**NPTEL**

**NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING**

**CDEEP IIT BOMBAY**

# ADVANCED GEOTECHNICAL ENGINEERING

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**Lecture No. 14**

**Module-2**
**Permeability and Seepage - 3**

Welcome to lecture number 14 of advanced geotechnical engineering course in the previous lecture we have introduced ourselves two methods for measuring the permeability we said that there are two types of methods in the laboratory one is a constant head test and falling head test and we also discussed about the achieve difference to achieve differences between these two test methods in this lecture which is permeability and seepage part three we will try to discuss about the factors affecting permeability and then we will introduce our ourselves to different types of the flows and the mathematics which is connected with these page phenomenon.

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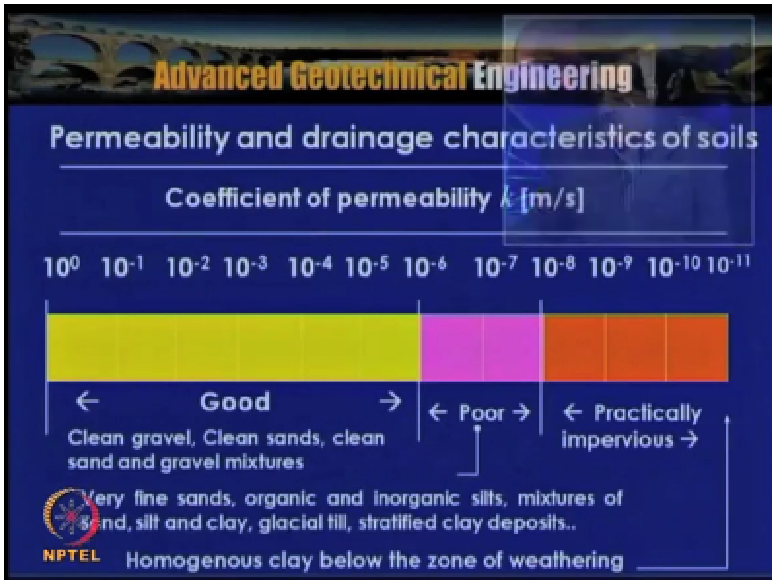


So this part of the lecture is permeability and see page part three so as shown in this slide the permeability and drainage characteristics of soils are shown the coefficient of permeability K which is actually mentioned in meter per second, if you look into this the one which is actually then there in the yellow color wearing it actually has in a good drainage characteristics when it comes to this pink color this particular range has the poor drainage characteristics and the color which is in orange here that is beyond $10^{-8m/s}$ which is actually has the practically impervious drainage characteristics.

So this particular these term abilities are possible for soils which are a clean gravel or clean science and clean sand with gravel mixtures the poor drainage characteristics or the soils which are actually having permeability in the range of $10^{-6}$ to $10^{-8}$ m/s this is possible for very fine science organic and in organic cells mixtures of sand silt and clay till stratified clay deposits so for this type of soils it is possible that the permeability can be in the range of $10^{-6}$ to $10^{-8}$ m/s for certain type of soils like homogeneous clay below the join of weathering.

These soils can actually possess the permeability in the range of $10^{-8}$ to $10^{-}$m/s we have different ranges of permeability 's and there is a unique property for the soil and the soils which can have the granular soils mostly have good permeability or very high permeability fine-grained soils and how low permeability.

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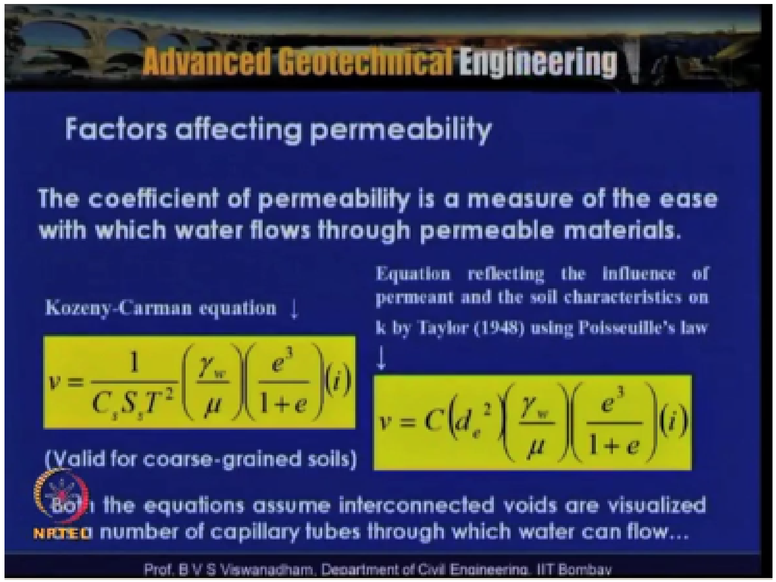


The factors affecting the permeability if you wanted to look into 8 the coefficient of permeability is a measure of the ease with which water flows to the permeability materials, so this is a you know put forward by Kozeny Carman and this in he has proposed an equation they have proposed an equation which is v = 1 / CS and S suffix T2 and multiplied by $\gamma w / \mu$ into eq / 1 + e into I so this is nothing but v = Ki the component K that is coefficient of permeability is indicated here by $1/ C_S S_s T^2 \gamma w / \mu$ into eq / 1 + e.

So this is according to Kozeny Carman this is basically valid for coarse grain soils and the taylor1 948 he has also proposed the equation reflecting the influence of the permeate and soil characteristics on the k and this is using the this is deduced by using the poisonous law which is given like this v = c into d2 the d is nothing but the particle size $\gamma w/ \mu$ $\gamma w$ is nothing but the unit weight of the permeate $\mu$ is nothing but the dynamic viscosity of the permeate eq / 1 + e into I so both this equation assumed that interconnect voids are visualized as a number of capillary tubes through which the water can flow.

So we have two sets of equations one is proposed by Kozeny Carman basically is valid for coarse-grained soils the other one is Taylor 1948 which is deduced based on the poisonous law which is given mice $v = CD^2 \gamma w/ \mu$ into 1 + e into I.

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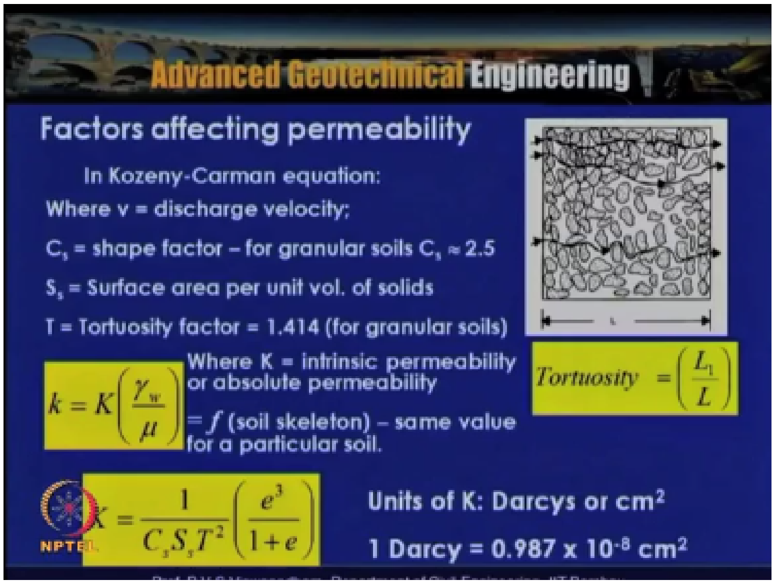


Now if you look into the Kozeny Carman equation the V which is nothing but defined as discharge velocity and the $C_s$ is defined as a shape factor for granular soils typically $C_S$ = 2.5 $S_S$ is nothing but the surface area per unit volume of solids, so the surface area of the unit volume of the soil suppose if you see here it is in the denominator and the factor T which is nothing but the touristy factor which is defined as ratio of the tortillas length that is nothing but a path taken by the water flowing through the soil along the voids.

That means that this particular length which is indicated here the wavy pattern is nothing but the tortillas path the length L is nothing but the length of the sample through which the flow is occurring, so the tortillas T is nothing but ratio of the tortillas length that is $L_1$ to L so for granular soils the tortillas t factor is 1.414, so we are here one parameter which is defined which is called as the absolute permeability or intrinsic permeability which is going to be constant for typical soil skeleton.

So same value will be there for a particular soil and particular state so the permeability coefficient of permeability is now connected with capital K and the $\gamma w/ \mu$ so capital K is equal to capital K is nothing but now 1 / $C_S$ and $S_ST^2$ x q / 1 + e, so the units for absolute permeability are intrinsic permeability are generally given in Darcy's or a centimeter square or meter square, so the units of absolute permeability which is also called as intrinsic permeability and which is formed to be you know function of the soil skeleton and it possesses the same value for a particular soil.

And one Darcy is equal to 0.98 7 into $10^{-8}$, so here we have said that coefficient of permeability is a function of the number of parameters like 1 least specific surface area and Tata Steel factor and void ratio and the shape factor for basically for granular soils, so the factors affecting the permeability can be summarized like this.

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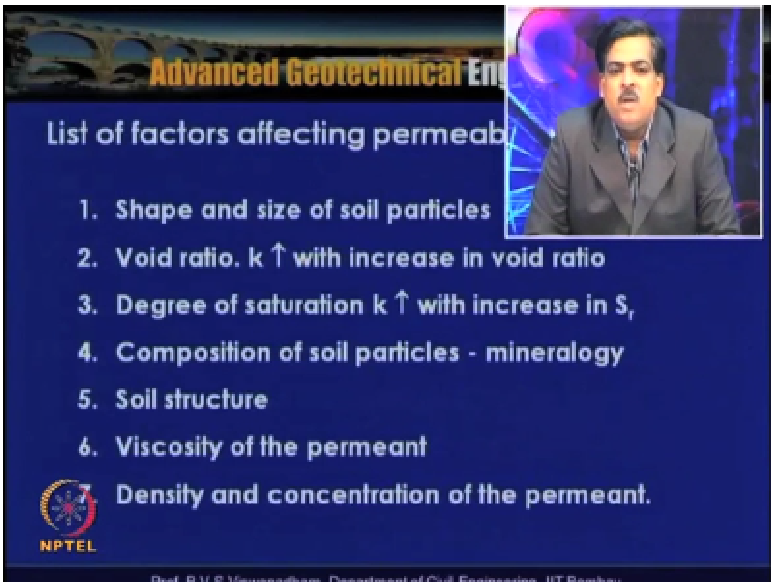


So based on the previous discussions by my equations proposed by Kozeny Carman or Taylor 1948 shape and size of soil particles that is shape of the soil particle whether it is angular or whether it is having if plate shape the particle and the size of the soil particles that means that larger the soil particle are smaller the soil particle and void ratio, so k increases with increase in the void ratio and degree of saturation also like k increases with increase in the degree of saturation for a partially saturated soils the permeability will be is a be less because of the partial saturation.

The composition of soil particles it also depends upon the mineralogy type of the mineral present in the soils so soil structure and viscosity of the Permeant at density and Centration of the perimeter, so list of the factors affecting the permeability are the shape and size of the soil particles void ratio degree of saturation composition of soil particles soil structure and viscosity of the permeant and density and concentration of the permeant and also like the compactive effort you know with the with the different compact your and different molding water contents there will be change in the permeability.

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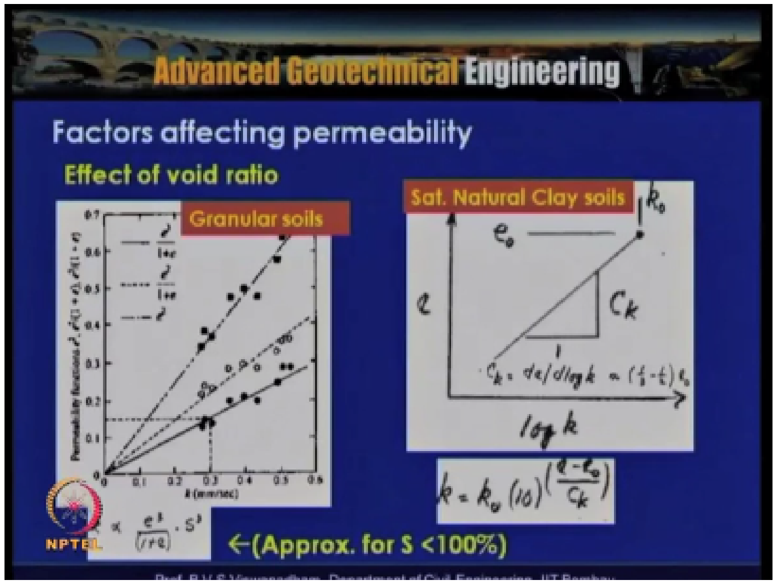


So here then the factors affecting the permeability what we discussed is that effect of void ratio and basically here on the left hand side the permeability which is which is permeability fact that is permeability factors like different eq / 1 + e $e^2$ / 1 + e and 2 are given and in the y axis and the per mobility in mm per second which is actually given on the x axis, so for branded soils k is proportional to approximately e3 / 1+ x degree of saturation cube, so this is approximately valid for this relationship is approximate for s that is degree of saturation less than 100%.

On the right hand side there is a plot which is actually shown for void ratio on the y-axis and log logarithmic of the clay logarithmic of k on the x axis, so it can be seen here this is for a saturated natural clay soil saturated natural clay soils, so this factor $_{CK}$ which is nothing but the permeability change factor and $K_0$ is the permeability in the at void ratio $E_0$ $K_0$ is the permeability at initial void ratio $E_0$, so once the pressure is applied or when the load is applied the primitive void ratio decreases in the process what will happen the permeability changes.

So the permeability change factor is defined as de / d log K that is the difference betwee$_n$ $K_2$ and $K_1$ permeability at different void ratios, so this is approximately 1 / 321 / 2 $e_0$ for a which is approximated as $C_K$ as 1 / 2 to 1 /3times the initial void ratio so k by knowing this permeability change factor we can determine permeability and in different stages and this is K is equal to $K_0$ into 10 place to - $e_0$ / K where e is the void ratio at a particular time and $e_0$ is the initial void ratio and the $C_K$ is the permeability change factor which is approximated as 1 / 3 to 1 / 2 times the $e_0$ and $K_0$ is the initial permeability at initial void ratio.

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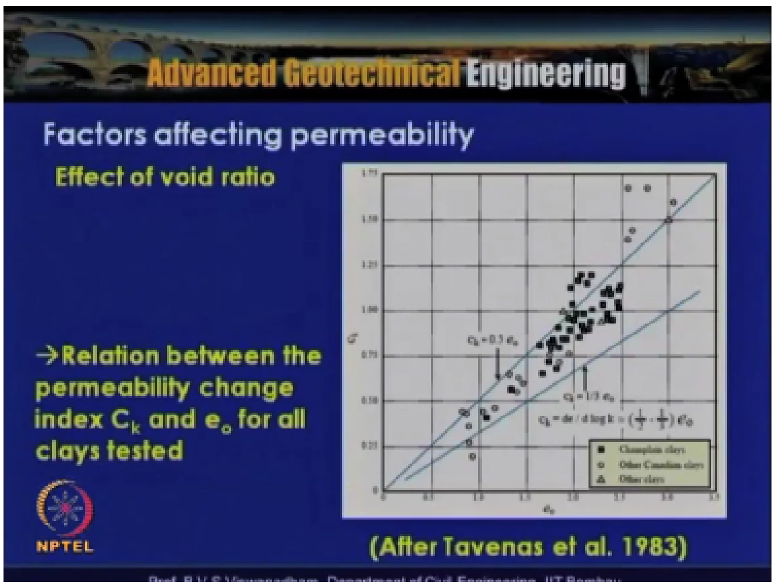


So in this plot the relationship between the permeability change index or permeability change factor $C_K$ and $e_0$ for all places tested or shown and this is after Terrance at all 1983, so here it can be seen that the permeability change index $C_K$ Is approximated as 1/ 2 to 1 / 2 to 1/ 3 $e_0$ naught and there are upper bound and lower bound values which are actually shown this is based on the clays for all the types of place tested and reported by Devon's at all 1983.

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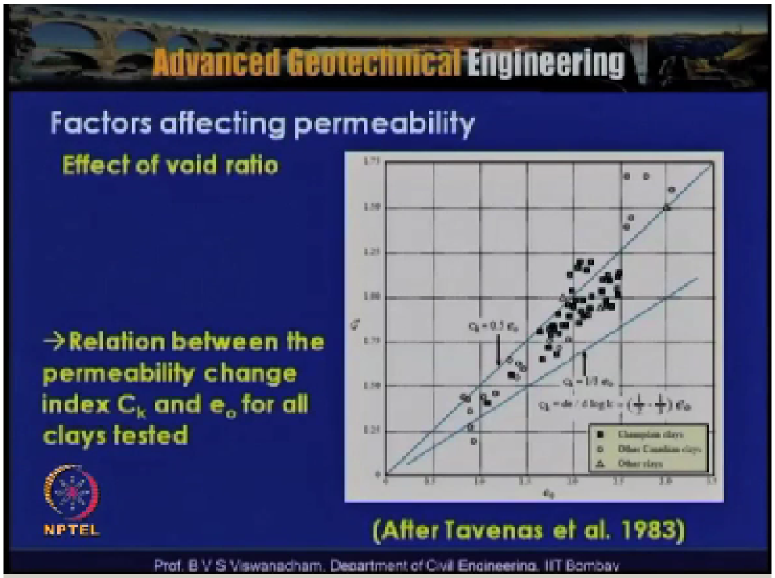


Now the next factor is that effect of grain size the permeability of the grain size depends mainly on the cross sectional area of the pore channels, so we knew that when you have what vary the pore size which is nothing but the D is proportional to the effective particle size let us say, so in that case we can approximate D = d 10 the pore size is approximated as 20% of the d10 that means that the smaller the particle size the finer is the pore channel since the average diameter of the portion in a soil at a given process T increasing proportional to the average grain says the permeability the granular soils might be expected to increase as a square of the some characteristic grain size so the permeability of grander soils.

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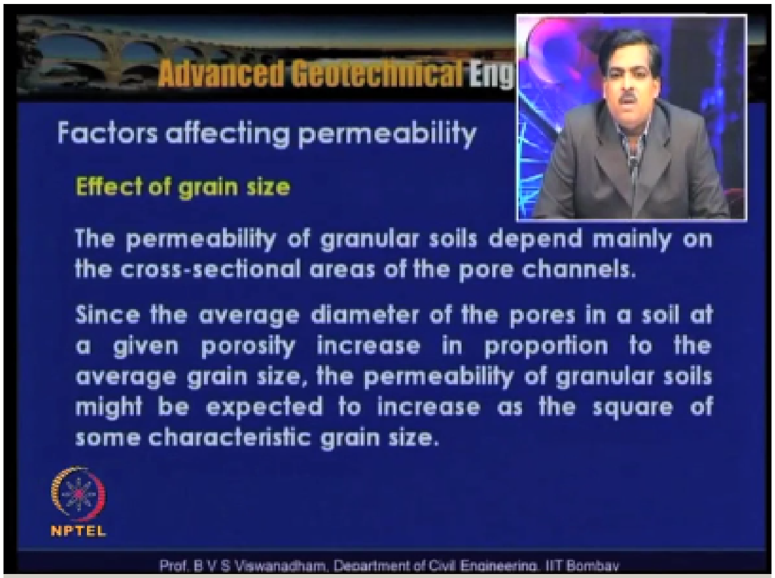


Might be expected to increase as a square of the some characteristic grain size generally it is considered as d-10 but the recent studies indicate that d5 that is soil which actually has 5% particles passing.

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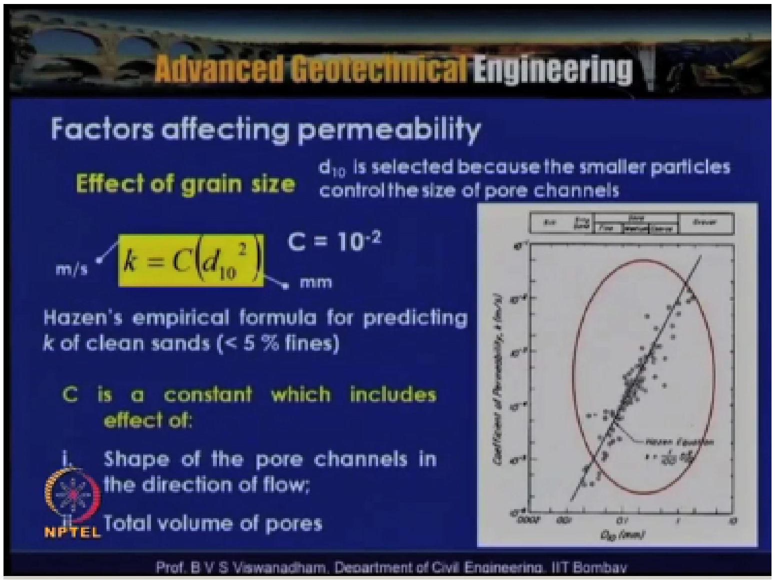


So the traditional the empirical formula for estimating the permeability was given by Hazen and the Hazen empirical formula for predicting K basically valid for clean sands is actually given here and which is actually valid for soil which is having less than 5% fines, so k = CD $10^2$ so what has been done is that number of sandy type of soils having less than 5% fines were taken and the constant head permeability tests were conducted and the correlation actually has been plotted and which actually indicates that the K in meter per second can be obtained with the constant C.

Which is housing having a value of $10^{-2}$ and d10 that is effective particle size in millimeter once we have this C = $10^{-2}$ and d10 in millimeters the permeability can be obtained in meter per second so for a by knowing the effective particle size at the first end you know to in order to estimate the permeability this particular relationship can be used, so C basically is a constant in this case it is equal into $10^{-2}$ which includes the effect of the shape of the pore channels in the direction of the flow and the total volume of pores.

So C is a constant which includes the shape of the pore channels in the direction of the flow and total volume of pores so d10 is selected because the smaller particles control the size of the pore channels, so in this case the Hazen's actually has considered the d-10 because the smaller particles control the size of the pore channels.

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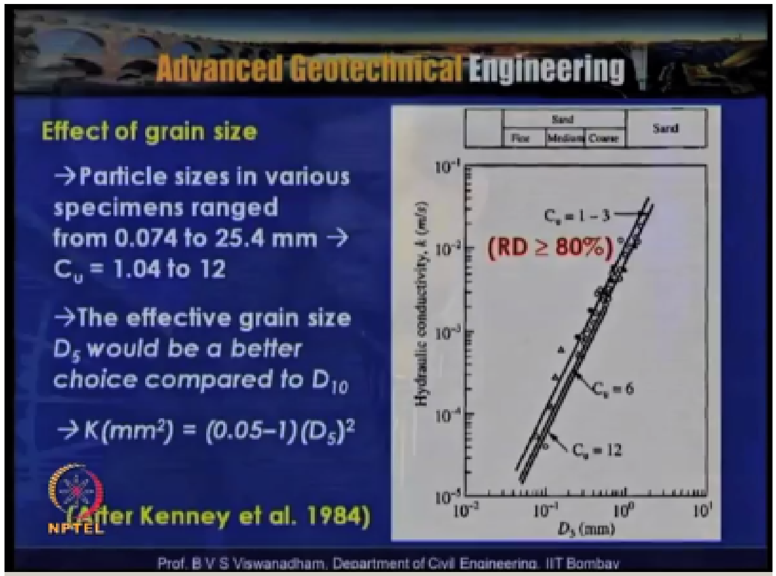


This particular correlation is presented by Kenney at all 1984 and this is with d5 that is on the x axis which is represented on the log scale and the hydraulic conductivity K which is actually represented on the y axis and the or sands which are actually having relative density 80% it at 80% dual-density more or less greater than 18% into density was considered and particle size of the sands which are actually used the soil which is used in the power of the various specimens it ranges from 0.04 to25.4mm and the quotient of uniformity is in the range of 1.04 to 12 and it is said that the K the absolute permeability in $mm^2$.

Is given as 0.05 - 1 into $D5^2$ well $D_5$ is in mm and this particular relationship was proposed by Kenney 1984 and the effective grain size $D_5$ would be better choice compared to $D_{10}$ according to the you know data correlated and presented by Kenney at all in 1984 the effective grain size was $D_5$ was reported as a better choice compared to detail and the factors affecting the permeability further ones to discuss the effect of the degree of saturation, so we have said that with increasing degree of saturation the permeability increases so K is actually proportional to degree of saturation.

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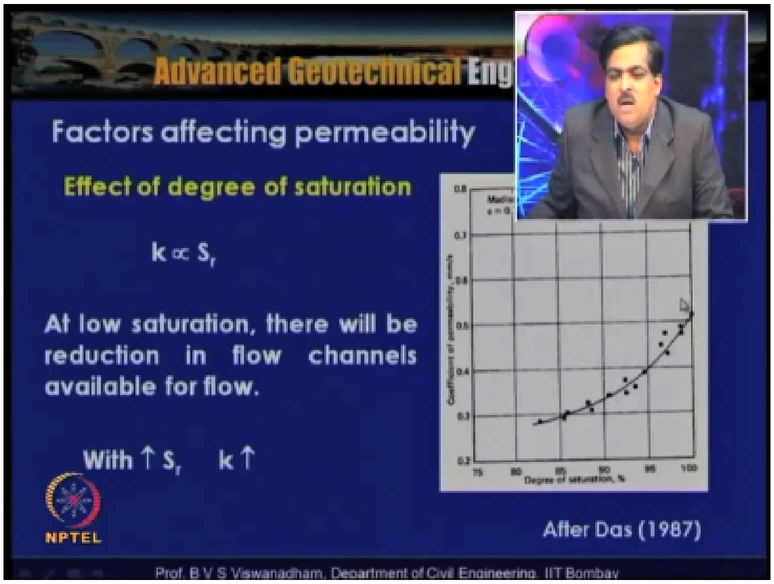


At low saturation there will be reduction the flow channels available for the flow because the part of the voids is actually occupied by the air, so with increase in saturation degree of saturation the coefficient of permeability of the soil increases, so here a measured data which is presented by after Das 1987 where degree of saturation is plotted on the x-axis and permeability is plotted on the y-axis for a typical sign where it can show that with increase in the degree of saturation there is an increase in the permeability.

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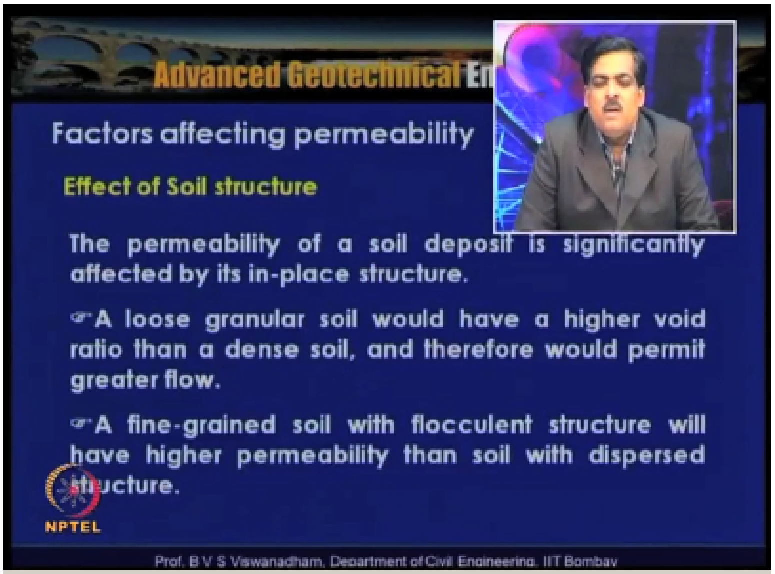


Further there is a important aspect which is required is that the soil fabric or soil structure or the arrangement of the soil particles within the given soil mass the permanent permeability of the soil deposit is significantly affected by it is in place soil structure his loose granular soil would have higher void ratio than a dense soil and therefore would permit greater flow, so loose granular soil would higher water I show then a denser soil so and then there would be a so it would permit greater flow similarly when you have what a fine-grained soil with the flocculated structure will have a higher permeability than the dispersed structure.

So if you look into the two types of extreme to soil one is closed and soil where can have a looser granular structure or same coarse grained soils can have a dense granular structure a loose granular structure can have higher permeability than the density internal structure similarly a fine grained soil with a flocculent structure or flocculent arrangement will have higher permeability with than the dispersive structure.

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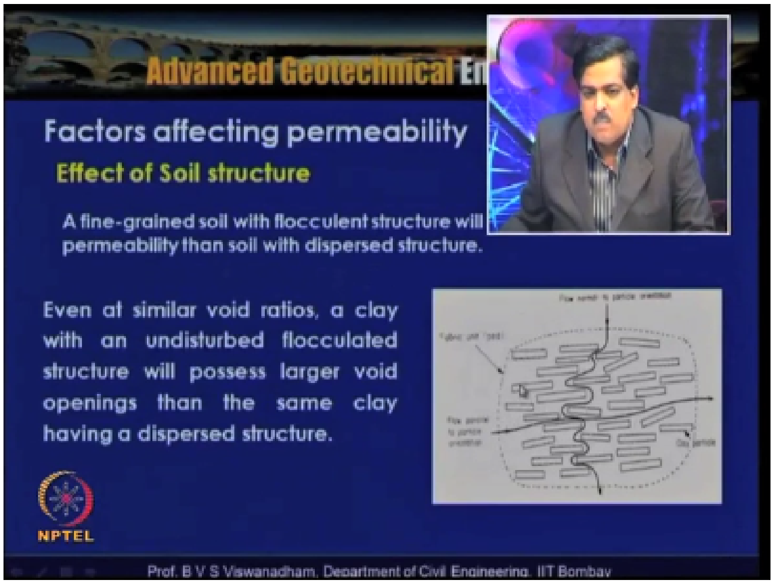


So here a fine grained soil with the flocculent structure will have higher permeability than the soil with a dispersed structure that is what we said even it does similar void ratios a clay with undisturbed flocculated structure will possess large wide openings then the same clay having a dispersed structure, so the path which is actually this is with the dispersed structure where if you can see and the permeability in this direction is found to be less and when you have a flow which is actually taking place in this direction because of certain available higher hydraulic gradient.

The permeability will be on the on higher side in this direction along the you know the flow which is actually taking place along the platelet particles.

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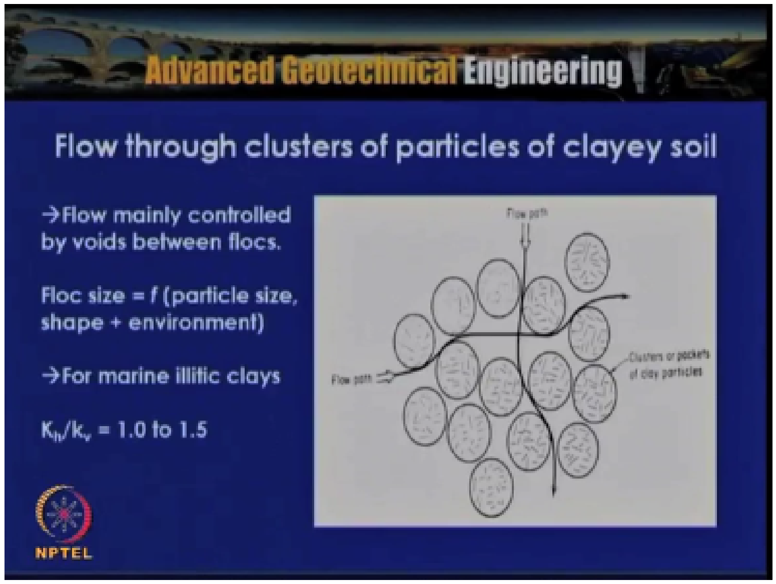


In the flow through clusters of the particles in clay soils so flow mainly controlled by the voids between the flocks and the flock sizes is a function of the particle size shape and environment in which these flocks have been formed and therefore marine a lytic place the permeability which is actually $K_h$ and $k_V$ will be equivalent to 1 1 to1.5 and the quotient of permeability of a soil with flocculent structure will be isotropic in nature in the sense that the flow the number of flow channels available to flow in any direction will be equal identical for a flocculent structure.

Whereas in case of a dispersed structure the flow along the shape of the dispersal this the panel laid particles will be higher compared to the their perpendicular direction because of the increase in taught city for the flow, so for the Marine electric plays the $K_h$ that is coefficient of permeability in the horizontal direction and the question of permeability in the vertical direction the ratio can be equal to 1 to1.5 depending upon the type of the normal in which they got deposited.

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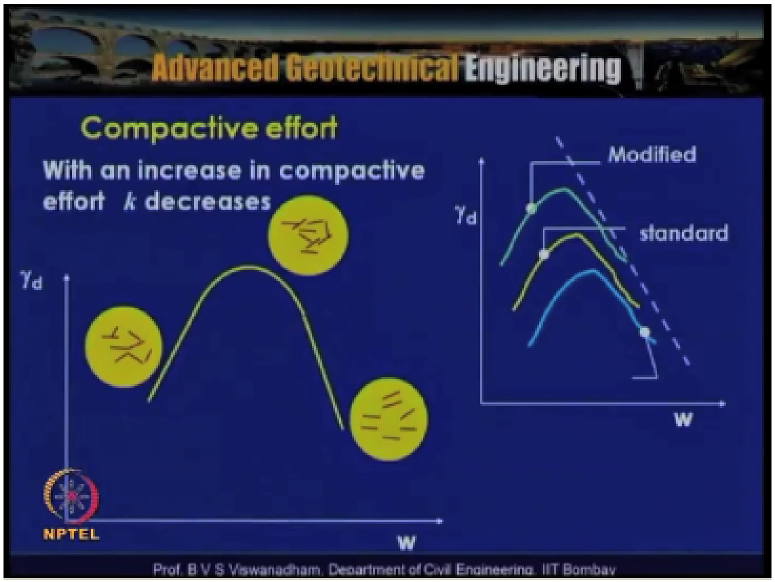


Similarly when you have got the compactive effort with an increase in compactive effort the permeability decreases, so for example here on they-axis there is a γd which is plotted here which is also shown here and the water content on the x-axis, so as we have seen for a typical clay initially this is this particular portion is the optimum moisture content and this side is the wet side of optimum and this side is the dry side of optimum, so at this point the density is actually maximum so lower void ratio will be there and here the density is less than the higher word ratio is possible.

And so as the water content is increased you can notice that the soil fabric changes from more or less from the flocculent structure to a dispersed structure, so the particles undergo in the process of the compaction the particles undergo rotation by about $90^0$ in the sense that what will happen is that the particles finally whence they reach of the wet side of optimum they start getting arranged parallel to each other, so in the process you know what we can say is that than the wet side of optimum the predominant soil structure in case of when you compact the soils is the disparity in nature.

There are same soil with the higher low lower water content but same density can actually have a flocculent structure at the maximum brightly dry unit weight and water up to water contained the soil structure is neither flocculent nor dispersed it actually has got the blend of both flocculent and dispersed structures, so here with the increase in the you know compactor for this is the lower compactor foot and this is the standard proctor compactor foot say and this is the modified proctor compact our effect and with increase in compact effect there will be a decrease in the permeability.

Because with increase in compactive effort there is an increase in the density and then decrease in the void ratio that means that the permeability decreases.

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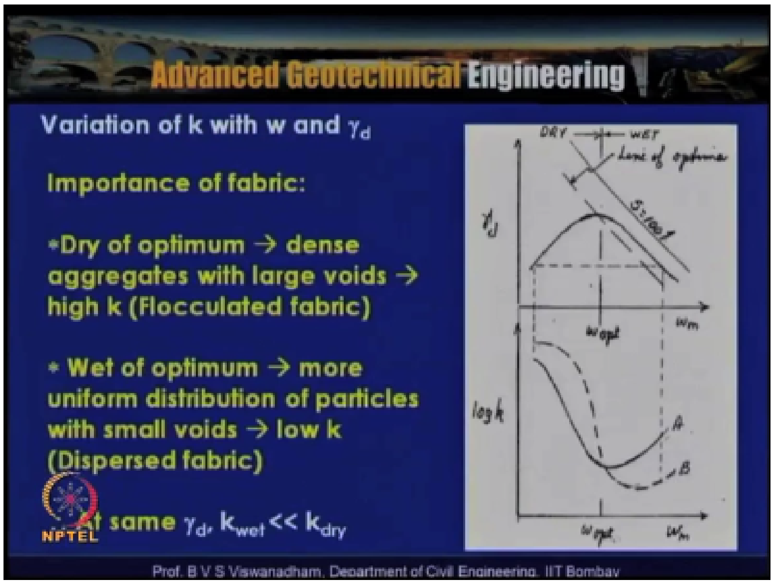


So here the variation of the k with water content and γd is actually discussed here the importance of the fabric is brought out here so in this particular slide which is actually shown here this is the compaction curve and this is the 100% saturation line at 0 air voids line and this is the line of Optimum's that is with increase in compact effort the compaction curves the maximum Peaks will be the occurring here and on the plot below what you see is the logarithmic K versus water content.

So what we notice that initially the permeability will be high and once it reaches to the optimum water content the permeability takes a dip and that is decreases and further there is an increase in the permeability, but towards the wet side of optimum you can see here up to certain extent here there is a possibility that the permeability is actually decreasing towards the wet side of the optimum, so the dry side of optimum the dense aggregates with larger voids will be there because of this also we discussed the different fabric or fluctuated structure will be there.

Because of that the high permeability is resulted in when they when we consider the Wet side of optimum the more uniform distribution of particles with small voids hence the low permeability can result and especially this is attributed to the dispersant fabric which is prevalent on the Wet side of optimum at same γd that is the dry unit weight you can notice that the permeability of the wet play is actually less than the permeability of the dry clay, so that is a reason why for certain type of applications it is advised to compact the clay.

Especially for constructing clay barriers it is advised to compact the clay towards the Wet side of optimum because the permeability will be les because there it is not the strength of the soil which is important the soil which is actually having you know the target permeability is important.

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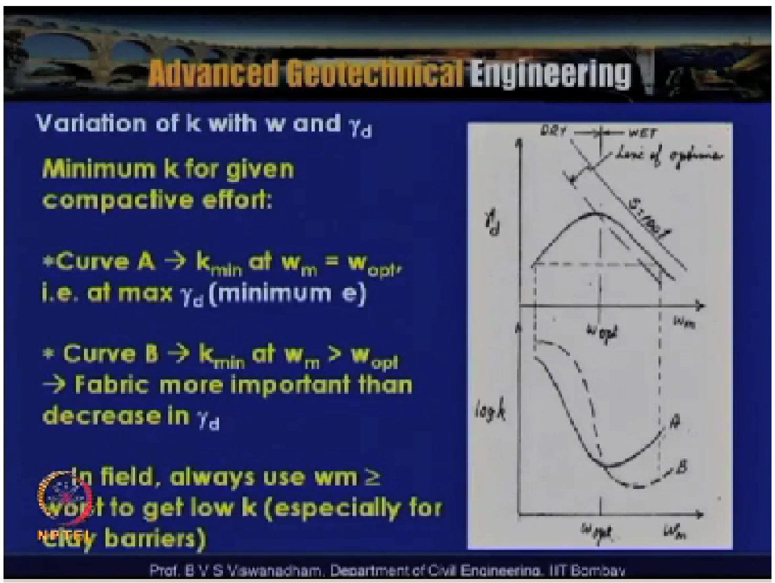


So here which is actually given like again with a minimum K for a given compact effort for example here the same plot which is actually shown here, but I would like to draw your attention to the two curves which is actually shown here this is the curve A and this curve B, so curve A well if you notice here K minimum is actually occurring at WM is equal to at the $W_{opt}$ that is the optimum water content that is at maximum γd the minimum void ratio, so k in moves actually occurring at the WM is equal to $W_{opt}$ in case of curve B that is here which is actually shown here curve B which is here.

Where came in who is actually occurring at wm greater than $w_{opt}$ so the fabric is actually more important than decreasing so this indicates that the particle arrangement is actually more important than the decrease in the γd, so in the field always use wm greater than or equal to wr to get low permeability especially for clay various that is what we actually have discussed in the previous slide also, so in this particular slide variation of K with water content come into d and real test to data.

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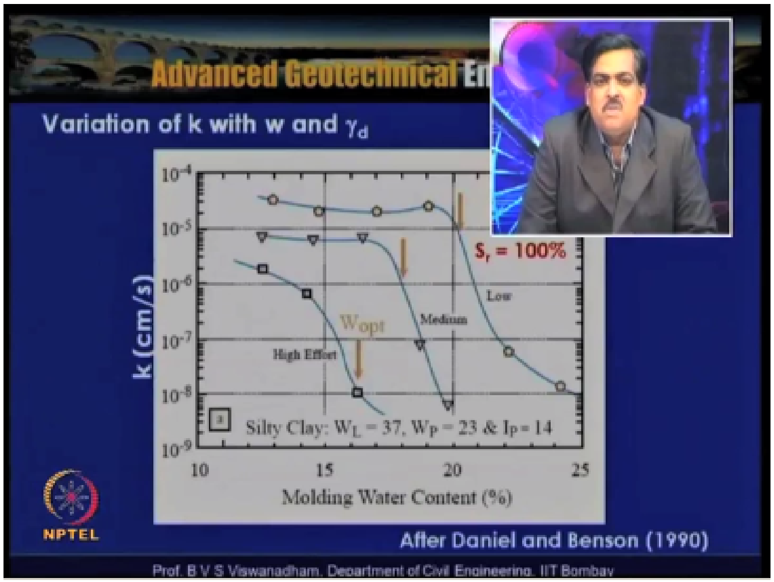


Is actually reported by Daniel and Benson 1980 is presented here on the vertical axis what you see is the permeability is given in K cm/s and the molding water content is actually given on the x axis and this is basically a silty clay with the liquid limit 37% and plastic limit 23% hence the plasticity index is about 14%, so these are the three types of compactive efforts are actually represented here or considered one is the low compaction low Proctor compaction that means that in this case the energy compactive energy is less compared to the standard.

Proctor medium is nothing but the standard Proctor and the high effort is nothing but the modified Proctor, so you can see that the effect of the compactive effort on the optimum where we can see that different up with the increase in the compact effort there is a decrease in the optimum water content and the second issue is that the typical distinct variation of the permeability with molding water content, so within increasing molding water content there is a decrease in the permeability and we see that beyond optimum for all the different all the types of compact efforts irrespective the compact effects you can see that it increased which actually happens beyond the outdoor, so this is for a higher effort we can see that the permeability decreases and here you can see that.

So beyond the optimum content beyond the optimum content but anyway when we come to the Wet side of optimum you know as we discussed in the previous slide we have to note that the length the type of the arrangement the particular arrangement place a key role then the density which is achieved.

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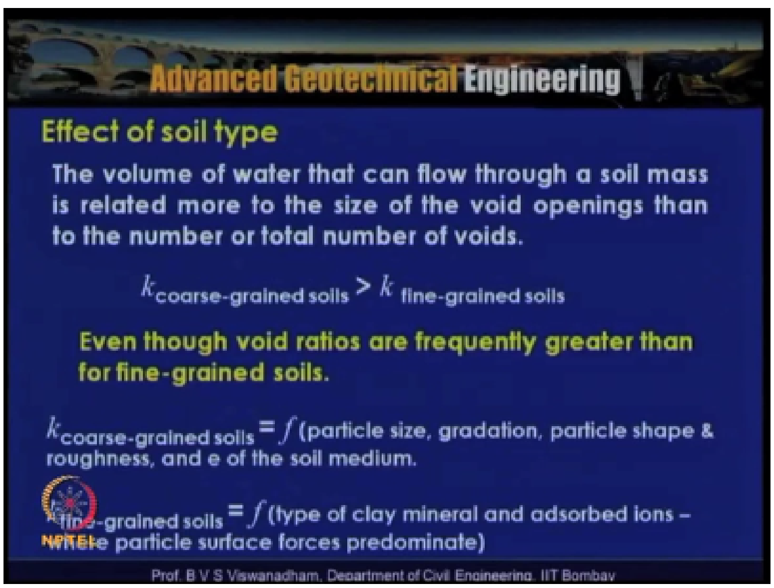


Further connecting to our discussion in affecting the permeability effect of soil type the volume of the water that can flow through a soil mass is related both to the size of the void work mix then the number of the total number of whites, so we if you note down the K coefficient of permeability of the coarse grained soil is always greater than K of the fine-grained soils even though if you look into the void ratios are frequently greater for the fine grained soils see fine grained soils can actually have very high void ratios.

So if you say that K increases with increase in void ratio which this argument is not really true when it comes to this particular you know factor so the K of the coarse-grained soils is greater than K of fine-grained soils in fact the k of the coefficient of permeability of the sandy soil is about million times than that of the you know1 million times of the clay soil.

So the K of coarse-grained soils is a function of the particle size gradation and particle shape roughness and wide ratio of the medium if you consider the coefficient of permeability of the coarse grained soils when you distort the factors, it is function of the particle size gradation particle shape roughness and the void ratio of the soil medium and a K of the fine-grained soils which is a function of the type of the clay mineral and ads or ions and where the particle surface forces actually predominated.

So when you have this one so the if you look if you look into this and if you consider the application of fluid mechanics to that then we will be able to understand why you know the K of course students oils is greater than K of fine-grained soils.

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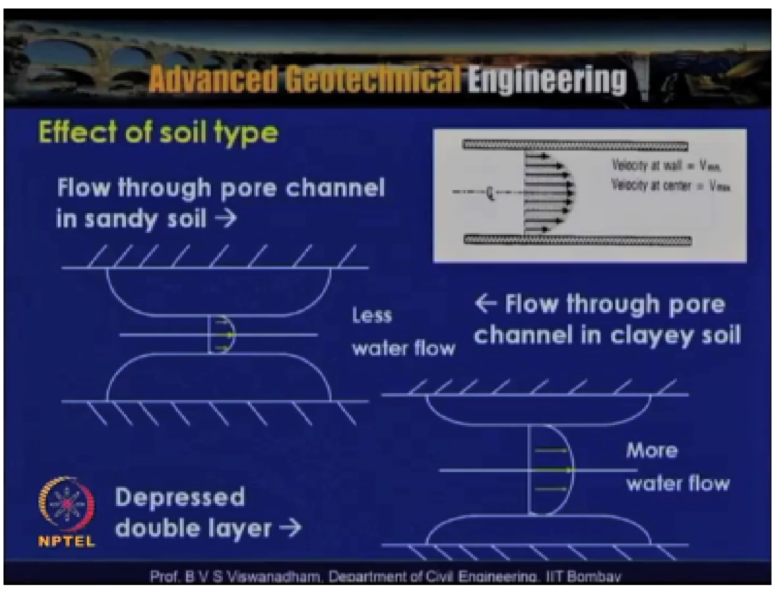


So in this particular slide what is actually shown is a typical flow which is actually happens through a coarse grained soil having you know let us assume that, if you have got a grain here and if you have got a grain here and because of the presence of roughness the velocity with which the water is actually flowing through the wines is actually decreases in the sense that along the boundary walls the because of the frictional drag the velocity drops to 0 and but at the mid distance from the that is D / 2D is the diameter of the pore at D / 2from the edge of the wall.

It can be seen that the velocity is actually maximum here, so the typical velocity distribution if you assume by using the flow water through two parallel plates and two parallel plates are actually considered as the edges of the you know the soil particles and the flow through the pore channel in a sandy soil is represented like this, when we actually consider you know clay soil we actually have the adsorbed water that is the adsorbed water which is actually there and then there is a possibility that because of the flow which is actually taking place this adsorbed water.

Layer and then because of the frictional effect the velocity here also drop down to 0, but at the center there will be maximum but when you consider the magnitude of this and magnitude of this particular v-max in the sandy soil v-max in the clay soil there is a marginal difference will be there similarly when you have got say depressor double layer with decrease with the adsorbent layer then there can be possible that you know more water flow can take place but however if you look into this velocity distribution though it is a loggers, but this is actually several magnitudes less than the flow through.

The pore channel in sandy soil so the phenomena of the higher permeability of the course grade soil can be explained using the concept of the water flow through the conduit.

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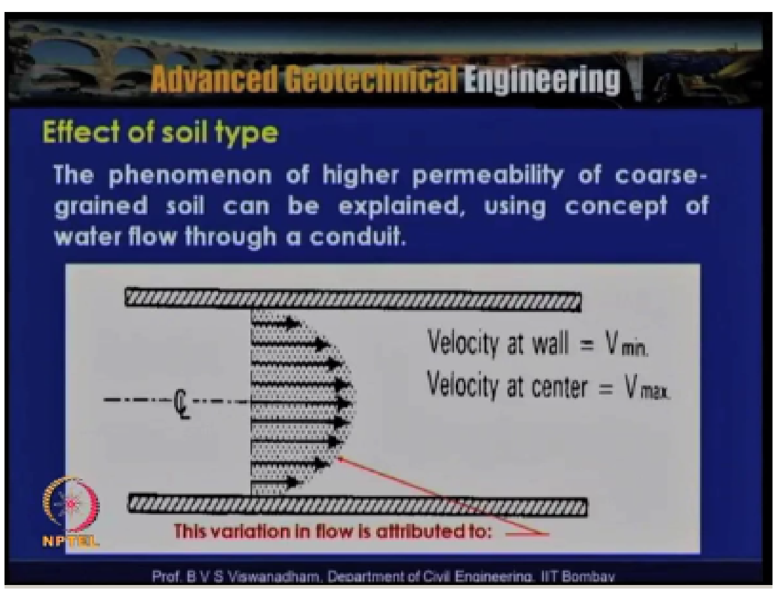

So because of this the particular code student soil will actually have higher permeability.

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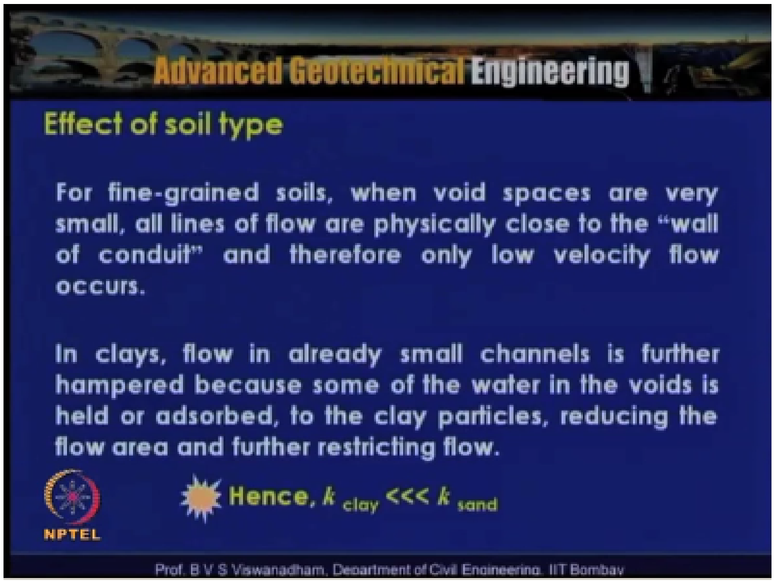


But when it comes to fine grained soil we actually have said that one is that adds or but you know when the water is actually flowing through the adsorbed water layer there is a decrease in the velocity distribution whatever it is nothing, but the type of the mineral which is actually present for example a for a fine-grained soils when white spaces are they are very small all lines of lower physically close to the wall of the conduit and therefore only low velocity occurs in place basically the flow is already occurs in small channels and is further hampered because of these some of the water whites is held or adsorbed.

To the clay particles reducing the flow area further and restricting the flow, so because of this particular explanation with the whatever we have discussed so far we can say that the clay of the coefficient of the permeability of the clay soil is much less than the coefficient of permeability of sandy soil.

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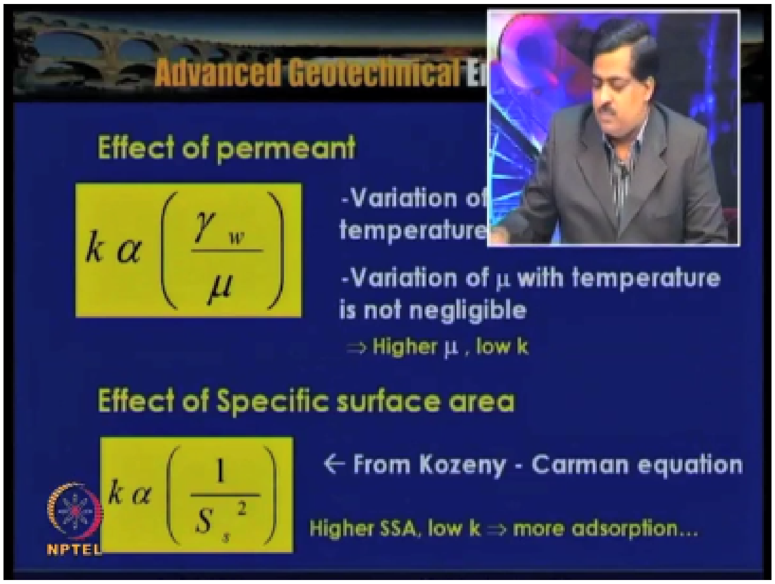


Now further one of the other factors which we have discussed is that effect of the permeate like if you have got the permeant which is actually given as you know K is proportional to unit weight of the permeant and the viscosity remained variation of the γw that is the unit weight of the water tremendous temperature is name visible, but variation of μ with the temperature is not negligible, so higher the you know dynamic viscosity of the permeant will be the permeability so with increase in you know viscosity of the pore fluid the permeability of the soil can be decreased.

So variation of the μ with the temperature is not negligible, but if you are able to increase let us say that the pore fluid is actually replaced with another pore fluid having a higher μ the coefficient of the permeability can be brought down and further we also discussed from the Kozeny Carman equation effect of the specific surface area, so here if indicates that higher the specific surface area lower would be the permeability that means that higher will be the solution surface area means for example when you take your light in light and multiple light the alight mineral the multiple which have actually very high specific surface area.

Compared to the can light mineral particles so that means that with an increase in the specific surface area the permeability of the soil decreases and also exhibits the this is attributed to the more adsorption.

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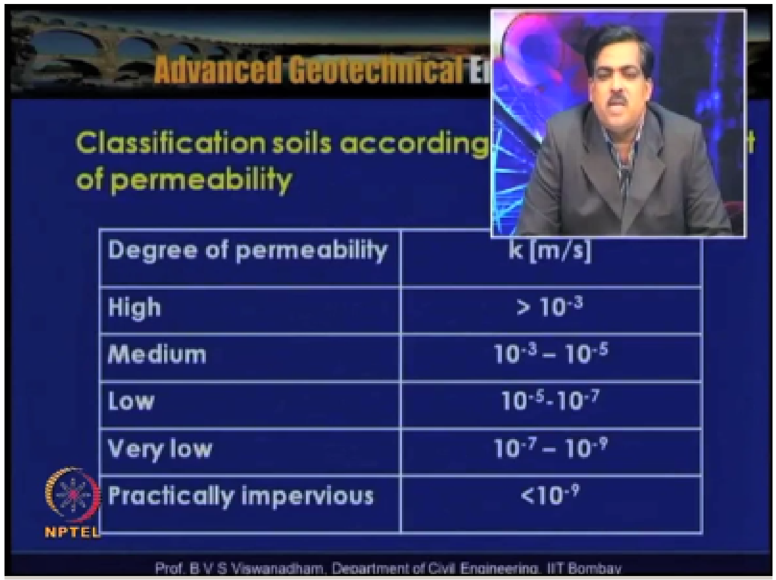


The classification of the soils according to their coefficient of permeability if you look into it can be given as degree of, so the soil can be classified based on the different values of the permeability when you say that permeability value in meter per second if it is greater than $10^{-3}$ we say that the soil actually has got high permeability and when the permeability is in the range of $10^{-3}$ to $10^{-5}$ m/s we can say that the soil is actually having medium permeability and low which is in between $10^{-5}$ to $10^{-7}$ m/s and very low that is between $10^{-7}$ to $10^{-10}$ m/ a second.

And the soil is said to be are classified based on the permeability as practically impervious if the permeability is less than $10^{-9}$ m/s.

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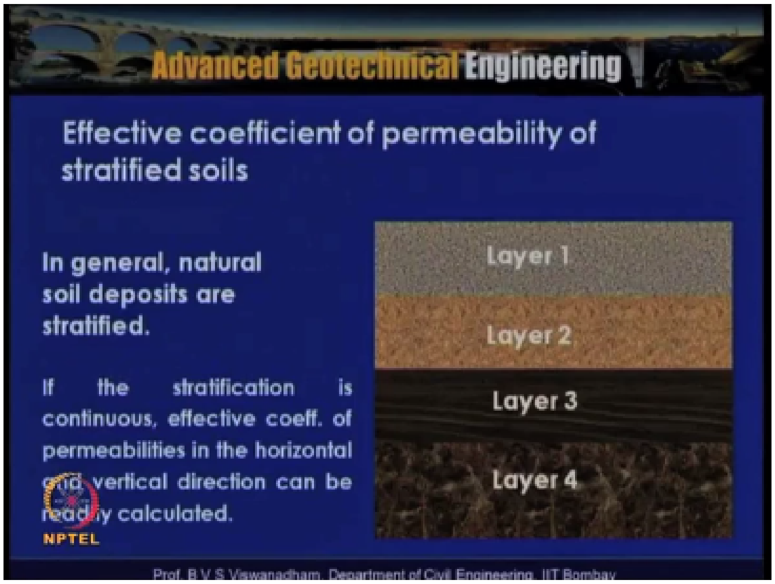


So we as of now we discussed for the homogeneous soils but we may not actually get the homogeneous soil deposits frequently, so the effect of the you know coefficient of permeability of the statuette the soils are the stratified soils, so in this particular case a layer 1 layer 2 layer 3 layer 4 the water can actually flow through parallel to the layers or water can actually flow up to downwards that is In the vertical direction that means that the in a given soil when you have got status so the water can flow in our general direction as well as vertical direction or upward direction because of some artesian conditions.

So in that case how to determine the equivalent permeability which we require to understand in general the natural soil deposits are stratified and if the stratification is continuous the effective coefficient of permeability in the horizontal vertical directions can be readily calculated.

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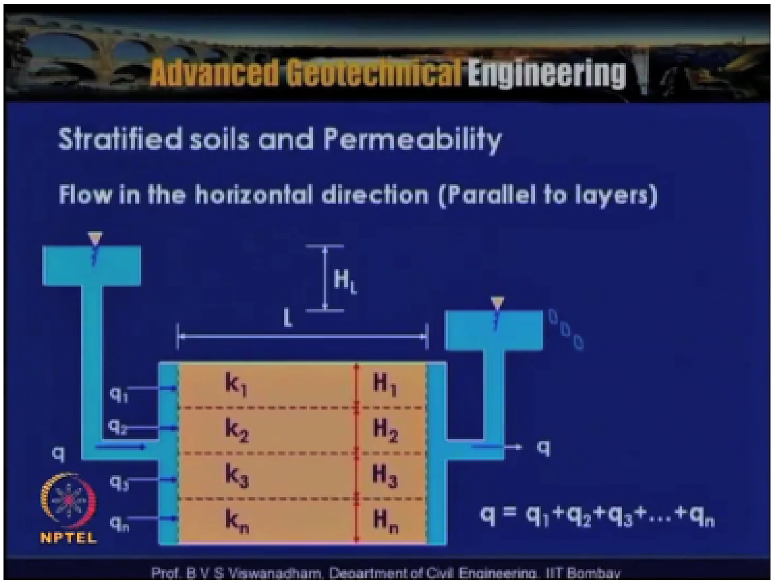


So in this particular discussion if you simplify by using our for determining the this particular condition of flow occurring parallel to the layers that means that if you have got say $H_1$ $H_2$ $H_3$ 2 H and n number of layers in a method or horizontally the flow in the horizontal direction that is parallel to the layers when it is actually happening let us assume that when we are the left hand side limb and the difference in head between these two is say $H_L$ which is nothing but the head loss between this point and this point.

And so the input is nothing but the water which is Q so these soils can actually have permeability is k1 k2 k3 k4 2 so on 2 Kn, so the equivalent permeability in the horizontal direction is that K equivalent in the horizontal direction are KH and the total thickness of the soil layer is nothing but H 1 + H2 + H3 so on - hm so here the condition is that q1 = q out with that what will happen is that the flow gets divided into you know depending upon the pyramid to the soil which is apportioned as q = q1 + q2 + q3 so on to qn.

So the condition here is that the head loss it actually occurs over you know a length of the sample and the discharge q = q1 + q2 + q3 so on to qn and then q which is actually comes out.

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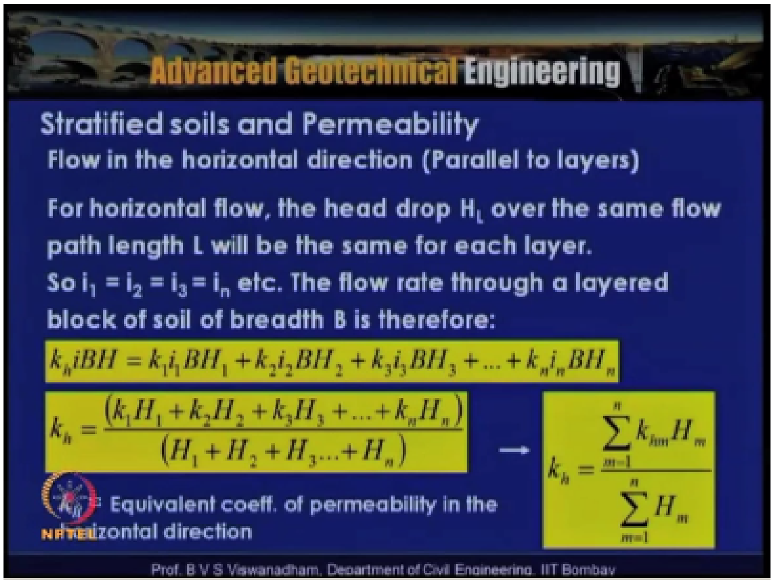


So with the based on that discussion for the flow in the horizontal direction parallel to the layers for horizontal flow the head drop HL or the same flow path length L will be the same for each layer, so because as the head law at last which actually occurs for a length of the sample yell though it is actually having the different type of the soil layers and the hydraulic gradient which actually gets dissipated in layer 1layer 2 layer 3 $I_1$ is equal to $I_2$ is equal to $I_3$ is equal to in, so the flow rate through a layered block of soil of breadth B.

B is the unit perpendicular to the plane of the figure which we considered, so with that we can say the $k_i$ a which is nothing but $K_H$ that is the equivalent permeability in the horizontal direction ie which is nothing, but the hydraulic gradient and which is the thickness of the soil strata and B is the bread the perpendicular to the plane of the figure which we considered, so K is nothing but $K_H$ is similarly for layer 1layer 2 layer 3, if you write layer 1 we can write it as $K_1$ $I_1$ be $H_1$ similarly for layer 2 $K_2$ IB $H_2$.

So when I computing the flow in the horizontal direction as q = q1 + q2 + q3 is on to qn I can write now by simplification $K_H$ is equal to $K_1$ H $_1$+ $K_2$ $H_2$ + $K_3$ $H_2$ and so on to K and $H_n$ / $H_1$ + $H_2$ + $H_3$ so on to $H_m$ so this is summation which is given as $K_H$ = m = 1 to n $KH_m$ into $H_M$ divided by $H_{m,}$ m is equal to 1 to N, so KH is nothing but the equivalent coefficient of permeability in the horizontal direction so for equivalent for determining the equivalent permeability when you have got started fertilize when the flow is actually occurring through the parallel to the layers we can determine the permeability.

And permeability has $K_H = K1\ H_1 + K_2 H_2 + K_3\ H_3$ so on to K and Hn / $H_1 + H_2 + H_3$ so on – Hm.

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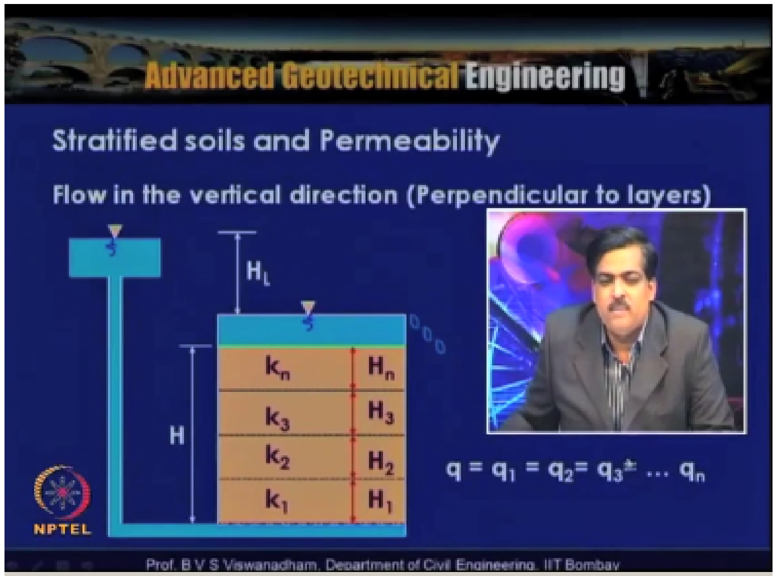


Similarly when you consider the stratified soils and permeability particularly the flow in the vertical direction that means that when the flow is actually happens perpendicular to the layers, so in this case here because of the higher head here the water actually takes platter flows upwards like this, but we have got different layers of thicknesses like $K_1$ having thickness of $H_1$ layer having $H_2$ having permeability $K_2$ layer having thickness $H_3$ and having permeability $K_3$ so on 2 layer having thickness H on to having permeability with km.

So but here what is actually happening is that the it is the head which is a you know gets apportioned is your I is equal to you know $I_1 + I_2 + I_3$ but what actually happens is that the q which is actually entering in the soil strata stratified soil and coming out to be equal that is q is equal to q1= q3 = qn with this condition now we can write down.

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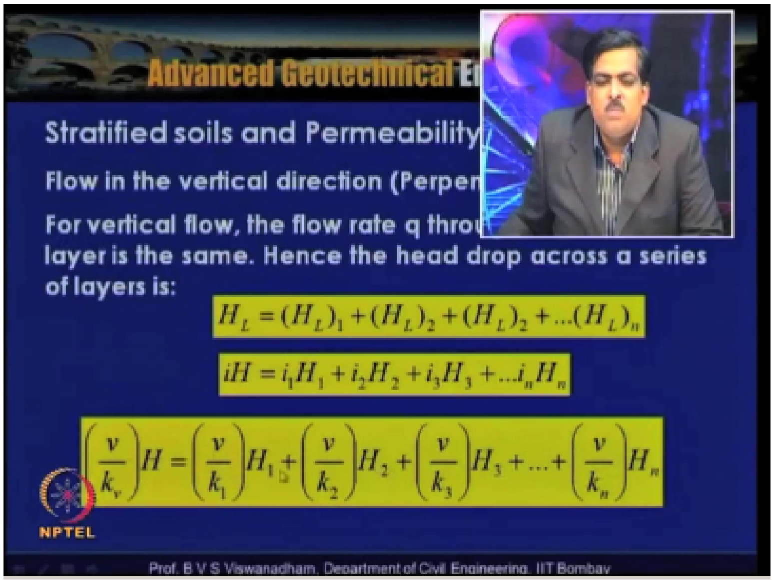
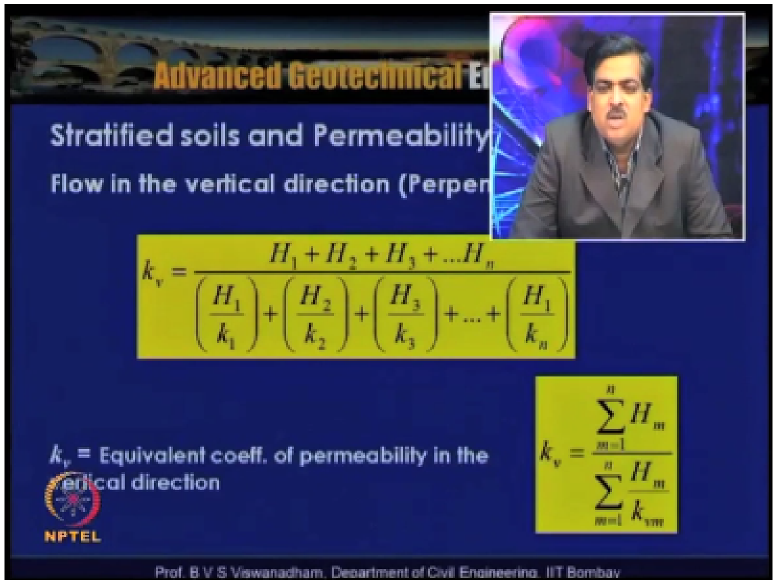



For the flow in the vertical direction that is perpendicular to the layers for a vertical flow the flow rate q through area a of each layer is same, so the head drop across a series of layers that is we can say that the head drop which is nothing but head loss in layer 1and then the total head loss is equal to had lost in layer 1 plus head loss in there - so on - head loss in the layer n, so we can write now with I is equal to H by that is the that is ΔH / L where L is nothing but the thickness of the layer when you put into that I can write as $H_L$ as IH that is in terms of H is the total thickness of the stratified layers.

And I 1 is the head hydraulic gradient occurred in the layer1 and H1is the thickness of the layer 1I do is the hydraulic gradient occurred in the layer two and hit you is the thickness of the layer two similarly I 383 and so on- I NHL by substituting v = $K_I$ that is nothing but I is equal to V/ K so in the case on the left hand side we can write as v / $k_v$ into H = V / $K_1$ into $H_1$ +V / $K_2$ into $H_2$ + V / $K_3$ into $H_3$ so on to V / Kn into H n so this particular expression when you further simplify. (Refer Slide Time: 43:01)




From the flow in vertical direction that is perpendicular to layers we can write it as kv = $H_1$ + $H_2$+ $H_3$ so on to $H_N$ / $H_1$ /$K_1$ + $H_2$ / $K_2$ +$H_3$ / $K_3$ so onto this is HN / $K_n$ so the K vertical permeability is the thing but M is equal to 1 to n $H_m$ /m = 1 ∑ 2 N2 $H_m$ by k vertical permeability of the particular layers, so the equivalent permeability of equivalent coefficient of permeability in the vertical direction so this can be used for both vertical flows flow occurring perpendicular to the soil status in the vertical direction the $K_V$ can be given as $H_1$ + $H_2$ + $H_3$ and so on $H_n$ to $H_1$ / $K_1$ + $H_2$ / $K_3$ so on to $H_n$ / $K_n$.

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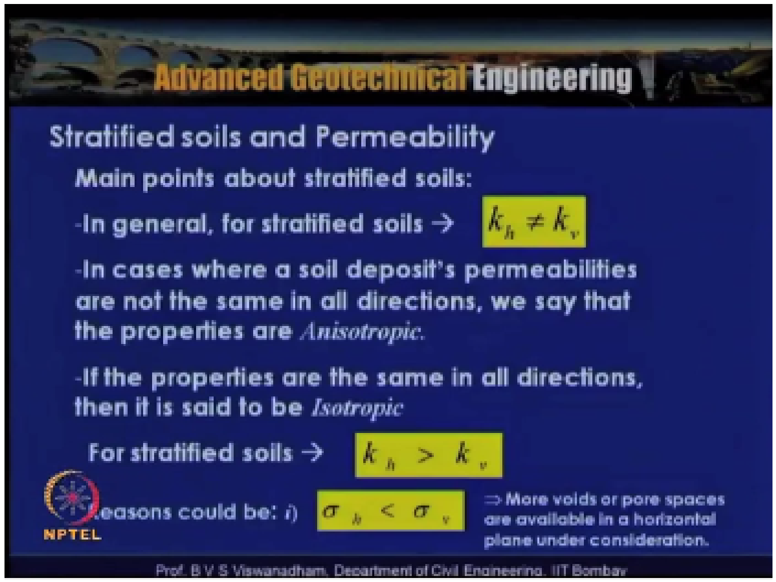


So the main points about the stratified soils we should understand is that in general for stratified soils what we have seen is that $k_h$ is not equal to $k_v$, so when you look when we say that the horizontal permeability is not equivalent to vertical permeability then we say that the soil is anisotropic in nature. In case where a soil deposits firm abilities are not the same in all direction then we say that the properties are anisotropy if the properties are the same in all the directions then it is called isotropic.

For example, when you are actually constructing an embankment with a material obtained from borough area and when you are achieving the you know the identical permeability because of the compaction then we can say that the permeability is isotropic in nature. But particularly when we are actually constructing earthen dams with different types of soils or when we are considering the flow occurring in soil status then they are generally in a entropic in nature, so for stratified soils we always we say that the $k_h$ is always greater than $k_v$.

The reason which is actually attributed to if you look into it the, if you consider from the you know coefficient of earth pressure at rest if you look into if you recall that one and which is nothing but k =kh /k =σh / σv when k is equal to say 0.5 σh =0.5times σv that means that for some saturated soils $k_h$ is actually less than $k_v$ σh is less than σv and for that $k_h$ will be greater than $k_v$, so more voids are more spaces are available in the horizontal plane under consideration that means that each, which the flow can takes place in along the horizontal direction is relatively higher compared to the vertical direction.

And because of this particular you have the number of voids which are actually available for the water to flow through in the horizontal direction is they are higher compared to you know in the vertical direction and because predominantly because of you know low horizontal stresses. But however in case of some more consolidated soils where the locking of the stresses takes place this particular you know deliberation is not valid.

So for stratified soils basically normally consolidated in nature there where σh is less than σv and the permeability is mostly that is $k_h$ is actually greater than $k_v$.

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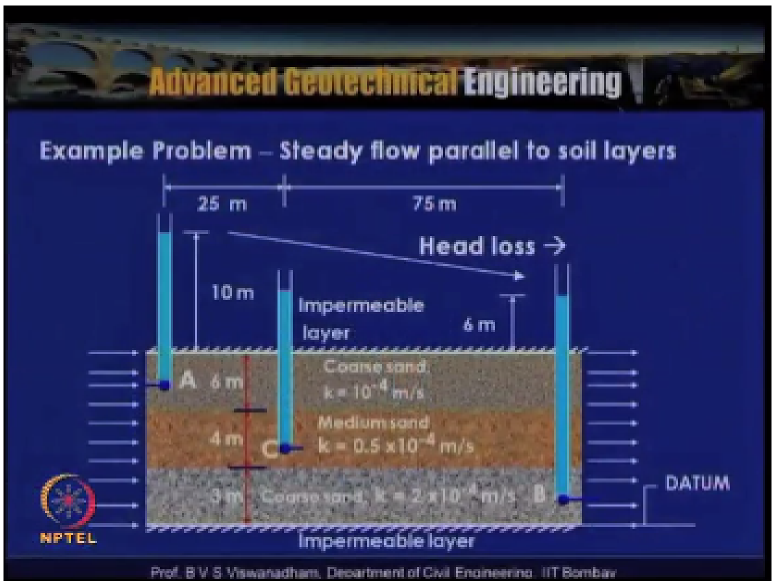


So this is an example problem based on the study flow parallel to the soil layers, here in this particular problem there is an impermeable layer at the bottom most and then top surface of the impermeable layer is actually given as the datum or considered as a datum and coarse sand which actually has got permeability of $2x10^{-4}$m/s and it is having a thickness of 3 meters about that there is a four meter medium sign and a six meter course and K= $10^{-4}$m/s and medium sand actually has got K=$0.5x10^{-4}$m/s.

Now at point A that is the height above this thing is about 10 meters and the total length is about 100 meters and the head loss is actually occurring from say A to B so we need to determine the equivalent permeability, the solution is actually as follows.

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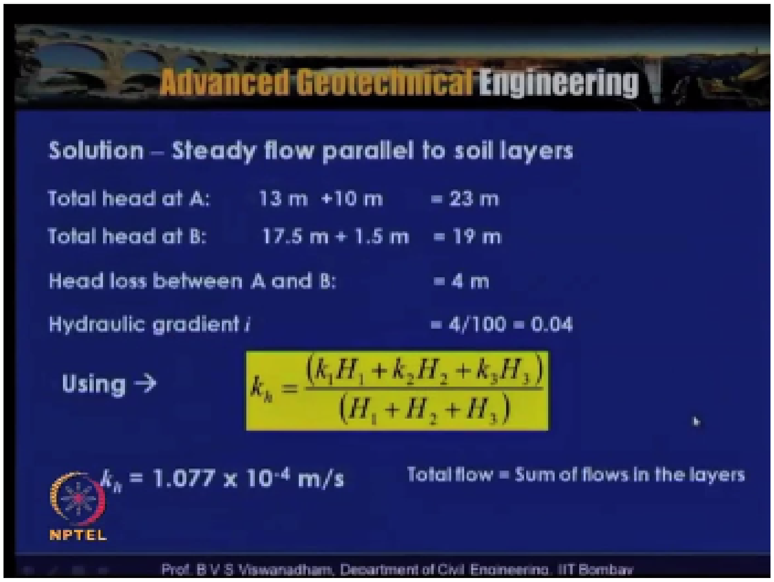


And they also assume that there is an impermeable layer at the at the top so the flow actually takes place parallel to the layers which are actually shown three layers are the coarse sand layer a medium sand layer and coarse sand layer below. The solution for this problem works out like this total head at A which is nothing but the 13m+ 10m that means that here the depending up on the location the thickness is that 6 + 4 this is 13 meters so the total head at A which is given as 13+10, 23 meters and the total height at B that is pressure head+elevation head which actually works out to be 17.5 +1.5 that is at B this is a above 1.5 meters, so because of that so this is 3 +4,7+3, 10 +3, 13 +10, so 23 is the head here and total head at B is about 19 meters so the difference of these two which is nothing but the head loss between point A and point B which is actually shown in the figure which is here point A and point B the head loss is actually is about 4 meters or a length of 100 meters between A and B.

So hydraulic gradient is nothing but 4/100 there is nothing but 0.04 using now in determining the equivalent permeability in the horizontal direction when the as the flow is occurring parallel to the layers it can be given as $k_1H_1+k_2H_2+k_3H_3/H_1+H_2+H_3$ so with that we can say that $k_h=1.077x10^{-4}$m/s and once we get this one the total flow can be estimated as which is nothing but kHi and H which is nothing but the summation of H1+H2+H3 or summation of the flow which is actually taking place in layer 1+layer 2+layer 3 that is Q1+ Q2+Q3 so here Q=Q1+Q2+Q3.

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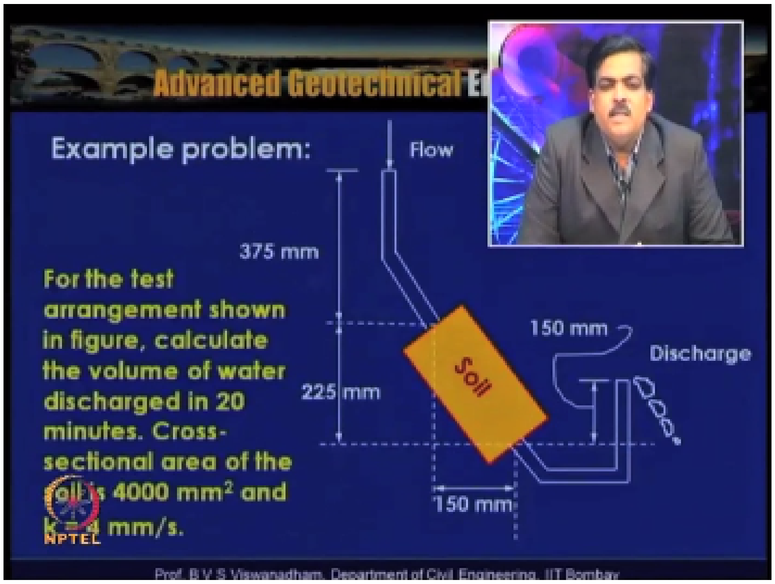


Now let us consider one more example problem in determining the permeability wherein in this particular arrangement which is actually shown calculate the volume of the water discharged in 20 minute the cross sectional area of the soil is 400mm$^2$ and the this ordinate which is actually here is 225mm and this horizontal distance is 150mm and this distance above this where the inflow and the suppress flow is actually discharged takes place the water flow takes place here so this hike is 375mm and above this horizontal line this height is about 150 mm, so the water flow that is discharged they expressed from this here. So the permeability of the soil which is actually placed here is having 4mm/s. So the solution for this problem works out like this.

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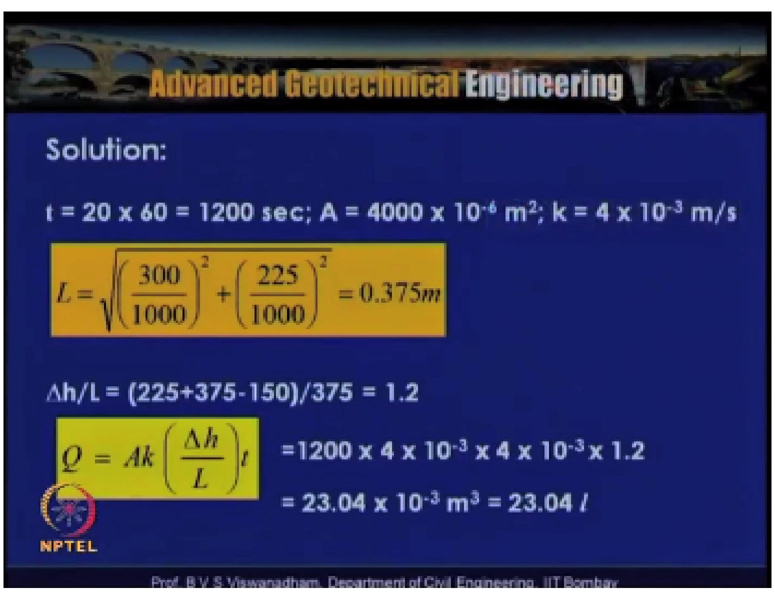

We need to estimate amount of flow which actually takes place in 20 minutes so by converting 20 minutes into seconds 20x60 1200 seconds and area of the cross section which is perpendicular to the you know the flow direction which is nothing but the area which is given as 4,000$mm^2$ which is can be converted into 4,000$x10^{-6}$ $m^2$ and the pyramid to the soil is in m/s it is $4x10^{-3}$m/s now here the length of the sample is the thing but the square of you know the vertical ordinate and horizontal ordinate and with that we can actually get as 0.375m.

So the Δh/L the hydraulic gradient is nothing but by considering 225 + 375- 150 we will be able to get this as Δh/375 that is the length of the soil sample, so Δh/=1.2 / using Q=Ak(Δh/L)t so we need to estimate the amount of water which actually flows for 20 minutes duration, so that is given as A which is nothing but $4000x10^{-6}m^2$ and the permeability which is actually given as $4x10^{-3}$m,/s and I draw the gradient is 1.2 so with that it works out to be $23.04x10^{-3}m^3$ which is nothing but about 23.04 liters. So in this particular lecture on CPS the permeability and the CDEEP part three we discussed it about the factors influencing the permeability and we actually have solved some couple of problems.

In the next lecture we will try to discuss about the flow CPS theories and then some relevant discussions pertaining to CPS theory.

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