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NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

CDEEP
IIT BOMBAY

ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 12

Module – 2

Permeability and Seepage - 1

Welcome to module two of advanced geotechnical engineering course. In this module we are going to introduce ourselves and discuss in depth about permeability and seepage.

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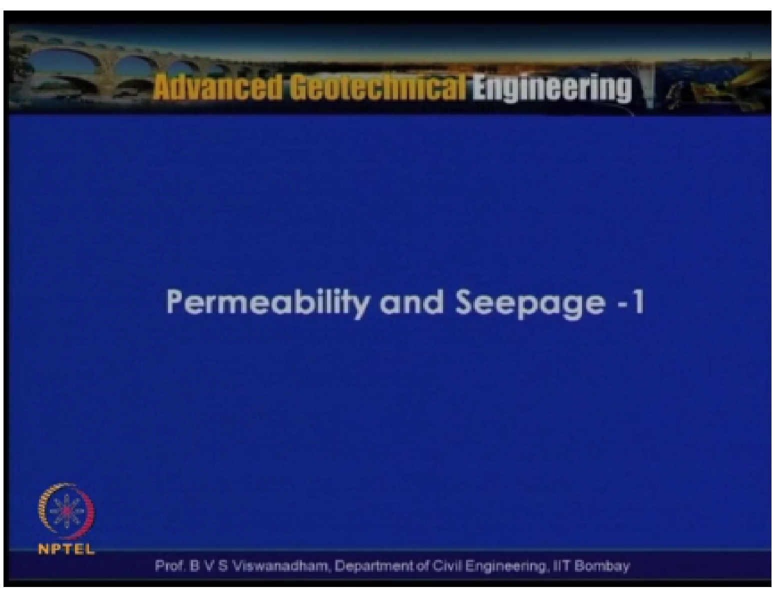

So this lecture is titled as permeability and seepage 1. As we have introduced already in the introductory lecture the module two which is nothing but permeability and seepage.

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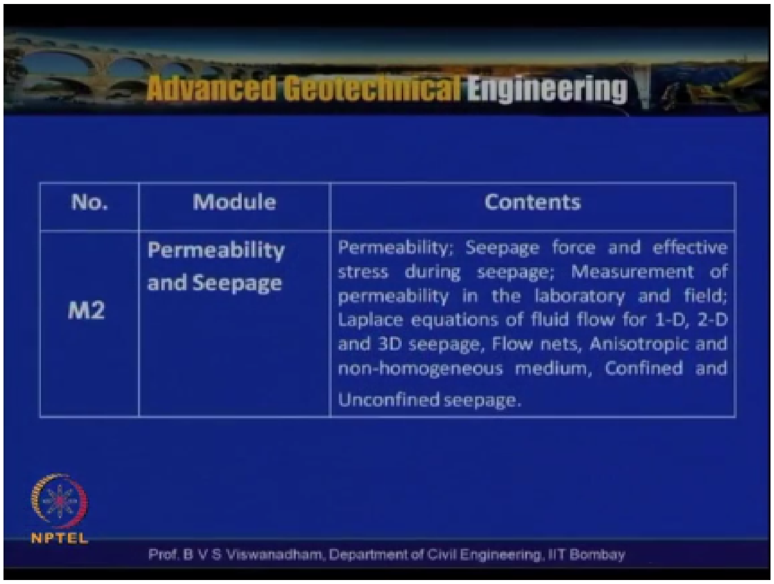

The contents are the permeability seepage forces and effective stresses due to seepage, measurement of the permeability in the laboratory, as well as in the field, Laplace equations of fluid flow for one-dimensional cases, and two-dimensional, and three-dimensional seepage, flow nets, anisotropic and non homogeneous medium, and confined and unconfined seepage. Along with this we are going to discuss about some practical problems. Particularly with the earthen dam construction and also some canal amendment construction.

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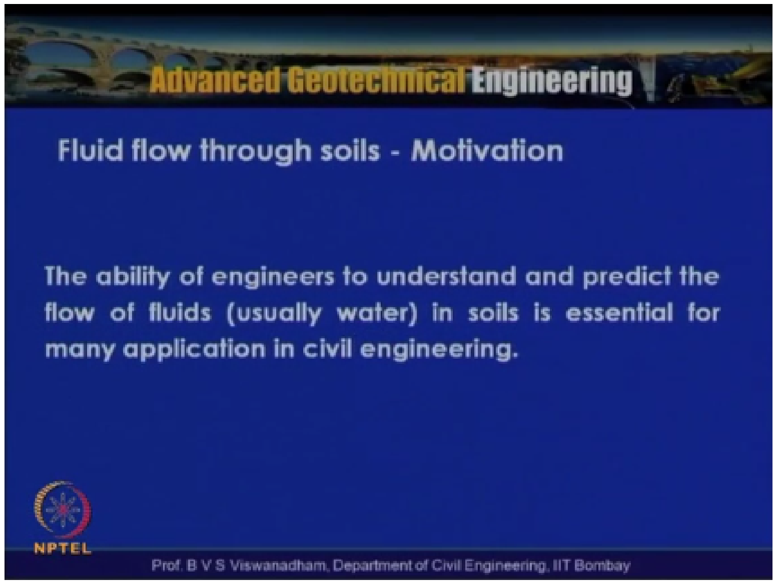

Fluid flow through soils the main motivation is that the ability of engineers to understand and predict the flow of fluids usually water. In case if the water, if the fluid is other than water that can be a contaminant then lot of work is actually happening in the unsaturated soil mechanics. So the ability of the engineers to understand and predict the flow of fluids usually water in soils is essential for many applications in engineering.

Many geotechnical structures or hydraulic structures which involve the water flow through the soils. So the motivation is that the engineer has to understand and predict the flow fluids in soils and which actually has got lot of prominence in many civil engineering structures.

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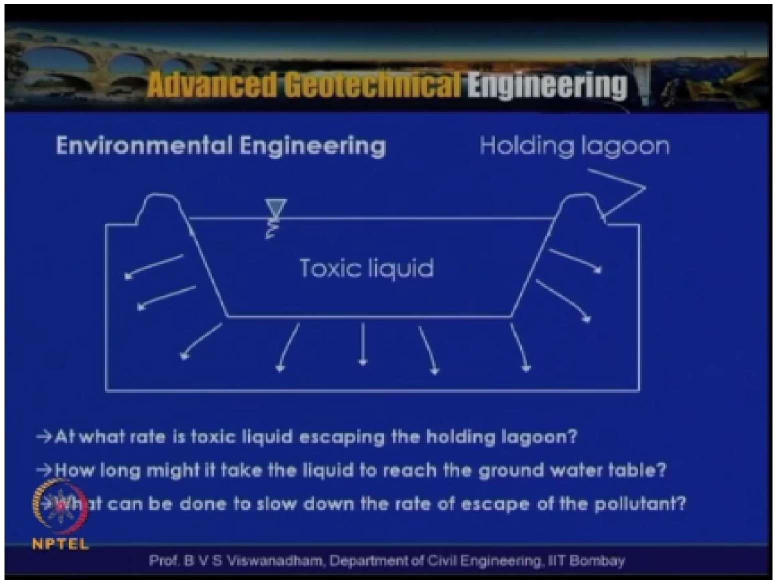

For example in the environmental engineering a holding lagoon, we are interested if you are storing a toxic liquid in the holding lagoon we are interested how efficiently we can confine this toxic liquid in the lagoon. So if at all if there is a leakage happens at what rate is this stock toxic liquid escaping the holding Lagoon, and how long might it take the liquid to reaches a groundwater table.

And what can be done to slow down the rate of escape of the pollutant which is nothing but the toxic liquid. So in this application problem we are interested at what rate this toxic per meant escapes through the holding lagoon or how long might it take the liquid to reach to the ground water table, and what can be done to slow down the rate of escape of the pollutant.

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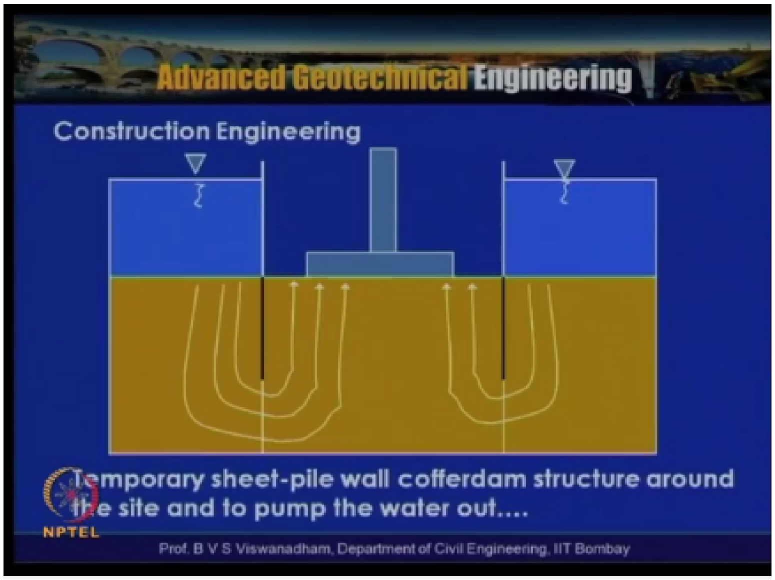

In the other side, on the other hand on the construction engineering particularly if you are constructing with in reverse or middle of a flowing river or a flowing water body we are interested in confining the particular localized area which is done basically by cofferdams. And the foundation for the either bridges or the structure which is being constructed will be mating.

So the temporary sheet-pile walls which are maybe which can be in rectangular implant dimensions or can be in circular in shape or square in shape. And they are actually constructed and then prevented the water flow into this area and that the area is actually available for construction of placement of the foundation. For example, in this slide a typical cross section of a cofferdam is shown here and basic idea is that when we retain the water surrounding water into the, then what how you know the flow can actually take place is actually shown here.

If you see here this particular portion the water enters the soil and then it actually flows up. So if there is, you know some stresses which are actually high get dropped here and there is a danger of, you know the foundation which is going to be constructed.

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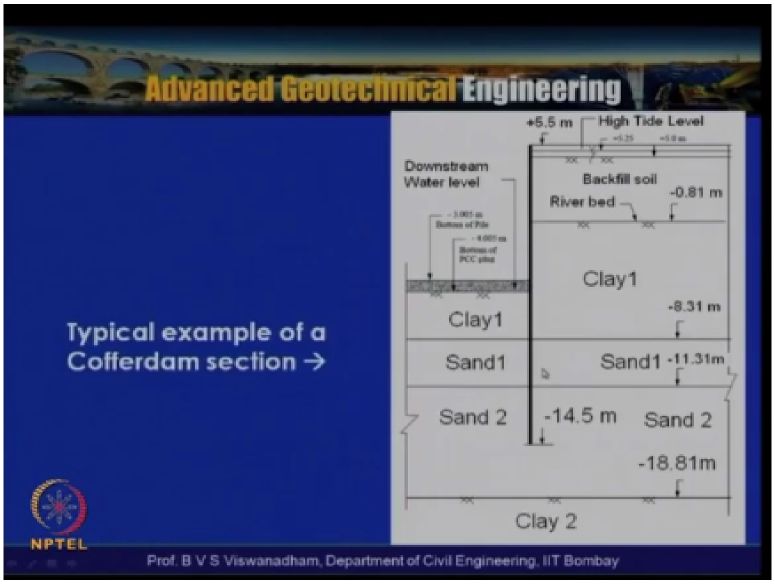

In this particular slide a typical example of a cofferdam section is shown. So wearing this is in a riverbed where we have actually got stratified soil, so the riverbed starts at -0.81m here, and there is one type of soil which is actually here clay which is fine grained in nature. So this extent is about 7m or so. Then we have got sand briefly which is named as sand one a type of sand about 3m.

Then for about seven meters we have here another sand type and then there is a clay. So if you are actually in order to construct a pier or a pier foundation what it is intended is to construct a cofferdam which is generally a sheet-pile wall which is driven into the ground. And thereafter, after putting the necessary tiles the excavation will be domed up to a certain level. And here in this particular case if you see where there is a river bed and above that there is a filling which actually has happened.

And then this is the high tide level or upstream water level what it is called, then in that situation in this practical situation this structural stability has to be seen for the water flow from the high tide level to the downstream water level. So this type of practical situations are actually coming up now, because of the ongoing infrastructure work which is happening currently in many parts of the world.

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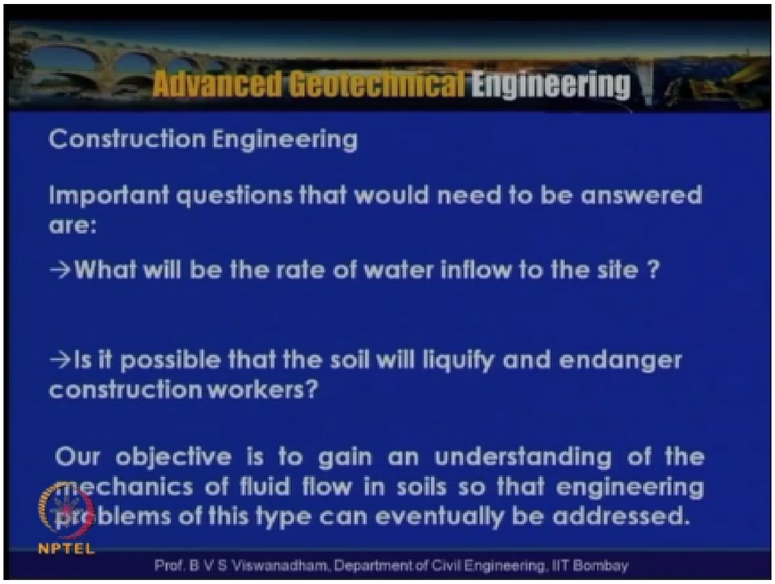

So in the construction engineering important questions that would need to be answered are what will be the rate of water flow into the site. So what will be the rate of what water inflow into the site, and is it possible that the soil will liquefy or lose the stress and endanger the construction workers. So our objective is to gain an understanding of the mechanics of the fluid flow in soil so that engineering problems of this type can eventually be address.

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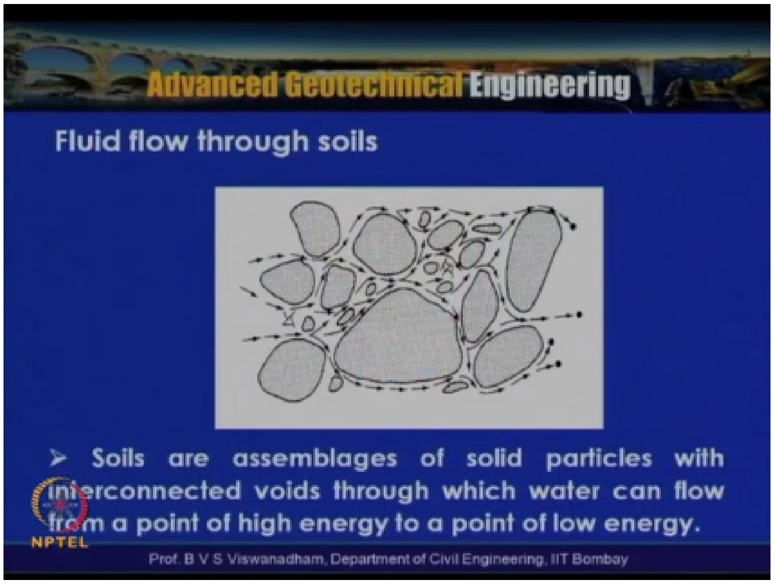

So if you consider the fluid flow through the soils as is actually shown in the slide water flows along the edges of this soil solids. So this particular path is actually the flow takes place along the edges and these are the voids within the soil solids. So water flows, so this is the path subtended by the flowing water, because of the availability of the some energy. So you can see here the flow which is actually subtended along the edges of the soil solids.

So the soils are the basically assemblage of solid particles and with interconnected voids through which the water can flow from a point of high energy to low energy. So soils are actually assemblies of solid particles with interconnected voids through which the water can flow from a point of higher energy to lower energy. So this study of the flow of water through porous soil media is important very much in geotechnical engineering, because it involves the rate at which the water flow through the soil.

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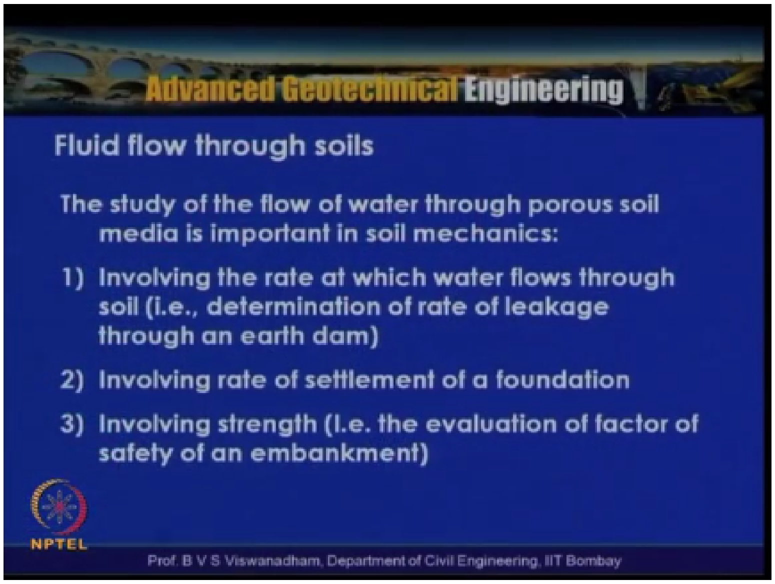

So it enables us to determine the rate of leakage through an at tap or involving the rate of settlement of a foundation. For example, if there is a foundation which is actually resting on certain type of soil and if the water is escaping out of the soil it will tell us that how much time the settlements will take place are the rate of settlements of a foundation. And involving the strength that is the evaluation of the factor of safety of amendment.

So it depends the point depending upon the rate of flow of the water out of the soil, the soil actually gains a strength. So it involves that the evolution of the factor of safety of an amendment. So in the construction from the fluid flow through point a point of view we are interested involving the rate of rate at which the water flows to the soil that is to estimate the determination of the rate of leakage through an earth dam.

And involving the rate of settlement of a foundation or involving the strength gain that is the evaluation of the factor of safety of an amendment or a dam which is being constructed on a soil.

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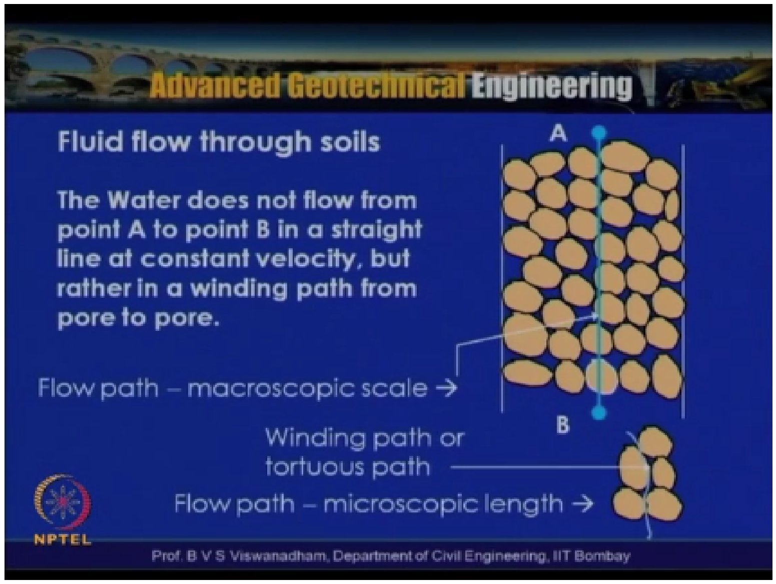

If you look into this the water does not flow from point A to point B, so in this particular slide these are the soil solid particles and point A and point B which is actually shown here. And this is actually called as the flow path which is on the macroscopic scale, but in reality as in micro point of view, microscopic point of view if you look into this and this is the path which actually which is subtended by the flowing water.

So this is called, this microscopic length is called or this path subtended, the actual path subtended by the flowing water is called winding path or the tortuous path. This length is called the, or this particular ratio of this length to this my macroscopic length is called the tortuoustic factor. So water does not flow from A to B if there is, you know the total header energy is actually same.

If water can flow from A to B if there is a difference of head only, that means that if the headed A is higher than headed B then there is a possibility that water flow can take place from A to B. Similarly if the headed B is higher than headed A then water can also flow from B to A. So this path subtended by the, actual path subtended by the flow of water of the path subtended by the flowing water in the soil solids is known as the tortuous path.

And the ratio of the tortuous lengths of the tortuous path to the length of the microscopic length are a length of my flow path which is called as a tortuoustic factor.

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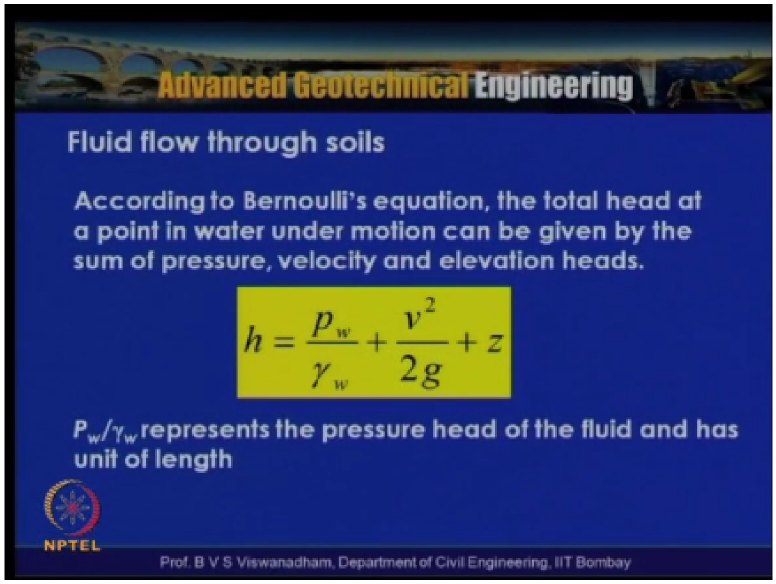

We have actually studied the Bernoulli's equation and we have defined this Bernoulli's equation as total head = pressure head + velocity head + elevation head. So in geotechnical engineering we also use this, the total head at a point in water under motion can be given by the sum of pressure, velocity and elevation heads. So $Pw/\gamma w$ represents the pressure head and which actually has got the units of the length.

And $v^2/2g$ is the velocity head and V is the velocity with which the water is actually flowing through the soil and Z is the elevation head.

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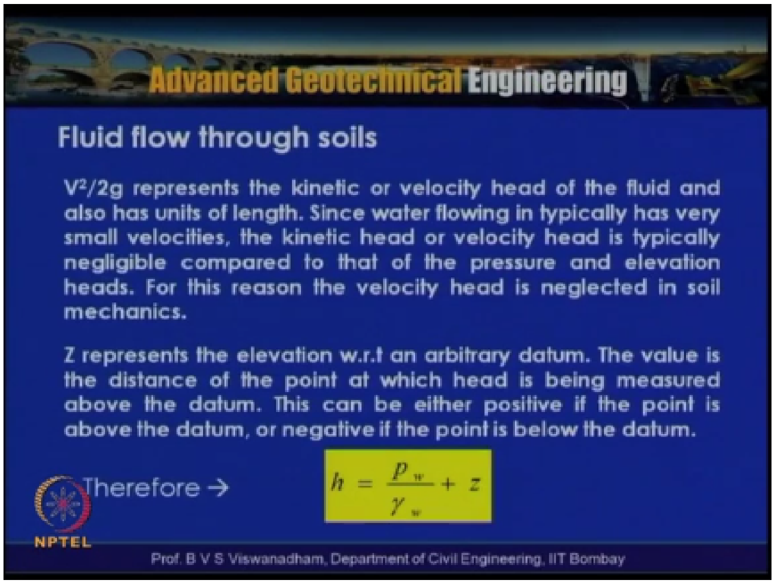

If you look into this particular you know application of this Bernoulli's equation in soil mechanics is concerned, the velocity head is actually neglected that means that the $v^2/2g$, the kinetic or velocity head also has the units of the length, but since the water flowing velocities typically has very, very small, the kinetic head or the velocity head is a typically negligible compared to that of the pressure head and velocity heads.

For this reason, you know the velocity head is neglected in soil mechanics, and Z represents the, you know elevation with respect to the arbitrary datum, the datum, you know we need to if you have a datum and the Z represents the elevation with respect to an arbitrary datum. So the value is the distance of a point at which the head is being measured above the datum. So this can be either positive if the point is above the datum it can be negative if the point is below the datum.

So therefore, the total head can be pressure head + elevation head. So water flows in soils only when there is a gradient in head H.

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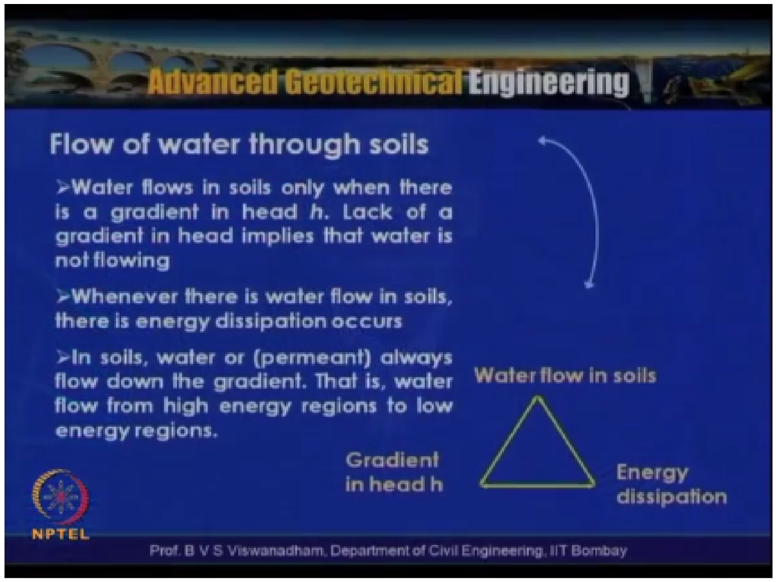

That means that a difference of head between that is when it is available then, you know there is a possibility of the flow. And the lack of F gradient is the head implies that water is not flowing that means that, if there is a inadequate head difference H, then that means that the water is actually not flowing. Whenever there is a water flow in soils there is energy dissipation occurs. Suppose when there is a water flow in soils the energy dissipation occurs.

So in soils water or permeant always flowed down the gradient that is water flow from higher energy region to the low lower energy regions. So the flow water flow in soil is only possible with the possibility of the gradient in head h, and energy dissipation and then water flow takes place. So in soils basically the water are permeant which is always flows down the gradient and that is water flow occurs from higher energy regions to lower energy regions.

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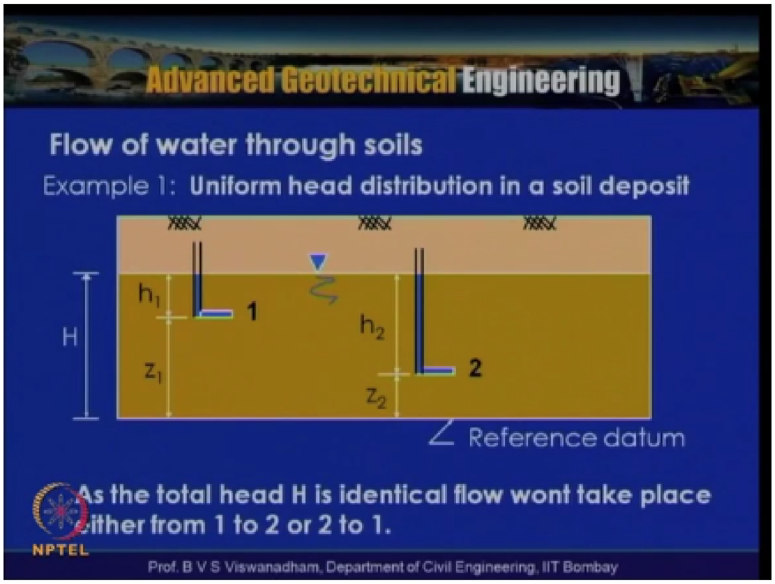

And in this slide example a slide which is actually shown a typical section having two soil profiles with a groundwater table which is located at a certain depth below the ground surface. And two points which are one and two and one is actually at a z1meters above the reference datum and is measuring a head of h1, and a pressure head of h2 is measured at a point 2 which is Z2m above the reference datum.

The thickness of the soil layer which is under the discussion is about H units. So the total head here at point 1 is nothing but the pressure head + elevation head which is nothing but H1 + z1. And here total head here is that pressure head + elevation head that is H2 + z2. So here as H1 + z1 = H2 + Z2 = H and the total difference is actually zero. So though, you know there is a difference in pressures here, pressure heads which are actually measured here the flow will take place either from 1 to 2 or 2 to 1.

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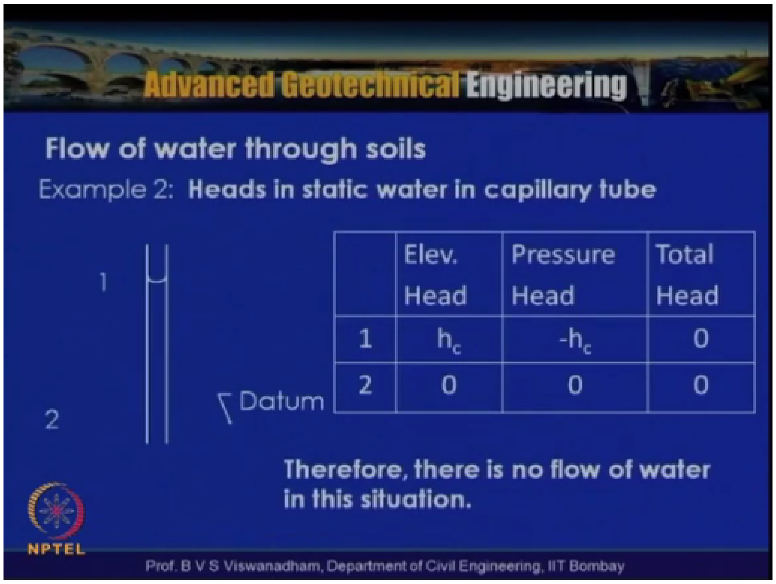

	Elev. Head	Pressure Head	Total Head
1	h_c	$-h_c$	0
2	0	0	0

In another example which we have discussed in the previous module about the capillarity situation. Let us assume that we have got the heads in the static water in capillary tube we actually have discussed with that this particular phenomenon which actually can occur, because of the in case of real soils, the soil solid water into a solid water interaction, because of the air solid water interaction.

So here if you have got a ground water table here or the water level and which is actually if it is considered as an atom, and that point is say 2 and HC is the head which that raise of water has actually taken place, because of the capillarity phenomenon. So that point B1, so let us consider here elevation head for the point 1 is HC units above this point 2. And pressure head here as the pressure entity is actually negative and which is actually - C.

So the total head is nothing HC+-HC the pressure head is negative here, because of the total head is equal to 0. In case of this situation here where you have what elevation head is zero and pressure head is zero so total head is zero. So therefore, the capillarity flow is not a typical flow situation, there is no flow of water in the situation which is actually occurring because of the a soil solid and water interaction.

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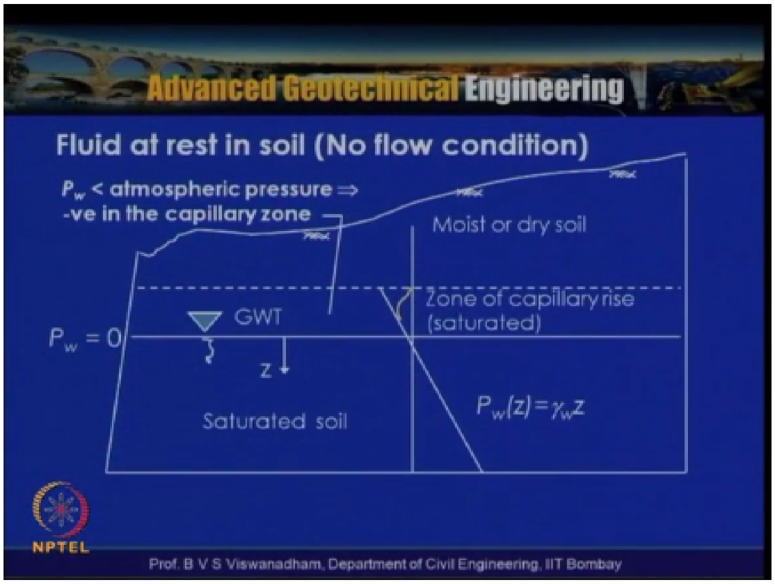

So this is actually shown, you know fluid at rest in soil which is shown in no flow condition. And here this is the zone of the capillary raise, if the soil is actually completely saturated it actually maintains that negative pressure here. But if there is a partial saturation there is a possibility that this pressure actually drops down to close to zero and then the dry soil will actually will be there above this level, above the capillarity ground water table level.

And this is the ground water table level and below this there is a possibility of hydrostatic water pressure that is pwz = γwz. So as the depth increases the water pressure increases below the ground water table. At this point at the surface of the ground water table the pressure of the water is equal to zero, because it is open to the atmospheric circle surface.

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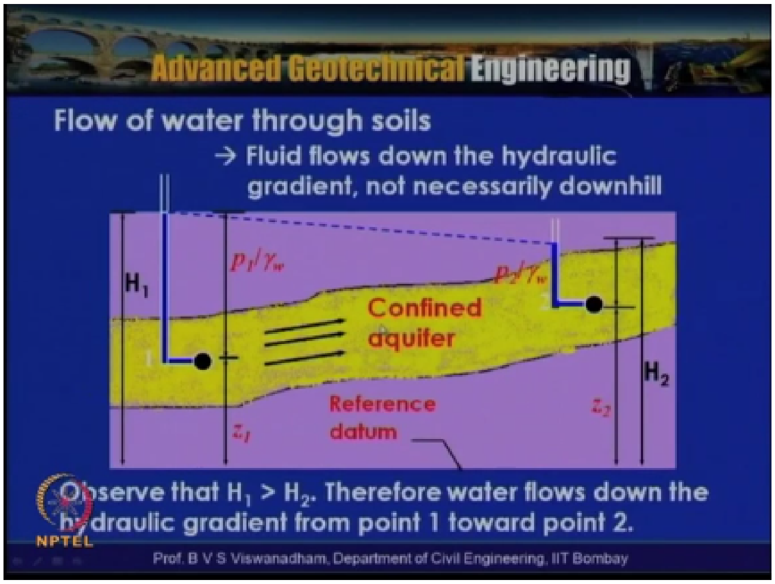

So in this particular slide what we have seen is that we have got a confined aquifer which is shown with a reference datum. And which is actually having a total head of h1 and on the left hand side and total head of h2 on the right hand side. So from the reference datum if you look into this and this particular point if it is named as one and if this is a named as two, then this point is nothing but H1=P1/γw that is not nothing, but the pressure head plus elevation head at point 1, for point 1 that is Z1.

So P1/γw+z1 and in this case it is P2/w+z2 which is nothing but the total head at H2. So if you observe that and if H1 is greater than H2 that means that water flows down the hydraulic gradient from 1 to 2, that means that the water flows down from here to here. So it is actually if with the H1 greater than H2 water flows down the gradient, so the difference between these two points difference of the heads between two points here 1 & 2 which is actually shown here which is actually called H1 - H2 and which is called as the head drop or head loss.

So fluid flows down the hydraulic gradient not necessary down downhill. So fluid actually down the fluid actually flows down depending upon the way the. you know the presence of the higher head and lower heads are prevalent in the surreal situations.

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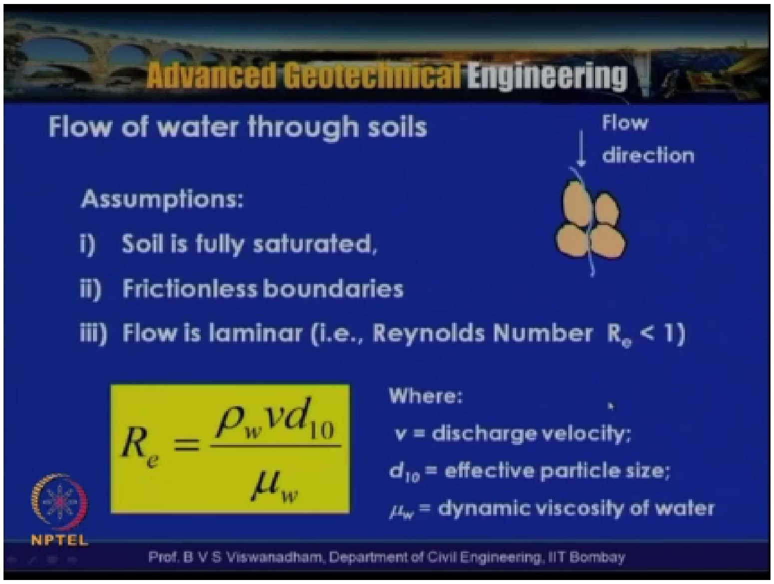

The flow of water through soils the main important assumptions which are actually worked out are thee the soil is actually assumed it to be fully saturated, and the boundaries between the solids are assumed to be frictionless boundaries, and the flow is actually laminar. That is in case of soil mechanics particularly flow of water through the porous media our soils the Reynolds number which is actually defined as ρW x V x d10 by µW.

Where d10 is nothing but the effective particle size µW is nothing but the dynamic viscosity of water, and V is the discharge velocity the water velocity which is actually through that macroscopic length or macroscopic area and ρW is nothing but the mass density of the flowing fluid. So for a flow to be laminar incase of, you know soil mechanics it is actually maintained as Re less than 1, you maximum the upper bound value is about 10 or so.

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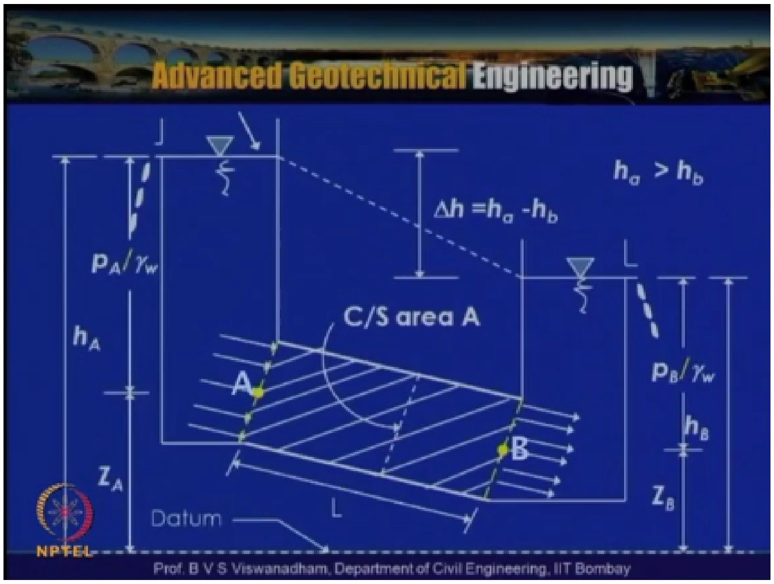

So in this figure the cross-section a typical cross section is shown here where we have what a data here and a point A and a point B we are actually interested in flow of water from A to B. So the point a is having a elevation head of ZA and a pressure head of PA/γw. In this case point B having elevation head of ZB and pressure a head of P/γw=HP. So P/γw, so the total head is equivalent to PB/γw + ZB which is actually nothing but hb which is indicated.

And here total head is nothing but PA/γw + ZA which is indicated here as a suffix A. So the difference in head between point A and point B over a length L which is if you would observed here HA - HB which is actually called as a head loss or head drop or a length L. And the soil actually flows the cross-sectional area which is actually open to the flow is this one, so this is actually along the length of the along the in the direction of the flow and this is perpendicular to the direction of the flow.

So if this is actually having for example, the entire length for example here if this is actually having a unit cross section area A then this length L then that means that the flow is actually occurring over a volume of AxL which is also called as a fluid flow fluid phase or which the flow is actually occurring.

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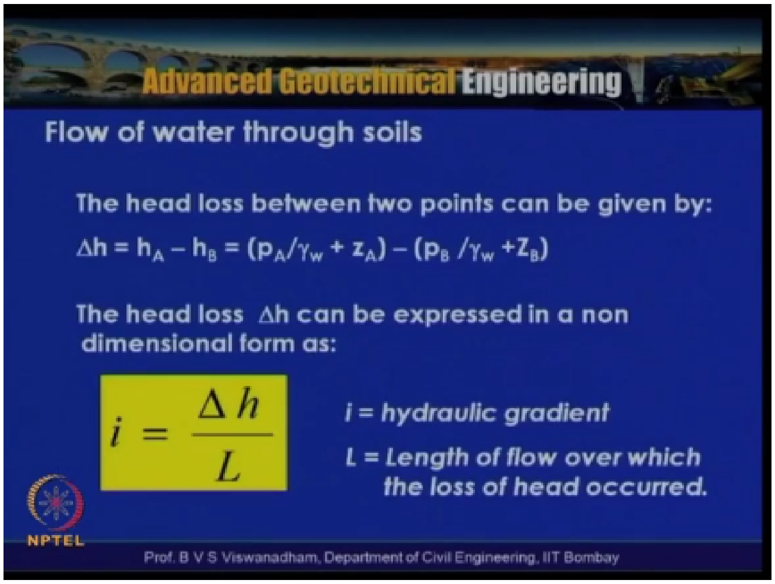

So the head loss between the two points can be given by $\Delta H = HA - HB$ which nothing but $PA/\gamma w + HA\ ZA - PB/\gamma w + ZB$. So the head loss ΔH can be expressed as in a non-dimensional form by using a definition called hydraulic gradient, hydraulic gradient is equal to $\Delta H/L$ where I is nothing but hydraulic gradient, L is the length of the flow or which is the loss of head occurred.

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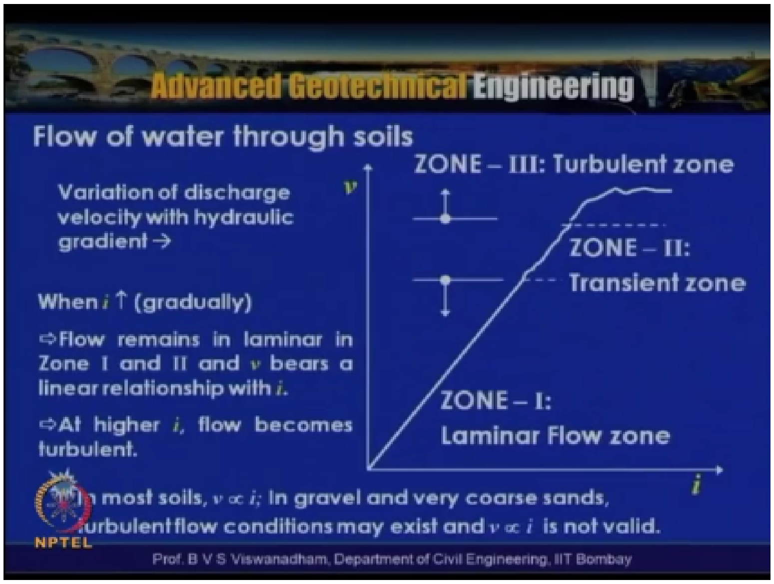

So there is a you know a relationship between velocity and hydraulic gradient where we have defined in the previous slide as I is nothing but the is a non dimensional form of hydraulic gradient over a which is nothing but a hydraulic gradient, and which is defined as head loss over a length L. So this particular slide shows the variation of discharge velocity with the hydraulic gradient.

On the y-axis what we see is the velocity, and then on the x-axis what we see is the hydraulic gradient I, and it can be seen that it is divided into three zones, the zone 1 and zone 2 and zone 3. The zone 1 is actually termed as a laminar flow zone it appears that you know this V is actually proportional to I in this region, and it exhibits a linear relationship. And then beyond zone one once this zone one boundary is cause it is actually termed as John two which is called as a transient zone, and beyond zone 2 which is actually termed as zone 3 which is called the turbulent zone.

So as the I increases gradually that is hydraulic gradient increases gradually, the flow remains in laminar in zone 1 and zone 2 mostly, and V bears a relation linear relationship with I. So what we have understood is that, the flow remains in laminar in zone 1, and zone 2 and V bears a linear relationship with I. At higher hydraulic gradients the flow becomes turbulent, that means that at higher hydraulic radius when the hydraulic gradients are high here the flow is actually becoming turbulent.

So in most soils V is proportional to I especially in gravel and very coarse sands the turbulent flow conditions may exist and V is proportional to I is not really valid. So in most soils V is actually proportional to I and the laminar flow conditions are actually established and they are satisfied. But in some gravelly soils or the soils which are actually having very large particle sizes our coarse sands turbulent flow conditions may exist.

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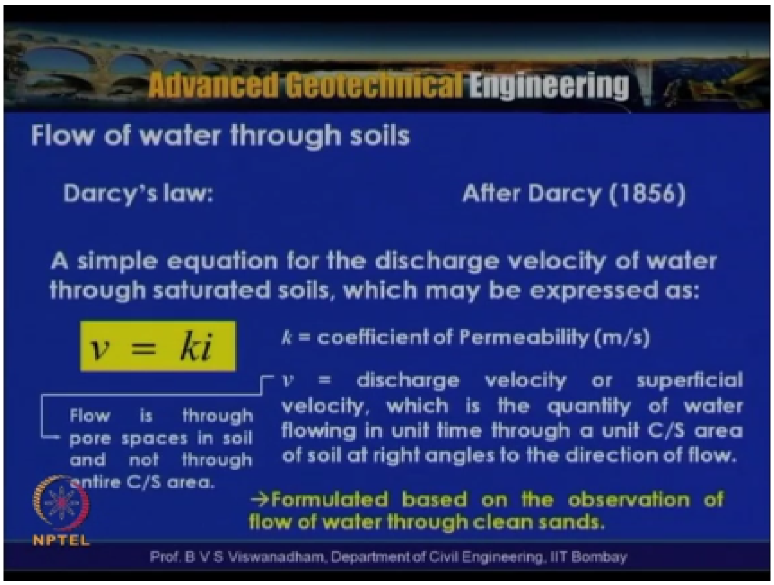

So this particular relationship with between the discharge velocity and hydraulic gradient it was given by Darcy way back in 1856, and as this is a simple equation for which the discharge velocity of the water through saturated soils can be expressed where by a relationship known as V = KI which is popularly known as Darcy's law. And where K is the coefficient of permeability the units are meter per second which is also called as Darcy's coefficient of permeability.

This is the one which is actually can be measured in the either the laboratory or in the field, and V which is nothing but the discharge velocity or superficial velocity which is the basically the quantity of water flowing in unit time through a unit cross section area of soil at right angles to the direction of flow. So the flow is actually through the pore spaces in soil and not through the cross section area, because of that, you know the discharge velocity is basically is called as a superficial velocity.

And this is formulated based on the observations of flow of water through clean sands, this particular Darcy's law which is actually has been you know formulated based on the observation through flow of water through clean sands. And further the Darcy's equation is combined with a continuity equation which is nothing but Q = VxA and A is the cross sectional area or which the flow is occurring.

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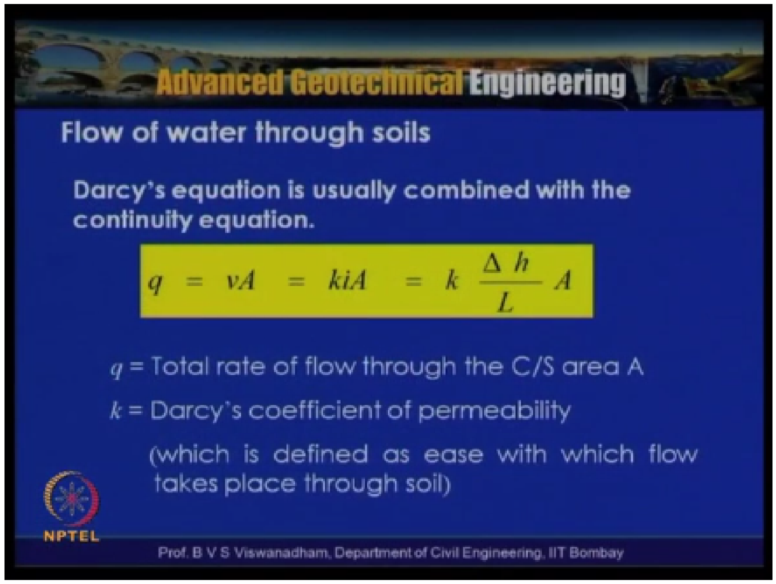

And which into multiplied by V we get discharge that is Q = VxA = KIA, where K is the coefficient of permeability and ΔH/L is nothing but the hydraulic gradient that is head loss over a length L and A is the area or which the flow is actually happening. So Q is equal to total rate of flow through the cross section area A, and K is the Darcy's coefficient of permeability. This Darcy's coefficient of permeability is defined as a property of the soil.

And which is actually defined as ease with which water can flow through the soil that means that some soils allow the water flow very easily and some soil is very difficult for the water to flow through the some soils. That means that you know this particular property is used in many ways in constructing many geotechnical structures.

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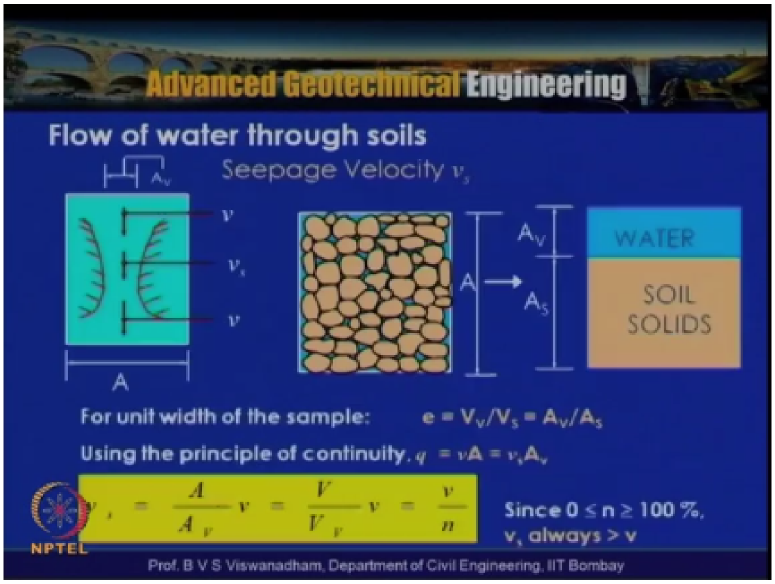

So here in this particular slide a terminal new term called seepage velocity is introduced. The seepage velocity is actually velocity which is actually happening through the voids, that means that if you consider a cluster of soil particles and water which is actually filled in the voids and the water and the water flow is occurring from say in this case from top to bottom and what actually happen.

If you take a magnified view of the distance between soil particles, so if this is actually happened to be A and this is actually nothing but the, that is area of the voids. So here before entering the velocity is V and here the velocity which is actually within the voids is called as the seepage velocity. Again once it crosses the void is actually discharge velocity. So here because of the interconnectivity of the voids through the soil only the seepage velocity the flow of water through the soil is which is actually indicated by AC phase velocity with the V suffix S.

Suppose if this is actually indicated as a two phase diagram as is actually shown here, then we have what water and soil solids and the total area of this is that area of water which is nothing but AV, and the area of the solids. And which is nothing but A=AV+S, and for the unit width of the sample if you take and the void ratio which is nothing but the volume of voids to volume of the solids, with that we can write as AV/AS.

And using the principle of continuity Q=V x A, and for A this continuity equation now we can write it as VxA that means that here V and then area which is actually available here is A. And when it comes to VS here the width got reduced now AV which is nothing but the VS x AV. So by using this VS is equal to we can write it by a by AV x V and this for a unit width of the sample we can write it as V by volume of voids which is nothing but, you know from if you take the definition of the porosity we can write it VS=V/N.

So the seepage velocity is actually nothing but 1/N times the discharge velocity. So as the porosity cannot be more than 100% VS is always greater than V, VS is always rather than the seepage velocity always greater than discharge velocity.

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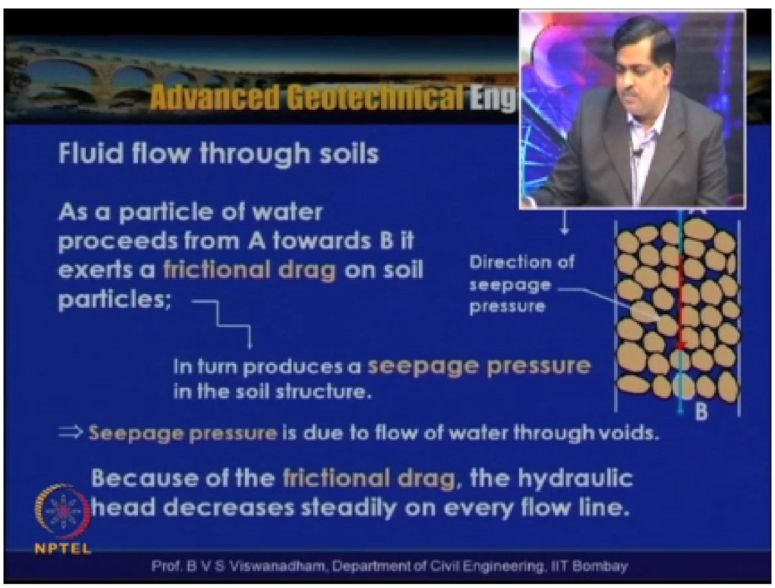

So as the particle of water proceed from A to B it exerts a pressure drag on the soil particles, that means that when the particle, when the water is actually flowing from A to B, because of the some head difference which is actually happening between A to B the water actually flows from A to B in the basis, this is called the direction of the seepage. So when the water flow is occurring from A to B as a particle of water proceeding from A to B it exerts a frictional drag on a soil particles.

So in turn it produces this, so-called frictional drag which produces a seepage pressure in this soil structure. Sometimes if the seepage pressure is excessive then it can lead to a failure in a for a geotechnical structure. So seepage pressure is due to flow water through the voids, when the water is actually flowing through the voids, because of the frictional drag exerted by the flowing water onto the soil solids the seepage pressure is actually generated.

So because of the frictional drag the hydraulic head decreases steadily on every flow line that means that as it actually drops down from A to B, because the energy is actually transferred in the form of exerting a pressure drag on the soil particles, the head actually decreases steadily from say from A to B in this example. And we actually have discussed that the total stress which is nothing but the effective stress plus water pressure.

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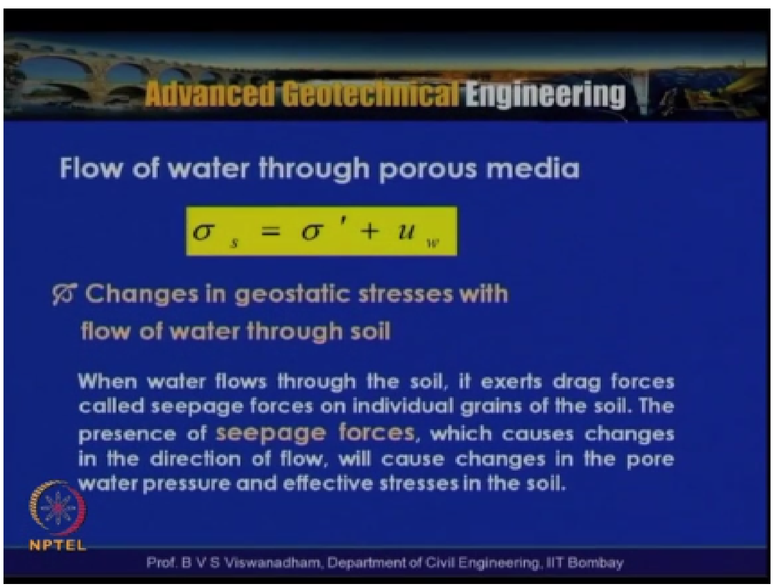

And we also have discussed this for a case where no flow condition that means that there is no difference in head between two points under consideration. In that case you know we say that hydrostatic pressures provide. So changes in geostatic stresses geostatic stresses are nothing but when that surface is horizontal and having a unit weight which is actually more or less constant along the in all directions.

And the change in geostatic stress with the flow of water the soils if you look into this when water flows through the soil it exerts a drag force called seepage force that we have actually discussed. And the presence of seepage force which causes the changes in the direction of flow which causes the changes in the pore water pressure and the effective stresses in the soils, because of that the changes actually happen.

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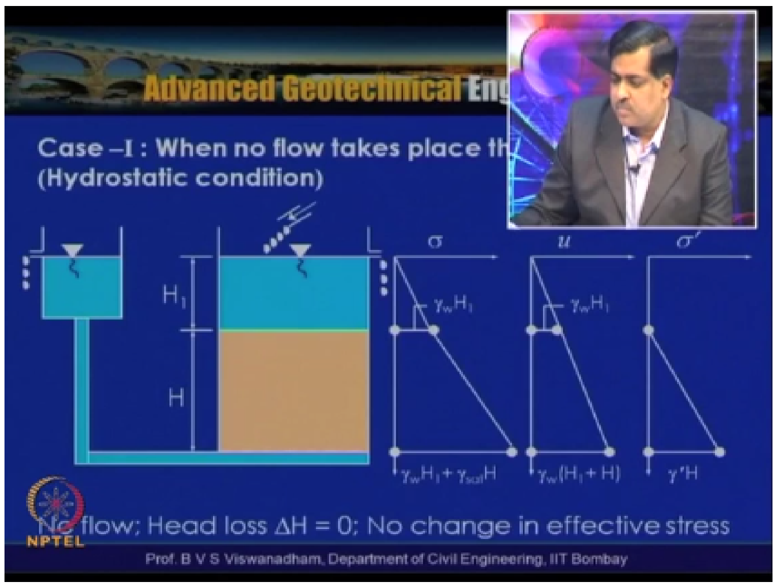

So in this particular slide three cases which are possible, one is that when no flow takes place through the soil a hydrostatic condition. So here we have got a soil which is saturated and having a thickness H and H1 is the head of water here which is maintained constant. And this limber which is almost at the same surface, then what we can actually see is that the total stress is nothing but γWh1+γWh1+γsatH.

And the pore water pressure is nothing but as the water is up to the surface and soil is completely saturated. So it is nothing but the γWh1+γW (HI+H). So here the effective stress is nothing but total stress minus pore water pressure, with this what will actually happen is that here we have got γ'H, that is here that is this particular condition is in no flow condition. And it also tells that the head loss is actually ΔH=0, because both at this point at this point that the total head is actually 0 are the same.

So because of that what will happen is that the head loss is actually 0, and another thing is that you know if H1 is say for example, even if it is 1m, 2m, 3m or a kilometers for example, the changes in the effective stress is not there. That means that it is independent of the thickness of the height of water above the ground surface. If the groundwater surface for example, say within this H then you know it can actually increase or decrease depending upon the changes which actually can happen.

For example, if there is a depletion of water table the effective stress increases, if there is a increase in water height there is a decrease in the effective stress. So here if there is a excessive increase in the effective stress and that also can lead to the crushing of soil particles and then the collapse of the soil. And if there is an excessive decrease in the effective stress that also can lead to the problems which we are going to discuss.

In case 2 here what we did is that when the flow takes place through the soil and we are actually referring here what we did is that, we took this limp down and that is below this surface, and where we say that when this situation is there water flows from through the soil from upward in the downward direction here. So this is the flow of water which is actually happening in the soil. And this H which is either difference between water levels between this surface and this surface and which is actually below this circle below this surface.

And for this case if you look into this the total stress remains same that is nothing but $\gamma Wh1$ and the soil is actually saturated here again $\gamma Wh1+\gamma satH$. But if in case in the previous case 1 when there is no flow of water then we actually have said that the pore water pressure is like this, that is $\gamma Wh1+\gamma Wh1+H$, but now here what is actually happening is that the water which is actually flowing from top to bottom here that means that here the, there is a head which is actually available at H units is available.

And by the time actually it comes out of this the available head is actually 0 for the water to flow through the flow, that means that over a length. So here the hydraulic gradient is nothing by it I is nothing but a h/H. And at the at the beginning of this point, the point where the soil surface is actually commences where the head available is H and at this point is the head available is zero, at this midpoint let us say H/2 units from here it is 0.5 times the small H is actually available here, 50% of the head available.

That means that 50% is already got dissipated or is spent in making the water flow from top surface to the middle surface here. So because of that region there is a drop in the or decrease in the pore water pressure, because of the loss of this head. So the pore water pressure at this point is nothing but γW+H1+H-H. So that makes actually the pore water pressure because when the water flow takes place from top to bottom at this point it is γW(H1+H-h).

So with that now again if you take the effective stress which is nothing but the total stress minus pore water pressure, at this point there is no change because the γWH1, but here what actually happens is that the pore water pressure when there when there is no water flow we have got effective stress as γ1H. But now because you know the these two terms will get cancelled, now what will have is that γ1 γ'H+H,W.

That means that here when water flows from point top to bottom that is in downward flow there is an increase in the effective stress. And if I if you replace that H as I times H we can actually say that γ'H+I I times HγW where H is the thickness of the soil layer or which the flow is actually happening and γW is the unit weight of water.

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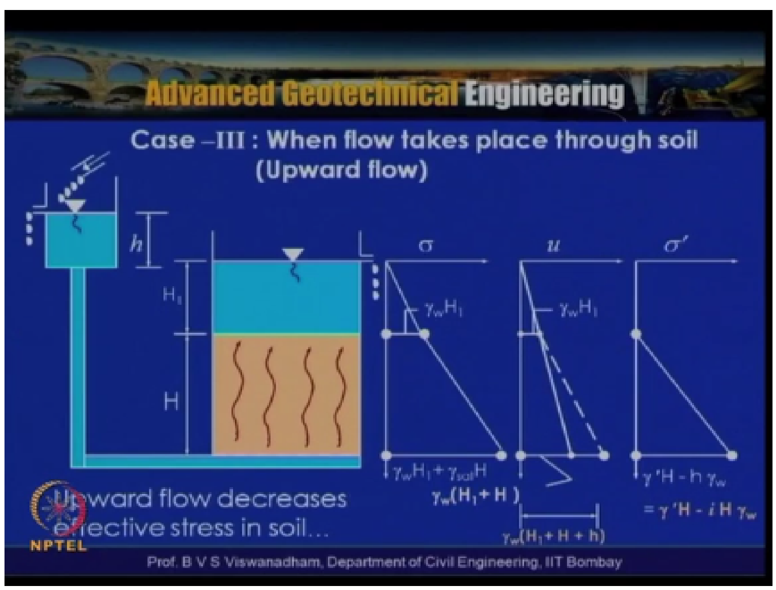

Now let us consider a case where case 3 when the flow takes place to the soil upward flow, that means that what we have done is that this limb actually has been taken above this water surface. And this water surface is actually maintained and this level our head is actually maintained here.

So when these are connected here interconnected and the water actually flows from this end to this end.

So this upward flow if you look into this decreases the effective stresses in the soils the total stress now if you look into the again it remains same γWh1 and γWh1 + γsatH. But here if you look into this the pore water pressure without any flow is nothing but γWh1 + h. But now what is actually happening is that the head available here is a h, the head available here is zero, that means that the hydraulic gradient over this length is that nothing but I = h/H.

And because of this what is actually happening is that the pore water, the head available at this point is here is nothing but γ, so the pore water pressure ordinate here is γW(H1+H+h). And here I tis γW(H1). So because of this what will happen is that if you take the difference of this and this because of the this particular condition what is actually explained here with that the effective stress is nothing but γH γ'H-HγW.

When we replace that H as I times HH, then we can write this effective stress at this particular point as γ'H – H,W, that means that when the water flow takes place from in the downward direction we have seen that effective stress increase, when the water flow is taking place in upward direction this particular situation is actually possible in the real conditions like in artesian conditions where you have got a more head of water than the hydrostatic head which is actually existing there.

Or it actually has got a source of water and that particular previous layer which is actually minute in pervious layer. In that situation this type of upward flow conditions are more common. So this γ'H - HγW where in effort flow causes the decrease in the effective stress.

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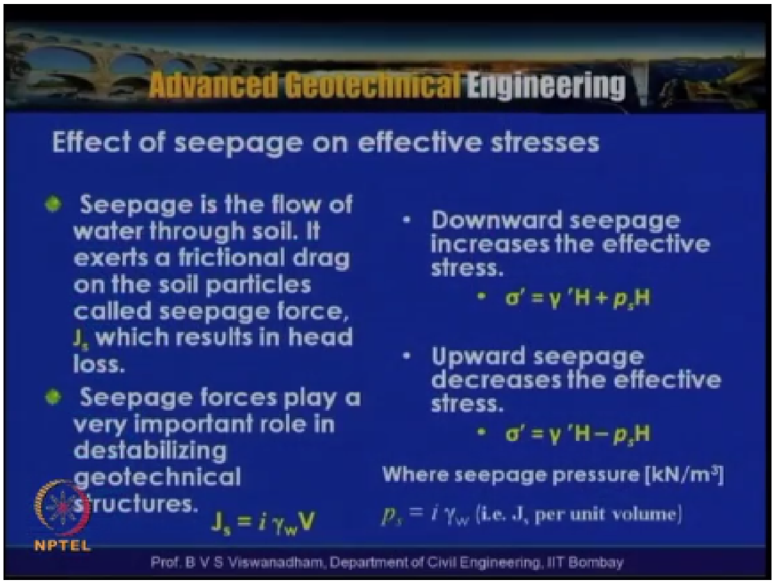

So what we have understood is that seepage is the flow of water this soil and it is a basically it is a phenomenon which actually have happen in soil. And basically it exerts a frictional drag on soil particles and which is actually called a seepage force which results in a head loss. And the seepage force, play a very important role in destabilizing geotechnical structures. And the seepage force per unit volume which is actually called as seepage pressure.

Say for example here the downward seepage increases the effective stress that is what we have actually said σ’= γ’H+IγW(H). So IγW when I replace it with PS then what we can say that downward seepage increases the effective stress, and upward seepage actually decreases the effective stress, that is nothing but σ’=γ’H-PSH, where PS=IγW, where seepage pressure which is actually having a units of kilo Newton per meter cube, and the PS is indicated by IγW.

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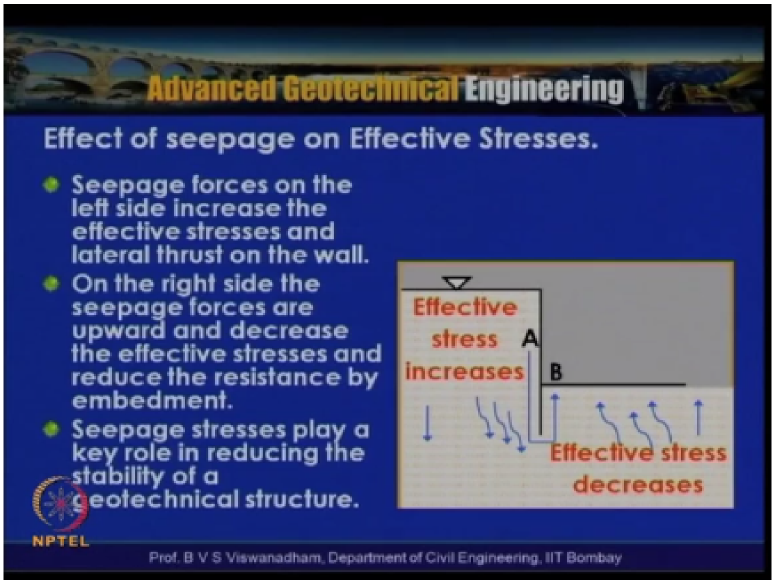

So if you take a hydraulic structure the water is actually retained at the upstream and downstream. So here when the water actually flows from A to B along this hydraulic structure at this here in this portion there is an increase in the effective stress and in this portion particularly there is decrease ineffective stress. So the decrease in the effective stress particular phenomenon causes situation where there is a possibility of endangering the stability of a particular hydraulic structure.

So on the right hand side what we see is that seepage forces decrease the effective stress is reduced, and the resistance to the embedment also decreases. So the stability of a structure is actually highly depend upon this particular portion where there is a upward flow occurs. So seepage pressure, seepage stresses play a key role in reducing the stability of a geotechnical structure retaining water in water body.

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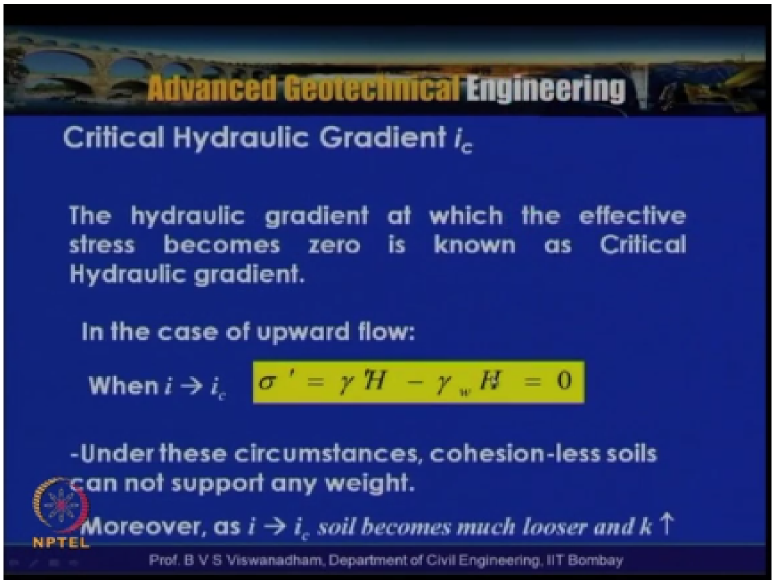

The hydraulic gradient at which the effective stress becomes zero is called as the critical hydraulic gradient. So here we are introducing a term called critical hydraulic gradient previously we said that hydraulic gradient is nothing but I = H/L which is nothing but a head loss or head drop over a length L. But if the hydraulic gradient at which the effective stress is becoming zero is known as the critical hydraulic gradient I suffix C.

So for example here we have discussed in the previous slides that σ' effective stress is equal to γ'H-IγW that is a nothing but with the γWH = 0, with that under these circumstances when I tends to IC the effective stress actually becomes 0 that is γ'H - γWH=0. Under these circumstances the coefficient of soils particularly the soils without any binding capacity cannot support any weight.

So when this situation of critical hydraulic gradient conditions exist the soil loses its supporting capacity. Moreover as I tends to IC, the soil becomes much looser and permeability of the soil increases drastically, that means that when I tends to IC soil becomes much looser and the permeability of the soil increases drastically.

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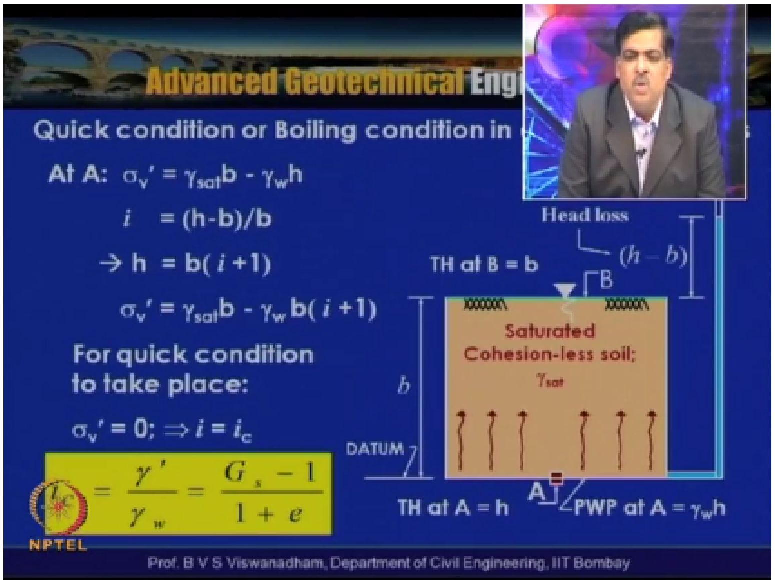

So here we are actually defining in this particular side a condition called quick condition or boiling condition in cohesion-less soils. The particular situation which is actually shown here is that there is a point B, and then there is a point A, and point A is at the elevation that is the datum. And total head at A=H, and total head at B=b. And here what we can see is that we have got a head of water and which is nothing but here that is H-B.

And total head if you look into this pressure the head is nothing but the H - B + B that is H units. So at point A the pore water pressure at point A is γWH, and at point B that is this is at this point here okay. So at A that is σV' that is nothing but γsatB that is the thickness of the soil layer into the saturated unit weight of the soil into B – γWH. So when I is nothing but H - B is nothing but the head loss or a length of the soil that is B.

So we can simplify that H = B(I+1) by writing I = H – B/B and by simplifying we can write H=B(I+1). And by substituting in σV'=γsat(B-γWH) we can by substituting we can write γsatB(-γWB)(I+1) we are written H in terms of B and I. So for quick condition to takes place σV' has to be 0, that means that I has tends to become IC. So with that what will happen is that IC=γ'/γW which is nothing but Gs – 1/1+E, or GS – 1/ by specific volume that is 1 + G is indicated as specific volume. So IC = γ'/γW which is nothing but GS – 1/1+e.

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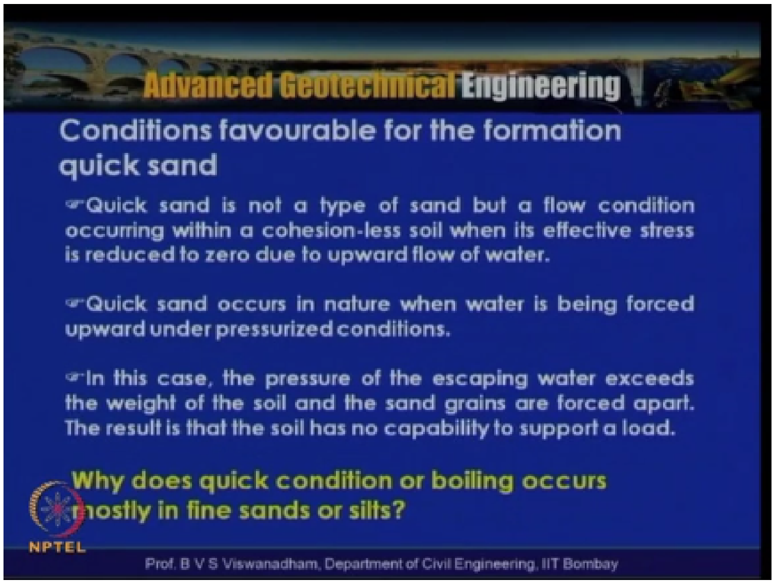

So quick sand there is a terminology which is actually comes when there is a, you know the loss of the effective stress actually happens drastically because of the phenomenon what we discussed is that, when the water flow happens the soil in the upward direction the soil loses all its strength. And then it loses the supporting capacity and we actually have what a phenomenon called quick sand phenomenon.

So quick sand phenomenon is basically a condition where water flow occurs in the upward direction and then there is a possibility of the loss of the effective stress. So one should note that quick sand is not a type of sand, but a flow condition occurring within cohesion-less soil or the soil which are actually not having any adequate binding capacity.

When it is actually effective stress is reduced to zero due to upward flow of water. So quick sand occurs in nature when water is being forced upward under pressurized conditions. So in this case the pressure of the escaping water exceeds the weight of the soil and the sand grains are forced apart and the result is that the soil has no capability to support a load. So why does actually quick sand condition or boiling occurs mostly in fine sands or silts.

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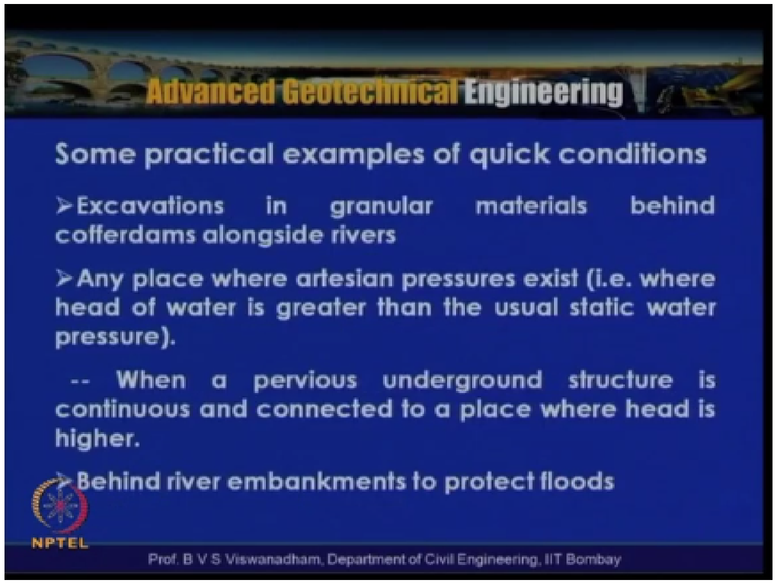

Basically is because of the binding capacity which is actually there. So some practical examples of the conditions are that excavations in granular materials behind the cofferdams along riverside alongside rivers. And any place where the artesian pressures exist that is where the head of the water is greater than the usual static water pressure. So this phenomenon what we said we have actually also said that when there is a higher head of water than the, you know in the soil beneath because of the either because of the water source or because of the some pervious layer beneath the impervious layer.

So in that situation the artesian conditions may exist, and when I suppose if the excavation is actually made in such type of soils and they can actually lose to the subjected to a phenomenon called a boiling condition, and particularly it can lead to a failure. When a pervious underground structure is continuous and connected to a place where head is higher, so and sometimes when behind the river embedment's when we are constructed on levees which are constructed to protect the effects.

So the quick and quick conditions are actually popular particularly in excavations in granular materials behind the in the riverbed particularly with the sandy soils. And any place where artesian pressures exist and if the soil is actually is displaced because of the excavation, because for air for installation of the utilities or some other reasons. So in this particular lecture what we actually have introduced ourselves is that this permeability and seepage one wherein we actually have discussed that, you know how and how important is water flow through the soil particularly in the application and design of the geotechnical structures.

And we also have defined a term called hydraulic gradient, and also a term called velocity and seepage velocity. And the seepage velocity what we said is that is with the relationship VS=V/N, and seepage velocity is always more than V, because seepage velocity is the velocity which is actually happening through the voids of the soil. And then we introduce a term called hydraulic gradient which is nothing but I=H head loss for a length L.

Then we also have introduced a term called critical hydraulic gradient, particularly I=HC/L, and where HC is nothing but head loss at a particular place where the effective stress is tending to become zero. And we also have discussed the three cases one no flow condition where total head is actually difference is zero, and one condition is the downward flow. In that case what we have discussed is that when the water flows downward there is an increase in the effective stress, when water flows upward because of the certain prevalent conditions and it can actually lead to the decrease ineffective stress.

One practical example what we discussed is actually a quick sand condition, and we said that quick sand is actually not a type of sign it is a condition of flow condition where water flows which is actually arising because of the water flow in the upward direction.

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