column, and the geogrid element are modeled as a elastic material short term plastic analysis as calculation procedure.

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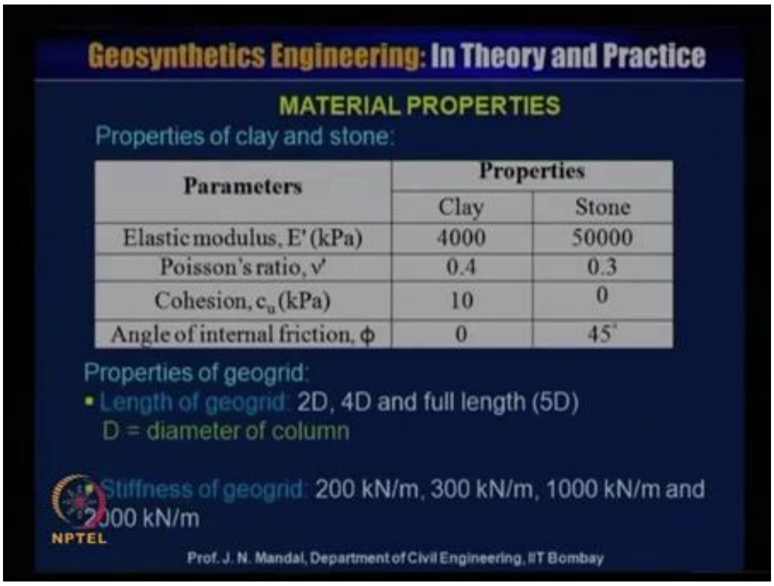

So, in this model we have introduced these properties of the clay stone and as well as the properties of the geogrid material. Now, here for the properties and the clay and stone, the parameter is elastic modulus e dash in kilopascal, clay is 4000 and stone is 5000. Poisson's ratio nu dash is clay is 0.4 stone 0.3 cohesion C u in kilopascal for clay it is 10 and for stone zero angle of internal friction phi is clay for 0 degree and for stone is 45 degree.

Now, also we include the properties of the geogrid, the length of the geogrid is varying from 2 D 4 D and the 5 D. So, maximum length of the geogrid is taken 5 D where d is the diameter of the column. So, we have checked the different height of the column with respect to the diameter of the column and we wanted to see that behavior of the encased stone column. Now, stiffness of the geogrid is 200 kilo Newton per meter 300 kilo Newton per meter 1000 kilo Newton per meter and 2000 kilo Newton per meter.

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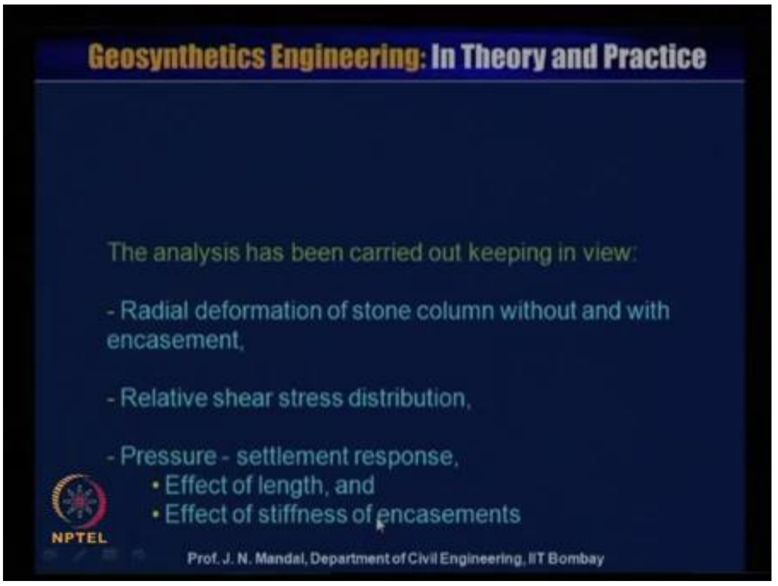

Now, this analysis has been carried out keeping in view that radial deformation of stone column without and with encasement relative shear stress distribution and pressure. The settlement response means in terms of effect of length and effect of stiffness of encasement.

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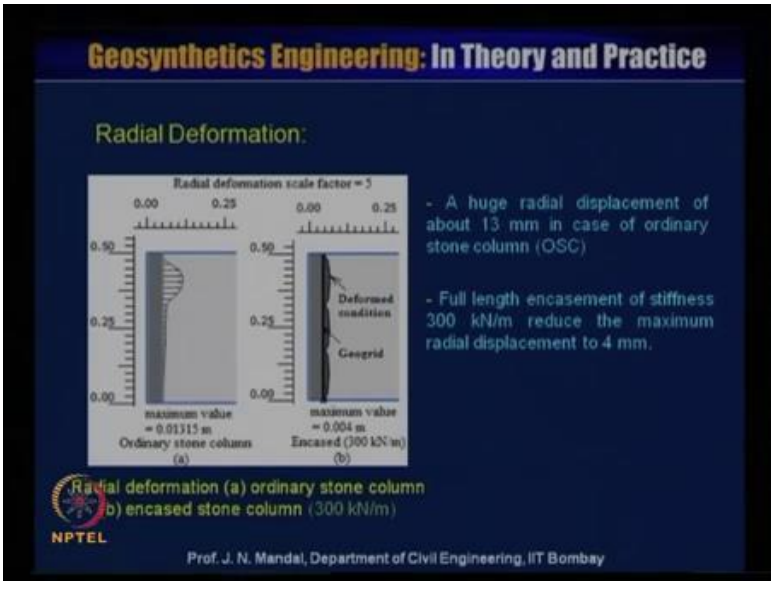

Now, we find that what will be the radial deformation, one if it is a ordinary stone column and this b when in the encased stone column and under 300 kilo Newton per meter. So, here that radial deformation scale factor is 5 and maximum that value is equal to 0.01315 meter for the ordinary stone column keeping in radial deformation scale factor is equal to 5. Now, this is for you can see the how the radial deform of the stone column when there is no geogrid reinforcement and this maximum value is 0.01315 meter. Now, when you introduce this geogrid material, so geogrid here will act as a encasement and this also due to application of the load it also deform.

So, this is the deformed condition for the encased stone column whose stiffness value is equal to 300 kilo Newton per meter and that maximum value is 0.004 meter with the encased is 300 kilo Newton per meter. So, what we observed from this analysis a huge radial displacement of about 13 millimeter in case of the ordinary stone column or O S C. Now, full length encasement of stiffness 300 kilo Newton per meter reduces the maximum radial displacement to 4 millimeter only. So, you can see that there is a substantial reduction in the radial deformation with respect to the ordinary stone column, so it means there is an effect of the encased stone column.

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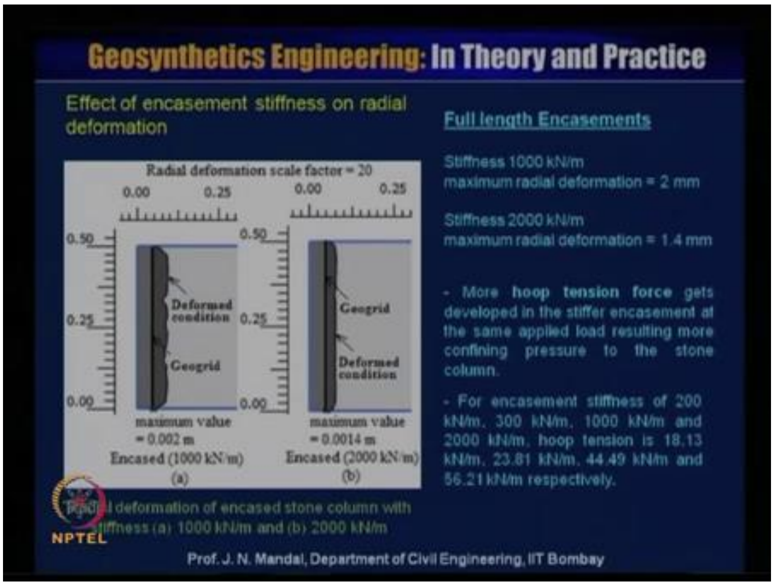

Now, effect of encasement stiffness on radial deformation, so here this figure show that radial deformation of encased stone column with the stiffness 1000 kilo Newton per meter this a and for b this stiffness is 2000 kilo Newton per meter. You can see here that what should be radial deformation when the stiffness is 1000 kilo Newton per meter and here radial deformation scale factor is equal to 20. So, when the stiffness is 1000 kilo Newton per meter then your maximum value is equal to 0.002 meter that is what we call the radial deformation. In case of when the geogrid reinforcement stiffness is 2000 kilo Newton per meter and radial deformation maximum value is 0.0014 meter.

So, it means that increasing the stiffness of the reinforcement there is a drastically reduction also of radial deformation. So, it means there is an effect of encasement stiffness on radial deformation. Now, full length encasement means stiffness when 1000 kilo Newton per meter maximum radial deformation is equal to 2 millimeter when stiffness is 2000 kilo Newton per meter maximum radial deformation is equal to 1.4 millimeter. So, what is happening, more hoop tension forces get developed in the stiffer encasement of the sane applied load resulting more confining pressure to the stone column.

So, for the encasement stiffness of 200 kilo Newton per meter or 300 kilo Newton per meter, 1000 kilo Newton per meter and 2000 kilo Newton per meter then hoop tension is 18.13 kilo Newton per meter, 23.81 kilo Newton per meter, 44.49 kilo Newton per meter and 56.21 kilo Newton per meter respectively. It means that when the stiffness of the encasement material is increasing and hoop tension also is increasing. So, that means that hoop tension play a very important role in case of encased stone column, now what is happening the relative shear stress distribution.

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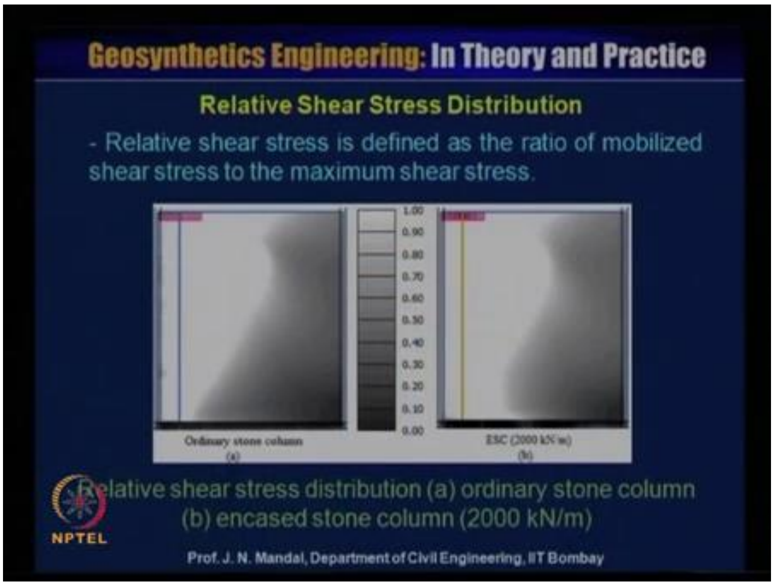

So, this figure shows the relative shear stress distribution a when it is an ordinary stone column and b when it is the encased stone column with stiffness 2000 kilo Newton per meter. So, you can see that there is a relative shear stress is can be defined either ratio of mobilized shear stress to the maximum shear stress. So, in this case of the ordinary stone column you can see that relative shear stress will be more, but in case of the encased stone column, this relative shear stress is reduced. So, it can be more observed when it will be in the color, but you can observe here the pattern of the relative shear stress distribution without and with the encased stone column.

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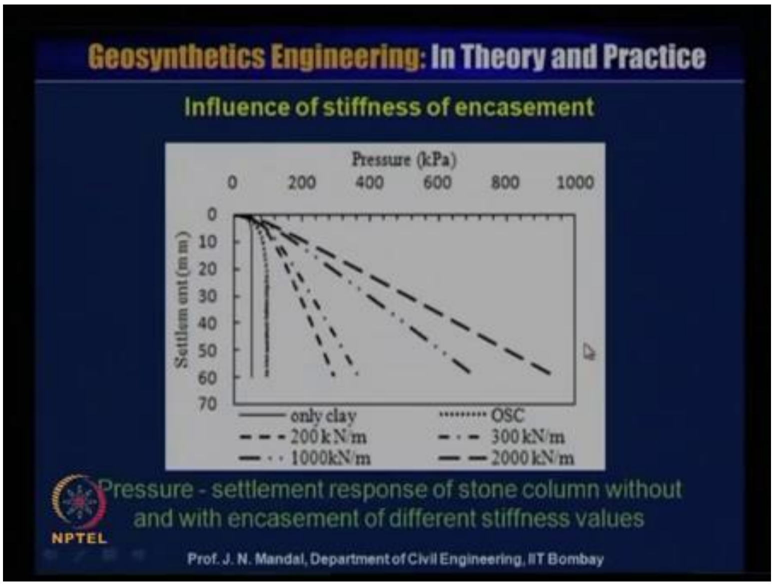

Now, what is the influence of stiffness of encasement, now here shows the pressure settlement, response of stone column without and with the encasement of different stiffness value. So, we have considered it is only clay, you can see the pressure versus settlement curve or only clay when it is the O S C. You can see the nature of the curve this is the curve between the pressure versus settlement. Now, we have provided the different stiffness value that is 200 kilo Newton per meter, 300 kilo Newton per meter, 1000 kilo Newton per meter and 2000 kilo Newton per meter.

So, stiffness is increasing, also pressure is also increasing and if we look that at a particular settlement, for example if the particular settlement is 25 millimeter. So, you can see that in case of only clay this value is very less, but whereas if you keep on increasing this stiffness, then the pressure also is increasing for example, if 2000 kilo Newton per meter for a particular 25 millimeter settlement. So, you can achieve the pressure in about 400 kilo Newton per meter. So, there is a substantial improvement of the pressure for a particular settlement it means that there is an influence of the stiffness of the encasement in case of the stone column.

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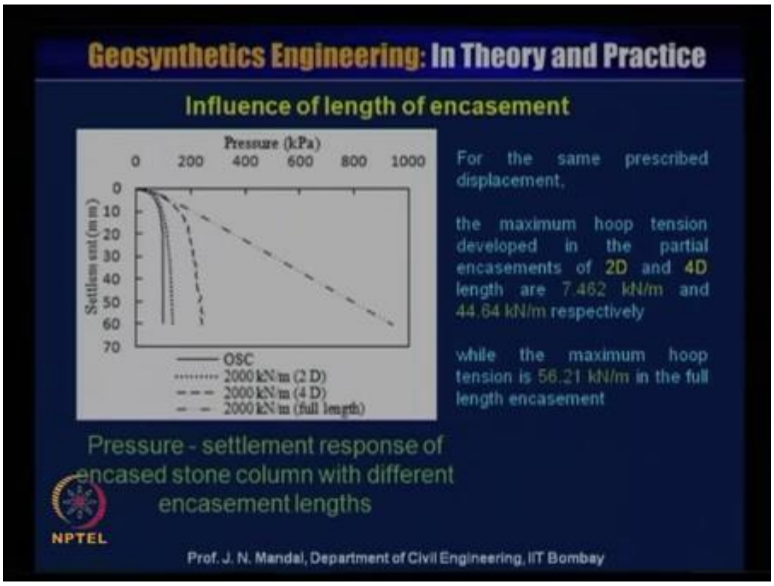

Now, what are the influences of the length of the encasement, now here show that pressure settlement response of encased stone column with different encasement length. So, this means that we know that what will be the diameter of the stone column, so length will be, we have taken 2 D length we have taken 4 D length and we have taken 5

D length. So, when you are taking the 2 D length, so what will be the nature of the curve between pressure and the settlement? You can see that pressure and settlement curve and this is the only that O S C here. Now, you are changing the length, but keeping the stiffness constant.

So, when it is 2 D, that means 2 times the diameter of the stone column and stiffness is 2000 kilo Newton per meter. You can have the pressure settlement curve like this, now when it is 4 D, that means length of the stone column is increasing 4 D that means you can see that nature of the curve that pressure is increasing with settlement. When it is a full length that means 5 D, but stiffness keeping constant that 1000 kilo Newton per meter you can see there is a substantial improvement in the pressure. Similarly, you can see that for a particular settlement when it is the only clay or only O S C or with the different length of the encasement, then there is a substantial improvement in the pressure for a particular settlement.

So, it means that there is an influence of the length of the encased stone column, so you have observed earlier that what the influence of the stiffness of the material is. Also you have observed that if stiffness keeping constant and if I wanted to vary the length of the encased stone column then how it affect how the influence occur in the improvement in pressure? Now, for the same prescribed displacement, the maximum hoop tension developed in the partial encasement of 2 D and the 4 D length are 7.462 kilo Newton per meter and 44.6 four kilo Newton per meter respectively while the maximum hoop tension is 56.21 kilo Newton per meter in the full length of the encasement. So, here also you can see that when you are changing the length of the encasement that hoop tension also how is varies, that means hoop tension also are increasing substantially, with the increase of the length of the encased stone column.

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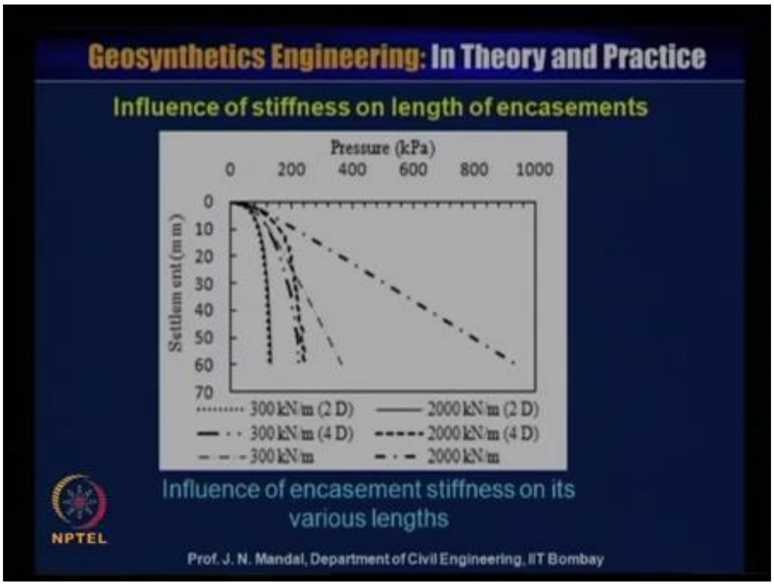

Now, here shows that pressure versus settlement what will be the influence of the encasement stiffness, one is various length. So, here we have considered the stiffness 300 kilo Newton per meter when the length is 2 D when the 300 kilo Newton per meter, but when the length is 4 D and also that 300 kilo Newton per meter, when here the length is 5 D. Similarly, if we check the stiffness 2000 kilo Newton per meter for 2 D length and 2000 kilo Newton per meter for 4 D length and 2000 kilo Newton per meter for 5 D length.

So, that means influence of the stiffness on length of the encasement, so here you can observe again that you are having the almost the similar nature of the curve, but there is an effect of the stiffness of the length of the encasement. So, that that means that stiffness is also increasing with increasing the length of the geogrid material. 2000 kilo Newton per meter gives substantially more than with respect to the 300 kilo Newton per meter stiffness value of the geogrid material.

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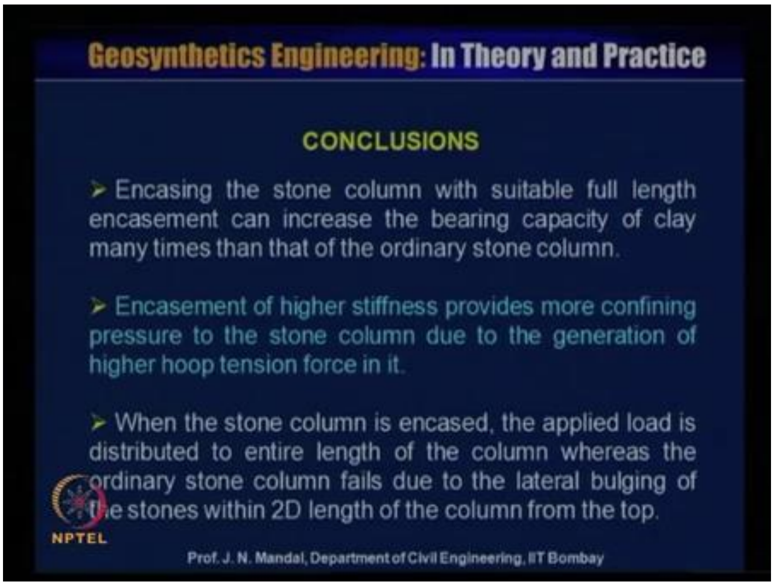

So, we come to conclusion that encasing the stone column with suitable full length encasement can increase the bearing capacity of clay many times than that of the ordinary stone column. Encasement of higher stiffness provide more confining pressure to the stone column due to the generation of high hoop tension force in it, when the stone column is encased the applied load is distributed to entire length of the column whereas, the ordinary stone column fail due to the lateral bulging of the stone within 2 D length of the column from the top. So, you can prevent the bulging by the inclusion of the geogrid material as an encasement.

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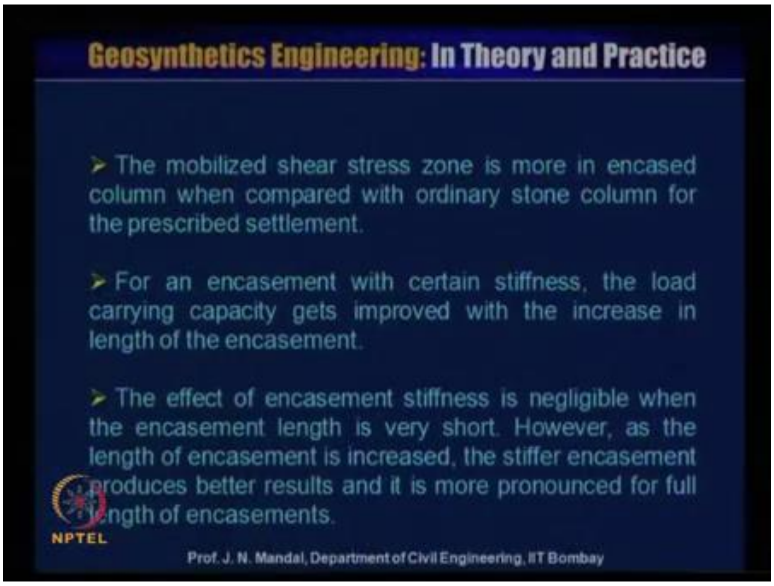

The mobilized shear stress zone is more in encased column when compared with ordinary stone column for the prescribed settlement. For an encasement with certain stiffness the load carrying capacity gets improved with the increase on length of the encasement. The effect of encasement stiffness is negligible when the encasement length is very short. However, as the length of encasement is increased the stiffer encasement produces better result and it is more pronounced for full length of encasements.

So, we have the idea about that what is happening in case of the encased stone column and what should be the stress distribution for only the clay and when you are introducing this geogrid as a encased stone column. How it is changing depends also on the stiffness of the material, also it depends on the length of the encased stone column, and also it depends on the hoop stress hoop tension. So, what is the role of the hoop tension and how it is varying over all we find that encased stone column is very suitable. And it is substantially provide this improvement in the strength of the foundation soil.

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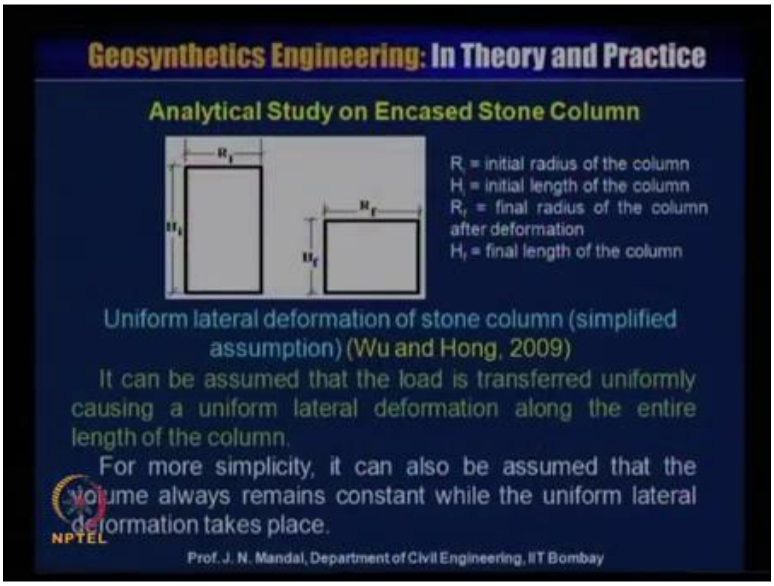

So, now we will analytical study of encased stone column, so here R of i is the initial radius of the column and H of i is the initial length of the column, and here the R f is final radius of the column after deformation and H f is the final length of the column. So, uniform lateral deformation of stone column is simplified assumption Wu and Hong 2009. It can be assumed that load is transferred uniformly causing a uniform lateral deformation along the entire length of the column for more simplicity, it can also be assumed that the volume always remain constant while the uniform lateral deformation take place.

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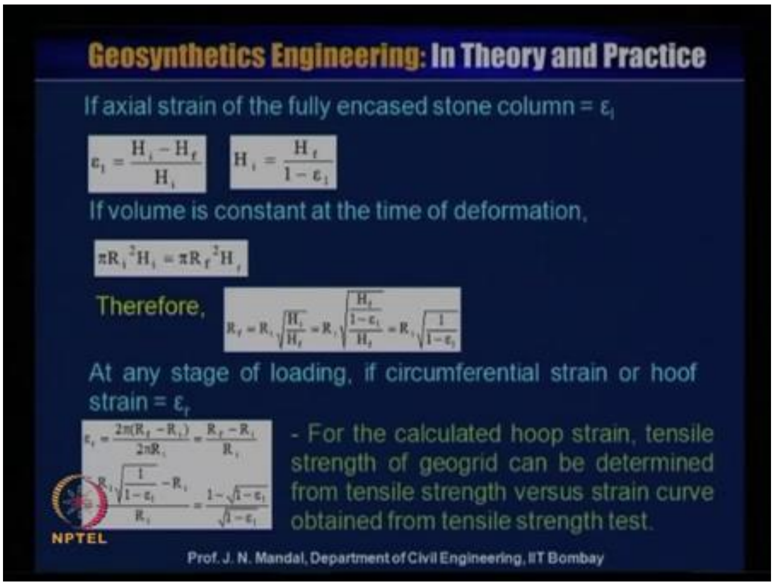

So, we can also consider that if axial strain of full encased stone column is epsilon 1. So, epsilon 1 is equal to H of i minus H f divided by H of i that means H of i will be equal to H f divided by 1 minus epsilon 1. As I said that volume is constant at the time of deformation, so we can write pi into i R i square into H i is equal to pi into R f square into H f. Therefore, we can write that R of f is equal to R i root over H i by H f that means is equal to R i into H f by 1 minus epsilon 1 by H f that is equal to R i into root of 1 upon 1 minus epsilon 1. Now, at any stage of loading if the circumferential strain of or the hoop strain this that is the epsilon r.

So, epsilon r can be written two pi R f minus R i divided by two pi R i that means this is equal to R f minus R i divided by R i again is equal to R i and this root of 1 upon 1 minus epsilon 1 because this R i is equal to R i into one upon 1 minus epsilon 1. So, you can substitute it here minus R of i divided by R i. So, this will be equal to 1 minus root of 1 minus epsilon 1 divided by root of 1 minus epsilon 1. So, we can calculate what will be the circumferential strain or the hoop strain that epsilon R using this equation.

So, for the calculated the hoop train tensile strength of geogrid can be determined from the tensile strength versus strain curve obtained from the tensile strength test. So, you can perform that what will be the tensile strength of the geogrid material, so if you know that what will be the strain value. So, from the stress strain curve of the geogrid sample, so knowing the value of strain you can calculate what will be the tensile strength of the required geogrid sample.

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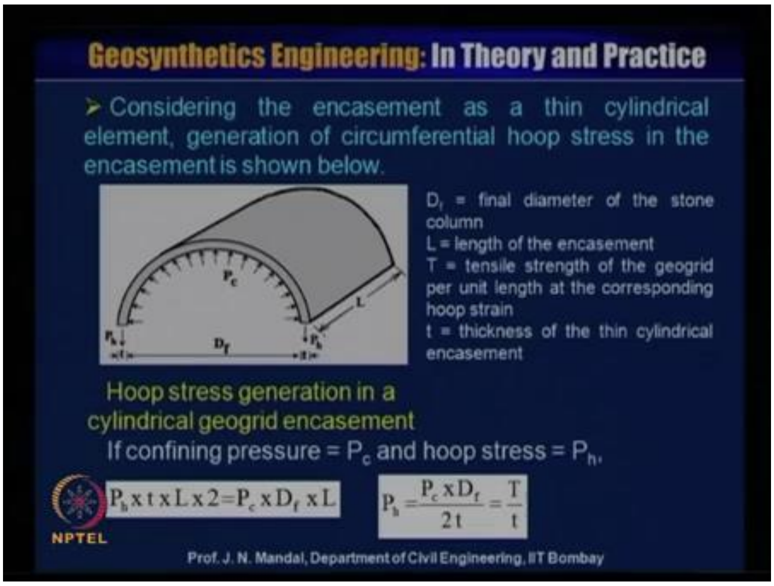

Now, considering the encasement as a thin cylindrical element generation of circumferential hoop stress in the encasement as it is shown here, it is a cylindrical element. And it is a thin very thin where D of f this D of f is the final diameter of the stone column and this is the L is the length of the encasement. Let us say that T is equal to tensile strength of the geogrid per unit length at the corresponding hoop strain, and here is the t is the thickness of the thin cylinder encasement thin cylinder encasement.

So, hoop stress generation in a cylindrical geogrid encasement this is the hoop stress P h is the hoop stress, if confining pressure is equal to P of 0 P of c and hoop stress is equal to P of h while it is acting here P h and thickness of the thin cylinder is t. So, we can write this P h into thickness t into length l into 2 will be equal to this is P c that confining pressure P c into this is D of f that final diameter of the stone column P c into D f into L. So, this will be equal to this so this force is downward this is upward so this will be equal to this. So, from this you can calculate what is P of h so P h will be equal to P c into D f divided by 2 into t. So, that is equal to T by t where t is equal to tensile strength of the geogrid per unit length at the corresponding hoop strain and this small t is the thickness. So, also you can calculate what hoop stress value that is also important to us.

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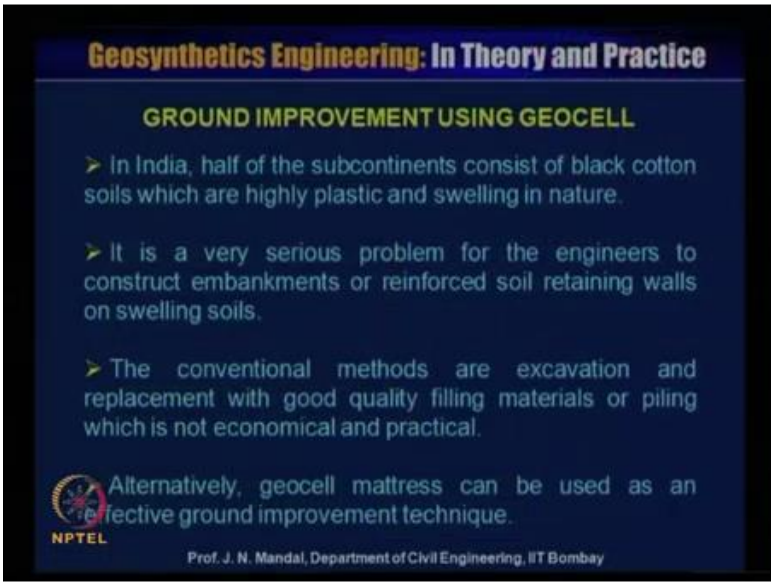

You know that what is the theory between for the geogrid material what strain value you should take into consideration and how you can determine that hoop stress how can determine the tensile strength of the geogrid material. This theory has been analog with a very cylindrical thin plate considering cylindrical plain theory concept, now I will talk about ground improvement using geocell.

Now, we should know that what is also the geocell in India half of the subcontinent consist of black cotton soil, which are highly plastic. And swelling in nature it is a very serious problem for the engineers to construct the embankment, or reinforced soil retaining wall or slope on swelling soil. The conventional method is excavation and replacement with good quality of filling material or the pilling, which is not economical and practical. Alternatively, geocell mattresses can be used as an effective ground improvement technique.

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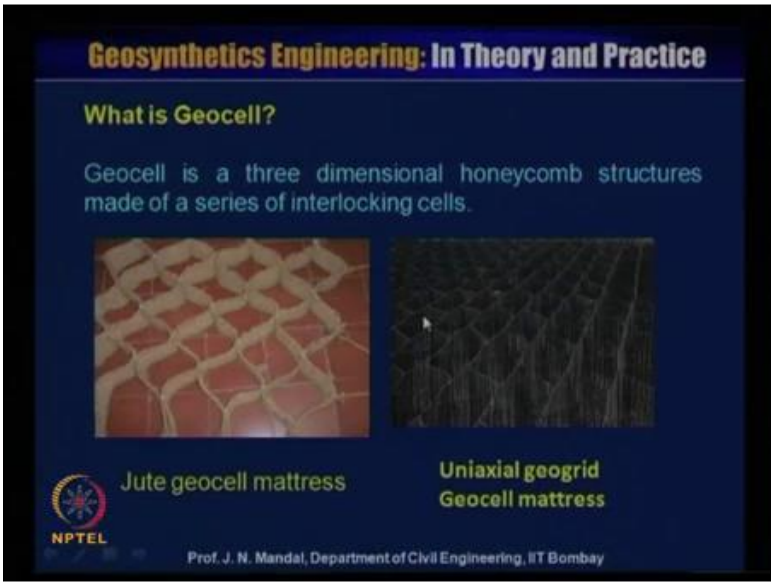

Now, this is what you call geocell, so construction of an embankment over the width for the relatively foundation soil open causes a problem for the design and as well as the contractor. So, what we do that most of the time we excavate and replace with the good quality of the soil material, but this is very costly and not economical even then if you provide for the pilling also it will be too expensive. So, alternatively we can adopt the three dimensional geocell structure. Now, this is the three dimensional honeycomb structure and this is physically confining the soil and improve the granular soil shear strength and increase in the shear strength means, that due to the confinement effect of the geocell.

It can provide very good bearing capacity and this geocell is made of high density polyethylene material strip form it may be that 100 millimeter width. And also the 300 millimeter length, and which can be connected by ultrasonically welded. It can be ultrasonically welded at approximately 300 millimeter inclusive and the job site, it can be collapsed configuration. When you place this geocell material directly on the soft soil and then prophet is opened in an like this kind of the material. This prophet can be opened in an accordion like fashion with an external stress assembly.

Then you can fill up here with a granular material and compacted with a vibratory, or hand operator plate compactor. So, this is one kind of the geocell material and also this material also made of the geogrid. So, you can make a 1 meter height also the geogrid material also geogrid geocell material is like this. Also there is an opening, so when you compact it, it can be properly compacted or any there is excess pore water pressure developed may be dissolved.

So, geocell is nothing but a series of interconnecting the cell and this is a polymer geogrid. So, it increases the bearing capacity on the soft foundation using slip line fill, I will discuss later what is the slip line fill and practical advantage to the contractor. It reduces the overall embankment settlement and reduces the differential settlement over various soft grounds, and it is cost advantage with respect to the traditional method.

You can also construct this geocell as I say with the geogrid, it may be the uniaxial geogrid. You may also make with the jute material this is jute geocell and this is the geocell made from the geogrid. It may be 1 meter height or width may be the 100 millimeter and length wise it may be about the 300 millimeter and geogrid also can be connected with the rod.

So, this material has a lot of advantage with respect to the pilling and all other kind of the system, so we will adopt this material. Also that one of the that important point is to be noted here that when you will use this material for the construction of the embankment on the soft soil. We should know what should be the ratio of the embankment width to the depth of the foundation and embankment, width to the depth of the foundation should be more than 4.

If the embankment width to the depth of the foundation ratio is less than 4 and then that case, there will be the additional resistance over the rigid head will be greater or should be calculated for each step. So, I am showing you that what should be the concept and what theory will be the adopted what is the slip line method and what will be the rigid head, so before that we will discuss some of the geocell.

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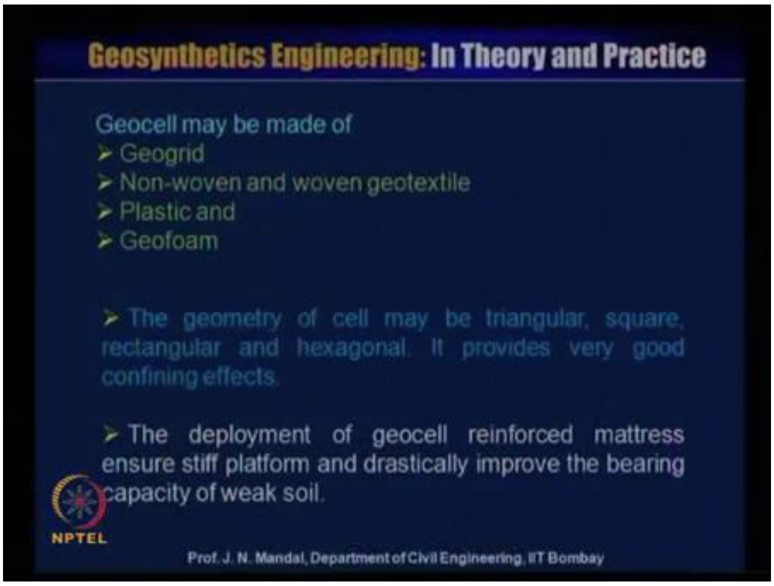

As I said the geocell, it may be made of geogrid, it may be made of nonwoven and woven geotextile. It may be plastic or it may be geofoam material itself which is superlight material. Lot of research work have been carried out with all these related area in this institute the geometry of the cell also may be in triangular, or square or rectangular and the hexagonal and it provide very good confinement effect. The development of the geocell reinforced mattress ensure stiff platform and drastically improve the bearing capacity of weak soil.

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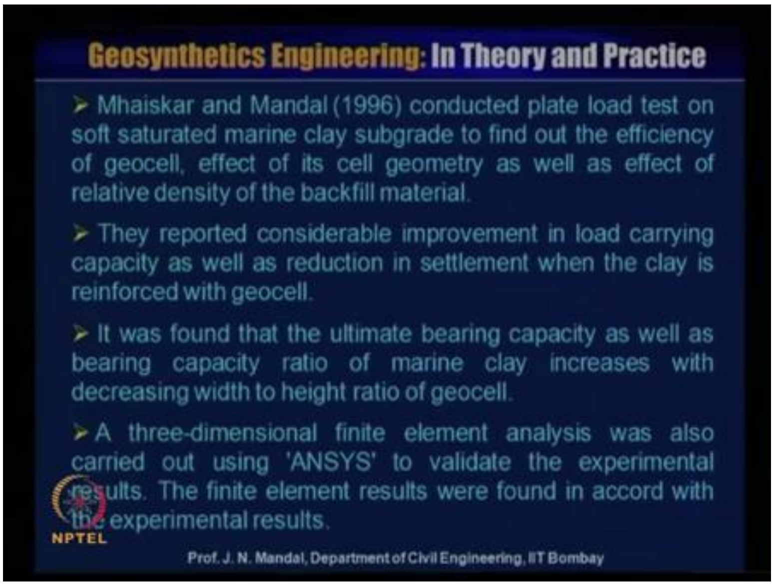

Mhaiskar and Mandal 1996 conducted plate load test on soft saturated marine clay sub grade to find out the efficiency of a geocell effect of its cell geometry, as well as effect of relative density of the backfill material. You have to optimize that what will be the size and shape of the geocell material you can vary the length you can vary the width. Ultimately, you are to develop a new material which is provide the more optimal value and also it has been performed with the different density condition. So, you can find out that what should be the improvement of the bearing capacity and as well as that reduction in the differential or the total settlement.

Now, they reported considerable improvement in load carrying capacity as well as reduction in settlement when the clay is reinforced with geocell. It was found that the ultimate bearing capacity as well as bearing capacity ratio of marine clay increases with decreasing the width to height ratio of geocell. Apart from this, a three dimensional finite element analysis was also carried out using ANSYS to validate the experimental result the finite element result were found in accord with the experimental result.

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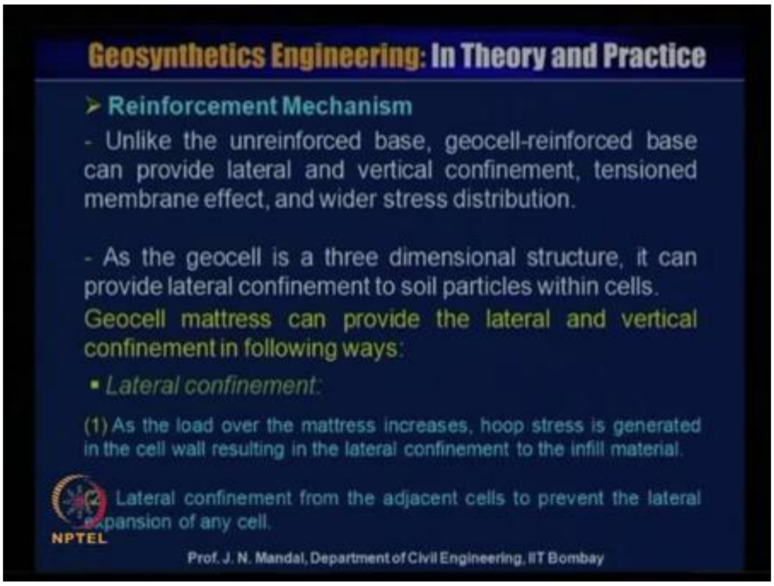

Now, reinforcement mechanism unlike the unreinforced base geocell reinforced base can provide lateral and vertical confinement tensioned membrane effect and wider stress distribution. As the geocell is three dimensional honeycomb structure it can provide lateral confinement to soil particle within the cells. Geocell foundation mattresses can provide the lateral and the vertical confinement in the following ways. Lateral confinement, as the load over the mattresses increases hoop stress is generated in the cell wall and resulting in the lateral confinement to the infill material. Lateral confinement from the adjacent cell to prevent the lateral expansion of any cell. So, you should know what the basic mechanism for the geocell material is…

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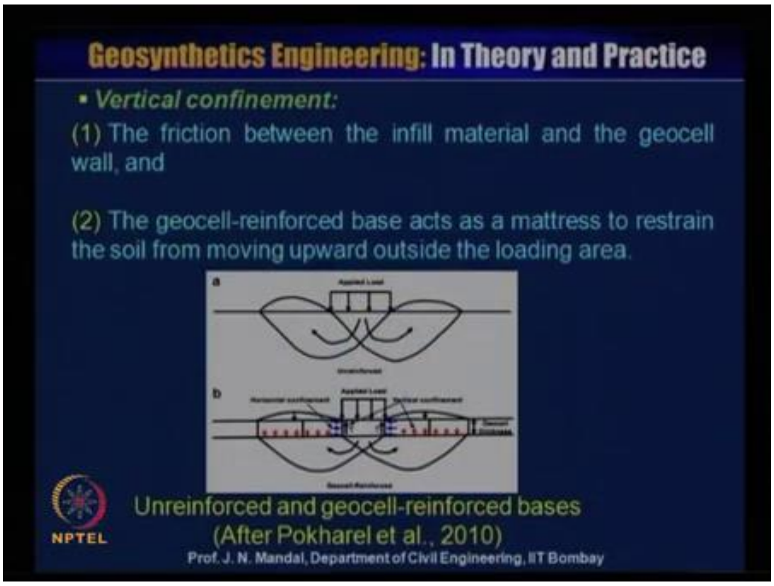

Now, vertical confinement, the friction between the infill material and the geocell wall. The geocell reinforced base act as a mattress to restrain the soil from moving upward outside the loading area. So, you can see here that one what should be the behavior of unreinforced and geocell reinforced base after Pokharel et al 2010. So, here for unreinforced when you apply the load you can see what will be the nature or failure pattern of the foundation soil.

In case of when you are introducing the geocell material and you can see that what will be the failure pattern, there is a horizontal confinement effect and there is also vertical confinement effect. So, I talk about this horizontal confinement effect and also this vertical confinement and here in this figure, it is illustrated where the vertical confinement and horizontal confinement is acting.

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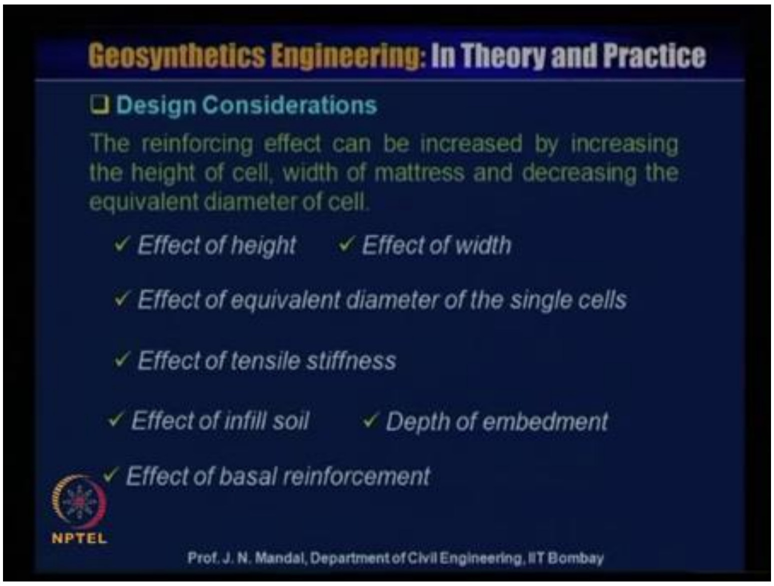

Now, design consideration the reinforcing effect can be increased by increasing the height of the cell, width of mattress and decreasing the equivalent diameter of cell, this effect of the height, effect of the width, effect of equivalent diameter of the single cell. Effect of tensile stiffness of infill soil and depth of the embedment are effect of basal reinforcement.

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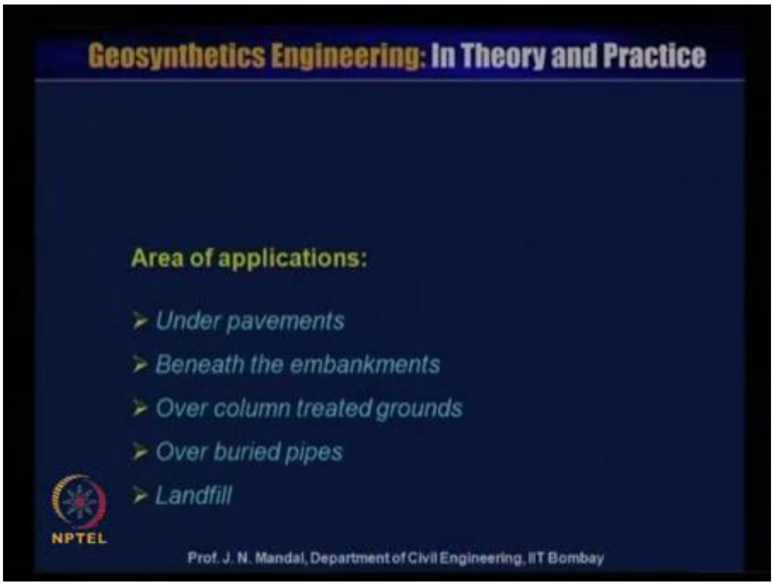

Now, some of the area of application under the pavement beneath the embankment over column treated ground over buried pipes or the landfill. Now, it can further that in different area it can be applied and it has been applied also in Indonesia. In India, also in the U K, in the Scotland there is an 8 meter height of the embankment. And 1 meter is the feet underline by the 7 meter of the organic shield with the undrained shear strength value above 30 kilopascal.

In such case a condition that geogrid foundation mattresses has been used and also that embankment material has been used as a pulverized fuel ash, and the different settlement has been observed only 40 millimeter. So, it has used in the different countries and it has a lot of potential application. So, you can use that uniaxial geogrid as geocell foundation mattresses and also that biaxial geogrid you can give in the vertical direction also, it has the different shape and the size. So, I finish my lecture today let us hear from you, any question?

Thank you.