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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 28

Module – 3

Lecture – 10 on Compressibility and Consolidation

Welcome to lecture series on advanced geo technical engineering we are in module 3 and we are discussing about compressibility and consolidation in particular we are dealing with methods for accelerating consolidation settlements then we have introduce ourselves the one of the prime methods is to pre load the soil but in many situations it leads to huge amount of surcharges which are require to be place and the timing periods which are actually require to weight are very long in such situations one of the viable options is to provide drainage in the radial direction.

So for that we said that there are vertical drains which can be inserted in to the ground at certain spacing’s and certain you know pattern and we said that it can be in the triangular layout or it can be in the rectangular layout or it can be in the square layout so based on this considerations we are actually discussing about this radial consideration. So in the process what will happen is that both radial and vertical consideration they do occur at a simultaneously and then possibility of accelerating consolidation settlements are possible.

So with that this site will be ready with you know by eliminating the primary consolidation settlement before the construction of a natural structure, but these increase in strength of the soil is limited to you know not more than certain magnitude because if we need to you know transfer the load to the soil then we have to resort to some other materials like some other techniques like granular piles or stone columns.

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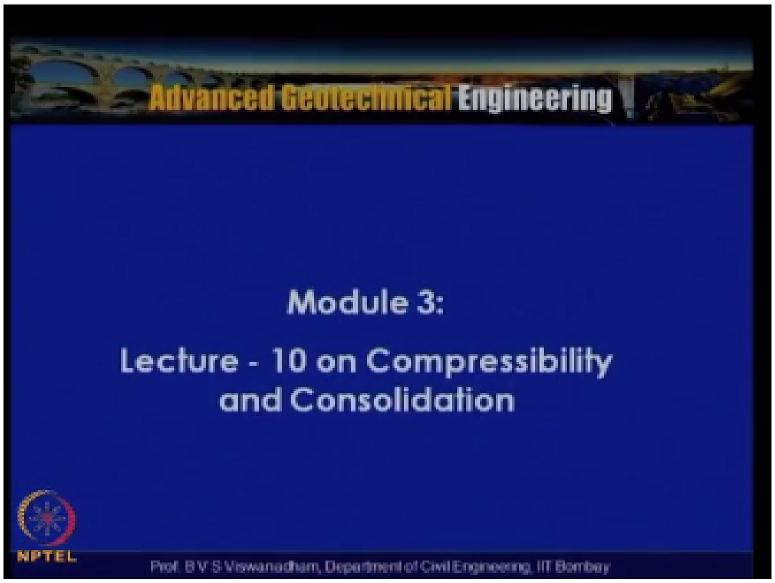

So this is module 3 lectures 10 on compressibility and consolidation, and we are actually discussing about the radial consolidation and theory behind this radial consolidation wherein 1948, as given the theory on the radial consolidation by assuming that only the radial consolidation teaks place and vertical consolidation is couple after you know analyzing for the radial consolidation.

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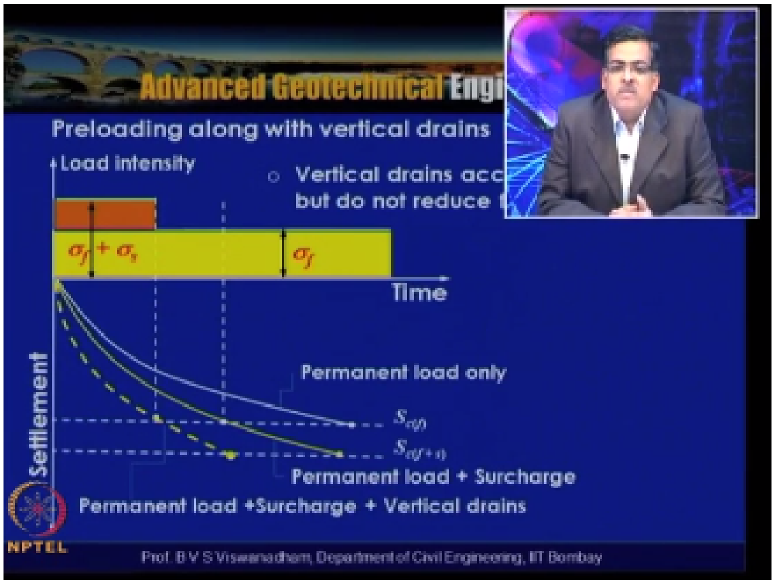

So in this particular slide this we have shown already and in this it shows that pre loading along with vertical drains so what it precludes is that the vertical drains accelerate the settlement but do not reduce the final settlements but the vertical drains they contribute to accelerate the settlements. In contracts just now I mentioned about stone columns or granular piles they accelerate the settlements as well as contribute to the reduce the settlement because of the reinforcing effect induced by the highly stiff material like stone columns.

So here in this particular the curve which is actually shown with broken line it shows that the settlements the you know the so-calls settlements occur in a less amount of time, so this implies that the site can be ready or the pre consolidation settlement can be you know ready in a given period of time. So this helps us to accelerate the consolidation settlements and then prepare the site for the construction.

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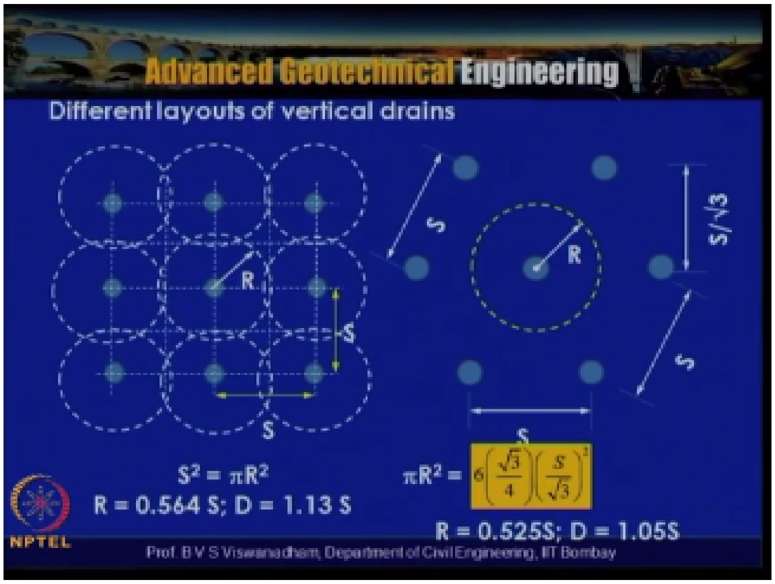

So these are the different layouts of the vertical range we have discussed one we said that is a square layout so wherein you see that the drains are actually place in the center so each drain will have a influence area and that influence area caters you know that caters to the particular that particular drain caters to the that influence area. So if larger the spacing then the efficiency of the so- called vertical drains also decreases.

Normally for see it started with sand drains and then how come to wick drains and then now the in model terms this vertical drains in the form of free fabricated vertical drains are very popular and the installation is faster and with that what will happen is that you know the drains can be reduced at a you know as minimum spacing as possible as 1.5 1 m to 1.5 m, so for square layout wherein the radius the effective radius d the diameter d are d suffix e = 1.13 s in case of triangular layout this comes out to be d = 1.05sso the procedure for calculating this tings for already discuss.

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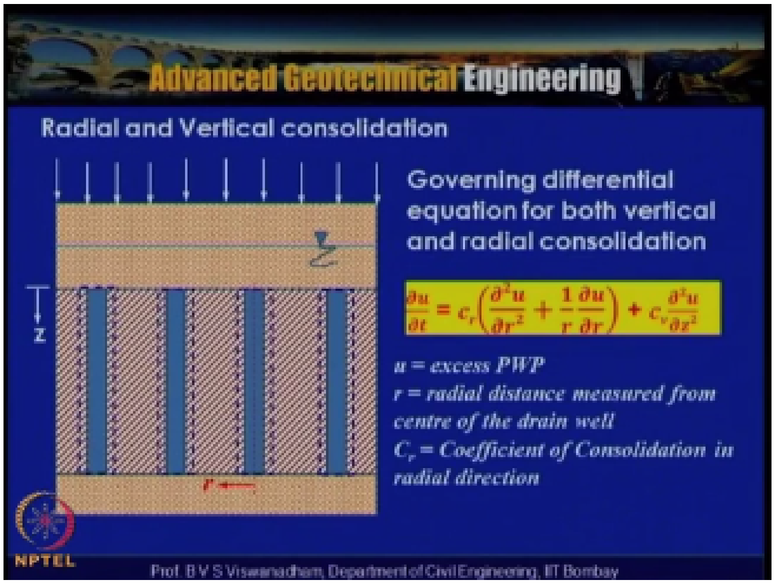

Now let us consider a soft clay which is you know strength and with vertical drains so the what you see in the blue color they are the blue color columns they are nothing but the sand filled drains are the drains which are you know have got certain discharge capacity so the, here what will happens is that each and every level there is a radial consolidation or radius takes place and then as well as the vertical drain is takes place depending upon the type of you know double layer or it has actually has got single layer.

So because of that what will happens is that you know you have double drainage or single drainage in vertical direction or it will have you know radial drainage. So but what we see in the in case of you know the so-called you know the sane drains a certain the broken line which is actually shown here that is the zone called smith zone and this possibly this can actually occur when you know the sand drains are actually installed particularly with closed pipe in soft clay.

So this is actually happen in one of the projects wherein the sand drains where installed in with the closed pipe and that actually has produced the enormous amount of smearing and we make which actually has made the you know the sand drains in effective and in a process what actually happens is that when the subject this to you know the stage by pre loading and because of the inefficiency of the installed sand drains the consolidation could not take place but from the t doctoral point of view is says that you know the stage wise loading can be release.

So because of this particular issues what will happened is that a collapse or if a failure of a stage wise bond will actually observed with that particular site, so the governing differential equation for both vertical and radial consolidation is given here wherein it says that $\partial u / \partial t = cr$ so c suffix r which is coefficient of consolidation radial direction it is also referred as ch. So we have discussed with that the ch which is actually more than cv because kh is actually more than kv and σh less than σ v for normally consolidated soils.

So with this $\partial u / \partial t = crx\ \partial 2\ u / \partial r2 + 1/r\ \partial u / \partial r + cv\ x\ \partial 2\ u / \partial z2$ so the first component of this equation it belongs to because of the radial drainage and the second component is conventional it belongs to the vertical drainage. So u is the access pore water pressure and r is the radial distance measure from the center of the drains well that means that from here center to the this resistance and a cr is the coefficient of consolidation in the radial direction.

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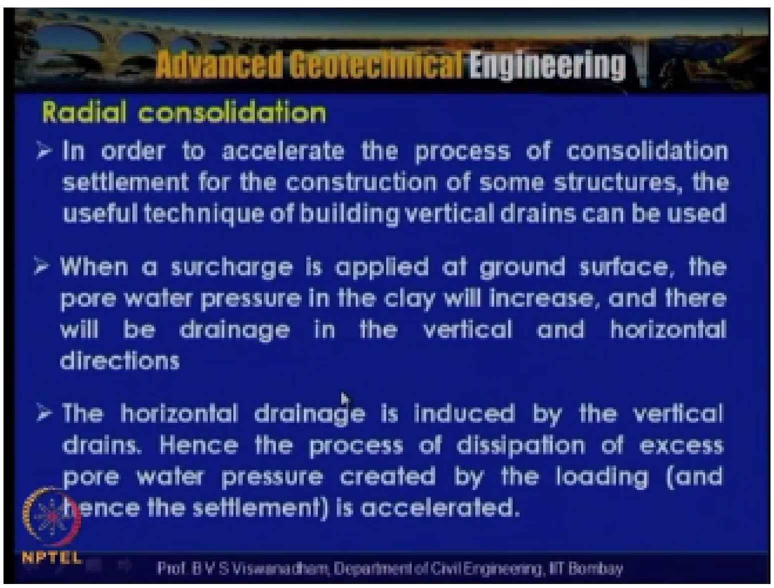

So in order to accelerate the process of consolidation settlement of the for the construction of some structures the useful techniques of building drains can be sued so when a surcharge is applied at the ground surface the pore water pressure in the clay will increase and there will be drainage in the and horizontal direction. So when the surcharge is applied you know there will an increasing in the pore water pressure and the drainage will actually happen in both vertical and horizontal direction.

And the horizontal drainage is induced by the vertical drains hence the process of dissipation of excess pore water pressure created by the loading that is hence the settlement is accelerated. So why the you know the radial consolidation are is effective because the way the horizontal drainage is reduce by the vertical drains and the process of dissipation of excess pore water pressure creates by the loading is accelerated.

Now in going to the theory of the vertical drains there are two cases which are actually have been derived here one is for pre stain case and other one is for equal strain case.

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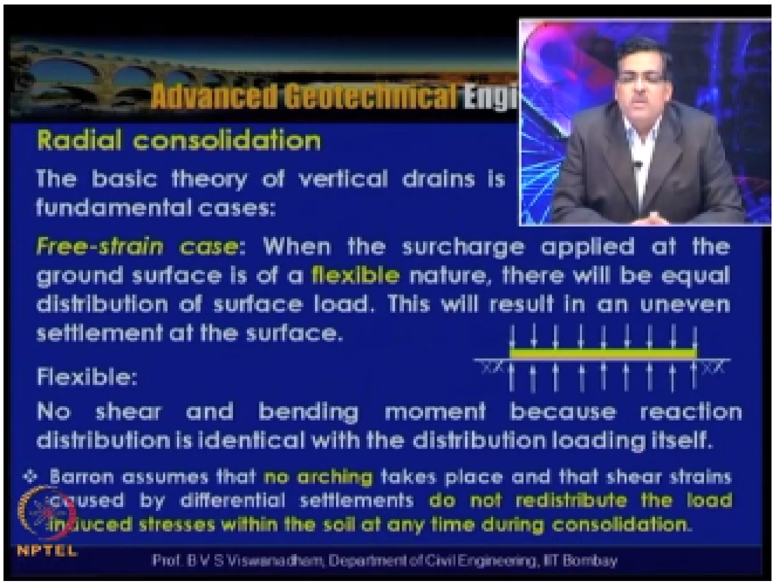

So free strain case is basically for flexible loading like an embankments when the surcharge applied at the ground surface is a flexible nature and there will be equal distribution of surface load that means that whatever the surface load will be there the reaction will be equal and opposite so because of this what will happen is that no bending moment and shear forces will generate and because as there is no the reaction distribution is identical to the distribution loading itself.

So because of that no shear and no bending moment occurs so because of this what will happens is that the stress are actually same but in order to keep the stress identical this settlements will be non uniform, so the Barron assumes that no arching takes places and that shear strains caused by differential settlements do not redistributes the load induces stress within the soil at any time during consolidation. So the first case is the free strain case where when the surcharge is applied at the ground surface is a flexible nature example an embankment construction.

There will be equal distribution of surface load this will result in a uneven settlement or differential settlement at the surface, so because it is actually shown here it typical flexible loading where the loading is shown here the reaction is shown, so as they both reaction and loading they are equal and identical are they are only thing is that they are in opposite direction. So because of that what will happen is that no shear and many moments generate.

So further Barron assume that no arching takes place and that the shear stress caused by the differential settlements do not distribute the load into stresses between the soil at any time during the consolidation so this a free strain case and which is actually for the flexible case more than cases if you are having a flexible condition and this condition will apply.

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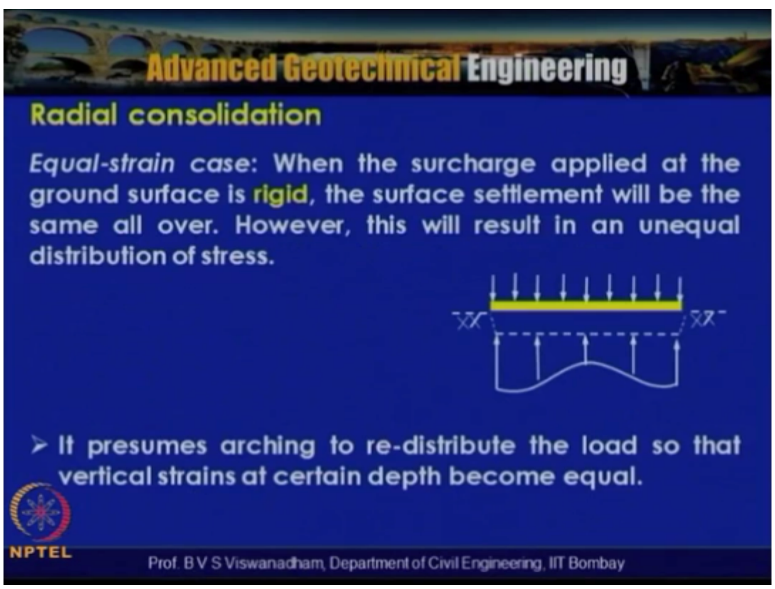

And equal strain case when the surcharge is applied at the ground surface is received that means is that if you are having a rigid foundation and the surface settlements will be same all over that means the settlements are taken surcharge this is the loading and the settlements are same all over and because the settlements are same in order to keep this the stresses will be non uniform here.

The reaction stress distribution will be non uniform here so this reaction stress distribution will be non uniform here so it presumes that you know the arching that you know it makes the archives the arching will be redistribute the load so this vertical strains at certain depth become equal. So they vertical stress so this vertical stresses redistribute in a such way because of the arching such a way that the vertical reaction stresses they distributed in a such way that you know the verticals trains at the certain depth are identical so this is a case of equal strain.

Now Smear zone one more thing which we have to discuss in the discussing about the radial consolidation is that test mere effect and this smear affect is to be very, very high for you know the sand drains conventional sand drains because of the reduction in the man roll dimensions sometimes even in case of fabricated vertical drains this so called smear is actually possible in case of even in case of free fabricated vertical drains.

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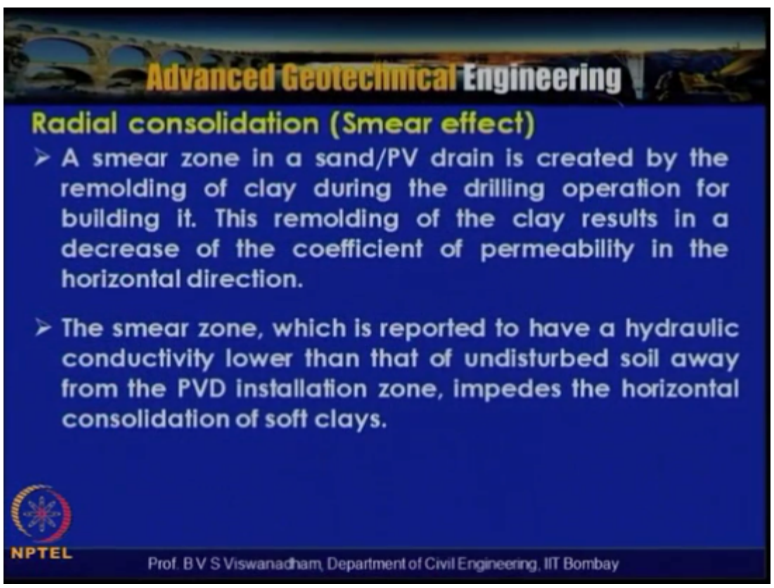

So smear zone in a sand or a free fabricated vertical drains is created by the remolding of clay during the operation for building it so this remolding of the clay results in decrease in the coefficient of permeability in the horizontal direction because the surrounding clay gets densities because of that what will happen there is the reduction in the coefficient of permeability so this smear zone which is reported to have hydraulic conductivity are permeability lower than that of undistributed soil away from the PVD installation zone so this actually impedes the horizontal consolidation of the soft clays.

So because of this lower permeability because this occurs because of the you know because the you will be confining increase in confining stresses required driving the man drill so because of that what will happen is that they surrounding soils gets densities and then because of this densification what happens is that there is the reduction in the coefficient of permeability.

So this reduction coefficient of permeability impedes the soils general consolidation of soft layers so instead of happening in a short duration of time it actually happen in long, long duration because that permeability in that zone is you know in comparison with the permeability in the undisturbed zone.

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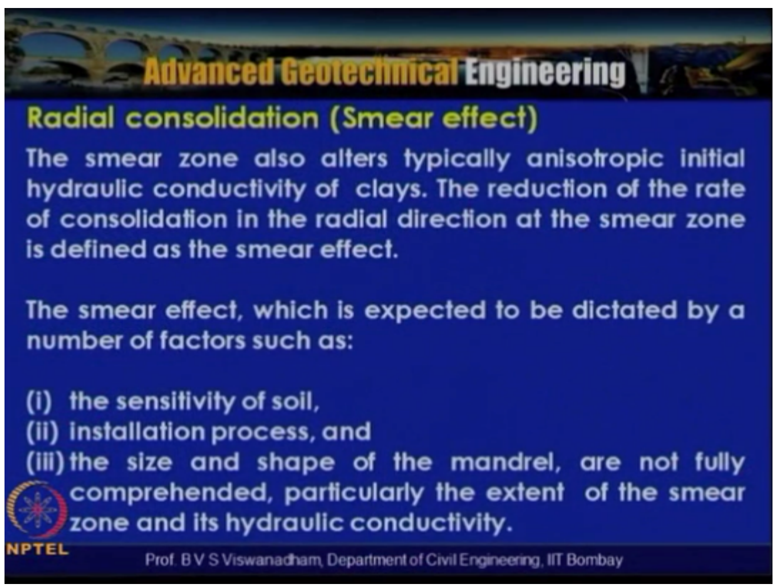

So the smear zone also alters typically the reduction of the rate of consolidation radial direction is at the smear zone so the reduction of the rate of consolidation in the radial direction at smear zone is defined as the smear effect so the smear effect which is expected to be dictated by number of factors such as the sensitivity of the soil and installation process and the size and shape of the man drill.

And basically they are not completely fully comprehended particularly the extent of the smear zone and its hydraulic conductivity so which is not very clear because the it the smear effect is gone to function of factors like sensitivity of the soil installation process and the size and shape of the man drill these are not basically they are not completely fully you know comprehended particularly the extent of the smear zone what is the extended of the smear zone.

There are some approximation which actually how been put for a investigators nod its hydraulic conductivity of that smear zone.

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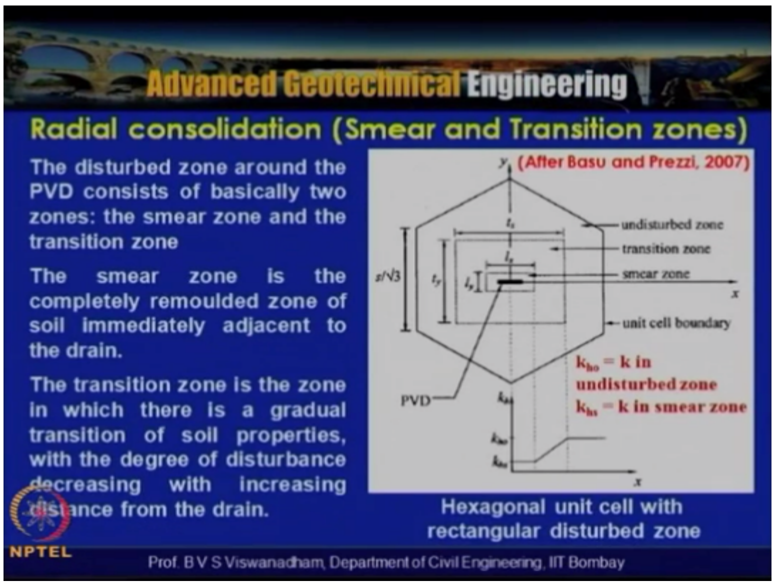

So this is according to Basu and Prezzel 2007 this is for you know PVD's so in PVD's what the portion is that it actually has got you know two zones one is you know three zones basically we can say surrounding the free fabricated drain one is the undisturbed zone that is ever from the drain and transition zone and then you know smear zone.

So there is a you know here for convenience is actually remarketed as the rectangular drain it can be seen that the smear zone is actually closed to the drain which is installed PVD and then this rectangular portion is transient zone and then this is actually is the hexongal portion which is actually shown is the undisturbed zone so the disturbed zone around the PVD consists of basically two zones smear zone and the transition zone and the smear zone is the completely remolded zone of soil immediately adjacent to the drain so this is completely remolded zone and the transition zone is the zone in which there is gradual transition of soil properties with the degree of disturbance decreasing with increasing distance from the drain.

So as we go away from the as we go away from the this one the soil properties actually gradually they change and then the decrease of the disturbance is actually decreasing with increasing distance from the that degree of the disturbance decreases with increasing distance from the you know drain so this is the hexagonal unit cell with rectangular you know distributed zone so where in this slide it depicts fro the reason to say in such that smear and soil transition zones are you know documented.

So let us consider for reducing the theory of the you know for particular degree of consolidation in the radial direction for both equal strain and you know free stain consolidation so here consider conventional.

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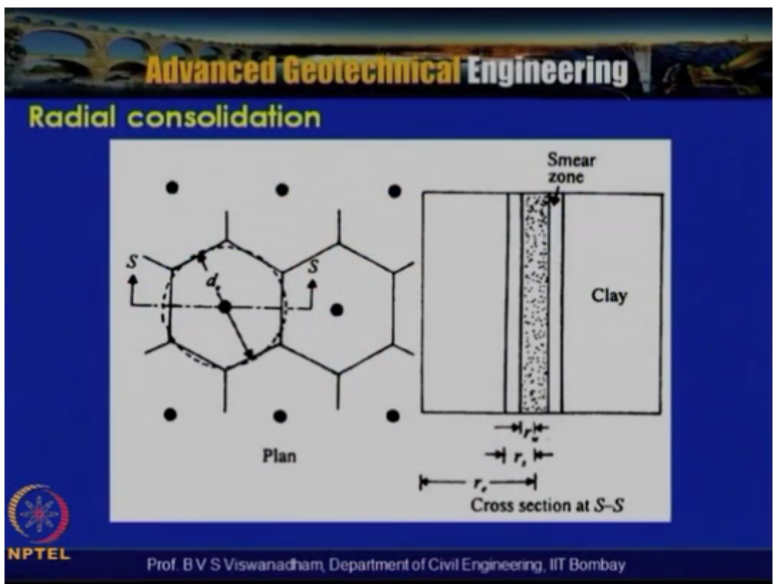

You know the theory is actually originally developed for sand drains but these theories can be extended to vertical drains without much you know difficulties so here this particular horizontal distance which is nothing but Re where two Re is nothing but De or as per our technology it can be capital D=De=2Re so that is the total influenced zone and this is the you know the zone which is actually called form the centre to this one Rs.

So that means when Rs=Rw, Rs=Rw means is that no smear that means when the installation has been taken up in such way that no smear actually has taken place so Rs/Rw so Rs is nothing but the centre of the from the centre of the well to the you know further end of the smear are completely remolded zone and Rw is nothing but the radius of the well so this is actually a cross section at S_S if you take across section this is how actually it take place this is one unit cell what we called for a typical triangular layout so this is the plan view of a triangular layout of the sand drains.

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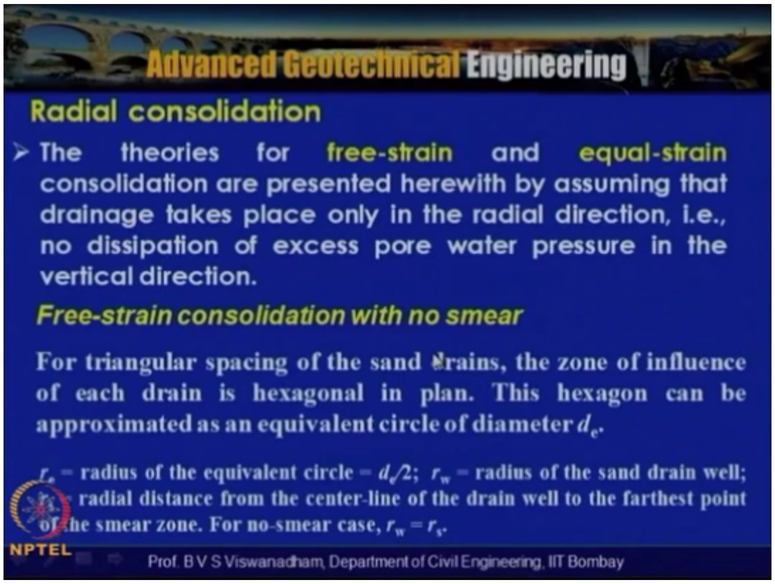

Now the theories for the free strain and equal strain consolidation are presented here with by assuming that drainage take place only in the vertical in the radial direction and no dissipation of excess pore water pressure in the vertical direction takes place so here we have decoupled in the sense is that the theories of free strain and equal strain consolidation are presented here with by assuming that that drainage take place only in the vertical in the radial direction and no dissipation of excess pore water pressure in the vertical direction so free strain consolidation with no smear so this is the first case.

We have actually has been considered afterwards we considered which smear and for triangular spacing of the sand drains zone of the influence of each drain is hexagonal in plan and this hexagonal can be approximated as an equivalent circle of diameter De where we said that De =capital De=2Re and Re is the radius of the equivalent circle.

Which is nothing but De/2 Rw=radius of the sand drain well and Rs is the radial distance from the centre of the drain well to the fastest point of the smear zone for no smear case Rs=Rw so this are the you know the notations which are actually defined in the previous figure which is actually shown in the previous slide.

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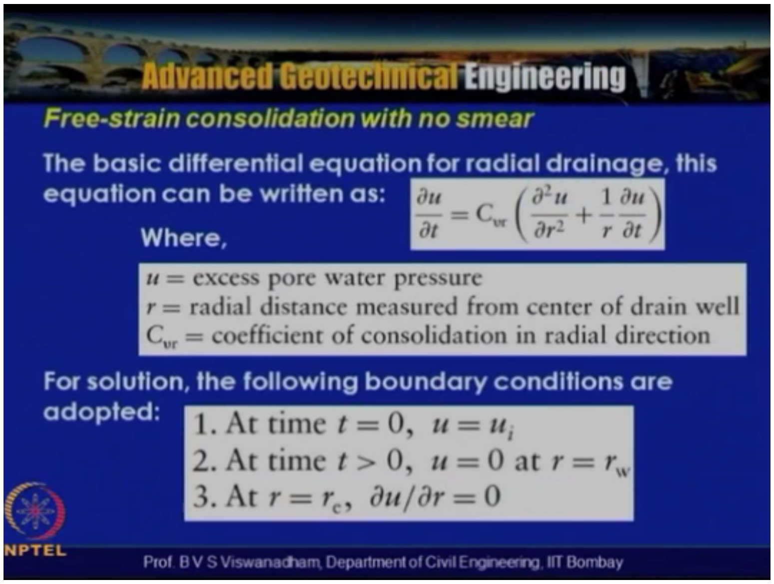

Now the basic differential equation for the radial drainage this can be written as $\partial u/\partial t=C_{vr}(\partial^2u/\partial r^2+1/r\ \partial u/\partial r)$ where u is the excess pore water pressure to be dissipated r is the radial distance measured from center of the drain well and C_{vr} is the coefficient of consolidation in radial direction this is also equivalent to Ch so for solution the following boundary conditions are adopted one is that at time t=0, $u=u_i$ that I nothing but the initial whatever the u_i the initial pore water that will increase in the $\Delta\ \sigma$ then $u=ui=\Delta\ \sigma$.

At time greater than 0 once the consolidation comes incises u=0 at r=rw that means that at the boundary of the well it is assumed that the pore water is 0 because the permeability of the sand drain is many times you know 10 to 1 million times more than the clay at time at r=rc that means that r=re were you know fastest end of that you know influence zone the $\partial u/\partial r=0$ that means that no consolidation no hydraulic drain is happened here.

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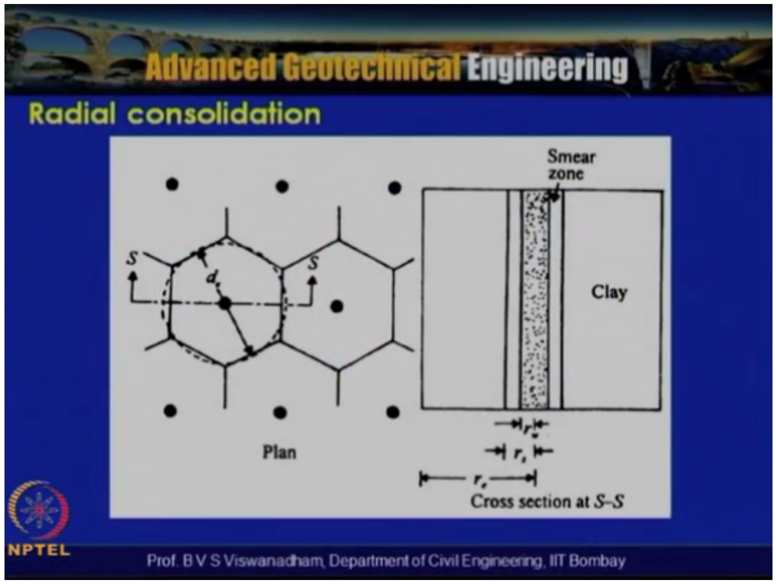

That is at this point when r/when at this point when you know here ∂u/∂r =0 is assumed here that means that there is no consolidation happens there.

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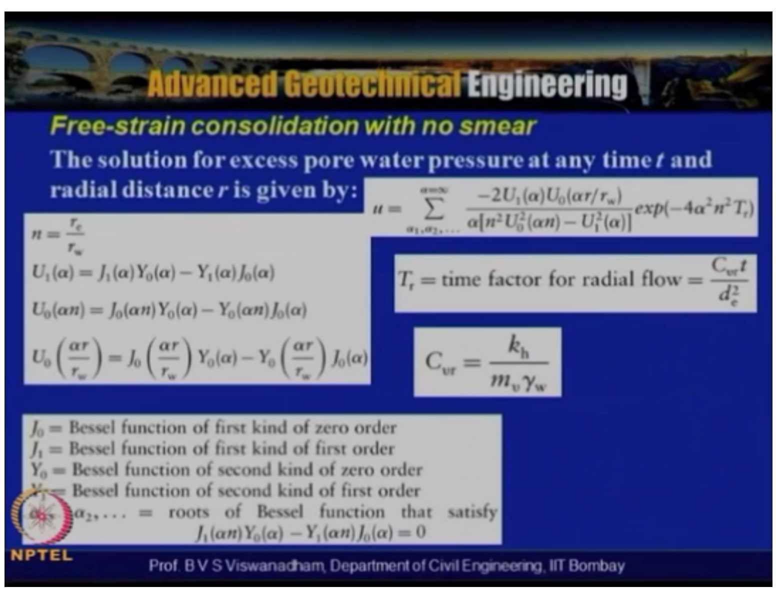

So by adopting these boundary conditions the solution for excess pore water pressure at any time t and the radial distance can be r is given by where it works out to be u with ∑ α1, α2, so on α ∞-$2e_1$ α u_o αr/rw/α within square bracket $n^2u_o^2$αn-un^2α exponential of -$4\alpha_2n^2$tr, tr is the time factor for the radial consolidation for the radial flow which is given by tcv, tcvr at tcr/de^2 so de^2 is nothing but now here you need to understand de2 is nothing but the effective diameter.

So n is nothing but re/rw or de/2rw nd then you know some bezel functions actually have been used and then the solution actually has been further simplified for the free strain consolidation no smear and Cvr =kh/mv γw so by knowing kh by knowing mv and by knowing γw we can actually calculate what is Cvr the r=cr.

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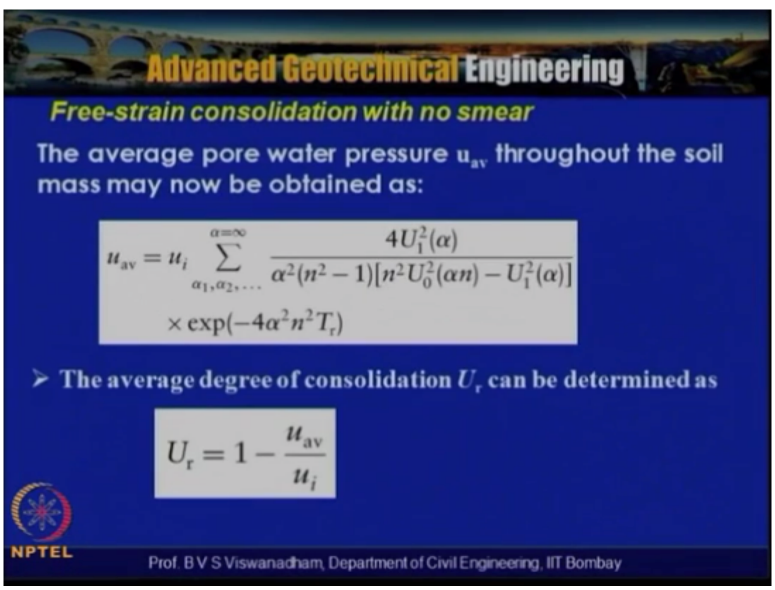

Now the average pore water pressure u average throughout the soil mass may now be obtained as u average is equal to u_i $\sum\alpha_1$ to α_2 to α∞$4u^{12}$α/α^2*L^2-1 and within square bracket and square u_o^2 α_n-u_1^2α and into exponential of you know -$4\alpha^2n^2$tr so the average degree of the consolidation can be obtained in radial direction has u_r=1-u average u average by u_i so u_r the average degree of consolidation u_r in the radial direction is given by 1-u average/u_i so with that you will get the u suffix r.

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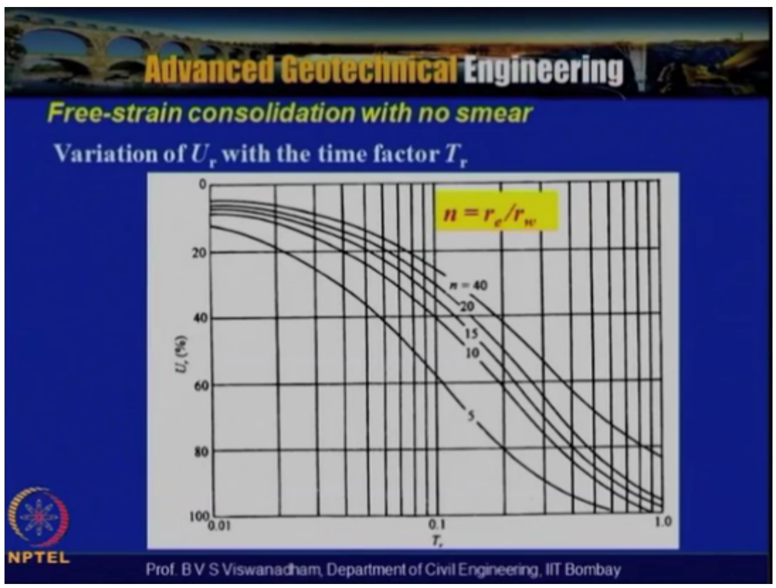

So this start actually with u_r verses pr where in for different values of n that is n=5, 10,15,20,40 like this for PVD's particularly because you know PVD's you know the diameter of the well because the PVD's come with you know some dimension fined dimension like that A dimension B dimension are having certain breath and thickness mostly the PVD's they come from the breath ranging from you know 95mm to 100mm.

And thickness is ranging from 3mm to 5mm so in the process what will happen these are actually approximated as the diameter of the well and because of that what will happen u actually tend to get the higher n values so variation of u_r with time factor P_r which is actually given here for different values of n where n=re/rw re is that you know they effective radius and Rw is the diameter of the well or drain.

So with that we can actually calculate by knowing for the certain time we can actually calculate what is the ur the degree of the consolidation.

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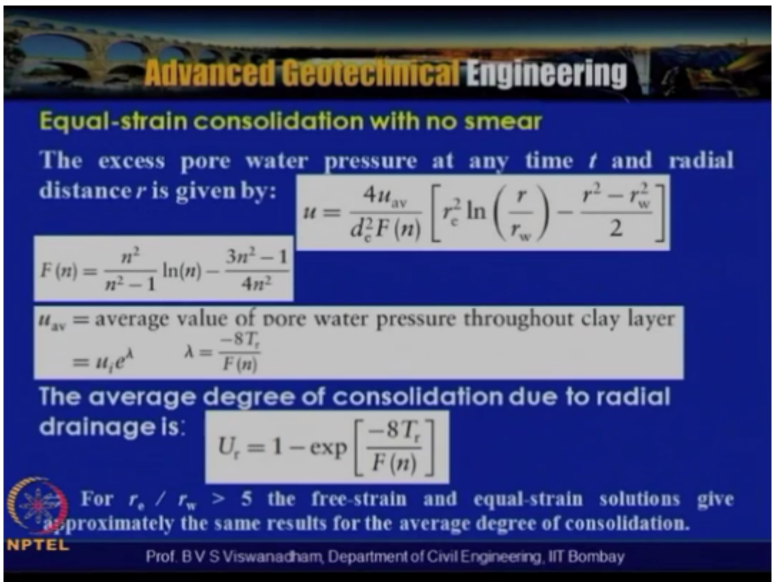

Now the equal strain consolidation with no smear this is actually case for the you know rigid case what we assumed and the excess pore water pressure at any time t and radial distance r given by u=4u suffix average d^2 function of n within sure brackets re^2 natural water of them r/rw $–r^2$-rw^2/2teh square brackets close so where fn function of n is nothing but n^2/n^2-1 natural logarithm of n-$3n^2$-1/$4n^2$.

So we can see that by substituting function n and then u average can be estimated like this which is nothing but average degree of value of pore water pressure throughout the clay layer which is nothing but u_i λ where λ=-8Tr/Fn where Tr=tcr/de^2 so the average degree of the consolidation due to radial drainage is given by U suffix r=1-expoenntial of you know –8Tr/Fn so for re/rw greater than 5 it has been you know you can noticed that it has been reported and it has been obtained that the both free strain and equal strain consolidation give approximately same results for the re degree of consolidation.

So for re/rw that is greater than 5 it has been noticed that the free strain and equal strain consolidation the yield you know identical results for the average degree of consolidation hence you know for the designed purposes with especially for PVD's and this condition is very much satisfied so because of that what will happen is that these equations are actually used in calculating the radial average degree of consolidation the radial direction and based on you know for given dimensions given layout whatever is actually obtained so with that we can actually calculated what is the average degree of consolidation after having obtained the average degree of consolidation.

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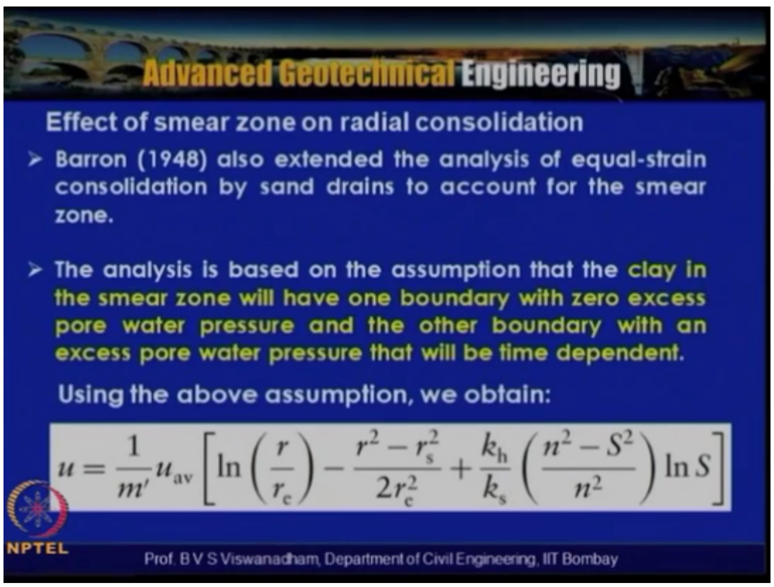

Then you know we can actually calculate club with vertical consolidation nd then calculate the u_{vr} where which is actually for both vertical and radial direction now let us previous whatever we had and we have discussed is that, that is for the you know without smear where Rs=rw now assumed that smear zone is actually is there because it is getting possible because of the what we have discussed about the sensitivity of the soil.

And the type of man drill what we used and because of that you know the smear zone or smear effect also have to be incorporated because we have discussed it that a smear effect actually impedes the degree of consolidation so Barron 1948 also extended the axis of equal strain consolidation by sand drains to account for the smear zone.

So analysis based on the assumption that clay in the smear zone will have an boundary on boundary with an excess pore water pressure and other boundary we can excess pore water pressure that will be time dependent so here in this particular you know analysis the Barron 1948 assumed that the clay in the smear zone will have an one boundary with an excess pore water pressure and other boundary we can excess pore water pressure that will be time dependent.

So on using the above the assumption we can actually obtained $u=1/m'$ u average natural $r/rc-r^2-r_s^2/2r_e^2+k_h/k_s*n^2-s^2/n^2$ log nurture logarithm of S where S is the you know that is smear there is you know S is nothing but the which is nothing but sc=rs/rw when s=1 and this actually reduce to you know without smear.

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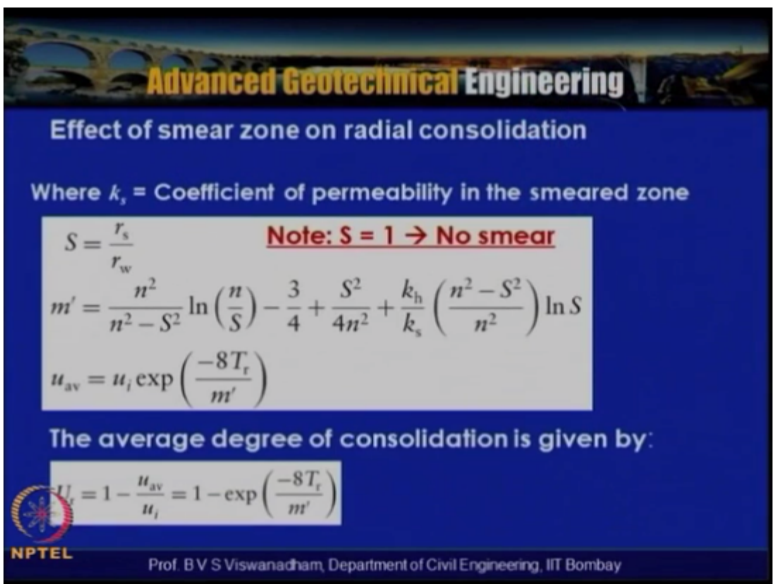

Now where you know k is the coefficient of consolidation smear zone and where S=rs/rw rs is nothing but the radial distance from the in the centre of the value to the fastest zone of this smear zone and m' is given by n^2/n^2-s^2 natural logarithm of $n/s-3/4+s^2/sn^2+k_h/k_s*n^2-s^2/n^2$ for S is equal to if I note that s equal to 1 that is no smear and the average degree of consolidation is given by $u_r=1$-u average by u_i with that what we can get is that 1-expoenntial of -8Tr/m'.

So instead of function n now is actually nothing but m' where m' is nothing but n^2/n^2-s^2 natural logarithm of S $n/s-3/4+s^2/sn^2+k_h/k_s*n^2-s^2/n^2$*natural logarithm of S and ks is nothing but the permeability of the soil in this smear zone.

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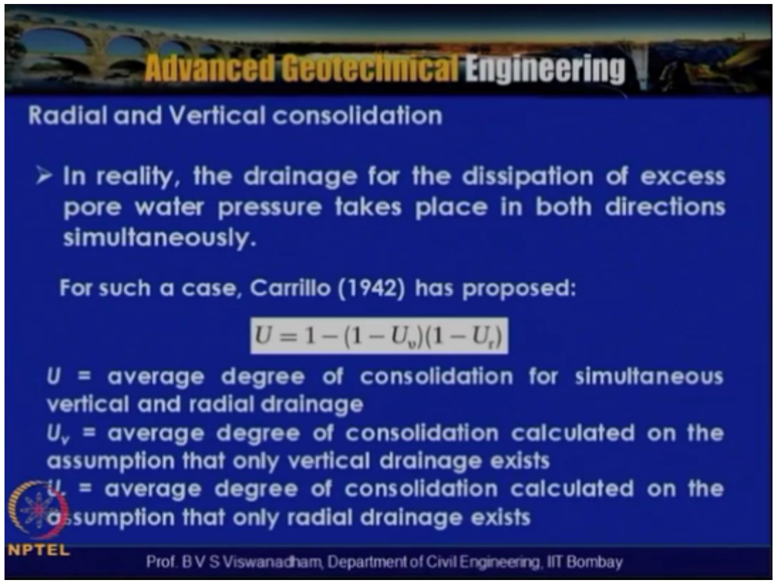

In reality we know that the drainage actually happens both in the excess both in the vertical direction as well as in the radial drainage so Carrillo 1942 he has proposed the following expression which actually nothing but u=1-1-uv*1-ur so by knowing you know after determining ur by equal strain consolidation with smear we can actually calculate uv this is by you know the convention method whatever we have discussed and then we can club and get the u which is nothing but uv u=u suffix v, r where this is actually average degree of consolidation for both vertical and radial drainage.

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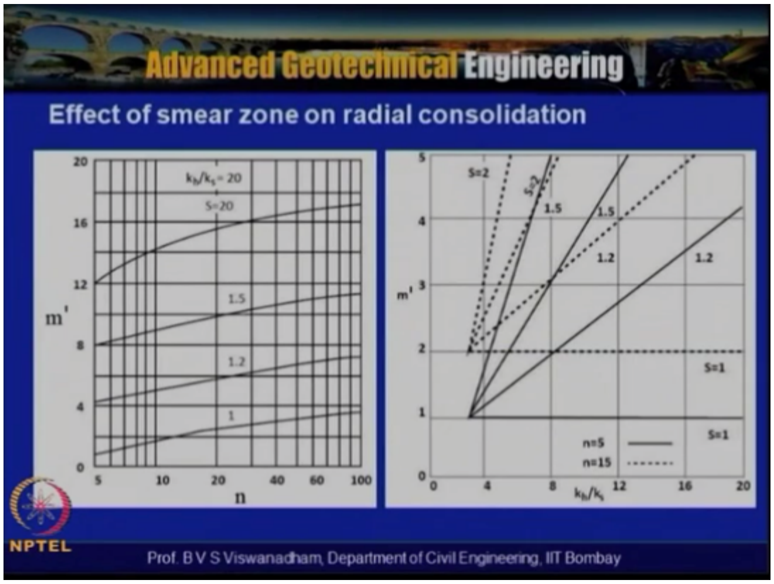

Now here the effect of the smear zone on the radial consolidation is actually given here and this chart is for left side chart is for n and this is for m' so you can be seen that for different values of s=1 s=1.2, 1.5 so this s=1 is that is no smear then with that what we can see that how the m values m' values change and this is actually only for kh/ks=20.

So in this case you know for two values of n that is n=5 and n=50 and for this is for s=1 with n=5 and this is you know n=5 nd s=1.2 and 1.5 so this actually starts actually show the effect of smear on the radial consolidation and the different values of ratios of kh/ks is actually assumed and with that you know it is assumed that how the m' actually where is with the values parameters which are vary.

Now the so before you know discussing bout the characteristics of the free fabricated vertical drain it is required to calculate of the understand about the design required with the pre loading with the sand drains of PVD drains.

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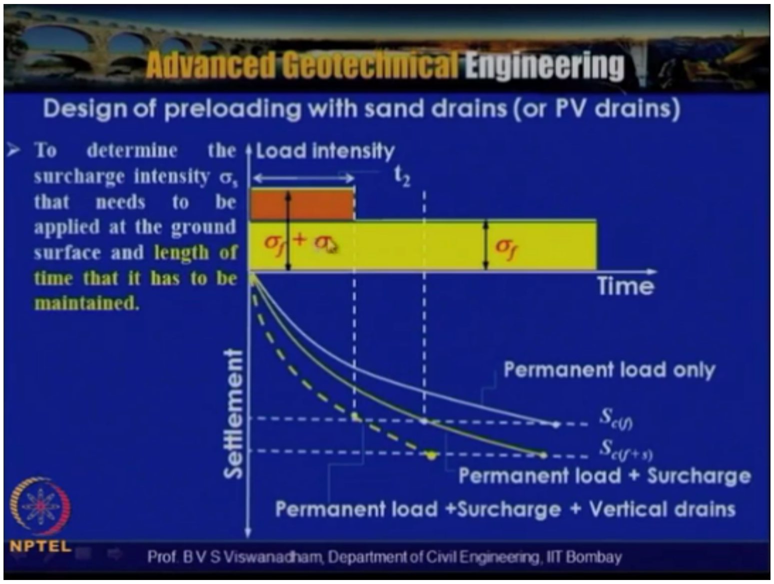

So here in this particular diagram which actually shown here so what we need to calculate is that if σ_f is the you know permanent surcharge which is actually you know which is going to be there nd we need to calculate you know what is that σ_s that is nothing but you know edition surcharge which is required and what is the time delay.

So many times what will happen is that time delay is actually given like 6 months or 9 months so in this 9 month you know if we wanted to complete say let us say certain degree of consolidation say 90% of degree of consolidation then we need to you know percale calculate what is the load which is actually required nd what spacing which is required.

So we have to start with certain assumptions and based on that we have to do if that assumption is actually proving to be over conservative it can be come to you can actually do the optimization so with that we can actually calculate what is the time which is required to you know accelerate the consolidation so the design basically it includes it remains the surcharge intensity σ_s that needs to be applied at the ground surface and the length of the time that it has to be maintained that is the length of the time or duration of the time which is required to be maintained.

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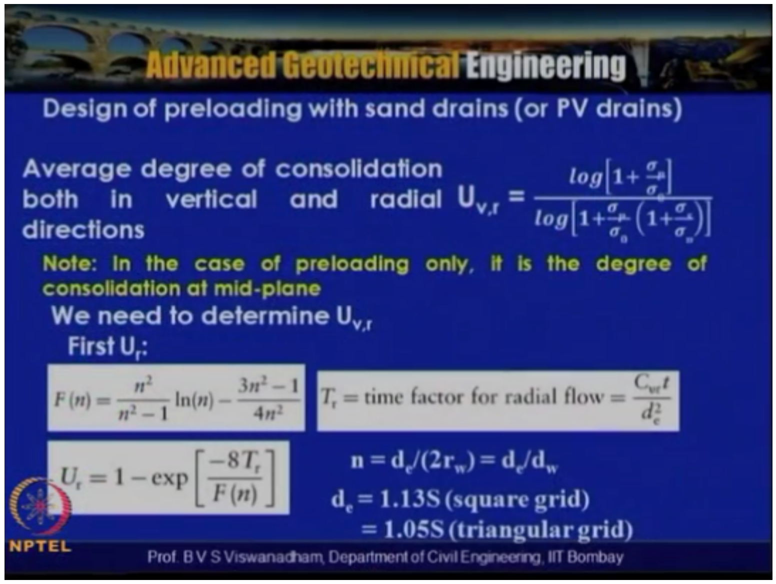

So for the doing that you know what we need to do is that we actually have to calculate average degree of consolidation both in vertical and radial direction and we also have to calculate what is the radial degree of consolidation and vertical degree of consolidation then we have to combine by using this method and calculate so here you know we need to calculate the average degree of consolidation both in vertical and radial direction in case of pre loading only we have said that it is the degree of consolidation at the bit plane.

But in this case it need not be like that it can be calculated in the position which we are going to discuss now so first what we do is that we assume that only radial drainage take place because of the provision of the you know sand drains or Pv drains so in this case by assumed layout let us say with certain spacing and certain pattern let us say we have got a skew grid men de=1.13s where s here is the spacing centre to centre spacing of the drains and de=1.05s which is for the triangular layout.

So by determining function n, n^2/n^2-1 the logarithm of n-3n^2-1/4n^2 and with that what we can actually get is that Tr is the time factor fort the radial flow can be obtained as for given time Tcvr/de^2 the cvr is nothing but the radial coefficient of the consolidation the radial direction and by de^2 many times what will happen is that in order to counter for this smear it is assumed that the ch=cv and once the ch is actually more than cv but in order to counter in order to consider the possible effect due to smear in the simple way by not considering smear and then it can be taken that cvr=ch=cv with that we can actually calculate what is Tr, Tr I nothing but the time factor for the radial flow where Tcvr/de^2.

Nd after having obtaining T_r and fn we can actually calculate degree of consolidation the radial drainage u_r=1-expoenntial of -8Tr/fn where n=$d_e/2r_w$ which is nothing but d_e/d_w and d_e=1.13S square grid at 1.05S for the triangular grid.

So after having obtained that before you know for as far as the PVD consent you know because the PVD is actually having dimensions which are actually nothing but the diameter of the well which is approximated based on the drain geometry and configuration so after Hansbo 1979 the diameter of the well is equalized like this.

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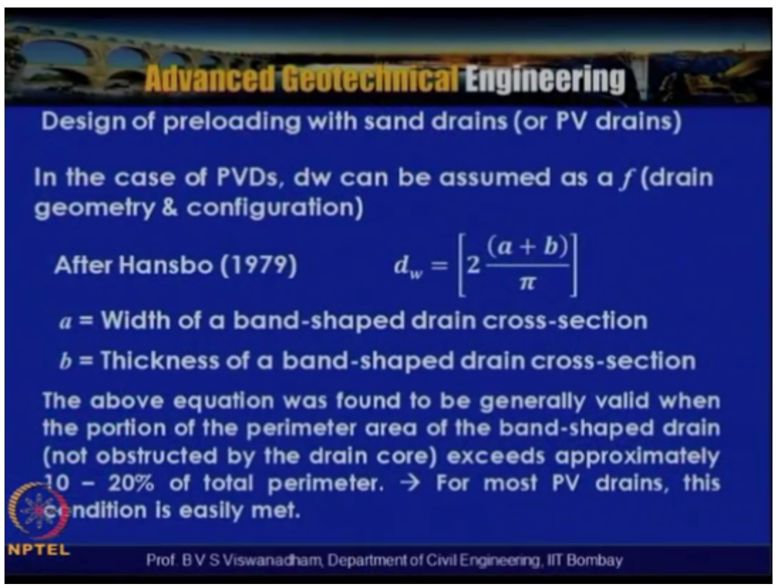

So dw=2*a+b/π so this actually has been obtained nothing but you know by equating πdw that is nothing but the you know perimeter of the diameter of the well is equal to 2*a+b where a is nothing but the breadth of the you know the PVD and B is nothing but the thickness so A is nothing but the breadth of the band shape drain cross section.

And B is nothing but the thickness of the band shape drain cross sectional so by equating you know 2*a+b=πdw we get the dw=2*a+b/π there are also some other considerations where in you know based on the analysis many investigated actually have come forward took forwarded different type of you know different equivalent diameter of the wells.

But however this prove to be universal in actually adopting in the design so the above equation as found to be in generally able when the portion of the perimeter are of the drain not abstracted by the drain quote exceeds approximately 10 to 20% of the perimeter total perimeter so for most of the PVD drains this condition is easily met for most of the PV drains this condition will be easily met.

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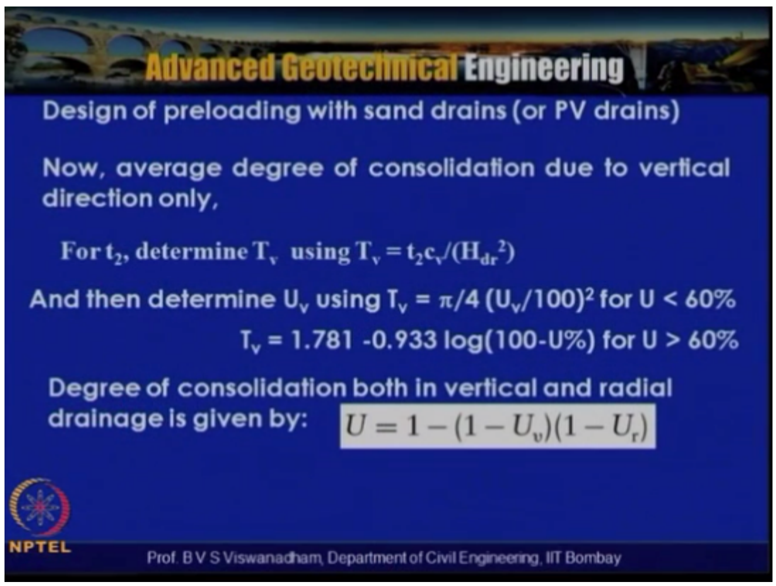

So after having obtained the radial drainage what we need to do is that the average degree of consolidation due to vertical direction only for this you know what we need to for time t2 determine you know tv which is nothing but t2*cv/hdr2 so here being vertical drainage by knowing that thickness of the clay we can actually calculate you know what is the time factor Tv and for time factor Tv after having time factor calculate the degree of average degree of consolidation vertical direction by using hither by using type of 1.781-0.933 logarithm of 100-U % for U >60% .

So after having obtained Uv then using the Carrillo 1942 expression e can actually calculate the Uvr=u=1-*1-uv*1-ur so with that we able to get the average degree of consolidation both in vertical and radial drainage so after having obtained the vertical and radial drainage this thing.

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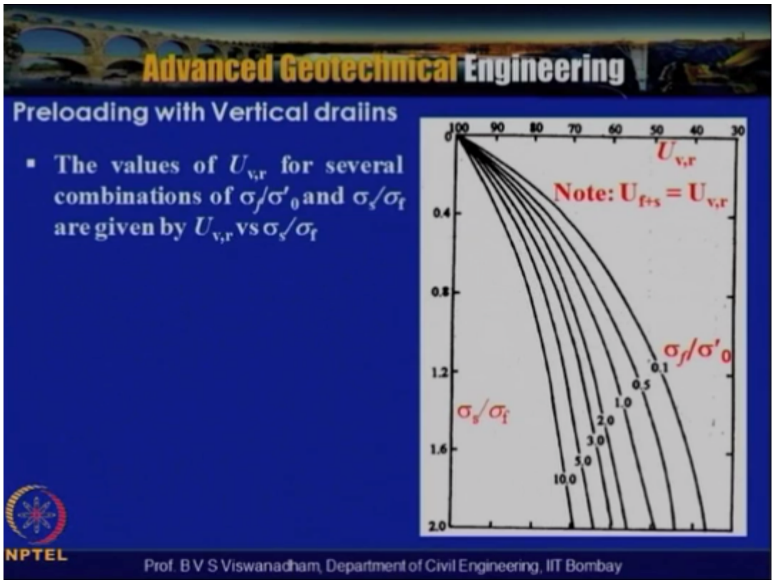

So once we get the Uvr and by knowing you know σf which is actually permanent load and σ_o' is effective stress at the mid of the layer we can actually calculate what is σs/ σf so here we need that previously we have said that u=uf+s=here we assume now this is nothing but uvr so with this actually what will happen is that the presence of drains because the accelerate the radial consolidation so you will have the you know σs/ σf values are very low values because the degree of consolidation will be high and the values are low.

So this actually tells that you know the pre loading which is actually required with you know with the drains is actually is very low magnitudes and so that you know the stability chooses the all other issues will not be there so we actually have discussed while discussing the pre loading you know we have example problem.

We have discussed and we said that you know when we wanted to have accelerate the consolidation by using pre loading we said that there is the you know fill which is actually required is about 2o7 kilo Pascal's and which actually indicates that you know require very high embankment for allowing the consolidation to takes place and there will be actually have stopped saying that for adopting the solution there can be some stability issues which actually can hammer the you know the process.

Now let us see the same example you know by provision of the drains so that will understand the drains in accelerate the consolidation and also bringing down the required use heights of the pre loading so this is in the continuation of the deign problem solve with the pre loading only.

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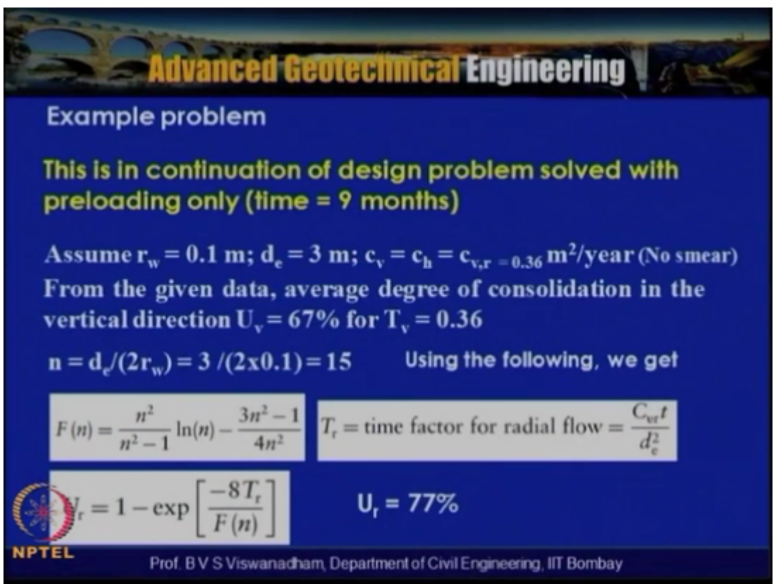

And at that time we said that the sight to be ready in time with 9 months so we also assumed that the same 9 months and assume that and assume that rw=.1 meters that means that .2 meter is the diameter of the drain and effective diameter is given as 3 meters and Cv is equal to ch is equal to cvr is given as .36 meter per year and no smear zone and from given data the average degree of consolidation the vertical direction uv 67% or for Tv=.36.

So based on that we can calculate first n and n=de/2rw which is nothing but 3/2*.1 so with that what we get is that 15 now using the following hat we get is that for n=15 you calculate what is function n so function n can be calculated by divide by n^2/n^2-1 natural logarithm of $n-3n^2-1/4n^2$ after having obtained function n after having obtained Tr nd function n you calculate ur so ur in what we get is that about 77%.

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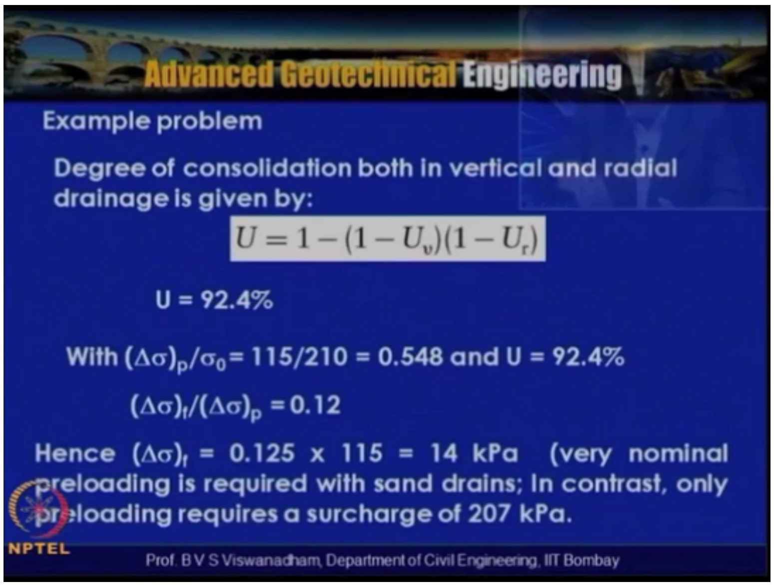

Now after having obtained you know this uv you know 67% and ur 77% by using the degree of consolidation both vertical and radial direction is given by u=92.4% so u=uvr=92.4% and from the given problem we know that Δ σ p/ σ_o or σf/ σ_o that is from the previous chart here σf/ σ_o where it actually shows that it is actually 115/210 that is .548 and U=92.4%.

So you can calculate and see from the curve here .5 that is somewhere here and 92.4 we can see that the σ_s/ σ_f is actually required σ_s is the height of the pre load which is required and σ_f is the permanent height and which is coming to around you know so this is .2 so this is .12 so what we get is that this comes to be .12 that means that you know what we required is about 14 kilo Pascal's so is about height of you know less than a meter it will provide is actually sufficient for the given soil properties but actually has been considered.

So very nominal pre loading is required so with the sand drains in contrast for the example what have we taken it actually 207 kilo Pascal's which is you know beyond you know the difficulties but you know as have been discussed actually that the considering the soil properties there are also some cases where people combine working consolidation as well as pre loading with that what will happen is that up to working with the help of working consolidation what we get is that you know the pre loading height will further reduce and then there is the possibility that you know the it can consolidation that actually happen and here with that what will happen is that you will have both working consolidation as well s the pre loading effects.

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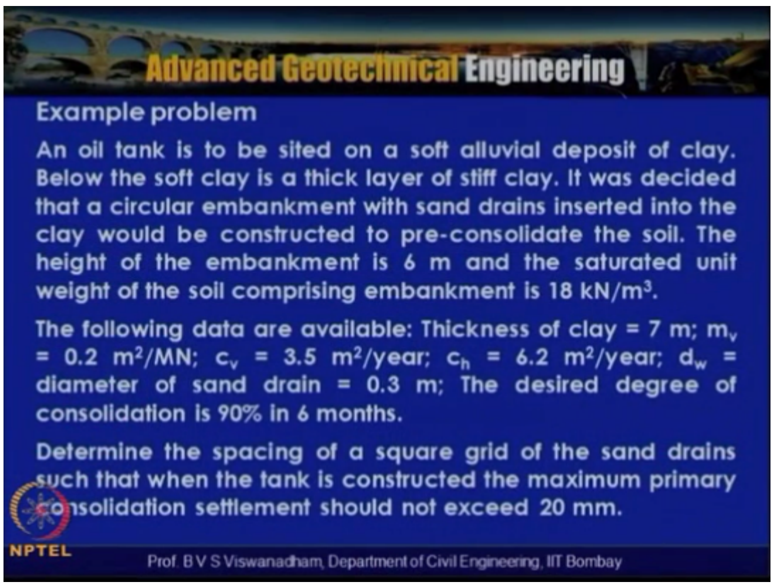

So let us take a problem were the oil tank is to be sighted on a soft alluvial deposit of a clay and below the soft clay is the thick layer of stiff clay so that means that it is actually has got only one way drainage it was decided that the circular embankment with sand drains inserted into the clay would be constructed to pre consolidate the soil the height of the embankment is 6 meters and the saturated unit were to the soils compressing the embankment is 18 kilo meter cube.

And the following data are available the thickness of the clay is 7 meters and coefficient of volume compressibility is .2 meter square mega Newton and Cv is 3.5 meter square per year and ch is equal to 6.2 meter square per year and cv is 3.5 meter square per year and ch=6.2 meter square per year and d_w is that diameter of the sand drain is equal to .3 meter so the degree of the consolidation is 90% in 6 months.

So it has been given year that desired degree of consolidation both in vertical and radial direction is actually given has 90% in 6 months and determine the spacing of square grid of the sand drains such that when the tank is constructed the maximum primary consolidation settlement should not exceed 20 mm so here the condition is that he calculate the spacing for a spacing for a square grid of sand drains or the so called vertical drains such that when the tank is constructed the maximum primary consolidation settlements should not exceed 20mm.

So now this square pattern has been given so and the spacing need to be assumed so by we can actually calculate de and by assuming certain spacing band then calculate fn and then calculate Tr and then calculate you know for different spacing you calculate and then based on once we get this ne then we actually you know desired consolidation and desired meets the desired conditions so this solutions is get to be done at your n.

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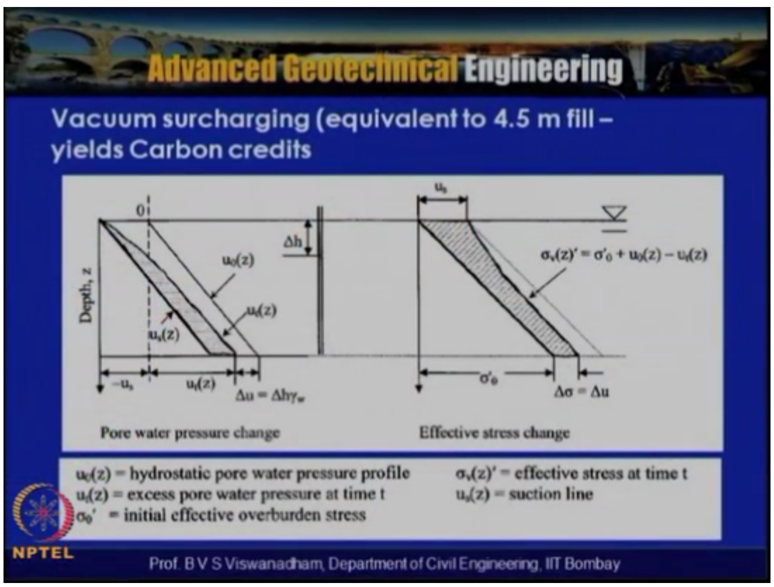

Now as, as been introduced one of the alternatives to substitute pre loading is working surcharge at the working consolidation and this is ctually gaining popularity the recent past because of you know the requirement of the reduction the carbon credits and so equivlnet bto 4.5 meter field basically is effective we can obtained by putting this vaccum consolidation so here the typical you know the pre loading to pore water pressure changes and effective surcharge changes due to pre loading or actually discussed and here you can see that this is in case of vacuum pre loading so we can see that this is the hydrostatic pore water pressure before any application of you know the pre loading joule to vacuum and what will happen is that moment working consolidation actually takes place the section which is gets reduced to –us here and –us here.

So with that what will happen is that the from that point onwards you know the soil trace to come to the radial consolidation so in the process what will happens is that the effective stress increases buy this amount any depth at σ_v that the σ_v' z= σ_o+u_oz-usz so with that the effective stress increases and this is the portion at to be you know dissipated so the u_oz is the hydrostatic pressure and utz is excess pore water pressure at time t.

So this actually has got a possibility that you know reduces the surcharge pressure and then this surcharge once it actually gets transfer to the entire soil and the effective stress increases by the amount by which the succession has been induced that means that if you are able to induce about the Pascal's of succession the effective stress increases by increased subsequently or period of that time about you know 80 kilo Pascal's.

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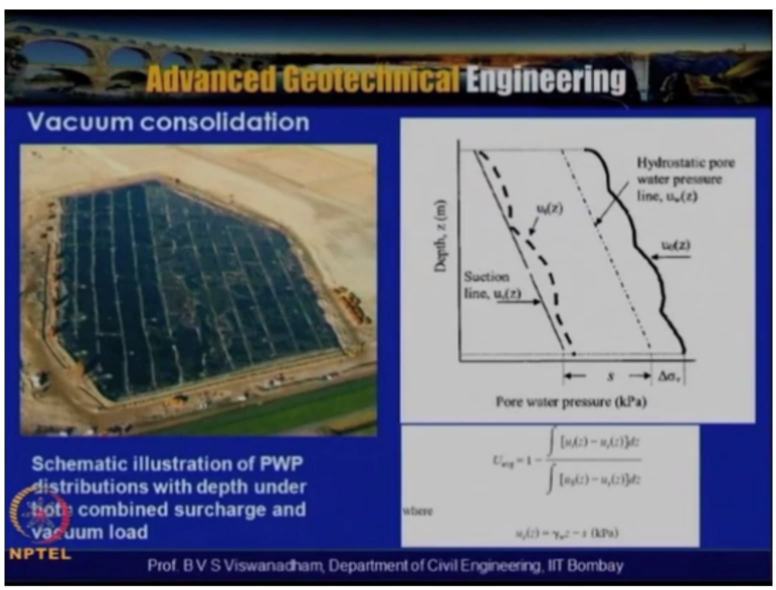

Now this particular slide actually shows the way typically vacuum consolidation is don at the sight so in this what actually has been done is that either with vertical drains it will be much more effective and faster and if you are actually having this drain which is actually connected with you know PDV's and what we need to do is that it actually need to connected to the pump where it actually the surcharge is maintained.

So where the succession should not subjected to any leak here so this is the hydrostatic pore water pressure nd within due to any possibility of some pre loading which actually happens in the process and this will be the you know u_0z and this get reduced to usz and work period of time and then you know the effective stress is increased by that mount so we can cruelly calculate what is the average degree of consolidation here.

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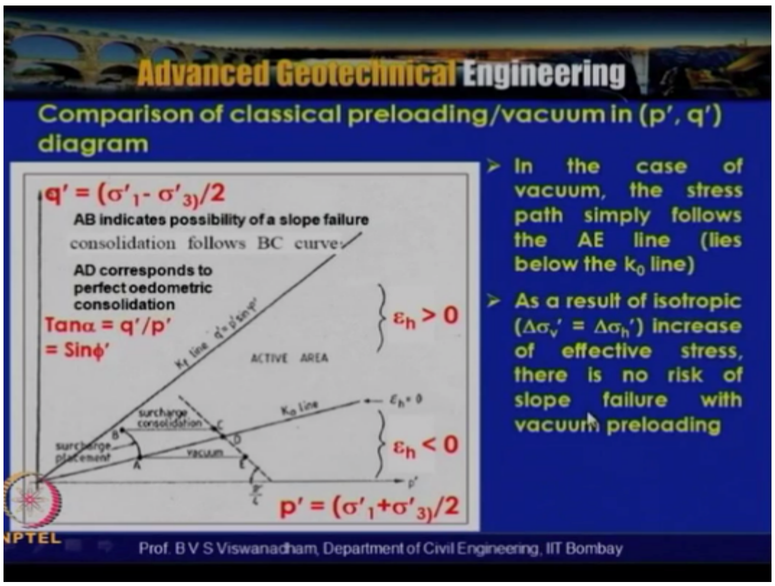

Now another advantage from the stress path diagram we can actually look into the when you take pre loading or vacuum we can see that from p' and q' plots where p'= σ1'+ σ3'/2 and Q'= σ1'- σ3'/2 so it can be seen here that in case of a pre loading there is always a possibility that AB is indicating you know the line actually traverses towards the failure line you know AP indicates the possibility of the slope failure.

And consolidation for also once you know if it touches the earth then there is the possibility that means that you know as we discussed in the previous problem if the heights re actually very high and when you do the pre loading and soft clays there is the possibility of the you know instability which actually can occur and the based where can use can actually come.

So when the in this case BC line indicates that you know subsequent surcharge in consolidation but where in case of you know in case of so called working consolidation that AD that is actually you know is the process of vacuum consolidation and were in the case of vacuum line the stress parts simply follows the AE line lies below the k_o line so AE line is the you know the below the K_o line.

That is K_o line is the at pressure okay so as the result of isotropy consolidation because the pressure vacuum consolidation identical in both the directions increase effect in the stress there is no risk of slope failure with the so the important you know understanding what we had from this slide is that the slope failure will actually not be arisen with vacuum consolidation but where as in case of pre loading there is the possibility of the you know slope failure baecuse before you know the commencement of the consolidation there can be a possibility of the failure.

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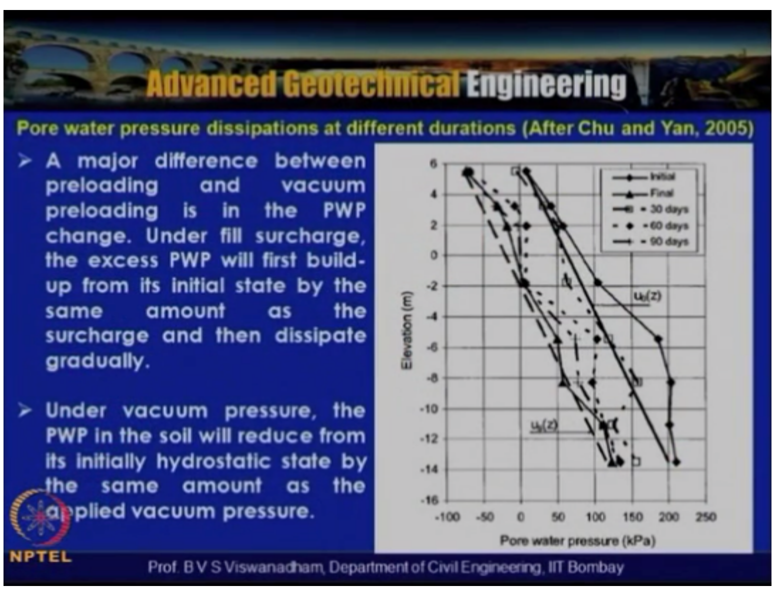

And in this particular slide after Chu and Yan 2005 a case study which actually has been monitored she can been seen that you make difference between pre loading and vacuum pre loading is that pore water pressure change and the field change under fills surcharge the excess spore water pressure will first built up from initial state by the same amount as a the surcharge has been dissipated gradually.

Under work in pressure the pore water pressure in the soil will reduce from the initially hydrostatic by the same amount as the apply vacuum pressure so here you can see that you know the when the pre consolidation is actually applied from here but actually reduces to this certain level and then over period of 30 60 70 days actually it increases to that one that means that the effective stress has the you know soil is actually transverse you know the soil effective stress can be water transfers to this soil there is the increase in the effective stress so with that what will happen is that under vacuum pressure the pore water pressure to the soil is reduced by initially hydrostatic state by the same amount the applied vacuum pressure.

So in this particular lecture what we discussed is that you know the theories behind you know using equal strain consolidation and you know for the radial equal strain and free strain consolidation and we said that for greater than 5 we said that both equal strain and consolidation yield is identical results hence especially for the PVD the equal strain consolidation is actually adopted.

So then we also discussed that design how it can be for with incorporating free fabricated drains so with this we will actually tried to design you know a particular time which is actually required you know in order to accelerate the consolidation for given layout of you know vertical drains system.

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