NPTEL

NATIONAL PROGRAMME ON
TECHNOLOGY ENHANCED LEARNING

CDEEP
IIT BOMBAY

ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 29

Module-3

Lecture-11 on Compressibility and Consolidation

Welcome to lecture series on advanced geotechnical engineering we are in module 3 lecture number 11 incompressibility and consolidation so in the previous lecture we have discussed about balance theory of three dimensional consolidation and we attempted to solve some couple of problems involving sand drains has been discussed that now the current trend of you know the vertical drains is in the era of you know free fabricated vertical drains so we will try to discuss about the more about the characteristics of prefabricated vertical drains.

And then we will try to do some couple of problems which are with the free fabricated vertical drains then we will try to discuss about you know how these of Penalties can efficiently be used in combination with vacuum consolidation which is the upcoming research topic in advance in geotechnical engineering frontier areas.

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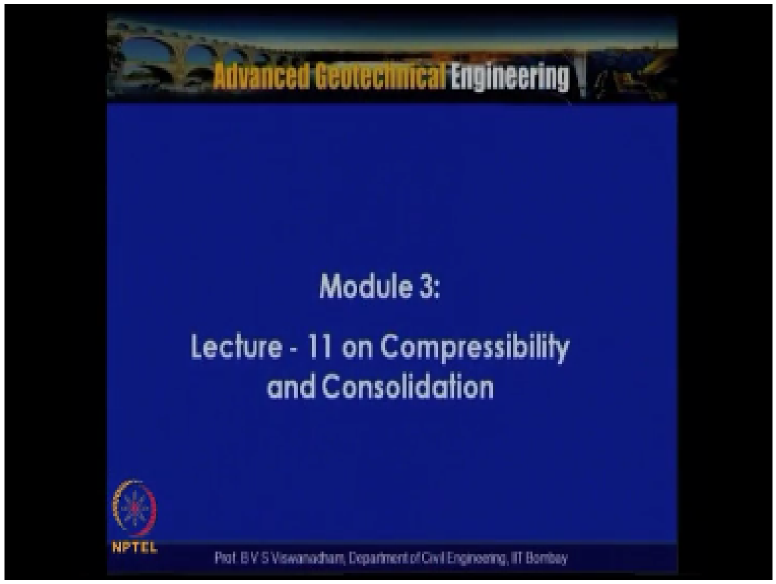

So this is a module 3 lecture 11 on compressibility and consolidation so we are under the theme here the methods for accelerating consolidation settlements.

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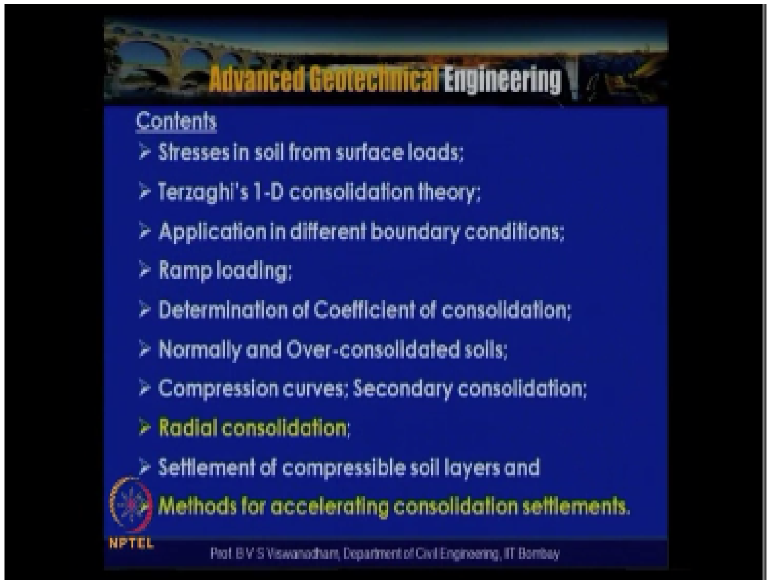

And radial consolidation and this is the continuation of the previous lectures so in the previous class we have discussed about a problem now the solution will be discussed so in the in this particular slide a problem where in ail tank.

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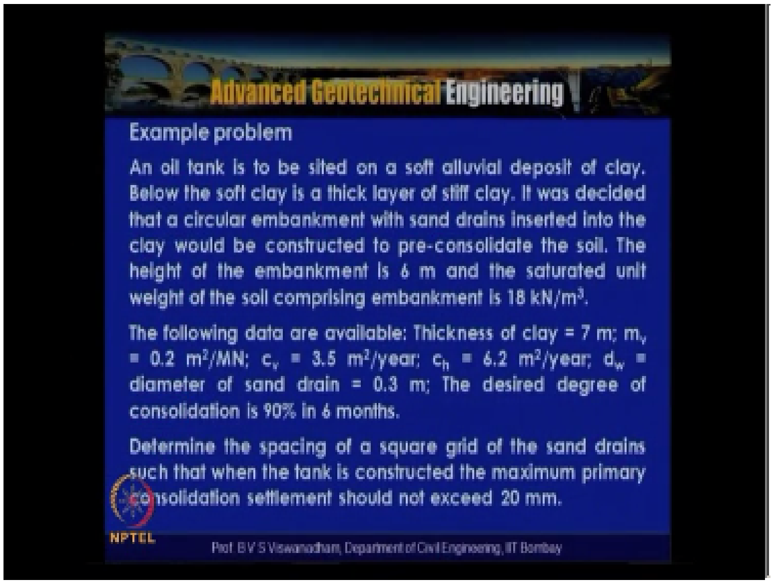

Is to be is constructed on a soft clay so for this what has been done is that in acircular embankment has been constructed with a set of you know the sand drains spaced at certain square pattern so we need to calculate the spacing of the square grid of the sand drains such that the tank is constructed the maximum primary consolidation settlement should not exceed when threshold not exceed 2 t-mo so that means that what we have to do is that we have to you know calculate the final consolidation settlement.

And the final consolidation settlement - this settlement that means that that much you know degree of consolidation up to that much degree of consolidation we have to have both vertical and a real to be considered and then the given properties of that you know we have been given you know coefficient of volume compressibility and coefficient of consolidation vertical direction and in the horizontal direction and diameter of the well has been given and the desired degree of consolidation is also given for nine ninety percent in six months.

So the time required to complete this achieve this target consolidation both in vertical radial consolidation is about ninety percent so let us look into the solution.

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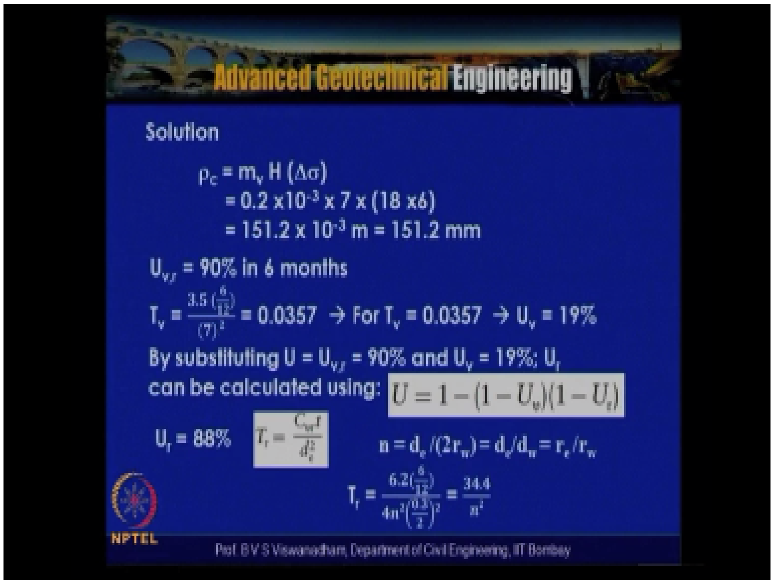

The solution runs like this first you can calculate you know the so-called row see the final consolidation settlement and this works out to be 1 51 mm wherein you are required to allow only you know about you know 20 mm settlement so 150 1 -21 51.2 -20 / 150 1.2 you will get the desired degree of consolidation but let us take UVR as ninety percent in six months so for this you know if UVR if it has to happen in six months and the thickness of the clay is you know is as even meters in a single drainage because the bottom is actually having stiff clay and TV is equal to 3.5 into 6 by 12 because six months / 12 it converted into years.

And what we get is that you know this in eh 3.5 that is constant of consolidation in vertical Direction divided by seven square so which is nothing but zero point zero three five seven so by using T V is equal to PI by 4 you buy 100 whole square we can actually calculate you is only nineteen percent now by substituting U =UVR =90% and UV =90% in clarion 1942 equation wherein you are can be calculated so solving for you are you get 88% now that means that whatever the arrangement.

We do with you know the so called the drain arrangement we have to you know achieve the consolidation in this order so the TR is equal to TCVR by D square now the D square the d is nothing but you know in the square arrangement we have been told so now N=DE by two RW or which is nothing but DE by DW is equal to RE by RW now here what we do is that we by substituting you know this n is equal to you know re by RW so with that what we can do is that d is equal to you know you can see that D is equal to two RE so that is nothing but you know when you come when you substitute.

This what we get is that TR is equal to 6.2 into you know 6 by 12 / 4 n square into point 3by 2 whole square so this point 3 by 2is nothing but the diameter of the well divide by 2 that is in terms of you know diameter of the well and n is nothing but the you know the ratio between the influence diameter that is DE by DW so with this what we have got is that TR expressed in terms of 34.4 n square has been actually obtained.

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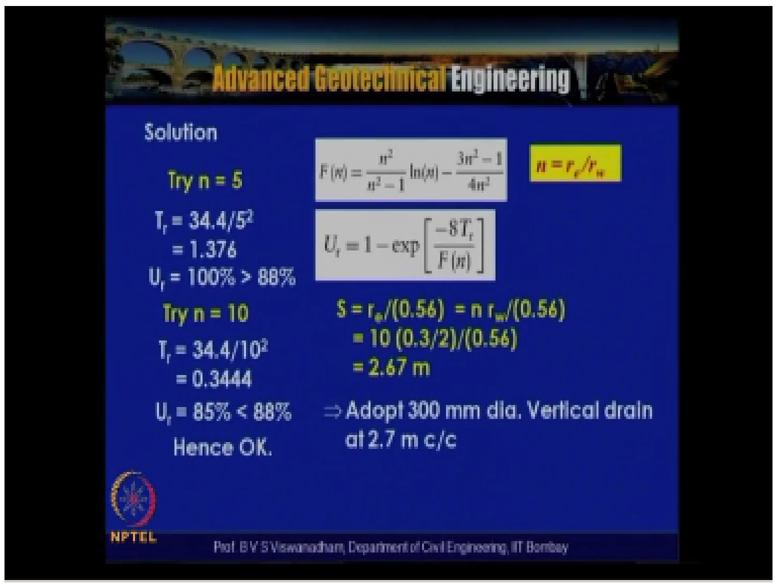

Now after having obtained now in terms of n square TR is equal to 34.4 by n square so we have to do the trial and error method so let us see that air is go to file that means that n is equal to five indicates that the drains are placed very close and with that TR, TR equal to 34 point 4/5 square which works out to be one point three seven six and which leads to you know one hundred percent either when you compute you know for n is equal to five you compute FN +l square by m square- 1 into natural logarithm of n -3 l square - 1 by 4 and square.

Once you compute you will get FN and after having obtained the value of TR then you compute UR = 1 - x x e to power of or exponential to the raised -eight ER by FN now so this works out to be you know one hundred percent that means that you know the desired consolidation is only radial consolidation is eighty-eight percent that means that you are we are on the conservative side now let us try another value n is equal to 10 so with the TR is equal to 34.4 / 10 square which reduces to 0 point 344 and.

Now again by computing FN and you are and you are value the computed value works out to be eighty-five percent which is less than eighty eight percent this you know in this order of n is equal to 10appears to be you know n is equal to 10or n is equal to nine appears to be in order so we can consider even n is equal to nine or n is equal to 10 if consider n is equal to 10 then what we can do is that the spacing can be determined for a square arrangement because we said that the square arrangement de is equal to one point 13 s so radius effective radius is nothing.

But you know / 1.13 by two so with that you know s is equal tore by point five six which is nothing but n into RW x 0 point five six with that we what we get is that RW is 0point 3 by 2 so 10 into because n is equal to 10 that is what we selected if you select n is equal to 9you will get 2.5 meters or 2.6 meter spacing so 10 in 2 point 3 by 2 divided by 0 point five six so with that we get a spacing of 2.67 meter per meter so what it says is that for the you know for the desired salvation of ninety percent to happen in six months theoretically without considering.

The spear effects and other aspects it works out that the 300 mm diameter vertical drain is required at2.7 meter center to center or it is in the order of like 2.6 to 2.7 meter center-to-center distance so in this particular problem what we have done is that we have calculated you are from the you know given target UVR value and then after having calculated you are we try to match this with you know with the different Sumerian values by trial and error method n is equal to 5 n is equal to 10 so with that the one.

Which is actually a layout or arrangement or configuration which gives the closer value to the desired your value is actually selected and after having obtained so this implies that the settlement will be of the order of not more than 20 mm when the nozzle when the tank is actually constructed and consolidation happens so that you know this limiting at all herbal supplements decided by the engineering charge are the design engineer based on the requirement or conditions of the site and also the requirements stipulated by the client now the similar lines this problem can be solved at your end by a road embankment is constructed on top of a 9.2 meter thick.

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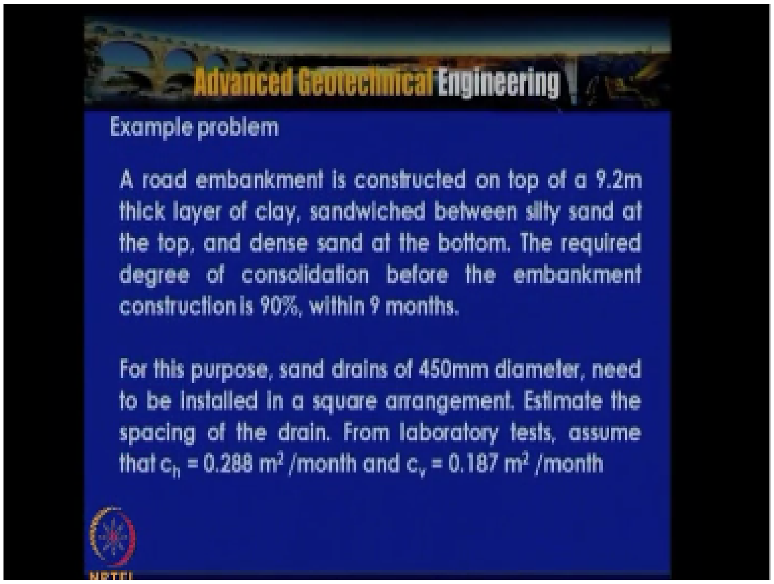

Layer of clay sandwich would between 70 sand at the top and then stand at the bottom that means that it is actually having double drainage and the required degree of consolidation before the embankment construction is 90% within 9 months that is with the double drainage and with the sand rains but that means that UVR vertical consolidation as well as radial consolidation has to happen within nine months and for this purposes and drains of 450 mm diameter need to be installed in a square arrangement.

So you can also consider you know extra the triangular layout and the square arrangement and you can compare you know how you know these you know spacing are actually very so estimate the spacing of the drain and from the laboratory tests what has been obtained is that CH =0.288 meter square per month and CV is equal to 0 point one eight seven meter square per month so in calculating TR the unit's need to be you know considered properly and herein this in addition to what has been actually asked.

We also calculate for the triangular arrangement also so that the layout of the sand rails can be compared in this problem we are in you know the procedure is actually very similar so what we need to calculate is that you need to calculate you know what is the you know for 90% and then you need to calculate what is the vertical consolidation and afterwards you know you need to calculate UR and afterwards you we need to calculate it you know the TR time factor in terms of you know some constant divided by n square.

So with that for different values of n =5,6,7,10 you can actually get what is the you know value which is actually closer to the desired degree of consolidation in the radial direction and be after obtaining that you know you can actually calculate based on the you know the space spacing of the spacing of the drain can be estimated you know for a given degree of consolidation which is satisfying the desired degree of consolidation and with that can be used for compared with square arrangement and triangular arrangement.

So before looking into the details of characteristics of PVD so we try to look into some you know typical applications where you know suppose if you are having approach road embankment on soft clays and one of the viable options is to you know if you are the load are the you know capacity if the consolidation required to be accelerated you know during the construction of you know this approach bank meant so one of the alternatives is to go for you know the PV DS below the you know below the base of the reinforced soil wall and here a typical cross-section.

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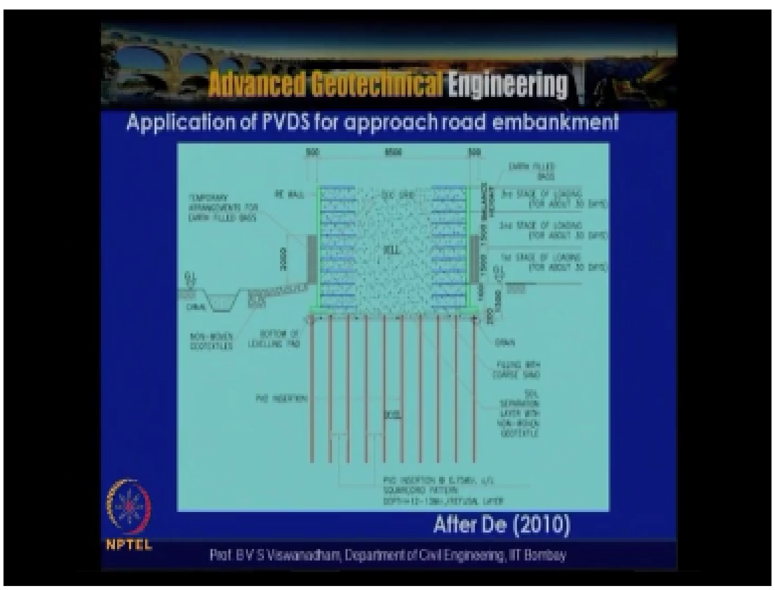

Of a back-to-back RE wall is actually showed wherein it actually has got a facing.

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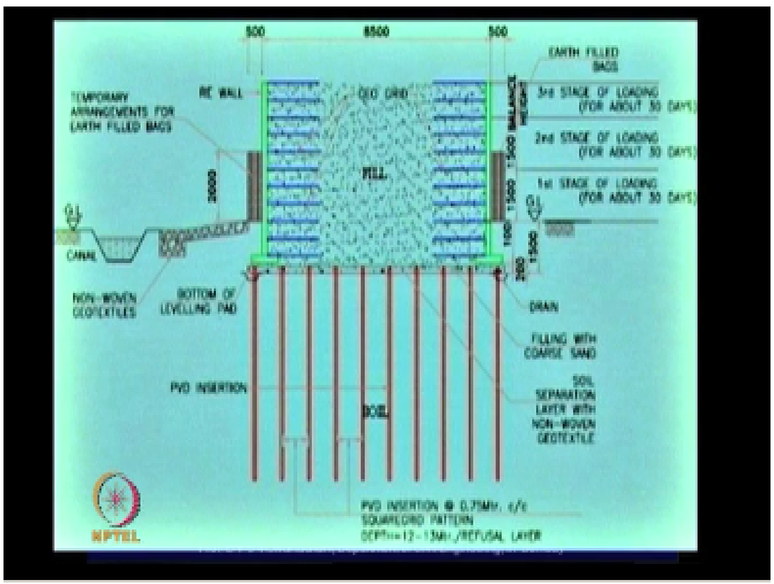

And a foundation pad and the drains are actually placed the along with a you know a drainage blanket at the top so this is one of the applications for the DVDS for approach Road of magnets.

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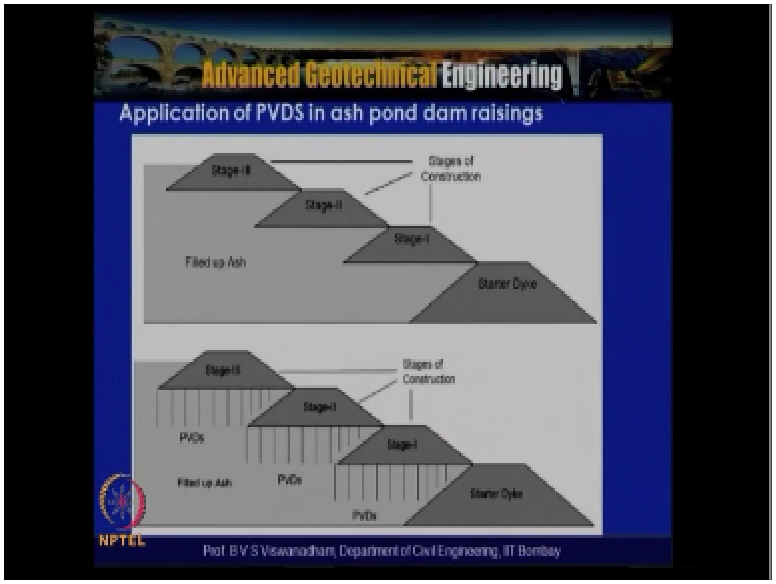

And this is in application of DVDs in ash pond dam risings like you know as you know we have the starter dike which is actually constructed on the by using the natural soil and then the ash is actually pinned up wind up so this generally happens in you know three stages are four stages so in order to ensure you know the accelerated consolidation and also in nowadays if that area is in the you know earthquake prone area in the at the onset of you know say earthquake.

The liquefaction susceptibility can be you know mitigated by you know using you know these PVDS in ash pond dam risings so it actually has got two advantages one is that it increases or accelerates the consolidation so once accelerate the consolidation means thus the fly ash our pond ash beneath the stage one embankment and subsequently stage one embankment-embankment will get dignified and the possibility of you know you know raises of excess pore water pressure the onset of earthquake /turbines can be averted.

So this is one of the you know very novel application wherein you know the PVD is actually issued for mitigating liquefaction susceptibility in fact other application of DVDS is that you know in some areas where contamination flumes are there and in order to drain out the training contaminating fluid this is one of the alternatives used to you know use PVDS and also nowadays in municipal solid waste landfills for a bioreactor landfill in order to went to the gas you know these you know use of PVDS uniformly.

So with that what will happen is that the gas collections will be uniform and then you know the waste strength actually gaining will be uniform that you know there has got to accrued benefits as far as you know bioreactor landfills the use of PVDS in bioreactor landfill see is concerned this is one of the novel application and in addition for the PVDS are also now being used along with in salty sand and sandy soils basically to safeguard are you know again is the attempt when the tradition of liquefaction actually happens because of the sudden catastrophic disturbance caused birth quakes or due to some loadings like blast loadings.

And these are actually proved to be very efficient and economical and lot of actual research is actually happening in these areas now let us look into the typical details of PVD so free fabricated vertical drain.

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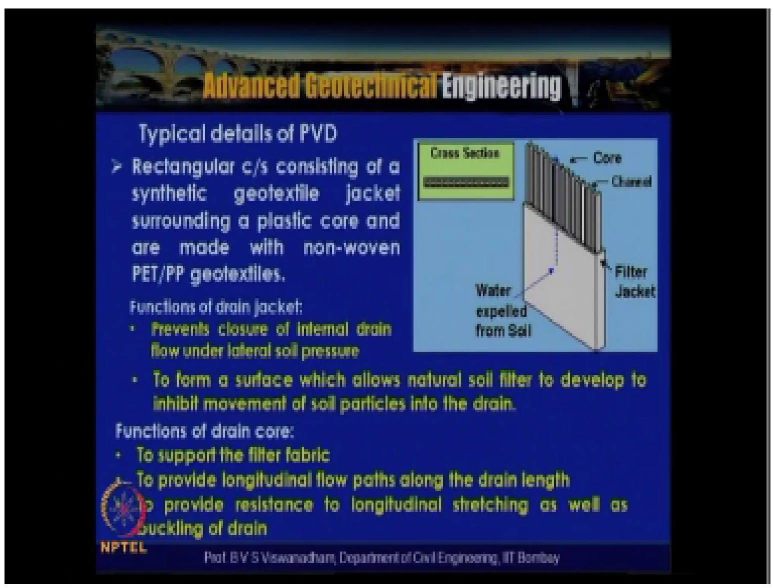

So in this particular you know slide what we see is a you know a typical plan view and a cross-section of a you know PVD and what we see is the filter jacket and inside is the code and between the course or the channels and it is connected it is covered by buy a filter jacket so as we said that this filter jacket is actually generally made with the non woven geotechnical either with the polypropylene or polyester or any other appropriate material and this core which is actually made with you know the HDPE are you know polypropylene core basically.

It actually has to be efficient in draining the water even under enough stress outskirt stress you're under these conditions where the stress is actually subjected so the rectangular cross-section consisting of a synthetic geotechnical jacket surrounding a plastic core basically they are made with PETNPPG or esters that is what we have just now discussed now each and every component actually has got a specific function so if you look into these functions of the drain jacket or federal jacket which is surrounding.

Which is surrounding this plastic Core is prevents the closure of the internal rain flow under lateral soil pressure that means that when the soil pressure when the soil pressure is exerted in the lateral direction you know the it prevents actually the closure of the internal rain flow under lateral soil condition and to form a surface which allows the natural soil filter and to develop to inhibit movement of soil particles into the drain so it actually also helps to you know form a natural soil filter to develop you know in art material to inhibit movement of you know soil particles into the drain.

So soil filter is actually developed to inhibit the movement of soil particles into the drain so that is the you know the prime functions of the drying jacket and the other you know functions of the drain core are the to support the fatter fabric that means that it gives and provide the longitudinal flow path along the drain length so the plastic core you know functions are that you know it provides the longitudinal flow paths along the drain length and to provide the resistance to the longitudinal stretching as well as the buckling of the drain.

To provide resistance to longitudinal stretching as well as buckling of rain so with the presence of you know the drain core it actually resists they you no longer longitudinal stretching as well as the buckling of the drain when we look into the quality of this PVDS we will understand that these during the installations they have to sustain certain tensile stresses otherwise what will happen is that you know the possibility of hundred mm you know width reduces to about you know at 80mm 70mm because of the necking formation which actually takes place.

So if the necking actually occurs you know very difficult to ensure you know the you know the so-called discharge capacities is one of the prime component which is actually is required in the design so in this particular slide we have discussed about the two prime more functions of a components one is drain jacket other one is drain core now this is the you know typical scheme of you know PVD installation.

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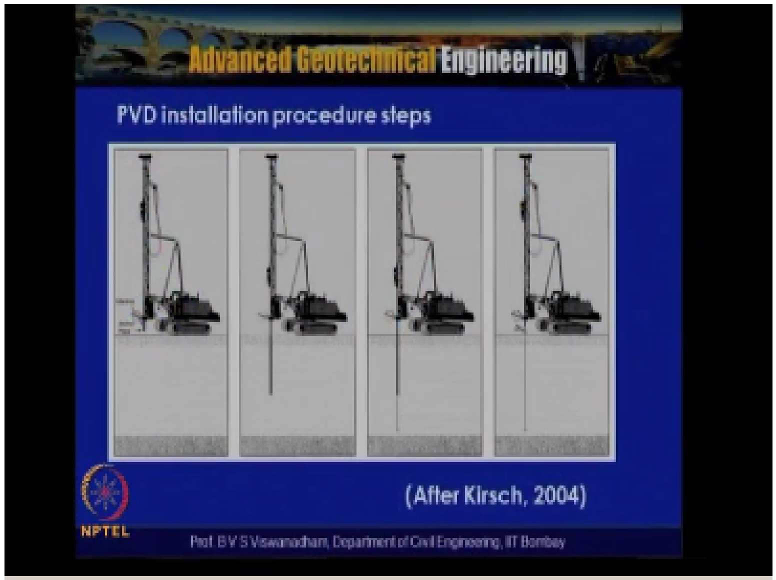

We have seen the installation in the site in one of the sites in wave Mumbai wearing this is this chaotic sketch is actually being shown here so the road is actually loaded and it is being driven with an anchor and you can see that you know the once the once it is in place here the mandrel is actually withdrawn so here there is an anchor is drawn so these mandrel are actually having different ships they have got rectangular mandrel surrounding the drain or you know the rhombus shape you know mandrels basically these mandrels have been designed from the construction practice point of view to reduce.

You know the so-called spearing affect our disturbance during the installation of these prefabricated vertical drains so here you know a typical installation as stage wise or installation of you know PVD is actually shown schematically so in this particular slide you know typical anchor bars which are actually used to keep the PVD.

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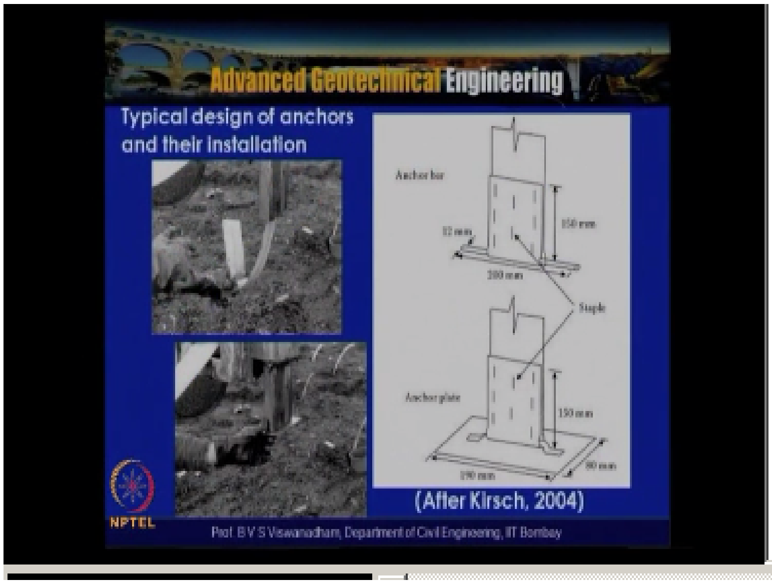

In place during the installation so in this particular photograph what you know has been showings that how the anchored our rod of talcum diameter and with a you know or lap of about 150 mm and here these staple pins are used to hold this in place to form a hooplike this and then you know then you know this anchor bar which is actually having 200 mm that means that if one atom um is the PVD Brett then to twice the you know Beth is actually use and you can see that this is placed here an them.

You know this is the mandrel this is the rectangular mandrels what we have seen is a tangle mantle in this case this is with the anchor plate arrangement wherein the plate will be there and then you know this is actually there is a possibility that this anchor plate can cause more disturbance you know as the as the as it is being pushed into the soil and you know it actually has got a tendency of developing the you know large smeared zones and this is actually schematically shown in the photograph here how the anchor plate is actually attached along with the PVD.

So this is the anchor bar and this is the anchor plate now as we have discussed that you know these PVDS actually they come in the rolls so we also have to take enough precautions to have the continuity in the sense that if we when we actually have you know rolls which are attached so this should be continuity otherwise what will happen is that the flow channels will not be continuous and then there is a possibility that you know the discontinuity.

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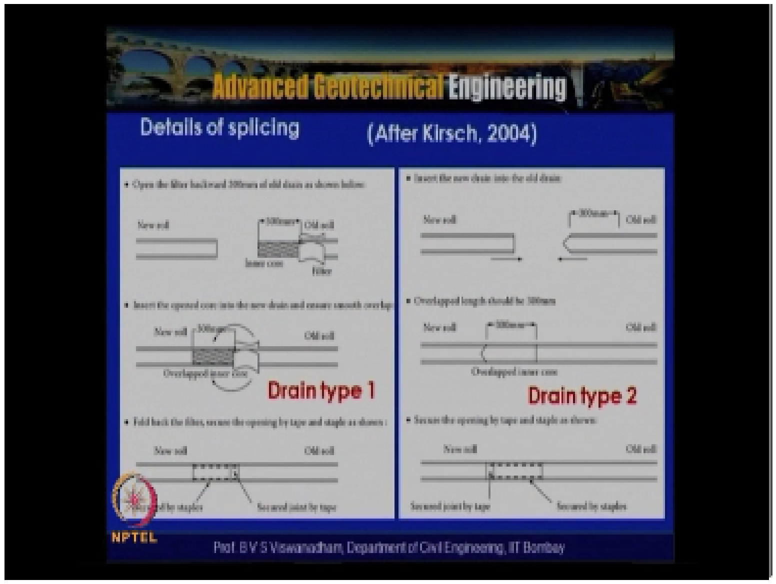

When it occurs at number of location drains will not be efficient so in order to avert these things for the typical type 1 and type 2 drain you know the what the field practice actually says is that this is the existing running role and then you know the filter can be peeled out like this and then it can be inserted so minimum 300 mm lap and then these are actually placed again so that the soil will not enter and though this is spacing back here so here this first step open the filter backward for about 300 mm of the world rain as shown here then afterwards insert.

The opened core into the new drain to ensure the smooth or lap and fold that the filter secure the opening by tape and staple actually as shown you here so you have to secure so that you know again soil particles will not enter through this particular job because you know we have discussed that one of the functions here if the soil particles enter into the drainage channels the efficiency of the drains will get affected and in the second then you know type drain type to insert the new drain into the world rain and war lab the length should be again here also 3n lemma and execute.

The opening by the tape and steps almost it is same it is universally it is adopted and also while testing the quality we also have to see you know how the joint is actually having effect on the tensile load strain behavior because if that war lapping is not adequate there is a possibility that the tensile stress and strain behavior will get affected in away there is possibility that you know we develops failure and then discontinuity so because of that there is a possibility.

That you know the functionality of the desired functionality of the system may not be achieved now let us look into certain prefabricated vertical drain properties there are three basic things one is that equivalent diameter of drain so this was actually discussed in the previous lecture.

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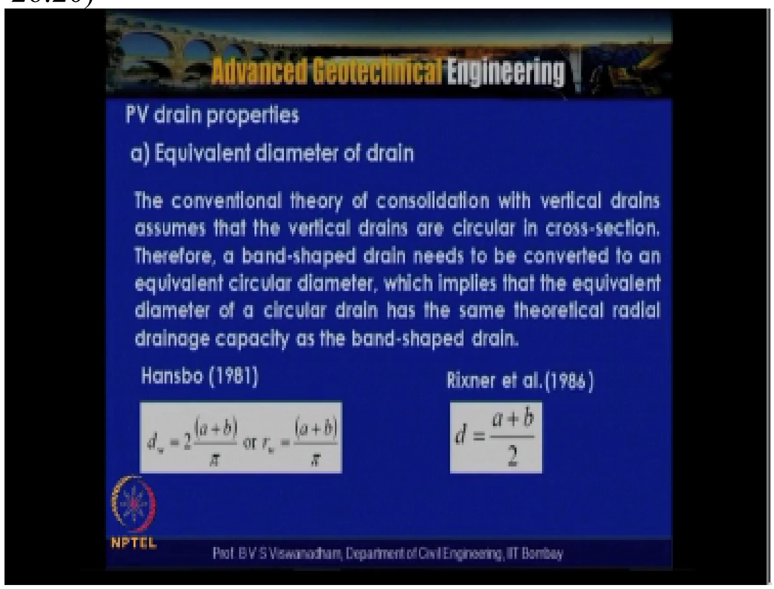

The conventional theory of consolidation with vertical drains assumes that the vertical drains are circular in cross-section so conventional theory of the consolidation with vertical drains basically assume that the vertical drains are circular cross-section there for a band shape would drain need to be converted to an equivalent circular diameter so a band shape with a rectangular drain to be converted into a equivalent circular diameter.

Which implies that equivalent diameter of circular drain has the same theoretical radial drainage capacity as the band-shaped drain so the conventional theory of the consolidation with vertical drains assume that the vertical drains so as discussed in the previous lecture the all the basic theories which are actually developed are for the circular cross sections so now the these drains these you know the number of equations and then parameter which are there have to be you know accounted for the different properties of the drains.

So one of the you know important aspect is that TW = 2 into a+ B π that is for the equivalent diameter of the well so converting the rectangular area so equating the rectangular area which is you know π DW is nothing but the parameter of the perimeter of the circular area of the well equivalent circle is equal to the rectangular perimeter so with that we get you know the radius as

A+ B by Y this is actually after an SPO 1981 and Rick sinner you know proposed that D=A+B to by 2 DW DRD =A+B by 2 and this was proposed based on. Some ferment element analysis results but however the universally this is actually adopted DW = 2 + B by five.

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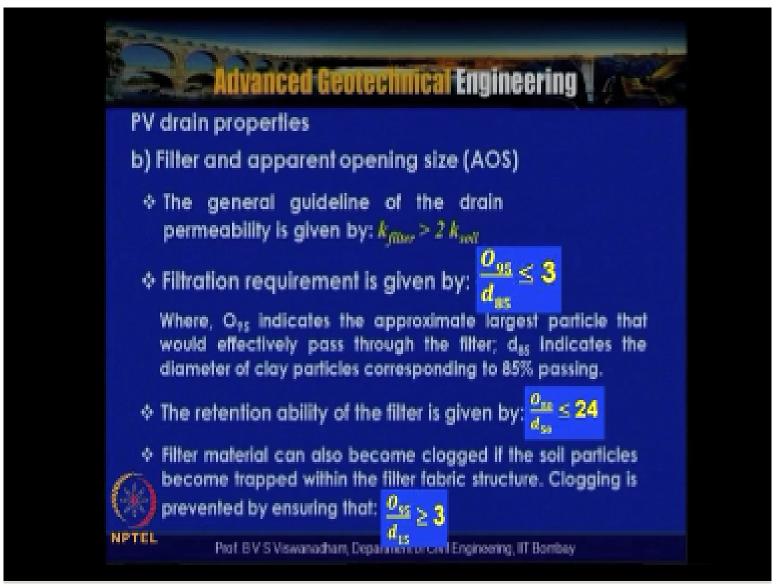

Now the filter and opening size as we said that you know the jacket filter jacket is actually made with the non while geotechnical style having a certain apparent opening size and having certain mass per unit area so the general guidance for the drain permeability is that k filter that is the permeability of the filter jacket has to be at least two times the permeability of the soil so we know that you know most of the place you know which are actually undergoing consolidation may permeability.

Let us say 10 to power of - 9 meter for a second minimum it actually should have 2 into 10 to power - 9 meter per second and filtration requirement is given by you know O 95 /B 85 should be less than or = 3 so O 95 that is the you know opening size indicates that an approximate largest particle that would have effectively pass through the effectors and D 85indicates the diameter of the clay particles corresponding to 85% passing so O95 by D 85 less than or = 3 and the retention ability of the filter is given by 0 50 /D 50 less than = 24 and the filter material can also become clogged.

If the soil particle becomes trapped when the filter fabric structure so in this case O 95 / D15 should be greater than or = 3 so clogging can be prevented if O 95 is greater than = 3 times 3 d 15 so 3 to 4 times 3 15 if it actually is there then the clogging can be prevented so filterer a barrier material of a filter jacket and can become clogged if the soil particles become trapped within the filter fabric structure that is the pores which are actually there when they are actually occupied with these soil particles the clogging can actually get.

You know mobilized and so the clocking is prevented by ensuring that O 95/ D 15 there is < 3 so the general guideline for the driver abilities that the Dane should have the filter should have more pure beauty than the soil and the filtration requirement is given by O 95 / d 85 less than or = 3 where195 indicates the approximate largest particle size that would effectively pass to the filter and D 85 indicates the diameter of the particles corresponding to 85% passing so the retention ability of a filter is given by 0 50 by d 50 which is less than or equal to 24 similarly.

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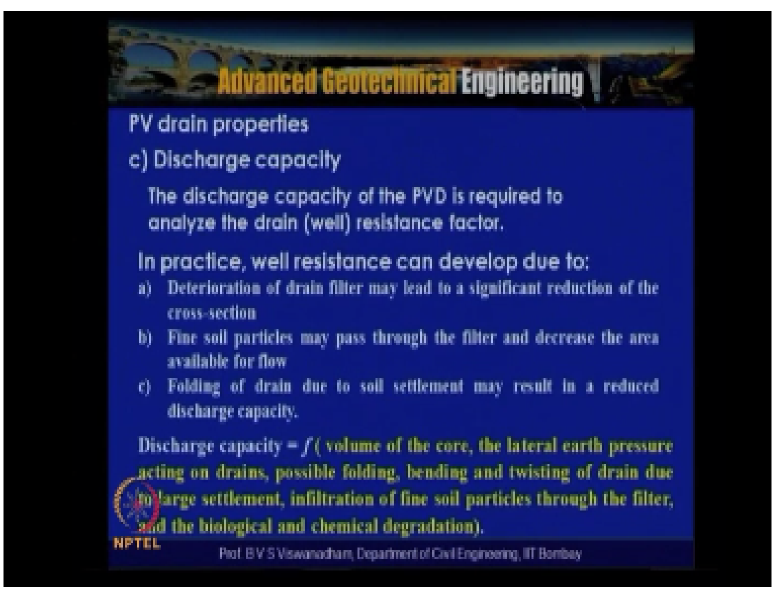

Now another important parameter as far as the discharge capacity is concerned so discharge capacity is basically is the flow volume of the flow happening through the PVD under a unit hydraulic gradient so the discharge capacity of the PVD is required to analyze the or well resistance factor suppose the lower the discharge capacity of the PVD then you know then efficient is the you know consolidation of a consolidation effect on the consolidation performance of a PVD stabilized soil.

So in practice actually well resistance can develop due to deter action of the drain filter may lead to significant reduction of the cross section and the fine soil particles may pass through the filter and decrease the area available for the flow so that means that the channels get blocked by the soil particles with that what will happen the effect to area for the water to flow will get decreased and folding of the drain due to soil settlement the result in a reduced discharge capacity so this we may have to note that the PVDS.

Which are actually flexible in nature and when the soil is actually subjected to you know settlements and these PVDS to do two reasons one is that the soil is subjected to settlements because of the onset of consolidation and the second thing is that due to you know the presence of the lateral pressure the drains actually subjected to so called the buckling that means that they can undergo at killing at one location two locations and three locations so even under those conditions you know in the buckle conditions.

It should be able to you know how the satisfy the required discharge capacity requirements so the discharge capacity which is nothing but function of volume of the core and lateral earth pressure acting on drains so this lateral earth pressure if wanted to be estimated this is actually obtained nothing but $K_H = K_0 \sum V$ at a given point if you are having a vertical effective stress and the K_0you know based on for normally consolidated as let us say you know point five times $\sum V$ you know is the lateral earth pressure.

At any point so the possible folding which actually can arise due to the reasons which have been explained and the twisting of drain due to large settlement and you know it can also happen buckling or it can also under go so twisting and infiltration of the fine soil particles through the filter and the biological and chemical degradation so the discharge capacity of a PVD which is actually installed in the field can actually get affected by the following factors volume of the cone lateral earth pressure acting on drain.

And possible folding and bending and twisting of drain due to large settlements and infiltration of fine soil particles through the filter and the biological and chemical degradation.

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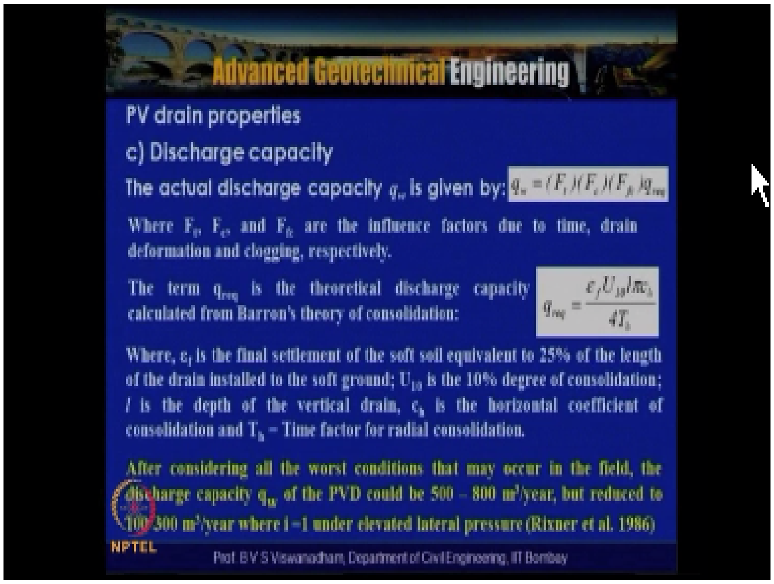

Now this discharge capacity is given by Q W = F T into you know FC in to FFC into Q required so this is where FC FT and FC and FFF see are the influence factors due to time drain deformation and clogging respectively so these factors are that FT FC and FFC you know in a I a multiple way required bacon required theatrical discharge capacity\ from calculated from the Barons theory of consolidation so that Q required can be obtained by ε F into U10 into l by into π c h / 4 the so where ε f is the final settlement.

Of the soft side equivalent to 25% of the length of the drain installed to the soft term and u term is the 10% degree of consolidation is the depth of vertical drain and CH is the horizontal coefficient of consolidation and TH is the time factor for the radial consolidation so the actual discharge capacity QW is given by FT FC into FFC into Q required and the term Q required is the theoretical discharge capacity calculated from barons theory of consolidation with that Q required is equal to ε F into U 10 into L into PI CH / for 2h where ε H is the final settlement of the soft soil equivalent to 25% of the length of the drain installed in the soft ground and UT in is the ten percent degree of consolidation L is the depth of vertical drain CH is the Argent coefficient of consolidation and TH is the time factor for radial consolidation.

So if you look into this the according to after considering all the worst conditions like due to settlement buckling and then deformation of the drain due to lateral pressure that may occur in the field the discharge capacity QW of the PVD could be around 500 to 800 meter cube per year so most of the manufacturers specified values are actually with the 500 to 800meter cube per year even under the lateral pressure conditions but reduce it to 100 to 300 meter cube per year where I = 1 under elevated lateral pressure.

So this is actually after so most of the most of the you know PVDS which are commercially available and they actually have the discharge capacity more than 100 meter cube per year so most of the PVD switch are actually available have got you know the pure the discharge capacity more than 100 meter cube per year so if this is there then you know.

We can actually consider and if this Q W is low then there is a possibility that you know it can actually get affected the drainage capability of the you know the PVD which has been selected and used it for you know draining water from the soil done set of consolidation. So in this particular slide a typical you know summary of discharge capacity specified in the different.

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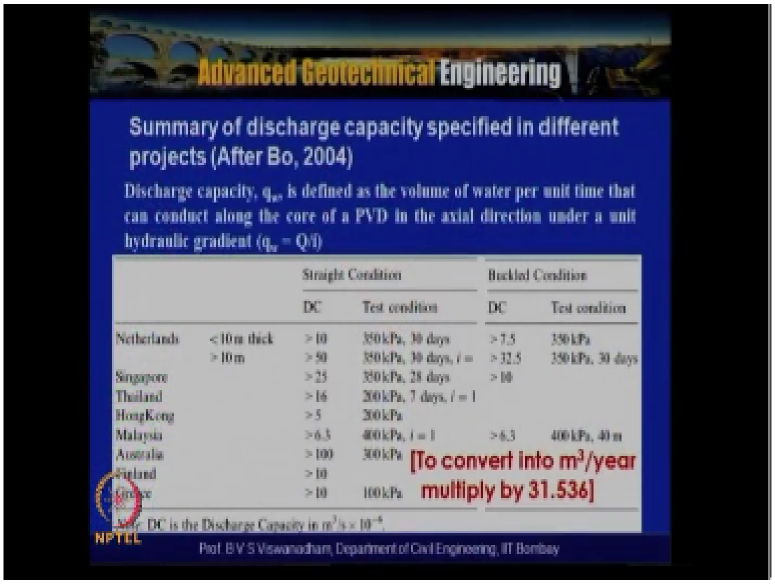

Projects is actually shown and discharge capacity QW is defined as the volume of water per unit time that can conduct along the core of PVD in axial direction under unit hydraulic gradient so Q W is the discharge capacity is given by Q by I and I is the hydraulic gradient and here you can see that you know the straight conditions and buckle conditions are actually prescribed here and in the Netherlands for you know the length the drain less than 10 meters are the thickness of the clay layer less than 10meters.

Then you know in straight condition it is you greater than 10and with is at the test condition is about three fifty kilo 350 s and 30days and in case of buckled condition it is you know 7.5 ok since thy which is when it is greater than 10 meters you know the state condition actually should have k dub you know 50 meter cube per actually second into 10 to power of - 6 so if you multiply this one with the with 31.5 36 we actually get into meter cube per year so you can see that even under the buckle condition for this case here which is 7 to 30 is about 200meter cube per year at three fifty kilo Pascal's of pressure.

So you know even into the buckle condition for the majority of majority of PVDS they actually possess you know the possessed the you know the discharge capacity I capacities in the range of you know 100to 200 or 300 meter cube per year so in this particular slide required drainage capacity as a function of PVD length and K of the soil is can be seen.

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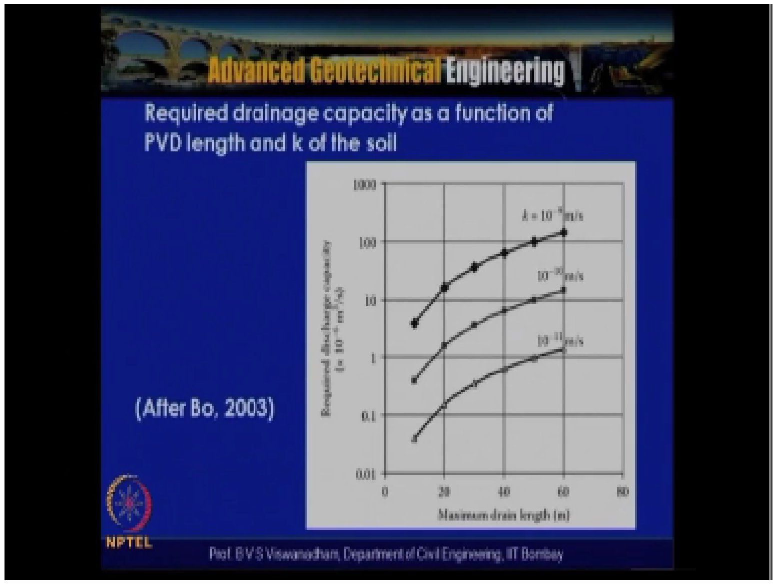

As the length of the drain is actually increasing and four and k of the soil is say decreasing then it can say that the discharge capacity falls down can be seen that as the length increases definitely yes there is an increase in the discharge capacity but let us say that for a length of about 20 meters this is the discharge capacity so with increase in you know permeability of the soil then the discharge capacity require requirement also increases because the larger the permeability the more is the water is pumped into the larger the permeability of the soil.

The more is the water pump it into the flow channels and so this the selected PVD has to be economical in you know understanding the requirement so if you look into the liquefaction mitigation issues with the you know with the sand silt ,silty sand constraint the first of all the installation in these sand conditions is sandy soil conditions little bit can cause worry and because of the frictional resistance offered to the mandrel and all mandrels of a you know the tool which is used for installing these DVDS and then you can say that with the decrease.

In permeability you know that means that there is anincrease in the required target desire discharge capacity for a given length now as has been told that you know because of the you know this jacketed actually supported to the core.

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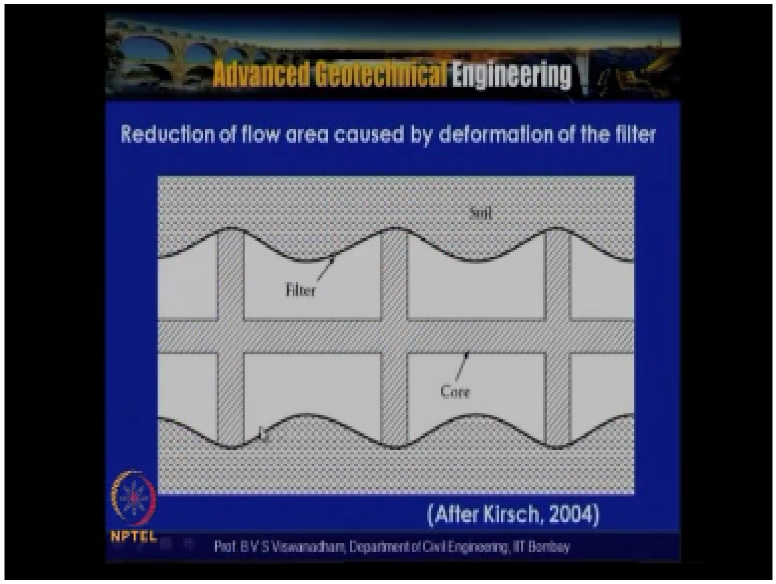

At number of locations so the certain portion which actually will remain unsupported so for a particular type of plastic core and which is like this and because of this soil it actually causes you know deformations so you can see that the certain area is actually where the necking actually takes place and in addition to that if these elongation conditions are actually club with this thing and then there is a possibility that it will get affected so the reduction of the flow area caused by the deformation of the filter can be seen from this slide.

So these conditions you know hamper you know the flow conditions to the flow channels and which in way in a way affect the performance of a PVD installed site.

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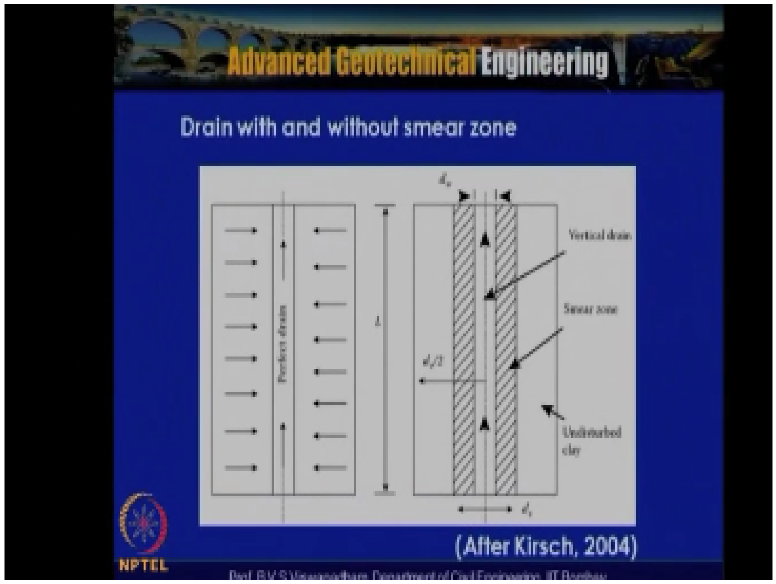

So this is a you know atypical drain with and without smear zone has been told that this is a condition where if you are actually having a perfect rain and the smearing ratio that is DS / DW =1 if that is the case that you know then that S= 1 wherein there is that is called as a perfect drain and when you are having you know this smear effect because of the disturbance caused by the anchor plate or you know the mandrel which is actually push.

It along with the drain in the installation process has been shown before as it has been shown before it can actually cause the smear and this is where zone is actually referred therein as the disturbance soil so the lot of actually work is actually happening you know to define the smeared zone as well as it was discussed in the previous lecture this spear zone so actually has you know Joel's like transition zone and you know transition zone and then smeared zone completely smeared zone is actually close to the drain and then there is transition zone.

Where the soil properties you know tending to grow store close to go close towards the undisturbed soil conditions and then there is undisturbed soil and undisturbed clay will be there so the time required for the radial consolidation for PV drains.

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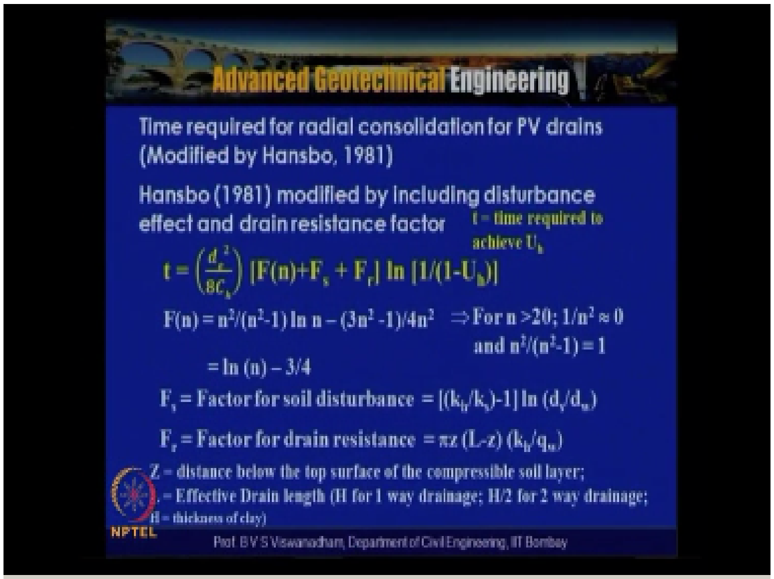

This is actually equation is modified by Hans Bo1981 considering the you know the disturbance effects and drain resistance factors Hansbo or 1980-81 modify for the time the time required to achieve you know the radial consolidation or horizontal consolidation t is equal to you know time required for it to a qu h is given by T is equal to DC square by 8 CH you know within brackets function n + +function s + function R of the bracket closed into natural logarithm by into square brackets 1 by 1-U H the then the square brackets close.

So here if you look into it there are three factors one is FN that we are aware of that and wherein we said that for drains without any smear and which is nothing but a function n is equal to n square by n square - 1 natural logarithm um n -3 and square - 1 by 4 and square and for as you know n =u know by DW and because you known value will be always more than 24 PVDS so 1 by n square is you know close to 0 and n square by n square -1you will tend to become one.

So because of that you know this FN is actually simplified as L n to the natural logarithm of n -3 by 4 so FN is actually given by L n of n -three x4.75 so FS is nothing but the factor for the soil disturbance and we are in that this because of the smear and which is actually taken care like KH by KS -1 into natural rhythm of DS by DW so DS by DW is also called as the smearing ratio that is the diameter of the smears own then you know diameter of the well where S=A a smearing ratio s dash we can SE and FR is the factor for the drain resistance.

So this is because of the you know the possible effects ill effects due to the effecting of the drainage discharge capacity our drains discharge capacity so the factor for the drain resistance is actually accounted which is FR= F Z into L -Jed into KH by Q W where in this particular expression for F R = PI Z to L -J into KH by LW Where Z is the distance below the top surface of the compressible layer and the then L is the effective drain length H for one-way drainage and hey if h is the thickness of the clay layer and h4 one by drainage and h by 2 for the two-way drainage in fact.

This you know when we try to simplify further when you take for the entire length then you get the expressions for the drain resistance factors a far end fr for one-way drainage and to a drainage within the drain so by looking into this we can actually calculate the time required to achieve your H U,UH are actually having the this you know FR the FN / FR which is actually say you know something like less than point zero five then you know the well resistance is actually can be ignored and you know it actually governed by the drain spacing only.

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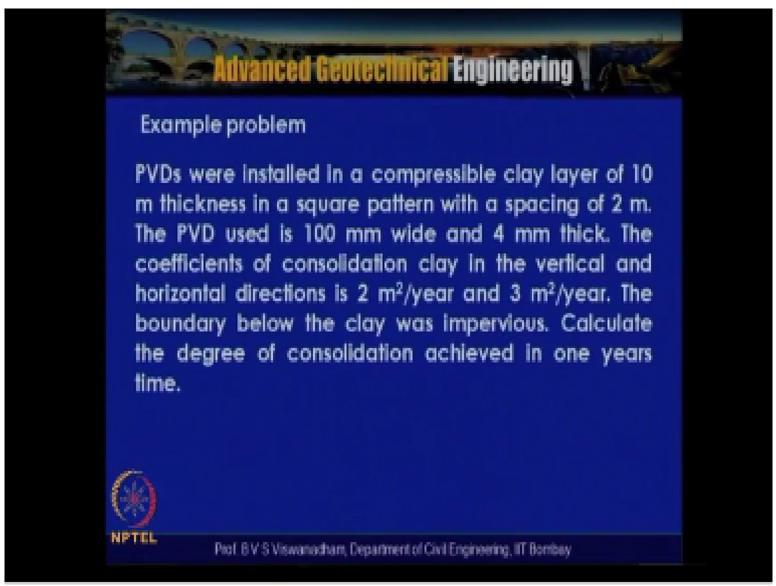

Now after having discussed the you know the PVD characteristics and you know the installation issues let us look into some couple of problems with PVD installed in a compressible clay layer of 10 meter thickness in a square pattern with a spacing of 2 meters and the PVD used is hundred mm wide and 4 mm thick and the coefficient of consolidation of clay is in the vertical horizontal general direction and which is actually given as 2 meter square 2 meter square per year and the 3 meter square per year and the boundary below the clay was impervious and what we need to calculate is they calculate the degree of the consolidation achieved in one year one year's time.

So here you know the dimensions of PVD is given and CH and CV are given and the end here is also assumed that no smear and no well resistance you know I need to be accounted the solution works out like this first estimate DE .

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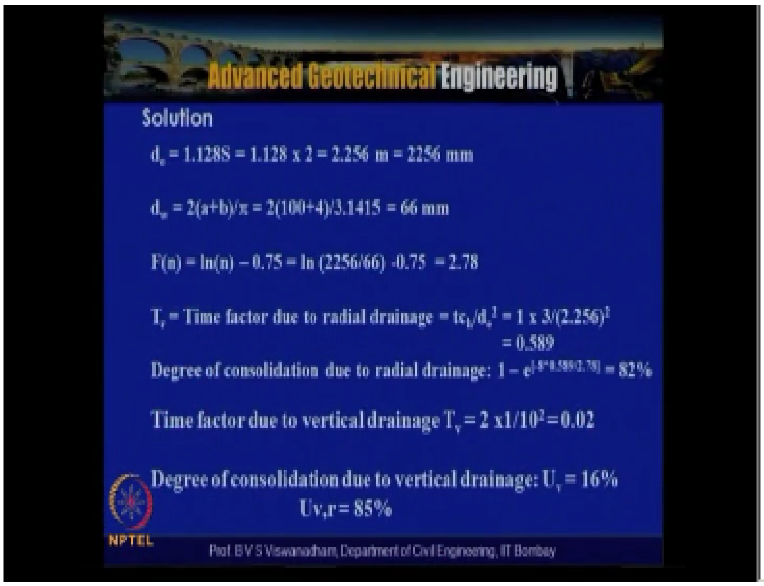

Because the layout which is actually given here is a you know the spacing of two meter square pattern so we can actually calculate D =1. 1 28 or 1.13 S=2 meters so with that we get the effective diameter as 2.256 which is nothing but 225 6 mm and DW is nothing but equivalent diameter of the well which we have considered 2+ B /π so which is nothing but 2 into 100 + 4 x3.1415 which gives 66mm then you calculate FN with a simplified version of l n n - 0 point 75 so L n 2 256 x66 -. 75 which works out to be 2.78 now the calculate the time factor due to radial drainage which is nothing but TCH by d square.

Where T we want in one year's time CH coefficient of consolidation horizontal direction is 3/2 point two five six two point two five six is nothing but effective diameter in the unit cell then you know it is a point 589 we get now calculate the degree of consolidation due to radial drainage we're in 1 -U know U to power of - 8.5 89 / 2.78after simplification we get a to two percent now the time factor for the vertical consolidation is about you know TCV by H square because it is one way to NH so 2 into 1 divided that is CV is 2 and 2 1 is the time / term square because of the single drainage is 0.02.

So by using T V = PI by 4 you buy 100 whole square calculate you know the UV and using the Corollas equation you can actually calculate what is UV are so by substituting V= 16% and UV is if UR = 82% and we can see that UVR is about 85% so the degree of consolidation which can be achieved in one year time by inserting drains at two meter spacing of the particular PVD which is selected works out to be of this day order.

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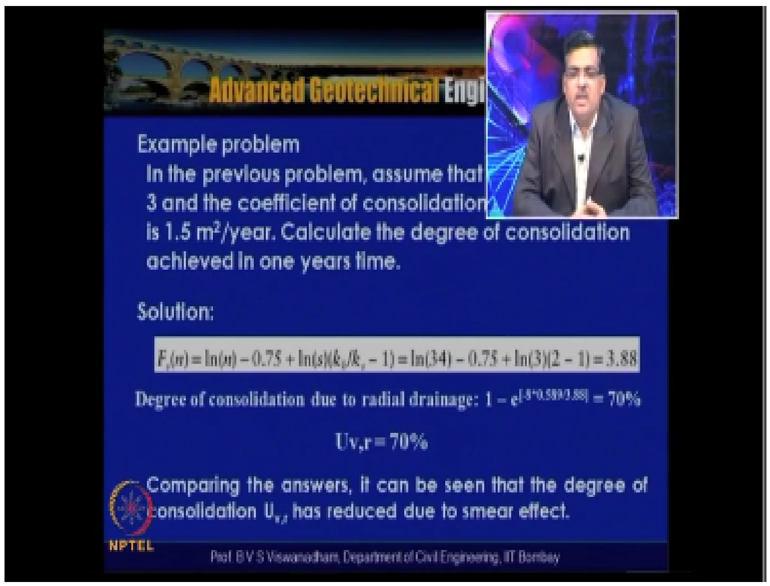

Now the let us consider the same problem assuming that smearing ratio is three that means that this particular performance is actually affected because of this meeting ratio and the coefficient of consolidation of this mere soil is given as 1.5 meter square per year so calculate the degree of consolidation achieved in one year's time so here for this FSN we are you know here it changes because we are in it actually has got the spear effect and with that what you actually get is that you know the so-called you know FSN which by taking into account of the spear effect so the degree of consolidation due to radial drainage is actually.

Now is instead of in the previous problem we have got like 82% now because of the inefficiency of the drain because of the occurrence of the smear at the onset of installation the degree of consolidation radiator drain is works out to be 70% so again by using the vertical consolidation that is about what we have got in the previous problem as 60% we can calculate now with this you know the UVR works out to be you know UVR works out to be you know this value is not correct but UVR is actually reduced so comparing. The answers it can be seen that the degree of consolidation EVR has reduced due to smear effect.

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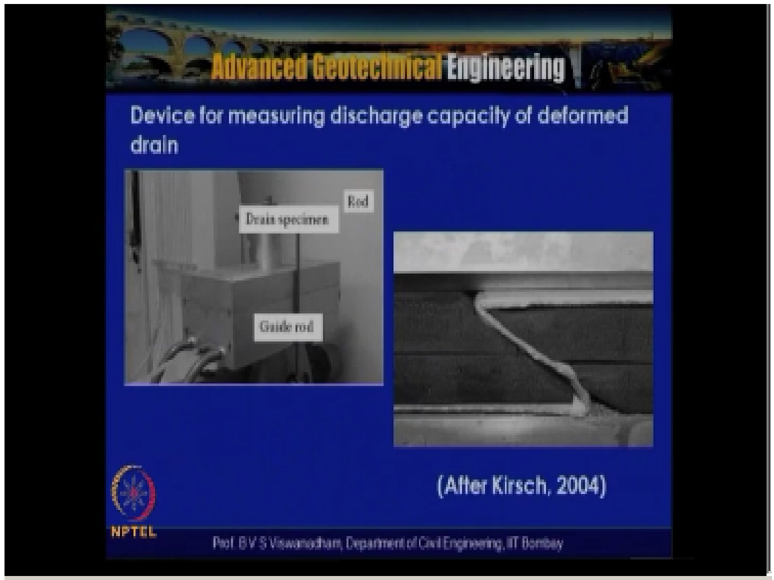

Now for this for testing these drains understates condition are deformed conditions several you know testing methods actually have been device and this is particular arrangement you know the drain with you know a former condition it can be seen that the flow is tested when the drain is under this type of deformed condition.

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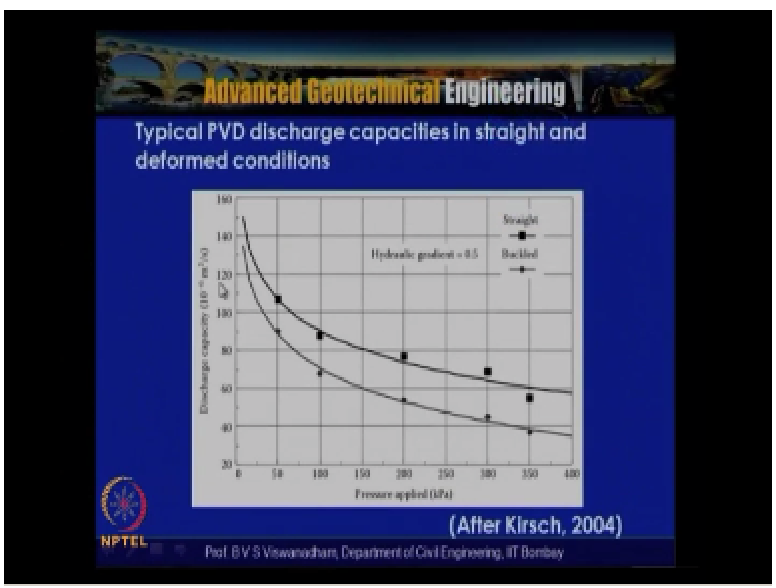

So when we compare you know the discharge capacities of the drains with the straight and buckled condition you can see that the buckle condition actually exhibits you know buckle condition actually exhibits. The lower discharge capacities so under this so here you can see that under the pressure so what we can see that you know 150 kilo Pascal's of pressure when it is applied the discharge capacity is around 16 to 10 to power of - 6meter square meter cube per second whereas this was actually is about 80.

So that means that there is a reduction of the discharge capacity because of these straitened buckled conditions so we have to ensure that these discharge capacities are actually adequate for suiting to the soil conditions so all these need to be considered similarly this is the tensile strength of the test for the PVD.

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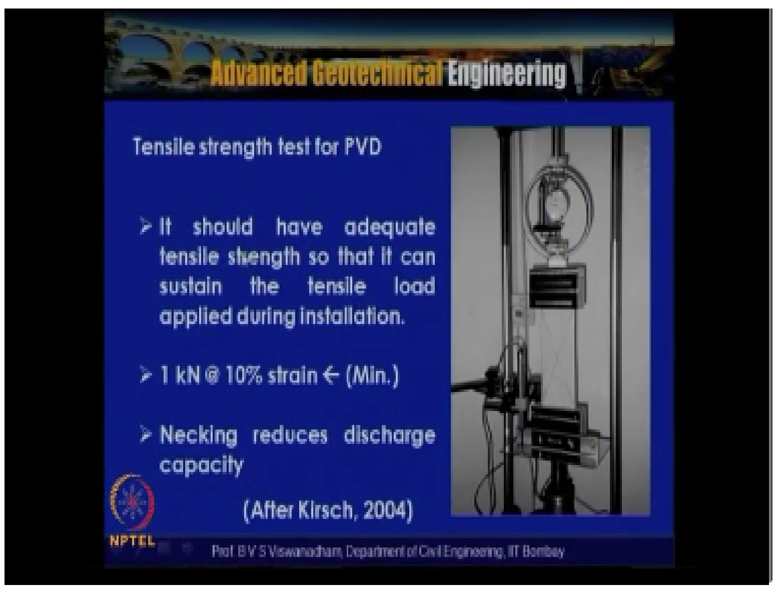

So it should have note that the sustain l strength should be such that it can sense does sustain the tensile load applied during installation so minimum 1kilo Newton is required at ten percent strain and necking actually reduces the discharge capacity so necking should be avoided so this is a typical you know constant rate elongation method testing for the you know combined PVD.

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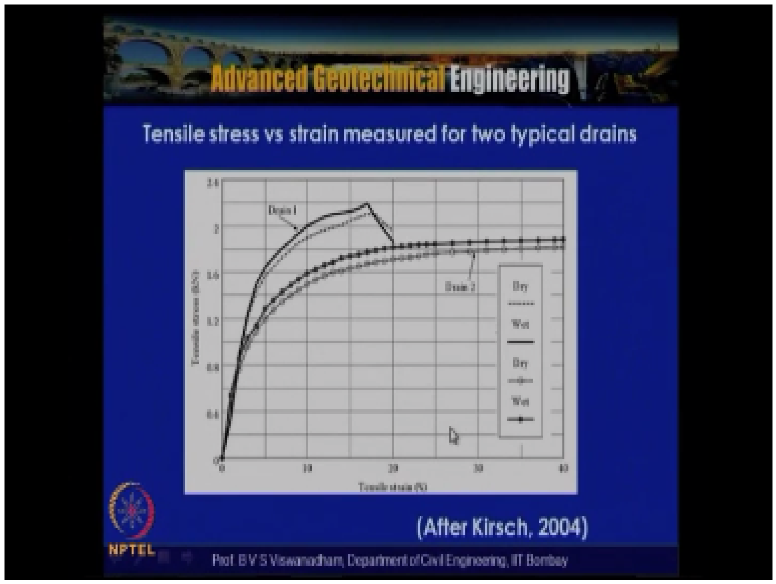

So this is the typical tensile stress strain measured for the two typical drains you can see that the drain one and drying too.

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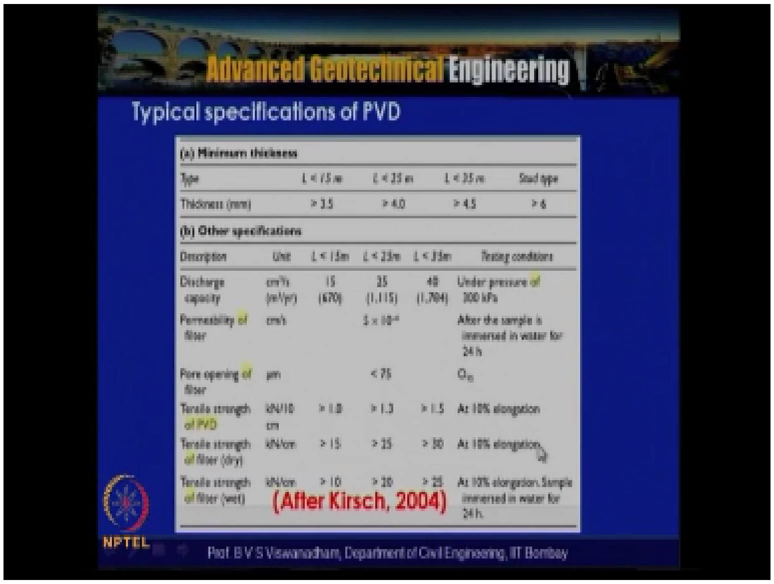

And these are the typical specifications of the PVDS which are followed in China for L less than 15meters L less than 25 meters and L less than 35 meters and wherein the thicknesses 3.5 4mm and 4.5 mm and you can see that the discharge capacities are about 60 70 and thousand and say eighteen hundred meter cube per year under the pressure of 300 kilo Pascal' sand the tensile strengths are actually there is a kilo Newton per ton centimeters is greater than 1 and 1.3and tensile strength the filter is also very important and tensile strength of the filter in better condition is also shown.

Here so tensors from the filter better condition is actually have to be less than you know this one but in the previous curve actually it was noticed that the tensile strength of the filter in the dryer in wet conditions actually more than dry condition.

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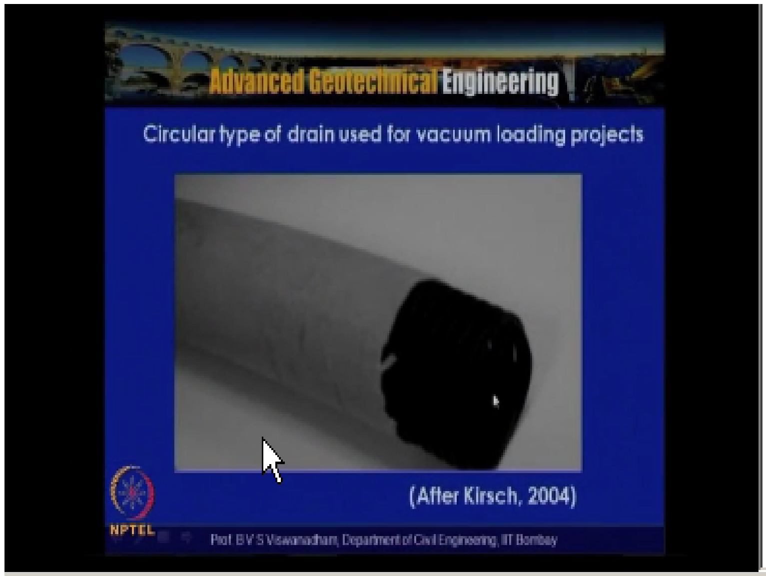

So this is the circular type drain used for vacuum loading you know projects so you can see that this is a typical drain use it for vacuum loading projects which is you know especially when the drain is actually connected.

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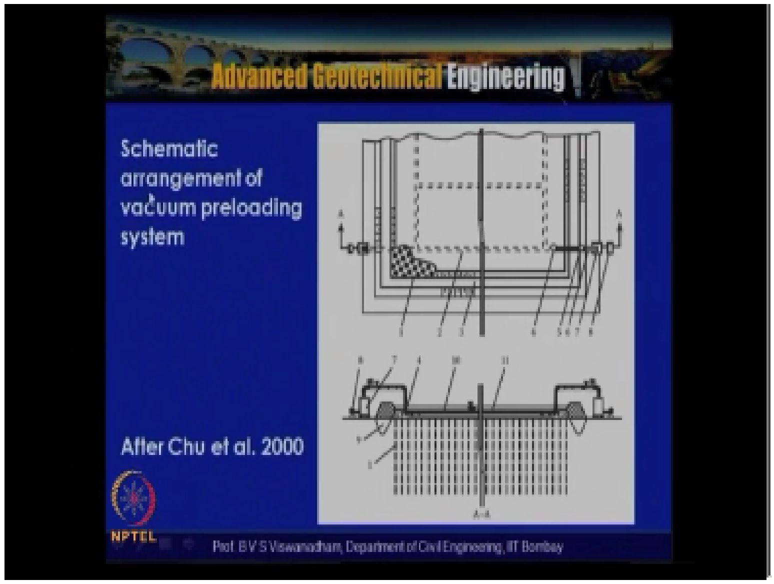

So this is the schematic arrangement of the vacuum preloading system now the currently the lot of research is actually happening in connecting PVDS directly to the vacuum pumps and with that what will happen is that the consolidation can be accelerated efficiently and without any preloading so this is a schematic sketch is actually shown here where we have PVDS and then different components which actually as you know which is connected to vacuum pumps is actually shown here.

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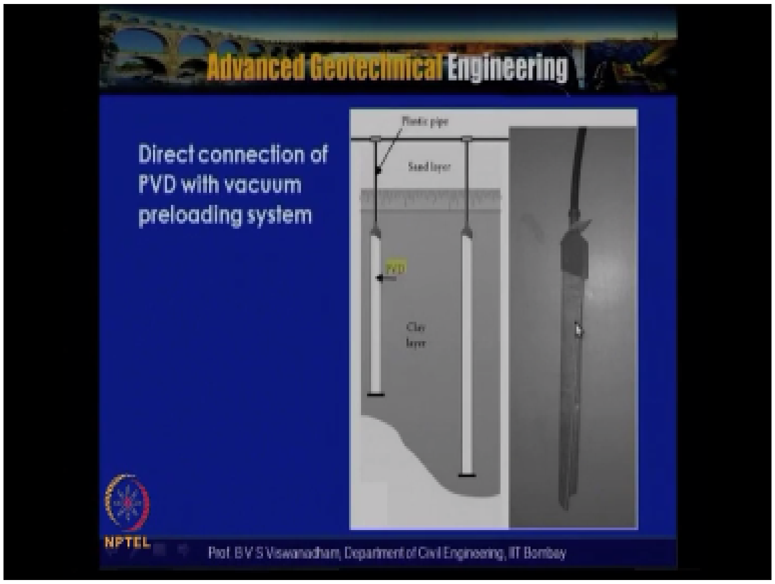

So here you can see that the PV Ds are connected directly to the vacuum pump so that the water is actually suckered into this so here in this particular arrangement of when we combine PVDs with the you know pivots in the in this case it is actually the PVD s actually have to do in case of vacuum pre-loading they have to do drain the water as well as apply the suction uniformly so in this way you know this will fiscal twin state for the better and efficient system so in this particular module.

We actually have discussed about the consolidation theories and thereafter we actually have disgusted you know the different types of conditions like normally consolidated and work-in solid soils and then finally we have discussed about methods for accelerating consolidation settlements consolidation and particularly we have discussed in depth about the you know vertical drains you know usage in accelerating consolidation and as a forward path we can see that a lot of potential is there for research in areas with the vacuum consolidation in combination with PVD and different applications of PVDS like as I said in the bioreactor landfills or mitigating liquefaction can be explored.

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