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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 15

Module-2
Permeability and Seepage – 4

Welcome to lecture number 15 under permeability and seepage 4 and this is under module 2.

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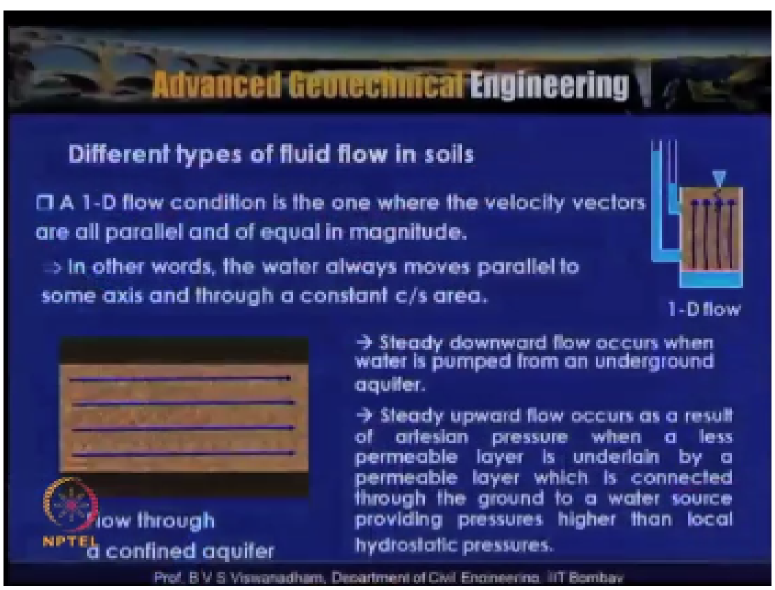

So in this lecture we are going to discuss about different types of fluid flow in soils and seepage phenomenon, Laplace equation of continuity and solution of those Laplace equations in one dimensional and two dimensional and three dimensional flow conditions, and then we will try to solve some typical problems. So what are the different types of fluid flows which are possible in soils it can be one dimensional, it can be two dimensional and it can be three dimensional.

A one dimensional flow condition is the one where the velocity vectors are all parallel and are equal in magnitude. In the conventional laboratory if you are doing a constant head test where the flow which occurs is one dimensional nature, because the flow occurs in a rigid container having a particular boundaries the flow happens in the vertical direction. A one dimensional flow condition is the one where the velocity vectors are all parallel and are equal in magnitude.

In other words water always moves parallel to some axis and through a constant cross section area, so if flow through a confined aquifer, a aquifer where two clay layers are there suppose if there is a sand layer in between and if there is a head which is actually driving the flow from left to right the flow can actually happen either from left to right or right to left. So steady downward flow occurs when the water is pumped from an underground aquifer or study upward flow occurs as a result of artesian pressure when a less permeable layer is underlined by a permeable layer which is connected through the ground to a water source providing pressures higher than the local hydrostatic pressures.

Suppose if you are having a less permeable layer and below that there is a permeable layer and if the permeable layer is actually receiving water because of some artesian conditions and the water can flow in vertical direction or can have higher pressures compared to the hydrostatic pressure. So in this in such situations upward flow is possible that is a study upward flow occurs as a result of artesian pressure when a less carbon layer is underlined by a permeable layer which is connected to the ground to a water source providing the pressures higher than the local hydrostatic pressures.

What is two-dimensional flow, mostly flow through earthen dams or flow through a sheet pile wall if your hydraulic structures.
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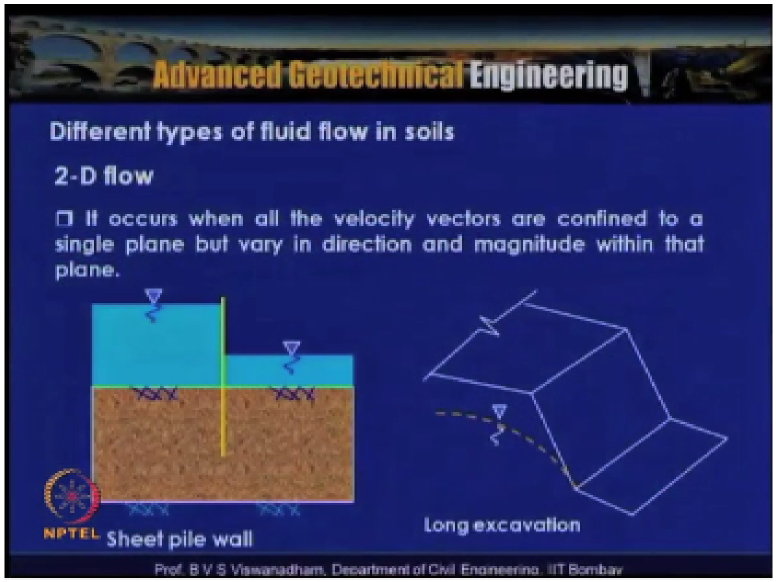

Or a particular Canal embankment where when you are retaining the water on both sides either in cutting or in filling the flow which actually happens is two dimensional nature. It occurs when all the velocity vectors are confined to a single plane but vary in the direction and magnitude within that plane. So if you are actually assuming x and z are the, z is the horizontal plane horizontal direction and z is the vertical direction.

If y is along the length of the canal or an earthen dam then we can say that theflow which actually happens in x and z direction, that means that the flow happens in xz plane, so in that situation in this slide which is actually shown here a sheet pile wall can actually have a two dimensional flow water flows downward here through this porous medium and then water actually moves upward in this region.

And by the time the water reaches here the head which is actually driving the flow dissipates, so this is the upstream side and this is the downstream side. In case of long excavation or a earthen dam where there is a possibility that because of the upstream water level water flows in this fashion, so at different planes if you take these are the you know this resembles completely but the flow which actually happens in x direction and z direction and is the plane exit plane. So these are the two examples for the two-dimensional flow conditions, then what is three dimensional flow in what situations the three-dimensional flow can occur.

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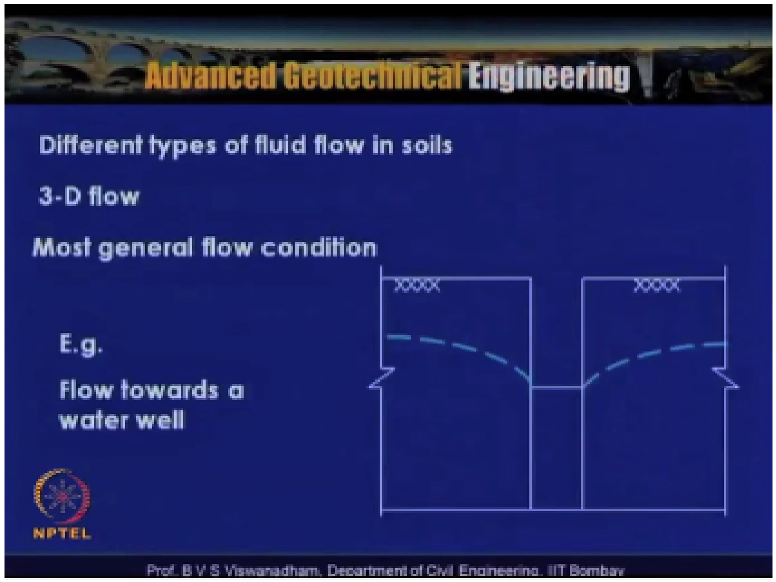

Three dimensional flow the example is that most general flow condition is that flow towards a water well. Suppose if you are having a water well there is a depletion curve water table here and the flow happens in three dimensionally, so this is example for three dimensional flow is flow towards a water well. So if the water flows in all the three dimension the directions that is in x direction, z direction and y direction and that is very similar in case of flow towards a water well.

In case of some ground improvement projects when we are actually using the free fabricated vertical drains or sand drains the flow actually happens also in three dimensional that is the because of the presences of the drains in the internal soil the flow happens in x and z directions as well as in y direction that is also another example for the three dimensional flow condition. So the multi dimensional flow in soils as of now we have considered.

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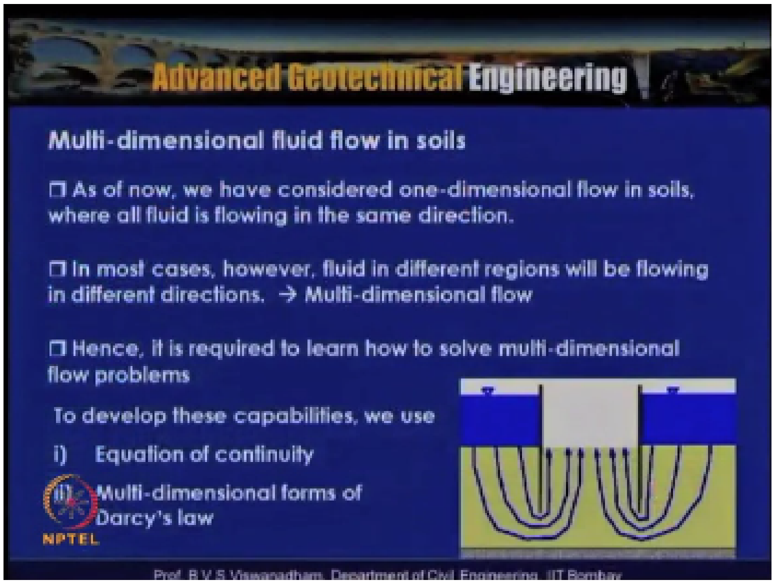

One dimensional flow in soils where all fluid is actually flowing in the same directions, in most cases however the fluid is actually different fluid in different regions will be flowing in different directions. So the multi dimensional flows are actually possible. so it is required to learn how to solve the multidimensional problems, so for this in order to develop these capabilities we use equations of continuity equation of continuity multi dimensional form of Darcy's law application.

So if you are having a cofferdam within the middle of the river the situation is that the situation where you have got the vertical sheet pile walls all around the periphery of the water so here water actually because of this the water tends to flow in this direction, this is the direction of the flow this is downward and this is upward and with the symmetry also maintains in the same direction, so it is required to ensure and to know and assess the stability of this type of structures when men are constructed along with the water.

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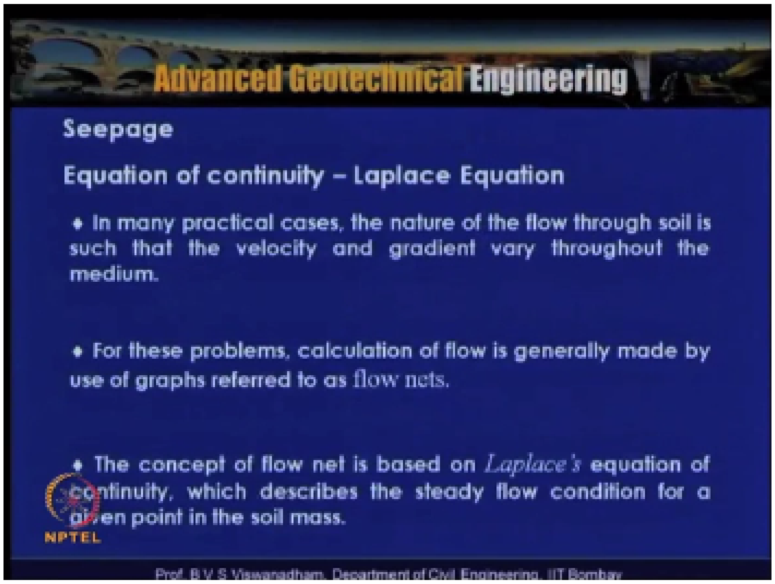

So the seepage and we have discussed about seepage phenomenon which occurs because of the prevalence of a head which is actually driving from our head to the higher potential to the lower potential. Equation of continuity and the Laplace equation is thought we are actually going to discuss in many practical cases the nature of the flow through the soil is such that the velocity and a gradient vary throughout the medium.

So for these problems the calculation of flow is generally made by the use of the graphs represented as are referred to as flow nets, so the flow rates are nothing but the graphical representation of the system of along the direction of the flow and in the direction perpendicular to the flow which are represented by the set of lines or a nest of lines which are actually in the direction of the flow or in the perpendicular to the direction of the flow.

From these problems the calculation of flow is generally made by the use of graphs referred to as flow nets so the concept of the flow net is based on the Laplace equation of continuity which describes the steady flow condition for a given point in a soil mass and this is actually has got applications in heat flow and electrical the current flow and other allied applications particularly in heat transfer or on the current electricity transfer from because of the high potential to the low potential. So the concept of flow rate is based on the Laplace equation of continuity.

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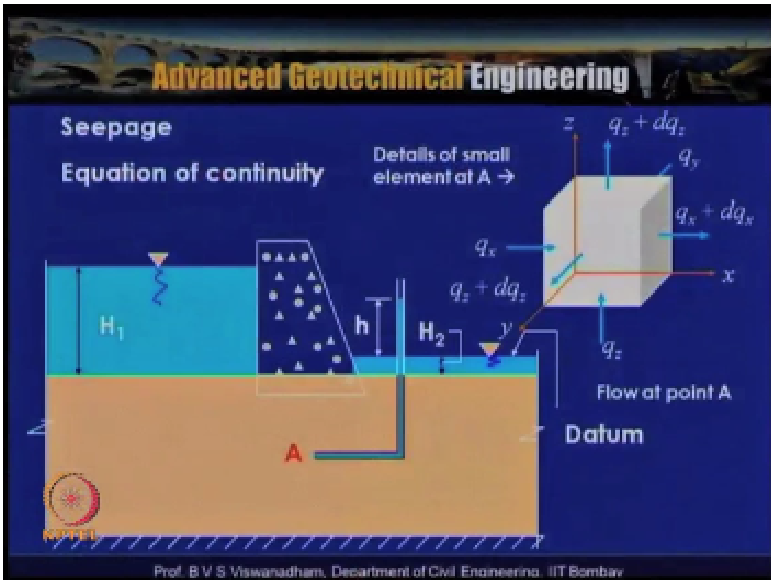

So in this particular figure a particular hydraulic structure which is actually shown here and the derivation or the use of the Laplace equation of the continuity is the one which we are going to discuss. So we are having a structure a concrete hydraulic structure which is retaining the water H1 is the upstream water level and H2 is the downstream water level and so this is called the tail water level and this is the upstream water level and at the point A let us assume that a small element which is actually having dimensions dx in along the x direction and dz along the z direction and dy along the y direction.

So the unit volume or the volume of the element is dx, dy, dz and that in that particular element is actually experiencing your flow in and flow out that means that qx can be the flow in and the qx out is the flow out of that element, so the assumption main assumption is that in the process of the flow when the water is actually flowing through the this particular element or any portion of the soil it is assumed that there is no volumetric change or no change in the effective stress.

So in this particular situation the a particular the enlarged view of details of the small element at point A is shown here the headed point A let us say is h and H1-H2 is the ΔH which is the potential drop which is actually happening from upstream level to downstream level and this top surface of this downstream level is assumed to be as the datum and this is the a previous soil and here is the impervious bottom where the flow can actually happen along this direction only flow cannot actually perpendicular to penetrate through this layer. And there is a certain thickness for this and the flow is actually happening from upstream level to downstream level, so the purpose of the structure is to retain the water and maintain this particular condition.

So here in this particular detail of the element which is actually here qx is the flow entering the dz and dy area and qx+dqx is the flow coming out so the net flow is dqx which is actually entering the plane dz dy area and coming out of the flow which is actually coming out of that particular plane is qx+dqx. Similarly in vertical direction qz is the flow which is occurring in a long area dx dz, dx dy and the qz+dqz is the flow which is coming out of that particular area.

Similarly qz in the y direction so we have got in the three dimensional conditions we have considered where in x direction and y direction and z direction.

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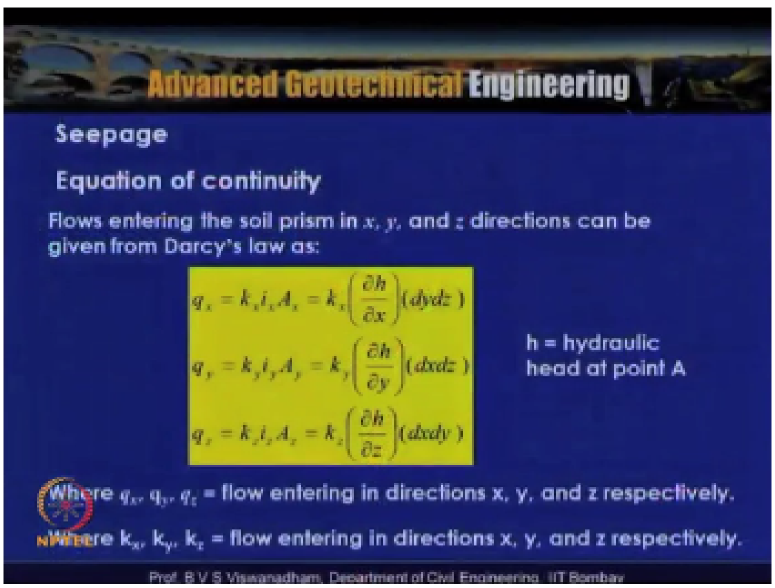

So flows entering the soil prism in x y and z directions can be given by from the Darcy's law as follows we knew that q $=k_i A$ and x is nothing but the cross sectional area through which the flow is occurring, so kx is the permeability in the x direction ky is the permeability in the y direction and kz is the permeability in the z direction. ix iy iz or the hydraulic gradients along x and y and z directions so we can write qx =kx ix Ax which can be written as kx(∂h/∂x)(dydz) and h is nothing but the hydraulic headed point here which was shown in the previous slide. Similarly qy=ky iy Ayi, so Ay is nothing but the cross sectional area along y direction and which is nothing but dxdz.

So ky(∂h/∂y)(dxdz) similarly qz=kz iz Az where sz(∂h/∂z)(dxdy) so where qx qy qz is equal to flow entering in the directions xyz respectively and where kx ky kz are the flow entering the directions xyz respectively.

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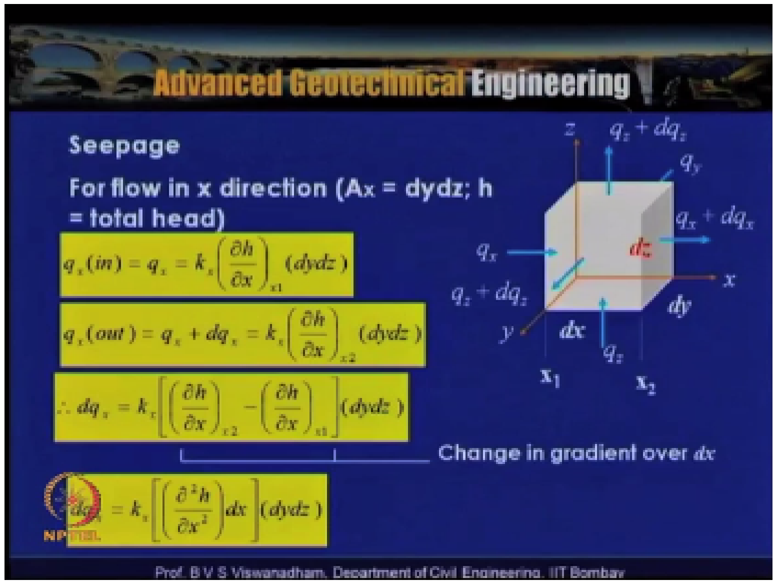

Now when the element when the water enters this element let us assume that qx which is nothing but qx in entering this particular area cross section area that is dy/dz and qx +dqx that is nothing but the qx out which is the one which is actually leaving the element okay, so x1 is at this point and x2 is at this point x2 - x1 is nothing but the dx, so we can write for flow in x direction ax=dy dz and h is nothing but the total head at point A where the elementals thus considered.

So we can write qx=qx in as kx ∂h/∂x1 that is at this point into dydz, similarly qx out we can write it as qx+dqx=kx(∂h/∂x)x2 dydz now the difference of these two is nothing but the net flow which actually has taken place that is nothing but dqx=kx(∂h/∂x)x2-(∂h/∂x)x1dydz so (∂h/∂x)x2-(∂h/∂x)x1 this particular term represents the change in gradient over a distance dx, so this can be written as dq =kx(∂^2h/∂x^2) dx(dy/dz) so dx(dy/dz) is nothing but a element volume which was considered in this particular derivation.

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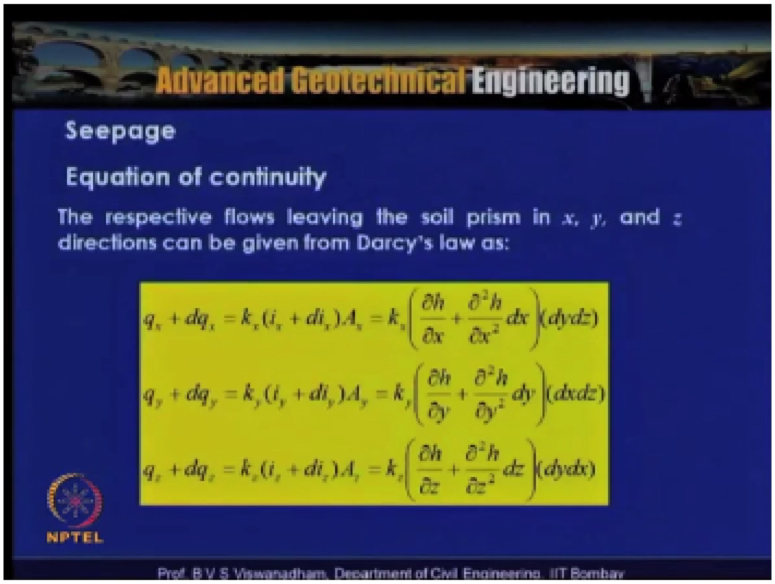

So using that we can actually now reduce that represent the respect to flows leaving the soil prism in x and y directions and which can be given again by applying the Darcy's law as follows $q_x+dq_x=k_x\ i_x+di_x$ that is A_x which is nothing but $k_x(\partial h/\partial x)+(\partial^2 h/\partial x^2 dx)$ dydz similarly in the y direction and z direction for the respective flows leaving the soil pressure can be computed. Now using the principle of conservation of the fluid mass for study flow through an incompressible medium.

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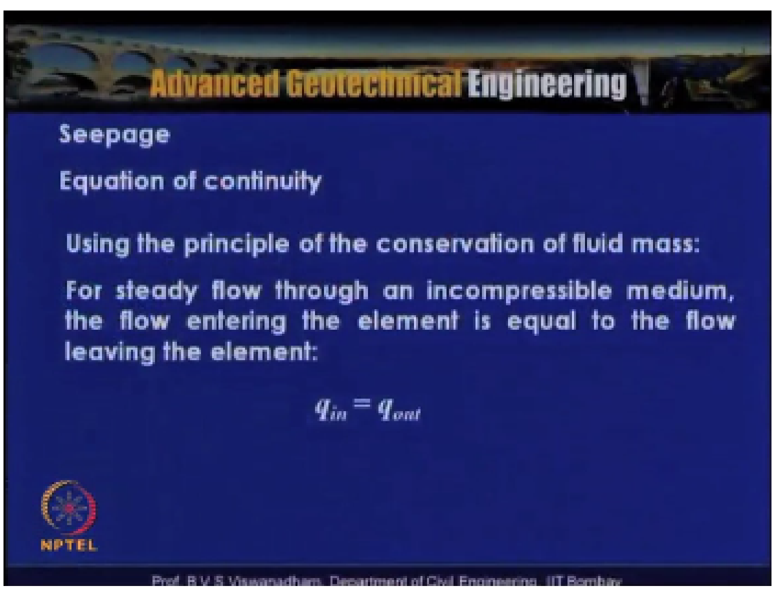

The flow entering in the soil element or flow entering in the element is equal to the flow leaving the element, so by equating the inflow is equal to outflow we can get like this.

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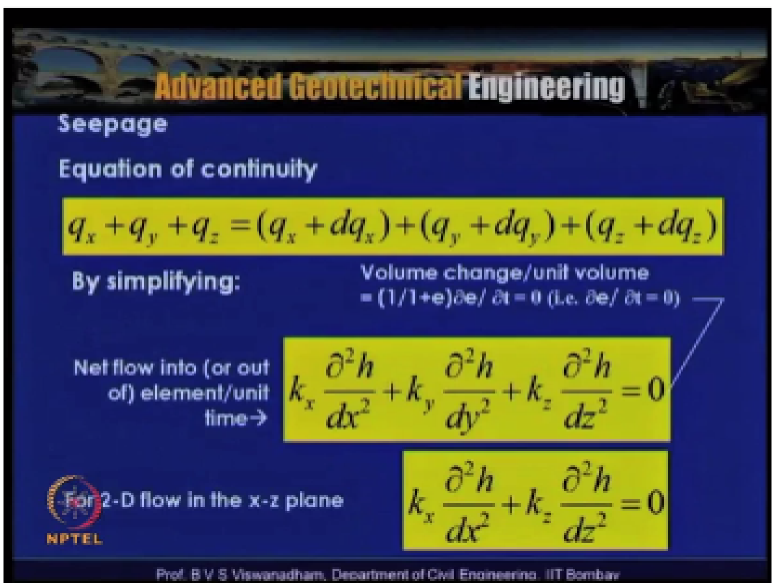

Which is nothing but qx+ qy+qz=qx+dqx which is the outflow flow leaving the along the x direction and qx + 2dqy in the y direction and qdz+ dqz is in the z direction by simplifying and we get and substituting the previous terms which we have discussed we get that the net flow into or out of the element per unit time, so nothing but kx $\partial^2h/\partial x^2$ + ky $\partial^2h/\partial y^2$ + kz $\partial\ ^2h/\partial z^2$=0 here the 0 represents that the volume change per unit volume which is nothing but 1/1 + e ∂/∂t=0 that means that is ∂/∂t =0 so because of that this particular term volume change per unit volume is 0.

But however in case of consolidation phenomenon where there is a volume change it happens that term will remain.

So in the steady state seepage conditions when no volume change takes place no volume volumetric changes takes place this particular term will becomes 0, so this particular term here is the equation of continuity when kx ky kz when they are not equal to 0 then kx =kx then and then they are actually perm abilities in xyz direction, so for three-dimensional flow condition the generalized the Laplace equation of continuity is kx $\partial^2h/\partial x^2$ + ky $\partial^2h/\partial y^2$ + kz $\partial^2h/\partial z^2$ =0, and for two dimensional flow in xz plane that means that for flow through seepage wall or for through an earthen dam or through in along excavation or a canal embankment problem kx $\partial^2h/\partial x^2$ and + kz $\partial^2h/\partial z^2$ =0.

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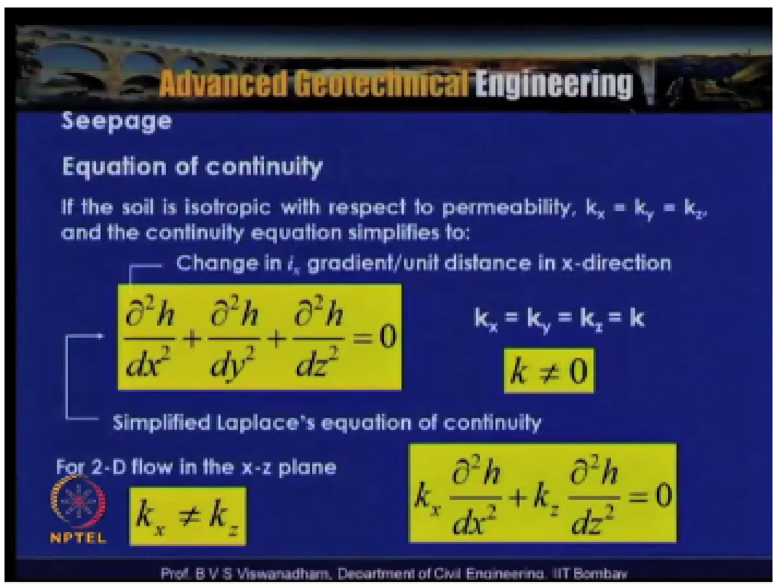

So if the soil is isotropic with respect to permeability then kx=ky =kz the permeability is equal that is kx =ky= kz =k and the continuity equation can be simplified to $\partial^2h/\partial x^2+\partial^2h/\partial y^2+\partial^2h/\partial z^2=0$ because kx =ky =kz =k which is not equal to 0, so because of that $\partial^2h/\partial x^2+\partial^2h/\partial y^2+\partial^2h/\partial z^2=0$ so this is the simplified Laplace equation of continuity for a soil having identical permeability in all the directions that means that in kx =ky =kz=k in xy and z directions when the permeability is identical that means that isotropic with respect to the permeability.

In case of a two dimensional flow or the XZ plane when kx not equal to kz we write it as kx($\partial^2h/\partial x^2$)+kz($\partial^2h/\partial z^2$)=0 if the permeability is identical in extent direction then we can write the simplified Laplace equation for the equation of continuity for two-dimensional case as $\partial^2h/\partial x^2+\partial^2h/\partial z^2=0$. So flow through a constant head permeability in the laboratory as we discuss with that this represents the one-dimensional flow.

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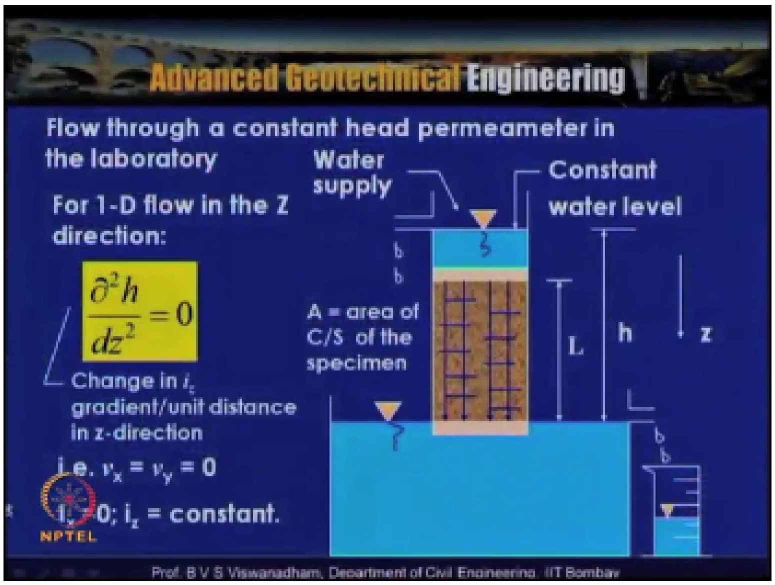

So here the water flow happens from vertically in the direction so this is the direction of the flow and these are the points where the head dissipation is actually taking place this is the available head this is the point where the head is there suppose if the head which is driving the flow is say h and by the time it reaches here the head is dissipated, so the hydraulic gradient is nothing but h/L which is nothing but the hydraulic gradient.

So for one-dimensional flow in the z direction the simplified equation of Laplace equation of continuity is $\partial^2h/\partial z^2=0$ where k is the permeability in the vertical direction. Change in the hydraulic gradient per unit distance in the z direction so $\partial^2h/\partial z^2$ represents change in the hydraulic gradient per unit distance in the z direction. Similarly if you are having in x direction it is it represents the change in hydraulic gradient per unit distance in the x direction.

If you are considering for the one-dimensional flow condition vx=vy=0 velocity in x and y directions are 0 and ix and iz, i=0 and iz=constant. So because of that the for the one-dimensional flow condition so these are the boundaries of the container and the flow which actually happens confined flow happens vertically in the downward direction.

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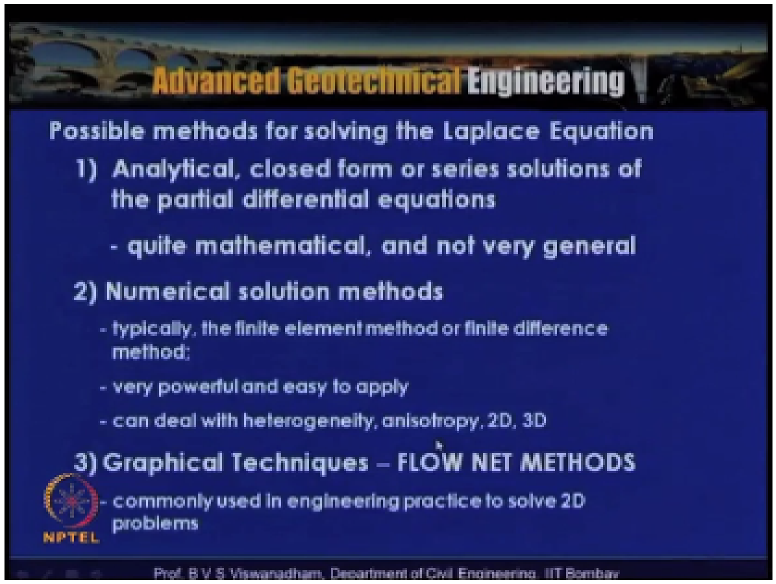

So possible so having discussed about the Laplace equation of continuity what are the possible methods which are available for solving the Laplace equation, analytical closed form or a series of solutions of the partial differential equations quite mathematical and not very general. Numerical and solution methods are available typically the finite element method or finite difference method very powerful and easy to operate and can deal with the heterogeneity anisotropy and two-dimensional and three-dimensional conditions.

So nowadays the software paradigm the finite element method based on software's are available which actually enable to deal with heterogeneities, anisotropies and two-dimensional and three-dimensional cases, and a graphical techniques which are actually popular and which are known as the flow rate methods commonly used in engineering practice to solve two dimensional problems, so at present in this particular lecture we are going to discuss about the flow rate method in the forthcoming lectures we will be discussing about some numerical solution method particularly for two-dimensional cases with ,without isotropic conditions.

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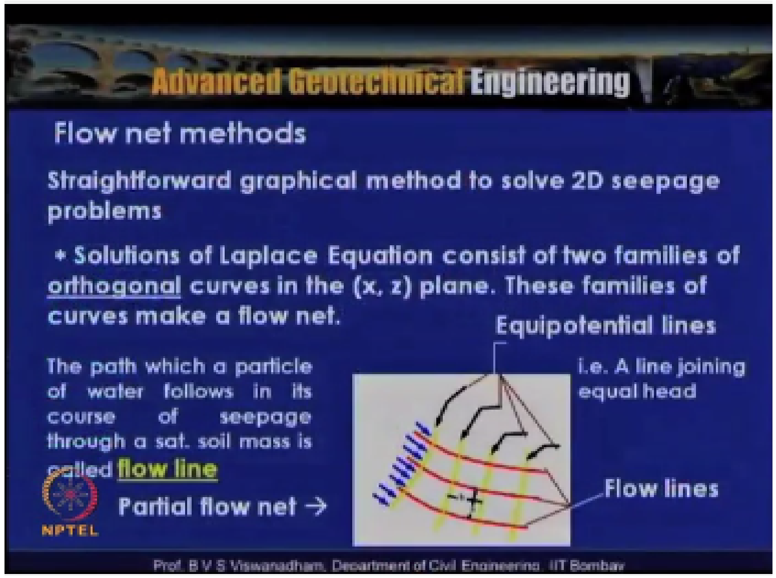

The flow net method is a straight forward graphical method to solve to seepage problems, the solutions of Laplace equation consists of two families of orthogonal curves in x and z plane exists a particular plane or which there flow is actually happening and that is the plane x and z are the planar which the flow is happening, so the family of these two sets of curves in x and z direction is known as the flow net.

So if you look into the figure which is actually shown here there is a system of the red lines which are actually shown here and there is set of a low lines which are actually shown here and this dimension which is actually shown as A and this dimension is B so this can be also indicated as B and length L this is called the ratio a/b is called aspect ratio or ratio a/b or b/l is called as the aspect ratio and these are actually called as flow lines and the space between these two is called as flow channel, so in this case in the partial flow rate which is shown here they are the two flow channels are there and the lines which are drawn within a local air they are called equipotential line which is the line joining the equal heads.

So if I take a head along this the total head will be identical similarly here the total head will be identical, but this is the direction of the flow but from this point to this point if H1is the head here H2 is the head here the H1 is actually greater than H2 so H1-H2 which is nothing but the ΔH that is the potential drop takes place between any two equipotential lines. The flow line is basically defined as the path which a particle of water flows in its course of seepage through a saturated soil mass this is called as the flow line.

So we have said that the flow rate is nothing but the nest of system of nest or a system of flow lines and equipotential lines.

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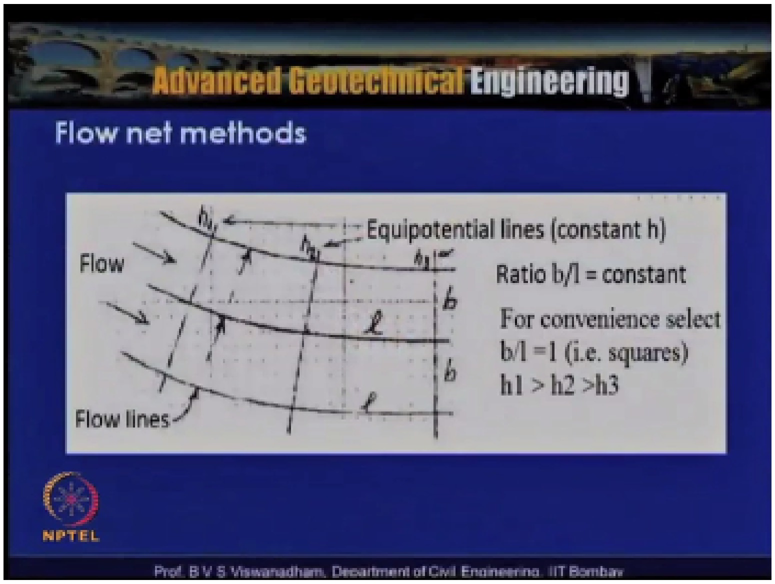

So in this particular slide schematically a partial flow net is shown here where this is the direction of the flow and H1 H2 H3are the heads at this particular equipotential line 1, 2 and 3 that means that along this line the total head is H3, along this line total head is H2, along this line total head is H1 that is why it is called as equipotential lines and L is this length and B the b/l are previous slide we have discussed it about a/b is called the aspect ratio this ratio of b/l should be equal to approximately constant and should be equal to 1 for squares for conveniently for convenience we select b/l is equal to you know as one a curvilinear squids and h1>h2>h3 indicates that as the flow actually happens the dissipation of the energy takes place.

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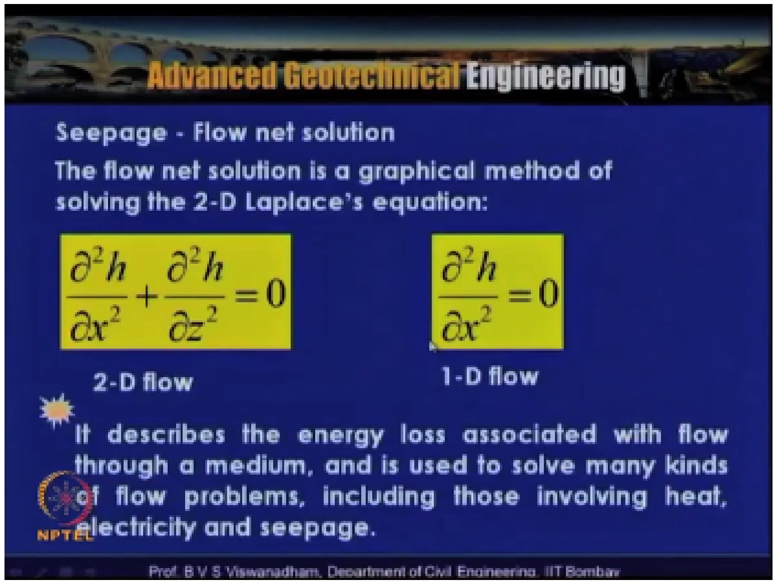

So the flow net solution is a graphical method for solving the two dimensional Laplace equation and for two-dimensional condition $\partial^2 h=0$ that is nothing but $\partial^2 h/\partial x^2+\partial^2 h/\partial z^2=0$ for a one-dimensional condition if the flow is actually happening in along the x direction it is called as $\partial^2 h/\partial x^2=0$ if the flow is actually happening only in the vertical direction that is say z direction then $\partial^2 h/\partial z^2=0$. So it describes that the energy loss associated with the flow through the medium and is used to solve many kinds of the flow problems including those involving the heat, electricity and seepage.

So this particular Laplace equation of continuity what is used in geotechnical engineering is also used in other allied areas like heat flow or electricity flow and of course where what we are using for the seepage.

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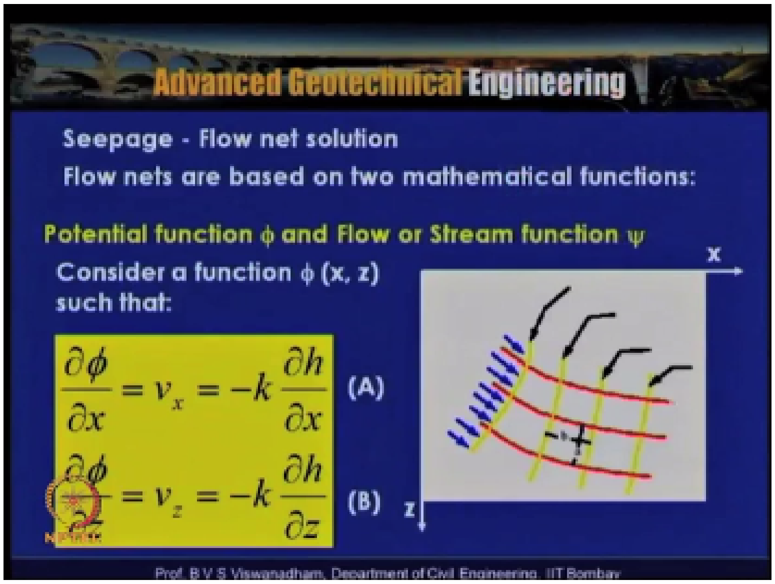

So now having actually said now we actually have seen that the flow lines and the equipotential lines what is the you know condition which actually which maintains the orthogonality, so in order to prove that let us actually try to look into this particular solution. So flow nets are based on the two mathematical functions one is potential function and that is nothing but the ϕ and the flow or the stream function that is ϕ. So now let us select say a potential function ϕ extended that is for the two-dimensional condition x and z $\partial\phi/\partial z$= that is nothing but the velocity in the x direction = $-k\partial h/\partial x$, minus is given because they head decreases in the direction of the flow.

$\partial\phi/\partial z = vz = -k\partial h/\partial z$ so let us put them as equation A and equation B, $\partial\phi/\partial x = vx = -k\partial h/\partial x$, $\partial\phi/\partial z = vz = -k\partial h/\partial z$.

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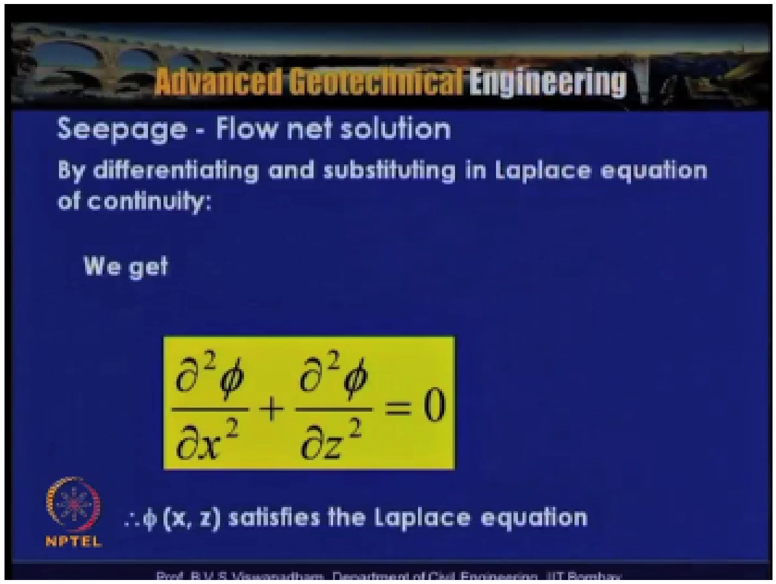

So by differentiating and substituting the Laplace equation of continuity when we substitute the previous the equations A and B and we get when we substitute in the Laplace equation of continuity for two dimensional flow condition we get $\partial^2\phi/\partial x^2 + \partial^2\phi/\partial z^2 = 0$ so this indicates that the potential function by xz in the two dimensional case satisfies also the Laplace equation so $\partial^2\phi/\partial x^2 + \partial^2\phi/\partial z^2 = 0$.

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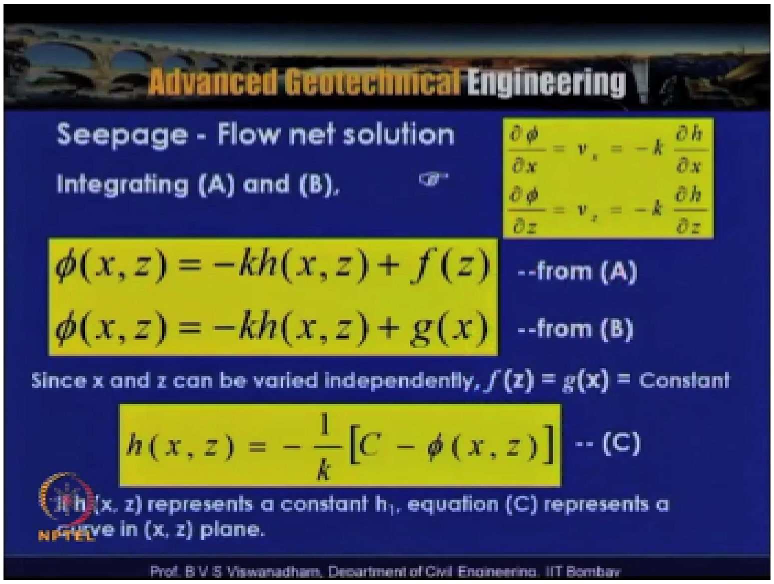

Similarly now when we take this integrating A and B that is the velocity functions we are written in the x-direction, z direction that is the previously we named it as A and B which is $\partial\phi/\partial x=vx=-k\partial h/\partial x$, $\partial\phi/\partial z=vz=-k\partial h/\partial z$ by integrating this particular functions we get $\phi(x,z)=-kh(x,z)+f(z)$ from that is from A that is this and from B we get $\phi(x,z)=-kh(x,z)+g(x)$ since x and z can be varied independently $f(z)=g(x)=constant$.

So with that we can write that is a C so we can write $h(x,z)-=1/k[C-\phi(x,z)]$ so if s if h(x,z) represents a constant h then the equation C represents a curve in the xz plane, so if xz represents a constant h equation C represents a curve in xz plane.

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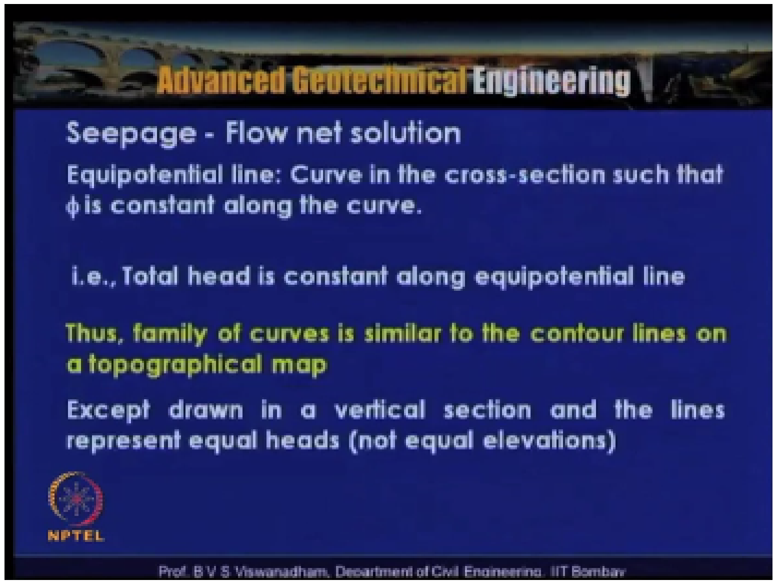

So equi-potential line the curve in the cross-section such that ϕ is constant along the curve that is why we call it as equi-potential line, so the curve in the cross section may basically it is a curve in the cross section such that ϕ is constant along the curve, so the total head is constant along the equation does the family of the curve family of curves is similar to the contour lines or a topographical map, so except drawn in vertical section and lines representing equal heads not equal elevations.

So what we are actually talking is that not equal elevations the elevations are different but total head is equal, so the total head is constant along the equi-potential line and equi-potential line is occurring in the cross section such that ϕ is constant along the curve. Now along such contours of say equal total head say $d\phi=0$.

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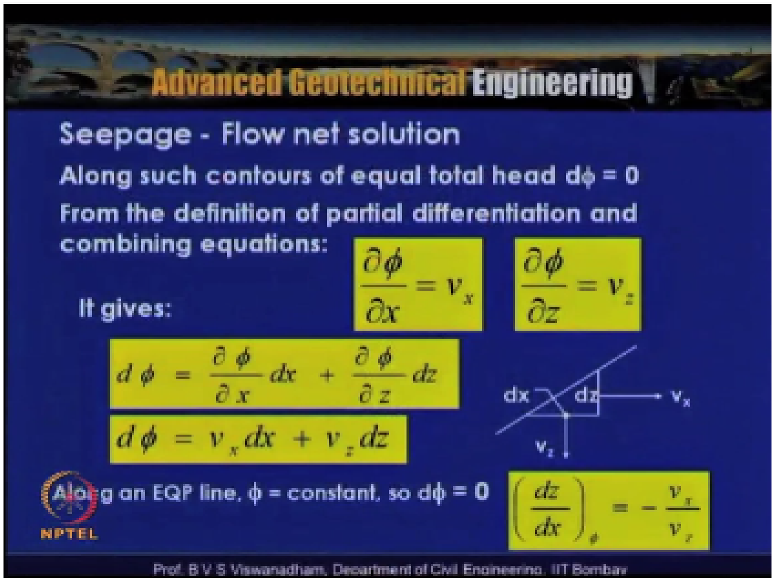

From the definition of the partial differentiation and combining this equation we can write now $d\phi/dx$, $\partial\phi/\partial x = vx$ and $\partial\Phi/\partial z = vz$ so vx is the direction of the this is the x direction this is the z direction and this is the one element dx and this is the dz in the vertical direction dx in the Y direction and this is the flow line so $d\phi = \partial\Phi/\partial x$ dx $+ \partial\Phi/\partial z$ dz so which can be written as $d\phi = \partial\Phi/\partial x$ is nothing but vx dx + vz dz is nothing but $\partial\phi/\partial z$ along an equi-potential line Φ is constant so when Φ is constant the differential of that is constant so $d\Phi = 0$ by putting this 0 what we get is that the slope of this line as nothing but this is an equi-potential line.

$dz/dx\ \Phi = -\ vx/vz$ so the slope of this equi-potential line $dz/dx\ \Phi$ is equal to $-vx/vz$ so what we have deduced is that from the definition of from the along a particular contour when you take a particularly potential line having the slope of the potential line we deduced as $-vx/vz$.

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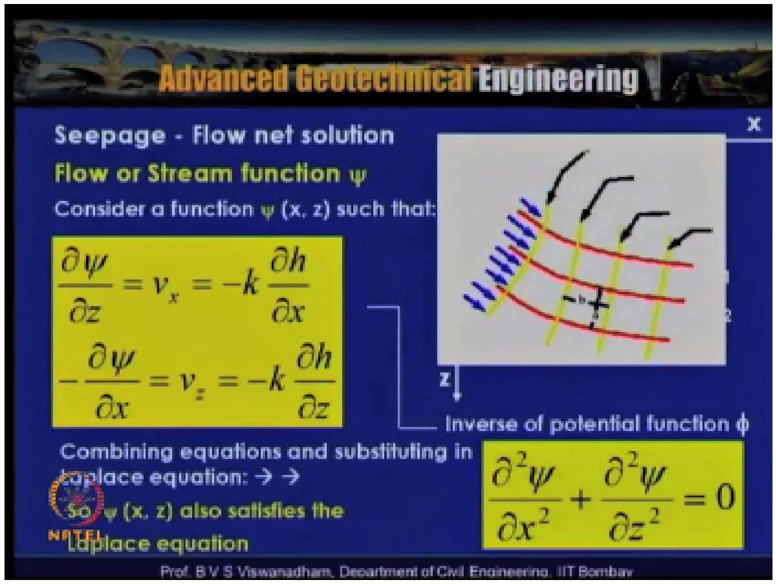

Similarly considering the flow or the stream functions ψ consider the you know a function of ψxz such that $\psi(x,z)$ such that $\partial\psi/\partial z=$ so $\psi(x,z)$ is nothing but the flow function or the stream function in the x and z direction and vx $\partial\psi/\partial z=-vx=-k\partial h/\partial x$, $-\partial\psi/\partial x=vz=-k\ \partial hy/\partial z$ so this is inverse of the potential function okay, so combining the equations and substituting in the Laplace equation of continuity we again will get that $\partial^2\psi/\partial x\ ^2+\partial^2\psi/\partial z^2=0$ when we substitute this these particular deliberations a say D and E in Laplace equation of continuity we get $\partial^2\psi/\partial x^2+\partial^2\psi/\partial z^2=0$.

So this represents that $\psi(x,z)$ also satisfies the Laplace equation, now this indicates that both $\phi(x,z)$ and $\psi(x,z)$ they satisfies the Laplace equation of continuity the system of this lines containing the flow function and potential function they form a flow net solution which actually satisfies this Laplace of the equation of continuity. So again now deduce the slope of this stream function or a flow line from the definition of the partial differentiation and combining equation.

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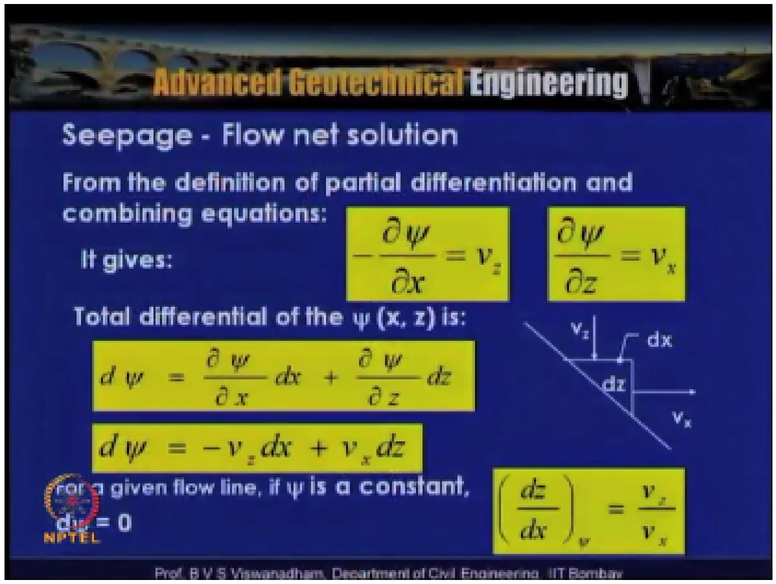

We can actually get $-\partial\psi/\partial x=vz$ and so this is the flow line and $\partial\psi/\partial z=vx$ so total differentiation differential of $\psi(x,z)$ is given by $d\psi=\partial\psi/\partial x\ dx+ \partial\psi/\partial z\ dz$ so $d\psi=-vz\ dx+vxdz$ this we have substituted here for a given flow line if ψis constant, so along a given flow line if the ψconstant the differential of that constant is 0 so $d\psi=0$ when you equate that we actually get you know $(dz/dx)\psi=vz/vx$. So the slopes are identical the product of that =-1 that means that both these flow lines and equi-potential lines are orthogonal in nature that is reason why while drawing the flow nets it has to be remembered that always the equi-potential line intercepts the flow line orthogonally.

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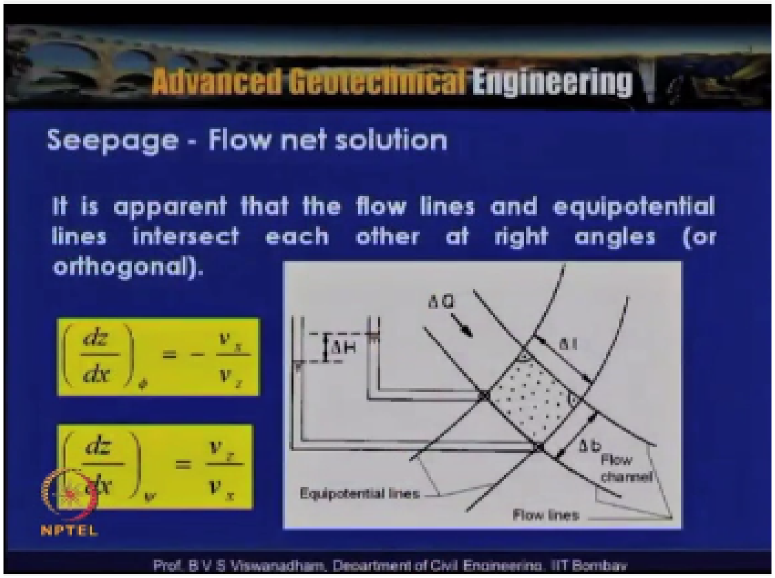

So it is apparent that the flow lines and equi-potential lines intersect each other at right angles are orthogonal to each other that is from these deliberations what we discussed the product of these slopes say m1 m2= -1 that represents the orthogonality condition. So here a particular system which is actually shown so this particular angle which is actually you know have to be 90˚ so this is the flow line and this is the flow channel this is the equi-potential line 1 and equi-potential line 2 so ΔH is actually is the pressure drop which is actually occurring from this equi-potential line to this equi-potential line.

ΔQ is the flow which is actually happening through this particular channel and ΔL is the length of or which this flow is actually happening ΔB is the so the area if you are actually taking ΔQ with the flow is actually happening ΔB into 1 the 1is actually is there in the other direction a unit area is a unit width is actually considered. So equation of use of continuity equation for solution of simple flow problems.

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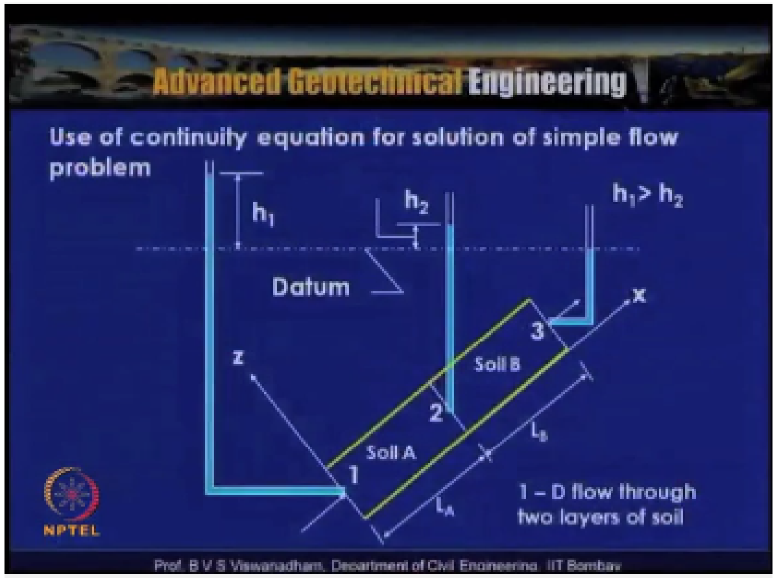

Let us say in this particular one-dimensional flow through two layers of soils or you know if we can actually deduce for two layers and then we can actually use for say in principle if H1 is the head here and by the time it reaches here the head has to be 0, that means that we have discussed with that if H is the head which is actually available and wore a length L then the hydraulic gradient here the head available is H and here this point is 0 that means L 50% of length L/2 it has to be H/2.

But when you are actually having two soils then the boundary conditions actually that different, so in this particular slide what we have considered is that we have got two soil, soil A soil B having two different permeability, but the flow occurs in along the X direction and that is the direction which is actually shown here and LA is the length of the soil A and LB is the length of the soil A and LA shall be put together is the total length and at LA the head which is actually available is H2 and at a point 2 that is the end of soil A the head is actually say H2 and H1 is actually greater than H 2 at this point it is equal to 0.

So this if it is assumed as datum so H1, H2 and then head availability here is 0, so this is the along the X direction and then point 1 is at beginning of soil A point 2 as the interface of at the interface of soil A and soil B and point threes at the end of that is soil layer B.

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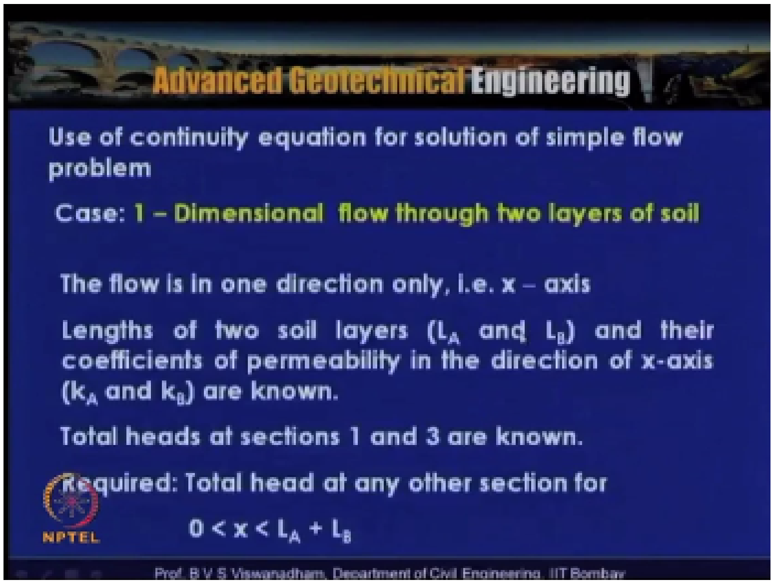

So in the case one that one dimensional flow through two layers of soil the flow is in the one direction only that is the x-axis the length of the two soil layers which are actually described as LA and LB and the coefficient of permeability's are given as ka and kb in the direction of x-axis the total head sections one and three are known required is that total head at any other section for length between 0 and LA+LB.

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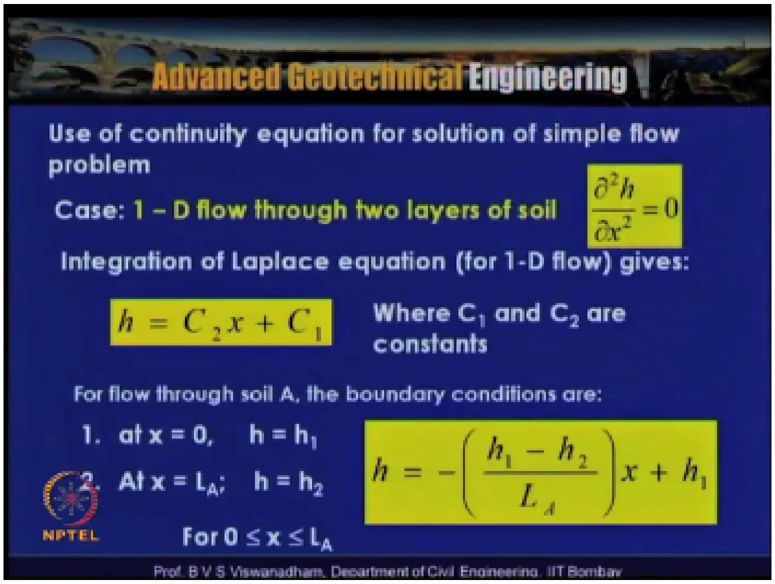

So integration of Laplace equation of for the one-dimensional flow which is nothing but along the X direction it is nothing but $\partial^2 h/\partial x^2=0$ which actually gives the H=C2x+C1, where C1, C2 are the constants for the flow through the soil A the boundary conditions what we can actually use is that at X =0 head is h1 because that is at the point 1 and a t X =LA that is at the end of soil A head =h2. When you substitute this in this particular H=C2X+C1, C1, C2 can be obtained and then we get actually H =-(H 1 - H 2/LA)x+h1. For 0 this is valid between 0 for X between 0 and LA.

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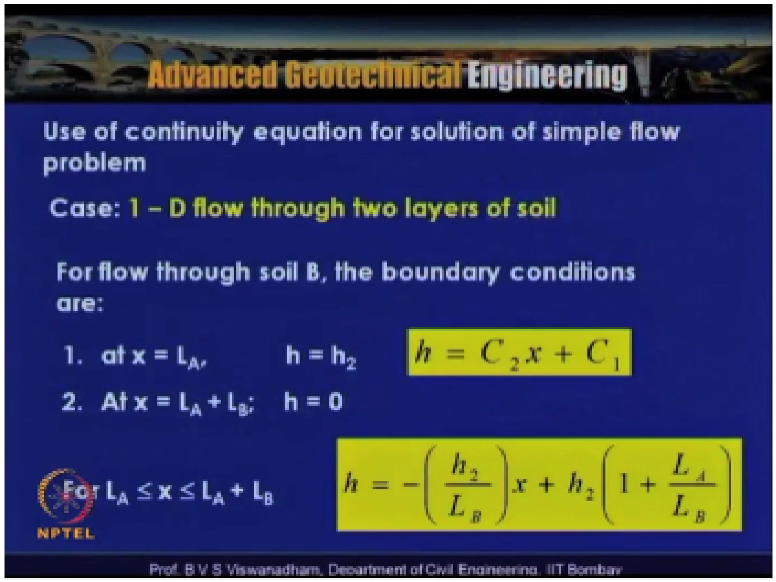

Now for the flow through the soil B the boundary condition can be given as at X=LA H is H2 that is beginning of soil B and by again by using H=C2X+C1 but using the new boundary conditions and at X =LA+LB that is the end of soil B, H=0 that is head available is 0 so when we substitute and determine C1 and C2 and simplify we will get H =-1/2 (h2/LB)x+h2(1+LA/LB) this is actually valid between from La to LA+LB that is it is at the end of soil A and to the end of soil B the total length.

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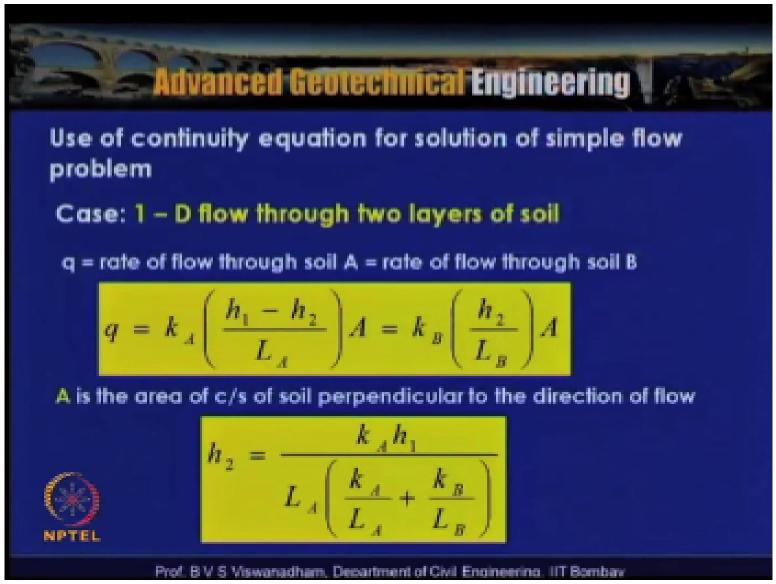

So Q is nothing but the rate of flow through the soil A and rate of flow through the soil B by but flows are equal because the same D which is actually driving so because of that Q =K(H 1- H 2)LA h1-LA, is the cross section area of soil a and cross section area of soil A and cross sectional area of soil B is also same so the rate of flow through the soil A can be written as K(H1-H2)/LA, LA is nothing but the length of soil A into area A which is the cross section area of the perpendicular direction of the flow and KB =KB(h2/LB) h2 is the head at 0.2 where the beginning of soil B into A.

So by equating and that simplifying we will be able to get h2 in terms of kA h1/La kA/LA+kb+LB so the h2 if you look into this when you substitute say that at LA=LB and ka=kb h2 is obtained as H1/2 that is correct because at the off length of the soil if thus both soils are actually having same permeability the head disparities will be 50% of the head war which the flow is actually happening.

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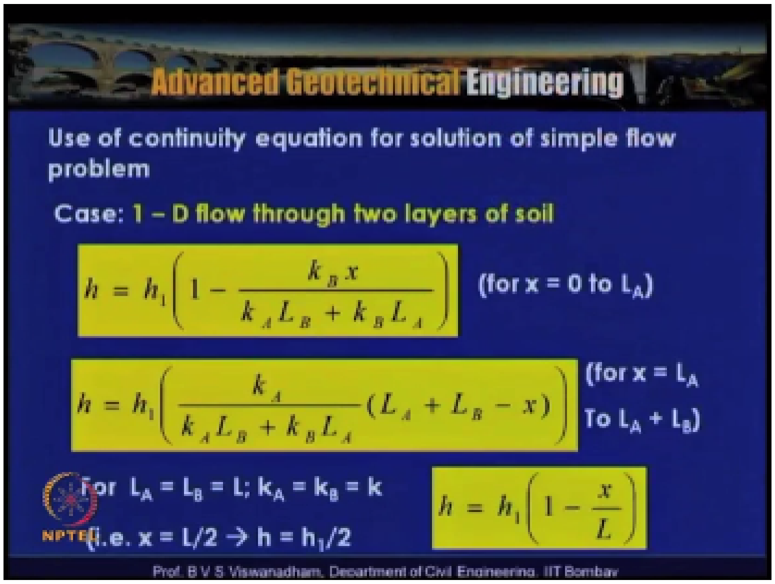

So further when you come use this one we actually have got two things for X =0to LA we have got H=H12 1 -kbx kaLB+ kb LA and for x =l LA to LA + LB then h is obtained has H1+ h1 ka/kaLB+kbLA(LA+LB-X) say here when we substitute LA=LB+L, kA=kB=k, H is nothing but H1(1-x/L) for say at X=0, H =H 1 when X=L, H=0 that means that the head available at the end of the soil is 0 soil sample 0 at mid height mid length of the sample that is X =L/2, h=h1/2 but this gives actually for the length up to X =0 to LA from X =LA to LA+LB the head at any point along the direction of the flow can be determined this is by using the equation of continuity.

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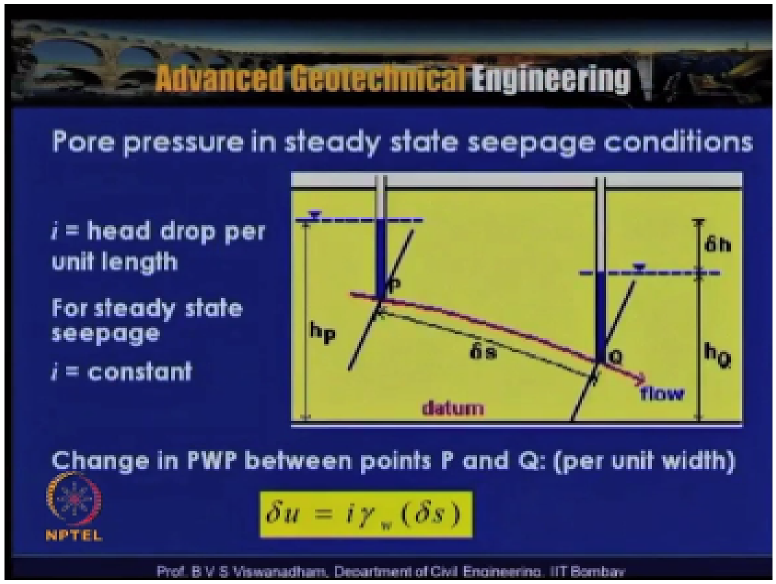

The pore pressure in the steady states if conditions so here in this particular slide where you are actually having this is the equipotential line and this is the direction of the flow that is the flow line what we call so between two equipotential lines let us say that that H is the drop and the elevation which is nothing but this hQ and this is the datum, so hi is nothing but they had dropped per unit length for steady state C ψ is constant so change in pore water between points P and Q is given by per unit weight which is given by $\Delta U = i\gamma W(\Delta s)$, $U = i\gamma W(\Delta s)$.

So the flow rate solutions particularly when water flows through a porous medium such as soil head is lost to the friction.

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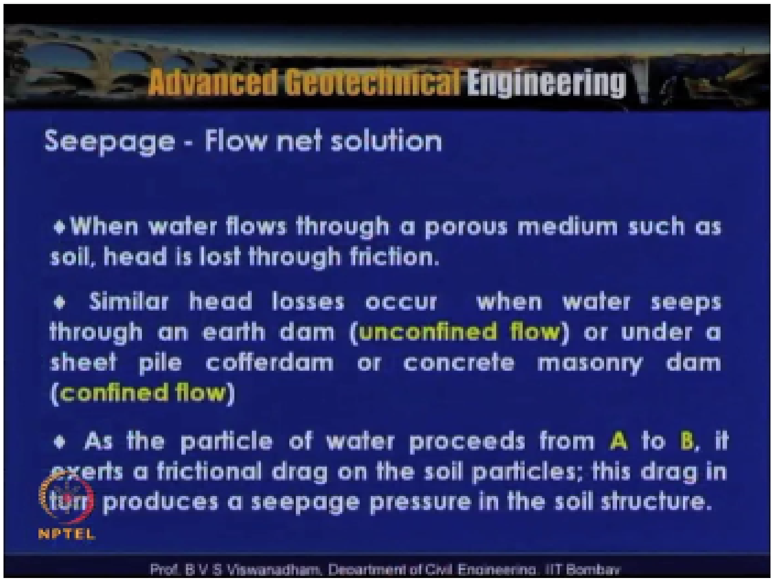

Similar head losses occur when water seeps through an earthen dam that is unconfined flow an example for an uncontained is attend dam or under a sheet pile wall coffer dam or a concrete masonry dam so that is actually given as a confined flow. As the particle of water proceeds from A to B it exerts a frictional drag on the soil particles that the dragon' ton produces a seepage pressure in the soil structure, so as the flow happens from higher potential to the lower potential the it exerts a frictional drag and the soil particles in turn it actually produces the seepage pressures.

So the hydraulic structures are required to be check it again which these seepage pressures if the seepage pressures are high there is then there is susceptibility of the different types of failures.

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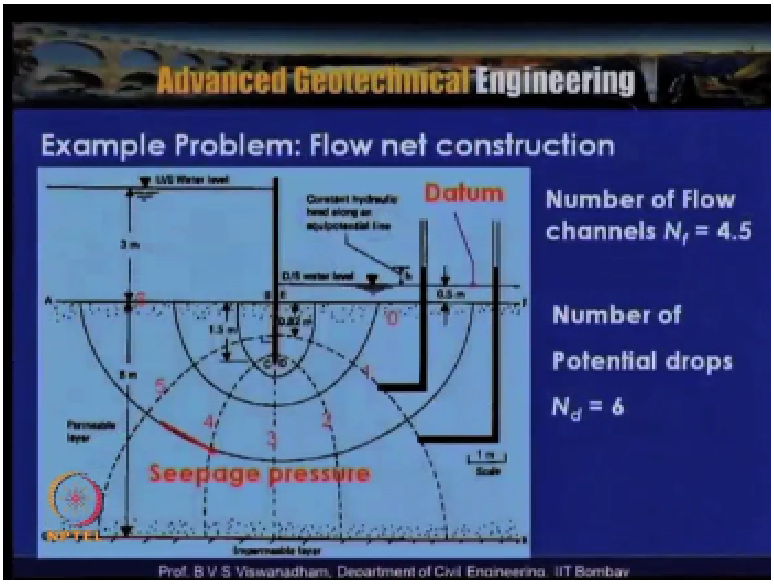

So in this particular slide an example problem of flow net construction is shown this is an example of a sheet pile wall which is retaining a water of 3 meter and the upstream side and on the downstream side this is called as a tail water level which is 0.5 meter is the you know the tail water level which is maintain so the drop or potential drop total potential head the drop which is actually given as 3 - 0.5 which is nothing but the 2.5 meters is the total drop.

Now here first of all the boundary conditions need to be identified before you know commencing the writing of the or drawing these flow rates are constructing the flow rates impermeable layers and trivial layers let us assume in the given problem this is the permeable layer and this is the depth of penetration of sheet pile 1 and here this is the impermeable layer and it can be a clay or it can be a rock stratum, so where the flow actually happens along this plane only so in identifying the boundary conditions AB which actually represents an equipotential line again EF which represents the equipotential line.

And similarly here when it comes to this particular line this actually represents the flow line because the flow actually happens along this boundary along this impermeable layer. So the first flow line is actually said as also line is a creeping line is called as BCDE is also called as a creeping line which actually creeps along the penetrated sheet pile wall so you can see here when it meets this equipotential line the orthogonality is actually maintained so in drawing the flow nets it has to be ensured that the orthogonality is actually maintained properly here.

So this is the first flow line subsequently depending upon the convenience like it can be divided into the configuration and geometry it can be divided into 5 or 6 flow lines so here we have got flow line 1 and flow line 2, flow line 3, flow line 4 and then the flow line 5 so the space between that is actually called as a a flow channel so this is one for channel 1, flow channel 2, flow channel 3 and 1234 this can be approximated as 4.5 or so.

So the number of flow channels here are 4.5 and now this is an equipotential line and this is an equipotential line and these are flow lines. Now here there is a flow line so the line which is actually if it is dropped here this being a flow line orthogonality here so this is an equipotential line this is a flow line so our technology I am maintaining the orthogonality we can draw another line another line so similarly here so these are drawn such away or selected such a way that the orthogonal D is actually maintained between a flow line and equipotential line.

So in this case if you look into this there are the numbering is done such a way for convenience it is numbered as 0 1 2 3 4 5 and 6 so this represents there are 6 potential drops so 6 potential drops mean the sense at sixth potential that is here the head available is say 2.5 meters at this point the head available is 0 anything by 2.5x0/12, 0/6=0. Similarly here 6 potential line means that is the 6/6x2.5 that means that the full head is available at this point. So the equipotential line AB is with a potential head of 2.5 meters equipotential line EF is having total head as 0 that is the potential available head available is 0 here.

So here second the potential draw potential line this is 1 2 3 4 5 and 6 so by knowing this number of flow channels and number of potential drops we can calculate the flow through a sheet pile wall and if it is an earthen dam we can also get what is the CP is actually happening through L turned down and our leakage.

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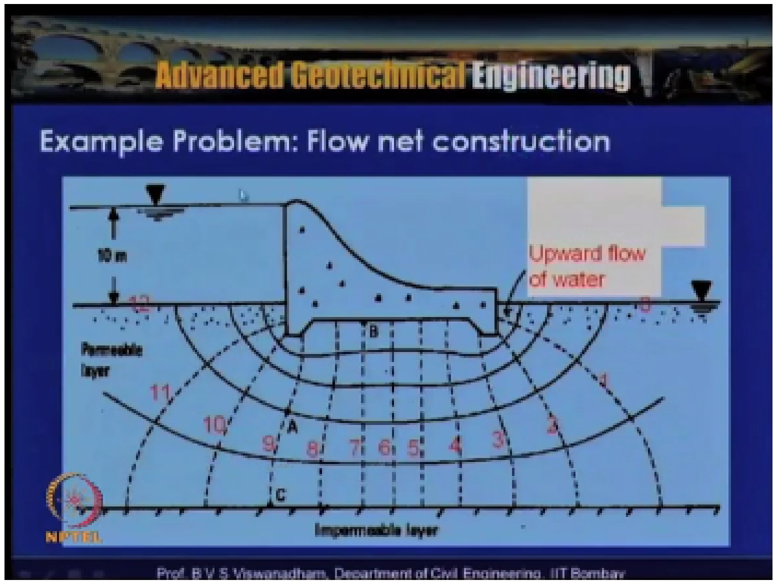

So this is another problem where the flow net construction for a year and where there is upstream water level which is actually written here the tungsten water level is at the base which is actually located here so this is the in permeable and this is the permeable layer the water flows in this direction so this is that these are the direction of the flows so if you look into this 1234 and 5 so you can say that the five flow channels are there and this is the last flow line so this is the equipotential line and this is the equipotential line and these are this is the first flow line where the creeping water flow actually happens along this.

And then perpendicular in the orthogonality we write the number of pollution lines so here 0 1 2 3 4 5 6 78 9 10 11 12 so that means that there is a total potential drops are there, so by knowing say 9/12 that is the 9/12x10 meters is the head available at this point so by knowing this total head and by knowing the elevation from the if this is the datum if this point is datum let us say that this is located at 2 meters that is by knowing this elevation we can actually calculate the pressure available at this particular point.

So in the process of C page there will be some dissipation by the time it comes here the head which is actually takes place 12 3 drops you time it undergoes so 9/12x10 and then if you take the elevation ahead with respect to the datum which is selected here we will be able to calculate the pressures at each point. So the calculation of this total heads and this pressure is important for assessing the uplift pressure distribution or the pore water pressure distribution along these things and the enterprise in turn which can be used for designing these hydraulic structures.

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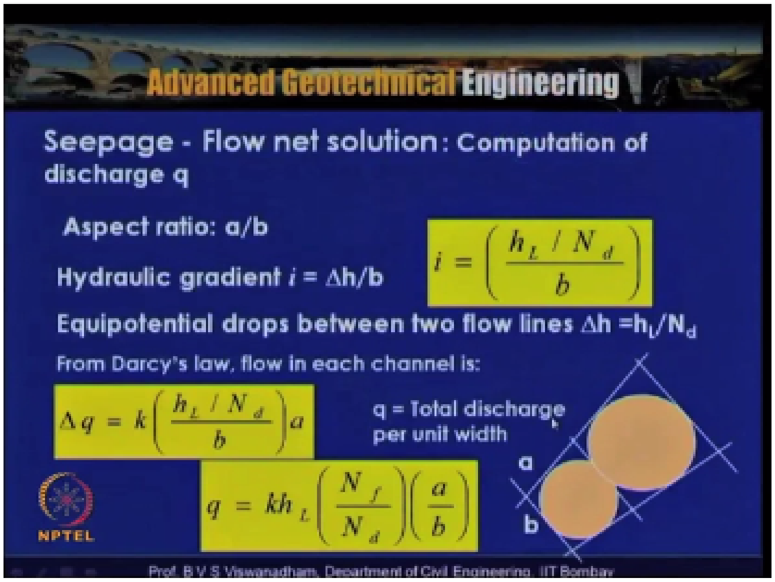

So the CP is particularly the flow net solution the computation of discharge which what we discussed is that the aspect ratio we is nothing but a by B which is constant basically they are curvilinear squares so hydraulic gradient i=ΔH/b so this ΔH is given by for one potential drop which is hL/Nd/b so we can great we can get this as a ΔH/B, so equipotential drops between two flow lines is ΔH/hL/Nd so from Darcy's flow, flow in each channel is given by ΔQ=Q(hL/Nd)/bxa.

If you wanted to purchase the total discharge per unit width then it has to be multiplied with thee we have calculated this per pair of flow channel now let us say that there are n number of flow channels then it is multiplied by L or here the total number of flow channels are indicated by N_f so we can write for a case where the flow is actually occurring through isotropic medium then Q=k hL the hL is nothing but the potential head into Nf/Nd(a/b) if the ratio a/b=1 then the a/b will be will not be represented.

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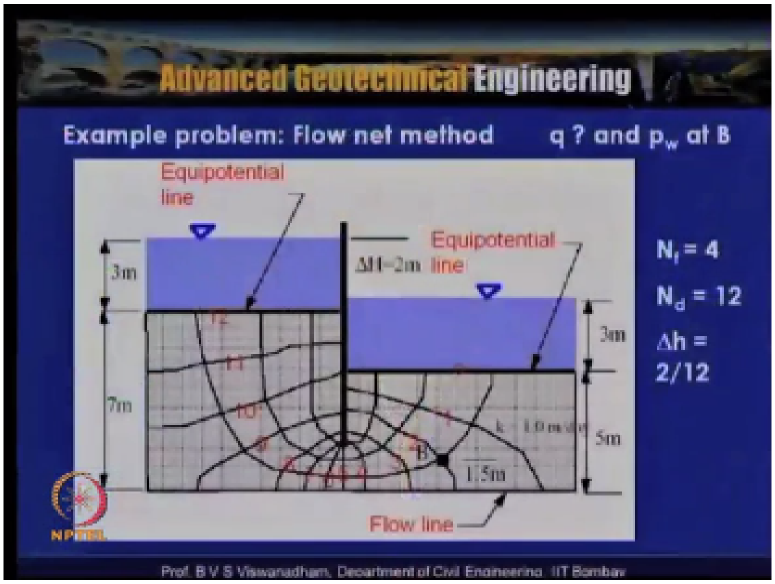

So consider this particular example problem where the flow rate method which is required to be an optic so based on this consideration this ΔH=2meters and this is the point where the datum has been selected so here based on the discussions here we can actually say that this is an equipotential line and this is an equipotential line and this is a flow line and flow channel 1, flow channel 2, flow channel 3 and flow channel 4 so we have taken an energy Nf =4,Nd=12 because there is 0 1 2 3 4 5 6 7 8 9 1011 12.

So if you wanted to measure say pressure at point B we can actually calculate total head at B is equa lto pressure at B + elevation at B suppose here it is given that 1.5 meters above the this particular stratum so that means that it is 3.5meters below this level that is 6.5meters below this level if this is selected as data then this will be -6.5 meters, so the pressure available here the total head is nothing but it is nothing but 0 1 and 2 and that 2 meters is the ΔH that is the head loss.

So 2 into that is 2/12=dt into this particular -6.5 meters so with that we will be able to get pressure at B =6.3 3meters and if the unit weight of water is taken as $10kN/m^3$ we can calculate the pressure at B as 68.33 kilo Pascal's so what we have done is that by with the total head which is actually available at this particular point and by knowing the elevation height we calculated the pressure at B, like that each and every point it can be estimated and this particular data is useful for calculating and as I seen failure against the heave and piping failures for these hydraulic structures which we will be discussing in the future course of deliberations.

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