**Soil Mechanics**
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**Lecture – 20**
Flow of water through soils-I

Welcome to lecture on flow of water through soils part one. After having covered the concept of effective stress in saturated soils and partially saturated soils and effect of fluctuations of water table on effective stress and capillarity phenomena, we will be now discussing what will happen when water flows through soils. How water can flow through soil and how important it is in the consideration of soil mechanics engineering. So in the previous lecture we have understood about this effective stress concept and we have discussed in length about total stress is equal to effective stress plus pore water pressure. Then we also discussed about the condition for partially saturated soils.

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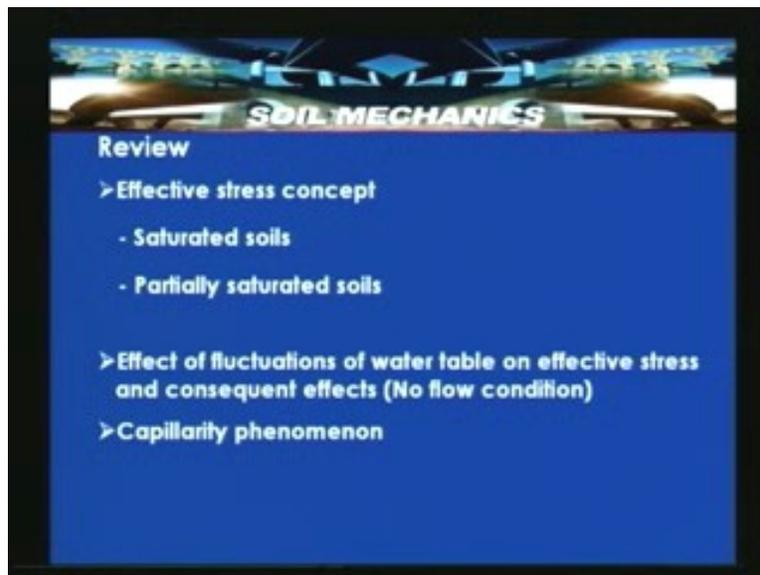
Then in case of fluctuations of water table under no flow conditions, we have discussed that what are the consequences of fluctuations of water table on effective stress and finally we discussed about the capillarity phenomenon. So in beginning of the lecture let us again look into the concept particularly the practical examples pertaining to capillarity phenomenon. So as we discussed in the previous lecture we said that there will be different types of waters in soil. The water table that is called ground water table which is this particular region and which represents the ground water region and here the capillarity zone or capillarity water which can occur and it can keep the soil under saturated conditions. This depends upon the type of the soil and another one is the gravitational water this is basically the intermediate zone which comes under the vadose zone and then soil water.

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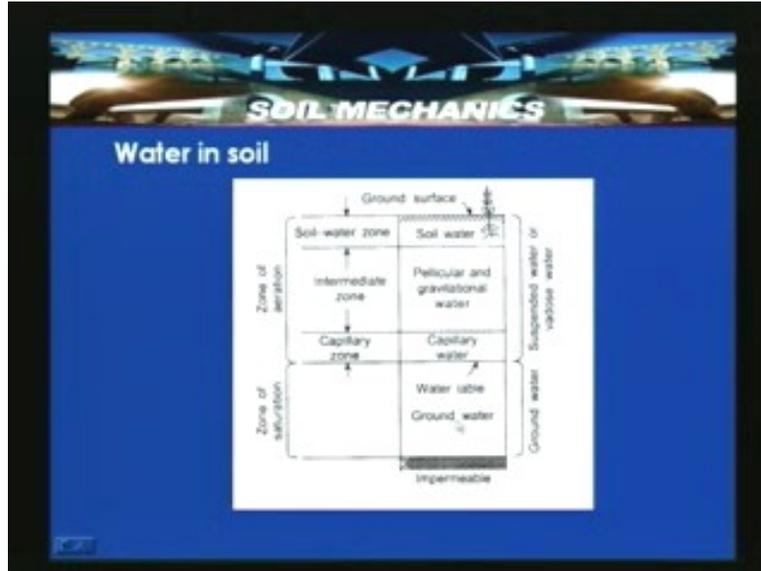
So what we have seen is that there is the zone of aeration. So that means there exist a partially saturated soil and there exist a zone of saturation that can occur below the ground water table. So while looking in to the physical examples of capillarity phenomenon we have introduced two examples in the previous lectures. Now we are just looking into them once again.

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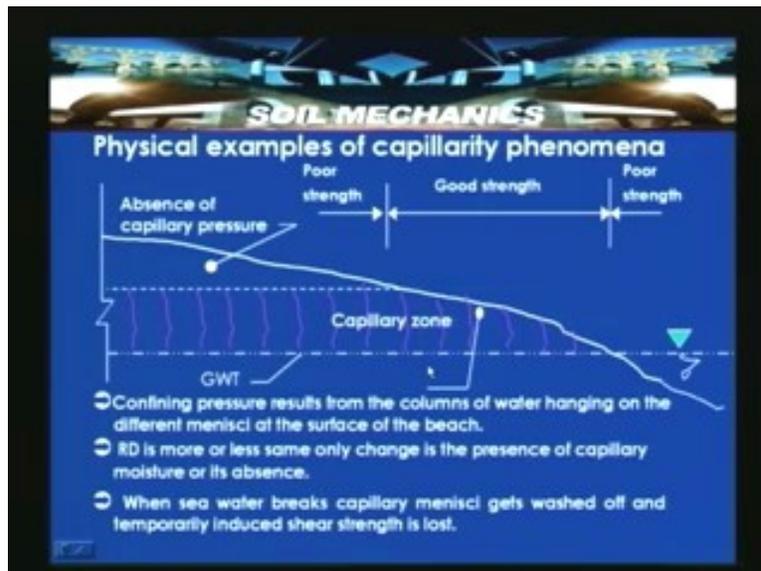
Consider in this slide along the beach we always come across the soil which is in certain region has got certain good strength or carrying capacity which can encourage movement of the vehicles or one can walk easily on that particular type of soil.

When you go away from the certain zone you will find again the soil of pore strength and towards the zone where the water breaks you will find again a soil of pore strength. The reasons could be entirely due to this capillarity phenomenon. So here in this zone where soil exhibits good strength, that is because of the confining pressure results from the columns of water hanging on the different menisci at the surface of the beach.

So when this remain in this condition the hanging water column which is there in the pore spaces will try to have something called negative pore water pressure which influences the increase in effective stress. That results in the soil of good strength. If you consider the relative density it is more or less same in entire location. So though the relative density is more or less same, only change in the presence of capillarity moisture and its absence. Because of this it exhibits this particular phenomenon. Particularly in this zone when the sea water breaks, capillary menisci get washed off and temporarily induced shear strength is lost. Because of the negative pore water pressure, this can over come once the wave breaks. Then what will happen is that, these menisci which are the hanging water columns which are there in the pore spaces of the soil can get washed off. In the process when the soil becomes again saturated then it looses all the strength. So this is one certain example where a capillarity phenomenon exists. Another example we discussed particularly incase of sand under moist conditions. That is partially saturated sands. For example when you have sand with partially saturated conditions you see that there is capillary water formed by the soil particles.

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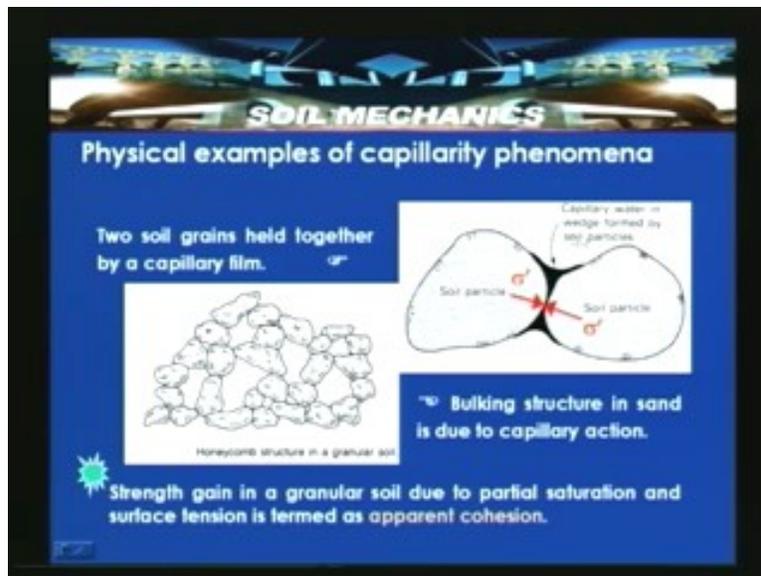
That means there will be a thin form of water which is surrounding these grain particles. Because of the surface tension force what will happen is that, the force in the menisci that is because of the surface tension which actually exerts a compressive force at grain to grain contacts. In the forces it actually resembles something like an enhancement increase in the shear strength because of the more friction. So this result something called bulking structure in sand due to capillary action.

So partially what is happening here is that the strength gain in granular soil due to partial saturation and surface tension is termed as apparent cohesion. This apparent cohesion is very significant under partially saturated conditions. But once when it is subjected to saturation what will happen is particularly this strength gain what ever we have got during the partial saturation, we can get rid of that then this apparent cohesion will disappear. So that is why this particular name is given for this cohesion called apparent cohesion. So let us define once again, the strength gain in granular soils due to partial saturation and surface tension is termed as apparent cohesion. Why we are required to study the flow of water through soils. Let us try to look into this slide. The ability of engineers to understand and predict the flow of fluids usually water in soils is essential for many applications in civil engineering.

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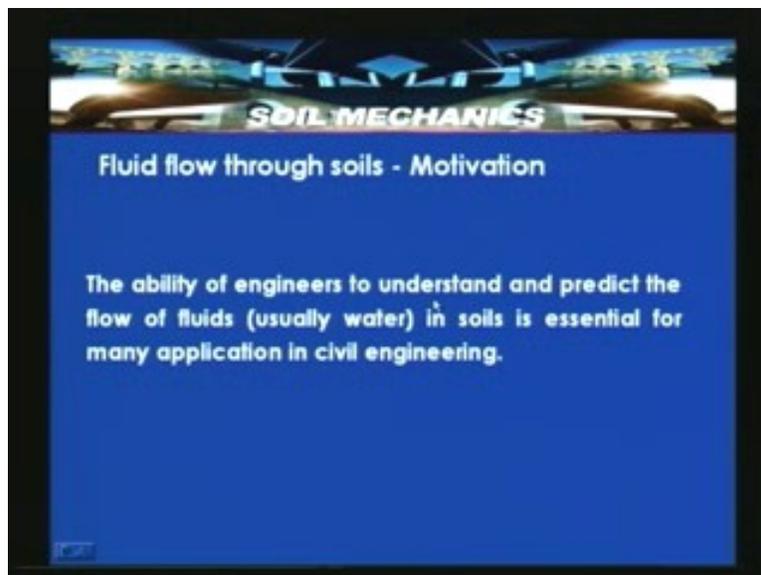
So having seen the application particularly, practical examples of capillarity phenomenon and effective stress conditions under no flow conditions. Now we will be trying to understand what will happen when the water flows through the soil. Let us look into the motivation behind this study. So consider it has got importance from environmental engineering or construction engineering point of view or dealing with certain construction activities in soil. Particularly this flow of water through soil or a fluid flow through soil is important and very significant. So consider here in this slide holding lagoon where a toxic liquid is stored. So the questions always will come is that whether we can retain particularly this toxic liquid in place or not.

Or at what rate the toxic liquid escaping the holding lagoon? So incase if you are not able to retain with a proper method at what rate it starts escaping the holding lagoon. And how long the liquid might take to reach the ground water table? So the rate at which it can flow through the liquid that is again needs an understanding about flow of water through soils. And what can be done to slow down the rate of escape from the pollutants. Is there

any possibility of constructing barriers? That is the question which is required to be answered.

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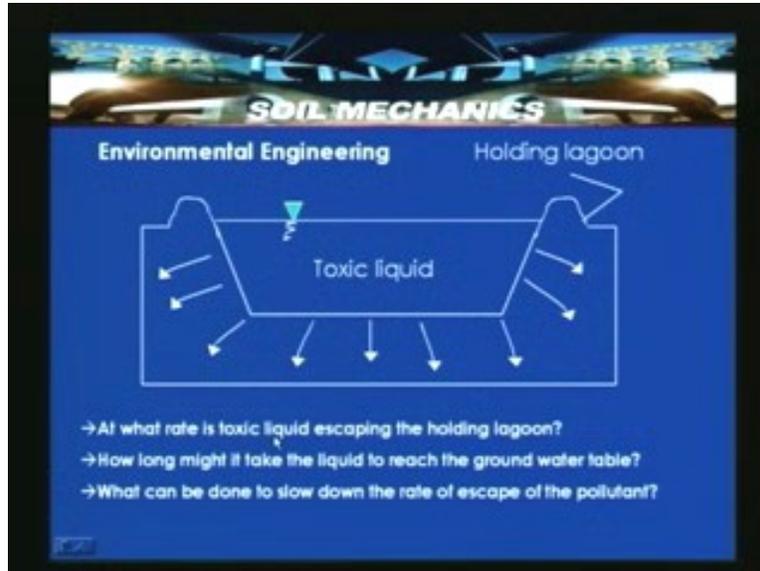
This can be done once we understand this particular study or a chapter on flow of water through soils. In terms of the construction engineering generally for bridge bear construction in reverse or so, a cofferdam which are constructed and for that a sheet pile walls basically this type of structures are driven in to the ground and water was retained on the upstream side and construction activity is carried out temporarily. So here the particularly what will happen is that when water is retained, the water tends to move or flow in this direction.

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Temporary sheet-pile wall cofferdam structure around the site and to pump the water out....
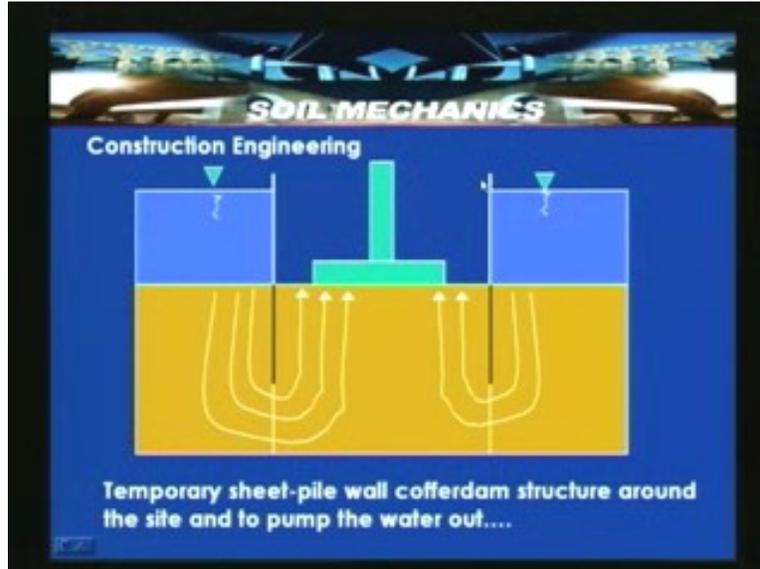
So in the possibility whether there is any instability due to flow of water in this particular location or not. So this is required to be understood from the construction engineering point of view. So the questions which are required to be answered in the previous slide for the construction engineering point of view are as follows. What will be the rate of water inflow to the site?

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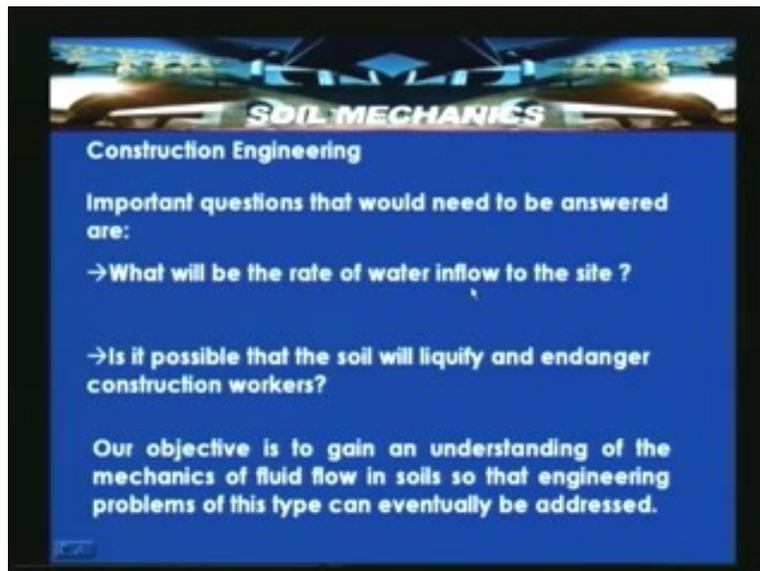
That means the site is referred here is the one which is in between the space formed within the cofferdam structure. Is it possible that soil will liquify and endanger construction workers? That means liquefaction is nothing but a momentarious loss of

shear strength because of the upward flow of water. So is it possible that the soil will liquefy and endanger construction workers? So our objective is to gain an understanding of the mechanics of fluid flow in soils so that engineering problems of this type can be eventually addressed. So this type of engineering problem we have seen like, for example holding lagoon or construction of a cofferdam structure. This can be answered once we understood the mechanics of fluid flow in soil so that engineering problems of this type can eventually be addressed.

Let us look into again soil which is nothing but assemblage of particles. So water can flow in any direction, it can take any path. So the path taken by the water is along the pore spaces within the soil mass. That means if you treat the soil or assemblages of solid particles, so this is the solid particles and this is a particular flow path in which water can take flow direction like this.

So this can flow once it is subjected to some higher energy here and lower energy here. Like current it flows from high potential to low potential similarly here the water tries to flow from higher energy to lower energy. So it can have innumerable number of flow directions or flow paths can be established. The flow of water path particularly water path within the soil particles is called tortuous path.

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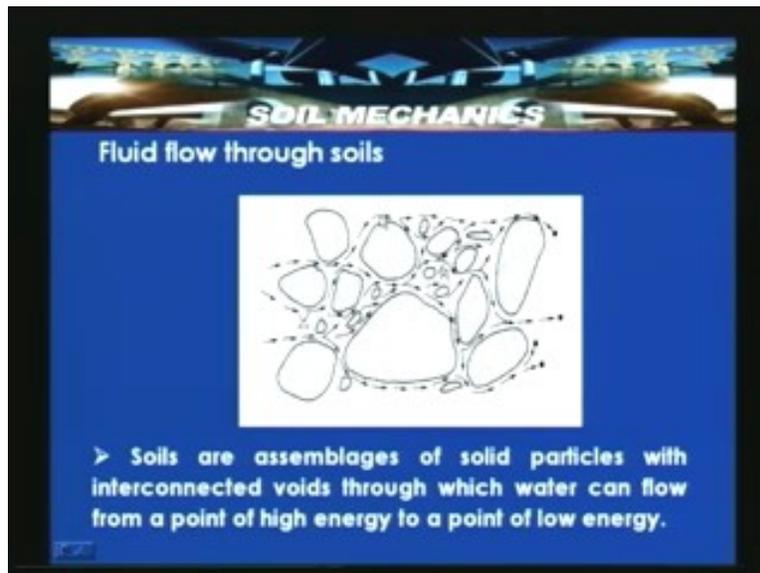
So soils are assemblages of solid particles with interconnected voids through which water can flow from a point of high energy to a point of low energy. So this is particularly for the flow to take place through the soil, it should have something called a high energy at an upstream point to the low energy at the down stream point. If that exists then the flow can take place. For example if there is no difference in energy then it indicates that the flow is not taking place. So it represents under no flow conditions it is called something called a hydrostatic condition, that we are aware from the previous lectures.

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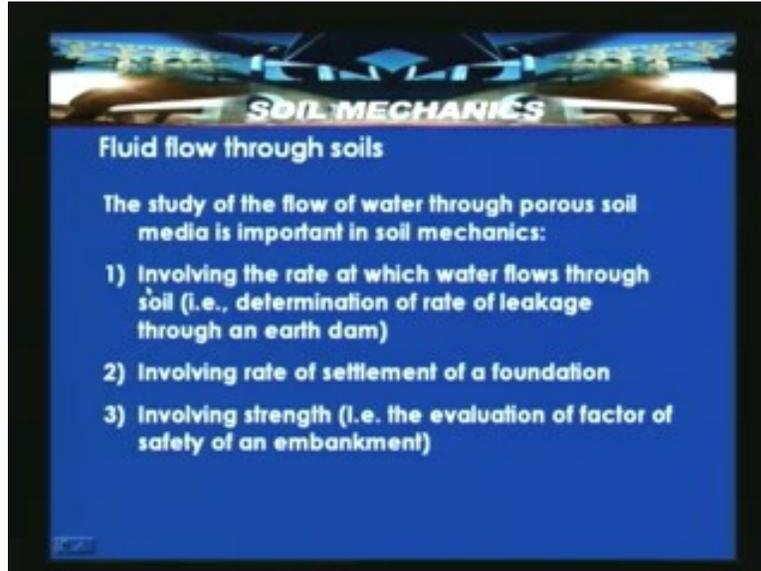
So basically the study of flow of water through porous soil media is important. Because if you look into this particular point one, involving the rate at which water flows through soil that means determination of rate of leakage through an earth dam. For example if you have got an earth dam the interest is that the rate of leakage of earth dam. So that is very much important to assess and to know in the design of earth dams. So involving the rate at which water flows through the soil. So sometimes it dictates for us to even select the materials particularly based on these criteria. When we wanted to have rapid water flow say for a parking lot where you wanted to provide a drainage medium then you need to have particularly a medium or soil at which water can flow rapidly. Where you wanted to say prevent migration of water then in that case you are required to have a material which can stop. Particularly this type of questions can be answered by varying the type of soil.

And involving the rate of settlement of foundation that means if you are constructing and the soil is undergoing consolidation, at what rates the settlements will occur? At what rate loads will transfer? And at what rate this effective stress transfer will occur in soils? If that we wanted to understand means the knowledge of fluid flow through soil is required. Involving strength that is the evaluation of the factor of safety of an embankment. So whether it is a long term parameter something called long term strength or short term strength depending upon the type of structure under consideration involving the strength of a soil. That also depends upon the amount of water which is flowing out of the soil. So this indicates that the study of flow of water through porous media is very important.

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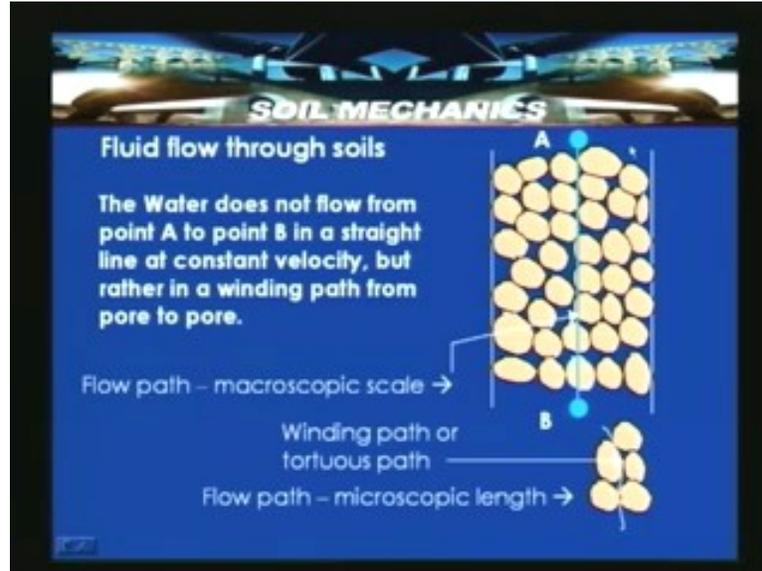
Now let us consider in this slide which is shown an assemblage of solid particles. The voids which are in between the blue ones what you are seeing, assume that they are occupied by water. Now A is the point and B is the point. Point A let us assume that having higher energy and B is the point having lower energy. So the flow can take place from A to B and this is the direction of the flow.

If in reality the flow path of water which generally look like this, which is a winding path or which is defined as a tortuous path. That is along the contact points or along the pore spaces of a soil medium. But like we did in effective stress what we do is that, we look into microscopic point of view and take a line passing through solids as well as pore spaces and contact points. So that is defined as a flow path under macroscopic scale. The water does not flow from point A to point B in a straight line at constant velocity but rather in a winding path from pore to pore and depending upon the size of the pore its velocity within the pore also changes. So at A it has got higher energy and at B it has got a lower energy. So it enables water to flow from A to B.

So what we have seen is that in this case the water when it is flowing through the soil particles it will have something called winding path or which is defined as a tortuous path. But in reality if you consider that A to B it is not actually flowing in a straight line from A to B but it is taking a path which is called a winding path or a tortuous path. Now let us look into the Bernoulli's theory of application of fluid mechanics. According to Bernoulli's equation we knew that the total head is equal to pressure head plus velocity head plus elevation head.

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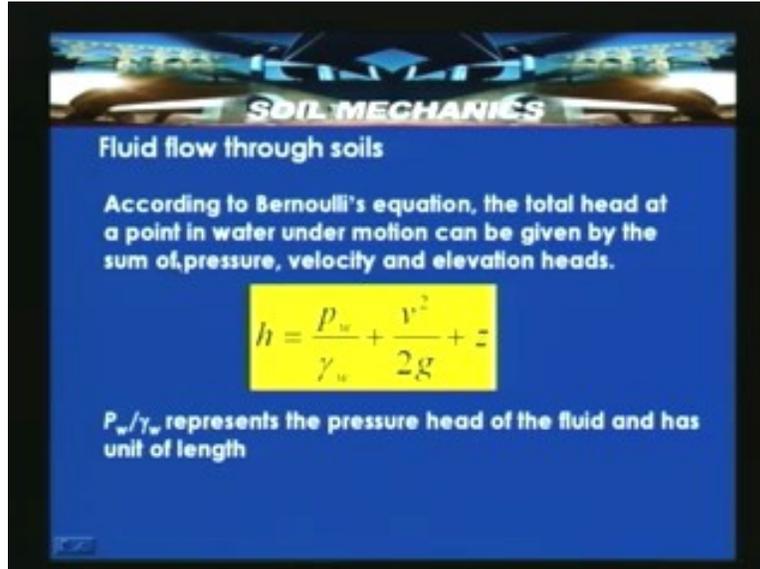
So here according to Bernoulli's equation the total head at a point in water under motion can be given by the sum of the pressure, velocity and elevation heads. So P_w by gamma w represents the pressure head of the fluid and has the unit of length. So $h = P_w$ by gamma w where P is that pressure, gamma w is the unit weight of water, v is the velocity of flow through the soil and g is acceleration due to gravity, z is the elevation in meters. If you look into this, the total head is the summation of P_w by gamma w that is pressure head plus velocity head which is nothing but v square by 2g+z. The z is nothing but elevation head with reference to a particular or a selected arbitrary datum. Now what will happen is that in case of soils when the water is flowing through soil. The velocity is so small, the v square by 2g term is very small.

What we generally consider in soil mechanics which is different from fluid mechanics is that total head is equal to pressure head plus elevation head. So v square by 2g represents the kinetic or velocity head of the fluid and also has units of length. Since water flowing in typically has very small velocities. The velocity head is typically negligible compared to that of the pressure head and elevation heads. So for this reason velocity head is neglected in soil mechanics. This total head in the sense what we do is that we write some thing like pressure head plus elevation heads.

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The z is the elevation with reference to an arbitrary datum. So the value is the distance of the point at which the head is being measured above the datum. This particular head measurement whenever we are taking, so the point from where selected datum to a point where the head is being measured is referred as elevation. This can either be positive if the point is above datum, negative if it is below datum. The sign convention what we follow is positive if it is above datum, negative if it is below datum. In soil mechanics the total head is defined as pressure head plus elevation head. So with the deliberation what ever we have discussed now and we found out that the flow of water through soil is very significant and has got lot of potential and importance in soil mechanics.

Let us look into the concept and mechanism, what happens when the water flows through soil. So water flows in soil only when there is a gradient of head h that means there should be certain energy so that water can use that energy and can flow through soils. So lack of gradient in head implies that water is not flowing. That means if the head which is available for the flow is less or inadequate, then it indicates that there is no flow taking place. Whenever there is a water flow in soils there is energy dissipation occurs. For the flow to take place it has to spend the energy that means whatever the energy it has got to enable the flow to take place, so the energy dissipation occurs.
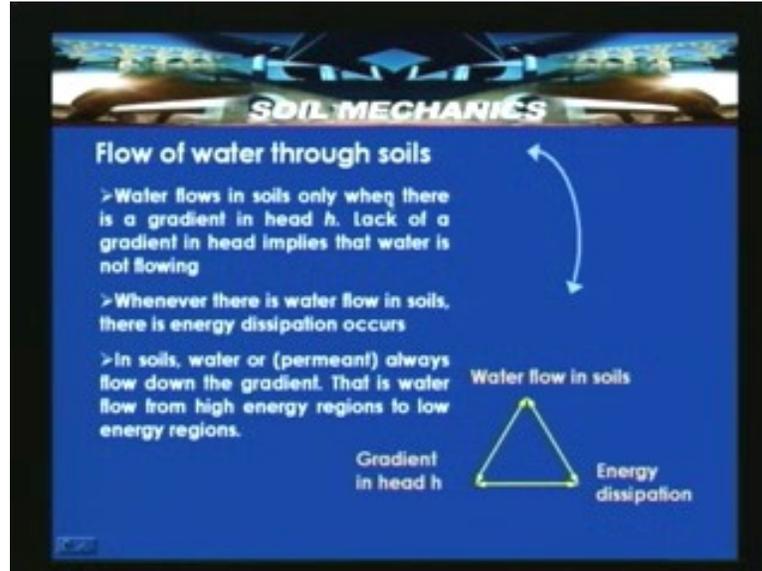
So in the beginning when the water is entering the soil phase it can have a full energy. By the time it comes out of the soil path then it loses all the energy. That means when the flow takes place to the soil a certain sort of energy dissipation occurs in soils, water or permeant. If the fluid which is different from water then in that case it is called permeant the one which flows through the soil is permeant which always flow down the gradient. That does not necessary need to have down the hill, if even under confined conditions or so. If there is a difference in head even in the upward direction also water can flow that means there is energy from point 1 which is lying at the lower level to point 2 which is lying at the upper level. It can flow by virtue of energy. So that is the water flow from higher energy to low energy. That means water flows from higher energy regions to lower energy regions.

Flow of water through soils which is linked with this particular legend here which is shown. Water flow in soils that means energy dissipation takes place. Even for water flow in soils to take place gradients in head h is required. If there is a gradient in head h then water flows in soils and then energy dissipation occurs. This we have understood that the flow of water through soils can take place provided if there is a higher energy or higher head at upstream end or point 1 where the energy is high. And point 2 for example where the energy is low. Then the flow can take place from one to two. When the water flows from one to two in the process it undergoes something called an energy dissipation process.
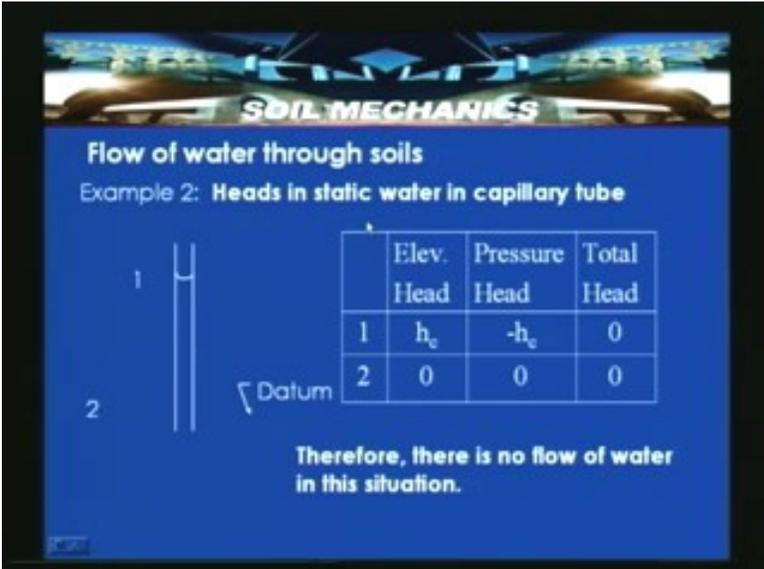
So let us consider a uniform head distribution in a soil deposit. So in this slide in example 1 where a ground water table is shown here. At two points here 1 and 2 where the pressure head is h_1 and elevation head is z_1. So this is the datum here. So total head is $h_1 + z_1$.

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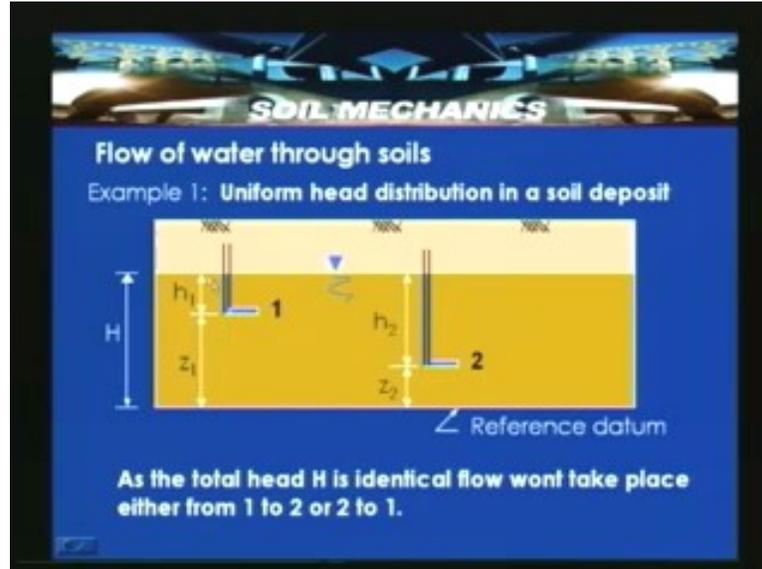
Particularly this point 2, the elevation head is z_2 that is very close to the datum and h_2 is the pressure head. So $h_2 + z_2$ is again total head H. If you look into it the total head at point 1 is H and total head at point 2 is again H. So as the total head H is identical the flow will not take place from 1 to 2. So this type of condition we define as hydrostatic condition. In the previous lectures, the determination of effective stresses what we consider is that the ground water table which is hydrostatic in nature. So in this slide what we have seen is that uniform head distribution in a soil deposit. So as the total head H is identical, flow will not take place either from 1 to 2 or from 2 to 1. Let us consider in case of head in static water in capillary tube.

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In previous lecture we saw that above the water table the hanging water column that is the column which are passing through the pore spaces sucks the water from the water table and keeps with it. That virtue of phenomenon called surface tension which is acting along air, water and inner surface of the solid grains. This is h_c, we have discussed and seen that as a capillary height and 1 is the meniscus. So let us consider two points that is 1 and 2. So this is that h_c which is above datum that is above ground water table level. Ground water table that is point 2 is at atmospheric pressure, where pressure is equal to zero. So water rising above that which is less than atmospheric pressure is negative.

If you consider at location 1 say elevation head is h_c meters above datum. This plane is selected as datum. Pressure head is minus h_c that is by virtue of the definition just now we are given. So total head is equal to elevation head plus pressure head. Total head is again zero. So two that is this point at datum elevation head is zero, pressure head is zero. So in the process total head is zero. So here there is no flow of water in this particular situation. This capillarity phenomenon is just because of the surface tension which is arising at air, water and inner surface of the solid grains. So this also demonstrates if that there is no head difference then the flow will not take place.

Now let us consider an example 3. So this is what we have seen the fluid at rest in soil at no flow condition. Even the capillarity phenomenon what we have seen appeared like flow but it is something called a no flow condition. So here that is one which we discussed is that pressure in water is less than atmospheric pressure that is negative in the capillary zone.

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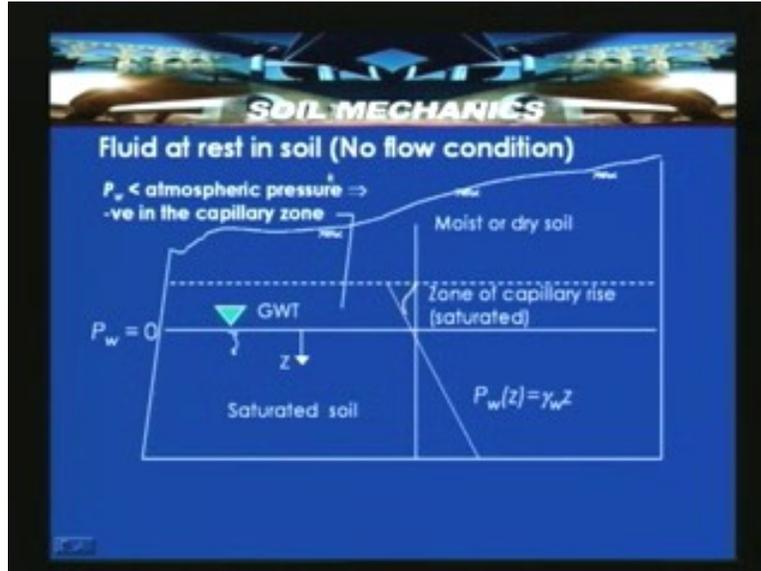
That is the reason why the pressure head which is taken as minus h_c and here is the moist dry soil and here below the ground water table again the positive pore water pressure exists. So this (Refer Slide Time: 27:41) is that zone of capillary saturation there a partial saturation exist then this negative pore water pressure tends to fall and then reaches zero and ultimately the pore water pressure is zero in this particular zone.

If it is dry because of the climatic fluctuations then it can change to zero there. So the condition what we discussed is the fluid at rest in soil at no flow condition. Let us consider flow of water through soils through a confined aquifer. So assume that here at point 1 at the elevation z_1. This is the reference datum here z_1 which is the elevation head and pressure head is P_1 by gamma w.

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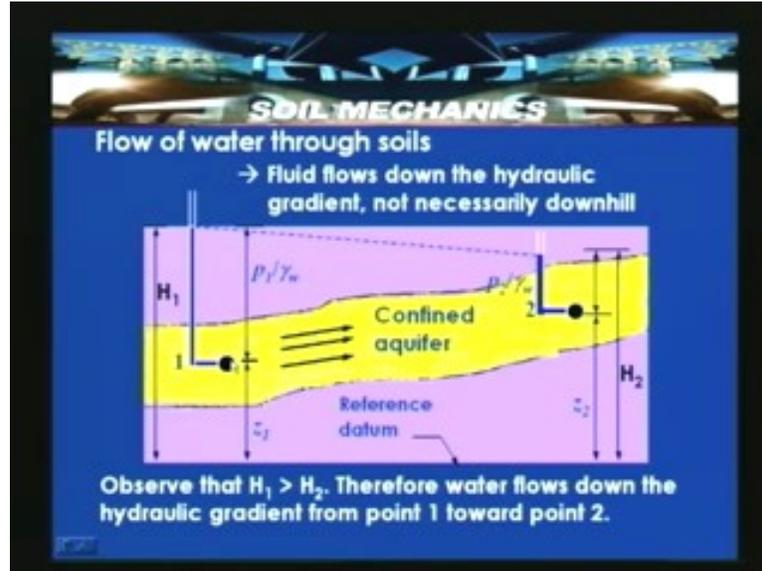
So at point 1 the total head is nothing but P_1 by gamma w plus z_1. If you come to point 2 the pressure head is P_2 by gamma w, plus z_2 is the elevation above the datum. So total head at point 2 is P_2 by gamma w plus z_2 that is H_2. If you observe that H_1 is greater than H_2 then water flows down the hydraulic gradient from point 1 towards the point 2. So this is the length l and over this length l, the loss of energy is occurring at this rate.

If you see H_1 and H_2 is the total head, the difference between two points H_1 and H_2 is referred as head loss. That is delta h is nothing but H_1- H_2. So for the flow to take place down the hydraulic gradient not necessary that down hill conditions should exist. Naturally when the down hill conditions are there, the flow can take place from higher level to lower level but it is not necessary that it should prevail always. If this conditions exist then water can flow exist from 1 to 2, if there is a head at point 1 is greater than point 2 that is when H_1 greater than H_2 with a loss delta h the water can flow with a certain gradient.

So when looking in to the flow of water through soils and we assumed that water flow takes place in a microscopic point of view along the tortuous path through pore spaces. There are some assumptions and then the theory which comes out is Darcy's theory. Basically the assumptions that are involved are where soil is fully saturated and friction less boundaries, assuming that when the flow to take place the boundaries which are free from any friction. And flow is laminar that means the Reynolds number particularly in case of soils it is defined as row v d_{10} by mew with row as the mass density and v is the velocity of flow which is called discharge velocity and d_{10} is the effective particle size and mew is the dynamic viscosity of water or permeant under consideration.The assumptions involved are flow to be laminar that is Reynolds number has to be less than one. In fluid mechanics we use around 2000 for defining the laminar condition but in soil mechanics which is different and indicated as R_e less than one, the flow to take place through soils under laminar resume conditions. Consider a saturated soil mass confined in

a cylinder having a length l and assuming that these boundaries are friction less and which is this point 1 and point 2 or point A and point B subjected to a head, total head is h_A with P_A by gamma w and Z_A elevation head.

So total head is equal to h_A and total head at point B is equal to P_B by gamma w +Z_B that is h_B. The head loss occurring between two points A and B is $h_a - h_b$. So here this is the cross sectional area A which is perpendicular to the direction of the flow. So in order to maintain this two total heads what happens is that a constant source of water has been being supplied, any extra level of water is collected in another jar. So here this particular head is maintained. So if you measure this particular discharge that is nothing but the one which is flowing through the soil.

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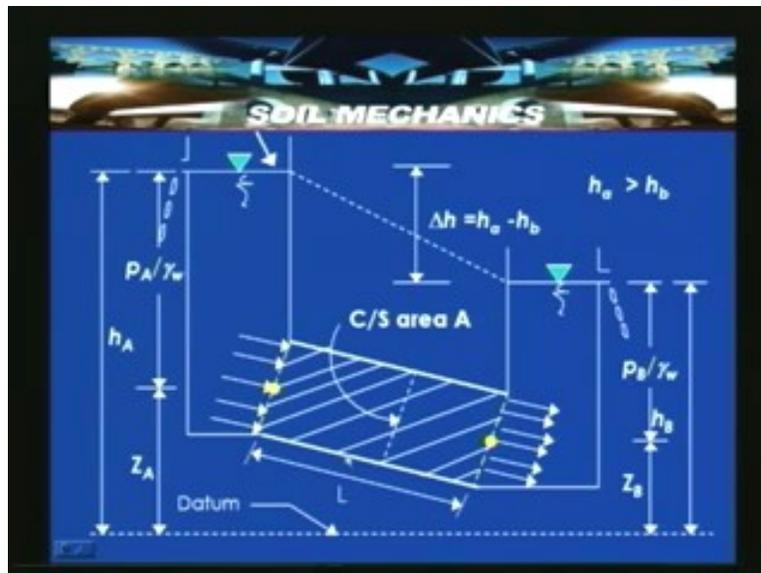
So this is the cross sectional area A which is exposed to the water to flow through the soil and delta h is nothing but $h_A - h_B$ the difference where h_A is greater than h_B. So the head loss between two points which is nothing but delta h is equal to $h_A - h_B$ which is (P_A by gamma w + Z_A) − (P_B by gamma w + Z_B). The head loss delta h can be expressed in a non-dimensional form in terms of a parameter called hydraulic gradient which is indicated by i = delta h by L where delta h is a head loss that is the difference of total head at point A and point B and L is the length of the flow over which the loss of head occurred. That means this is the one which is something like macroscopic point of view, a straight line passing through pore spaces as well as solids which is an imaginary line taken as the flow path. So i = delta h by L, very important parameter pertaining to flow of water through soils is hydraulic gradient which is defined as delta h by L.

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So when the water flows through the soil, v has got certain relationship with i. So i which is plotted on x axis and v which is on y axis. The v is called a discharge velocity or superficial velocity. It is called superficial because it is the one where the water flow takes place through the soil solids as well as through water in the pore spaces. But in principle the velocity of force through the grains or through the solid grains is different. That is one definition which we are going to look shortly. If the hydraulic gradient increases gradually the flows remains laminar that means v is proportional to i and it remains in laminar region.

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And when the hydraulic radiation increases it transforms into zone two which is called as a transient zone. Above that zone two, it is zone three which is called turbulent zone. So when i increases gradually the flow remains in laminar zone in zone one and zone two and v bears a linear relationship with i. So both in zone one and zone two, v bears a linear relationship with i. At higher hydraulic gradients that is higher values of i flow becomes turbulent. So in most of the soils v is proportional to i, in gravels and in very coarse sand the v to be proportional to i is not valid. That means in most of the soils v is proportional to i means the laminar region exists and gravel and very coarse sands turbulent flow conditions may exist and v is proportional to i is not valid. So flow of water through gravelly soil or so, a certain type of the regime which takes place is the turbulent regime where the Reynolds number is no longer less than one. So by looking in to this relationship between velocity which is discharge velocity or superficial velocity and hydraulic gradient, Darcy has proposed an equation based on proportionality between discharge velocity and hydraulic gradient.

After Darcy 1856 this is known a simple equation for relating the discharge velocity of water through saturated soil. Basically the assumption is the saturated soil which may be expressed as v =k i, where v is the discharge velocity or superficial velocity, i is the hydraulic gradient and k which is defined as coefficient of permeability very important parameter pertaining to flow of water through soils. So k is also called Darcy's coefficient of permeability. The units of coefficient of permeability is equivalent to the velocity that is meter per second in SI units. So v here that is the discharge velocity or superficial velocity which is the quantity of water flowing in unit volume through a unit cross sectional area of soil at right angles to the direction of flow.

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So v is nothing but discharge velocity or superficial velocity which is the quantity of water flowing in unit volume through unit cross sectional area of soil at right angles to

the direction of flow. So flow is through the pore space in soil and not through the entire cross sectional area.

So if you look into it the flow which is taking place in to the pore spaces which are available in between the solid grains not through the entire cross sectional area. That is the reason why this particular velocity which is indicated in this Darcy's equation v = k i is called discharge velocity or superficial velocity or to some extend it is given name called frictious velocity. So this particular Darcy's theory or v =k i equation is formulated based on the observation flow of water through clean sands, on ideal condition a clean saturated sands, so the flow of water through clean saturated sands. So Darcy's equation is usually combined with continuity equation for determining the total rate of flow through the cross sectional area A which is exposed for the flow to take place. Which is continuity equation which is nothing but q = v that is the discharge velocity and A is the cross sectional area over which the flow is occurring.

So q is the total rate of flow through the cross sectional area A = v times A. Then substituting for v = k i, we can write q = k i A. So which is this Darcy's coefficient of permeability or the coefficient of permeability k is defined as ease with which the water flow can take through this soils. So as we know that we have got different types of soils. So we required to know this particular parameter which can be measurable in the laboratory as well as in the field and which is a parameter which can help in selecting the particular type of material for a particular application.

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So let us look into it this particular case. What is this velocity which is taking place or which is occurring when the flow is actually taking place through grains? Consider a saturated soil assemblage matrix with solids and water, if you idealize now which is nothing but water and soil solids for a unit width has got area which is area of voids and area of solids. So in a total area A which is exposed to flow it is having $A = A_v + A_s$. The

total area that is the cross sectional area over which the flow is taking place with a head loss occurring at point one and two, for example if there is point one and two which are imposing the flow to take place from one to two, then the flow takes place.

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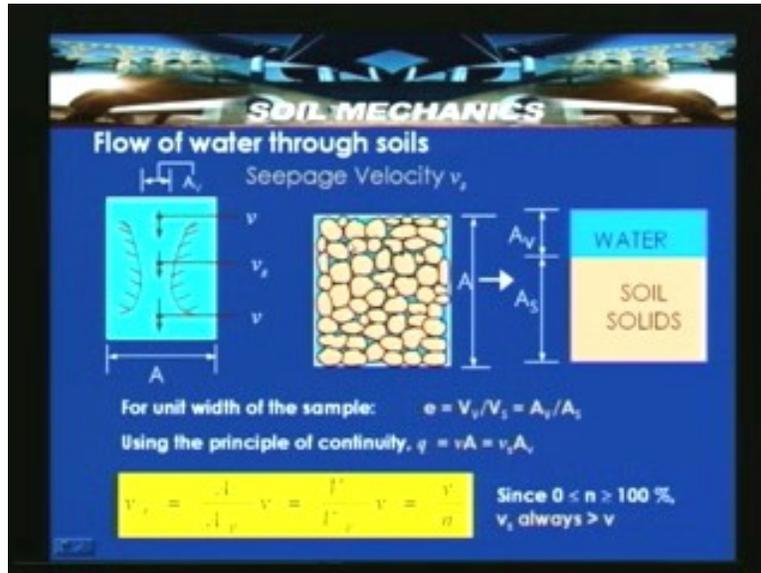
So here the velocity which is occurring through the grains is termed as seepage velocity. Then what is the relationship between seepage velocity and then the so called discharge velocity? Let us consider an enlarged view of the particular grain at the grain surface and then the place where water is flowing. So this is the pore space over which the water is flowing through the soil (Refer Slide Time: 42:03). So at this particular point the pore space or water has actually got larger area, so still the velocity is v. This v is nothing but represents something which is taking place over the area A, over which the flow is occurring. And v_s is nothing but the velocity which is taking place through the grains that is at the void space between the grains.

So if there is a reduction in this particular area that is at the area of voids at this particular point. Because of that there is a chance that this particular velocity has to be more than this discharge velocity. Because there is a reduction in the particular void space with that water again conforming to the continuity equation, what will happen is that the flow rate has to be equal to the one which is entering the entire soil mass through the one which is taking place through the voids. So for the unit width of the sample if you look into it the void ratio is nothing but volume of voids to volume of soils, that is defined as area of voids to area of solids for a unit width of the sample.

Now using the principle of continuity, q = v into A, v is the discharge velocity which is occurring over an area A and v_s is the velocity v which is actually taking place through the grains. That is the flow velocity which is taking place through the grains over a space that is nothing but area of voids. So if you look into the entire soil mass the v_s is defined and given name as seepage velocity. The seepage velocity is the velocity which is

nothing but a flow velocity which is actually taking place through the solid grains. So here $q = vA = v_s A_v$. So by substitution $v_s = A$ by A_v into v. A by A_v in to $v = v$ by V_v in to v. So by using this definition again what ever we have defined, v by volume of voids that is nothing but one by porosity.

We have related $v_s = v$ by n, where v is the discharge velocity, n is the porosity. As the porosity of the soil always have 0 to 100 percent. So this particularly if you look into it v_s will be always greater than one. As n cannot be more than 100 percent or so. With that what will happen is that the seepage velocity is always more than one, even that now can be verified here because of the reduced volume or area of cross section to the voids there will be an enhancement increase in the velocity. The seepage velocity is always more than flow velocity. The seepage velocity is the velocity which is actually taking place through solid grains. So the relationship between the seepage velocity and the flow velocity or discharge velocity is nothing but $v_s = v$ by n, where n is the porosity.

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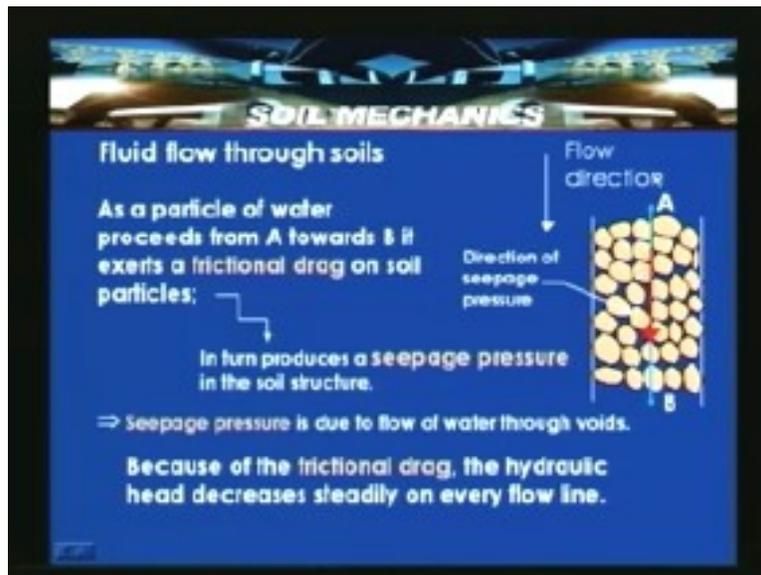
So if you consider in the flow direction, flow will occur from A to B if there is a head loss taking from this point. And the velocity particularly when the flow is taking place from A to B, as a particle of water proceeds from A and towards B it exerts a frictional drag on soil particles. This special drag is nothing but the energy whatever the water is losing while flowing through the soil. So as a particle of water proceeds from A to B it exerts a frictional drag on soil particles.

So the direction of this, particularly in turn produces a seepage pressure in the soil structure. So the seepage pressure will always occur in the direction. If the flow is taking place A to B, top to bottom then it is called downward flow, bottom to top then it is called upward flow. So seepage pressure is due to flow of water through voids. So because of the frictional drag the hydraulic head decreases steadily on every flow line. For example if this A, B is considered as a flow line, so the hydraulic head decreases

gradually. For example if there is a delta h here and L is the distance between A to B. Then delta h by L which is nothing but hydraulic gradient. So the water loses the head as it flows from A to B.

So as a particle of water proceeds from A to B it exerts the frictional drag on soil, in turn produces seepage pressure in the soil structure. So the direction of the seepage pressure is always in the direction of the flow. So seepage pressure is due to the flow of water through voids. Because of the frictional drag the hydraulic head decreases steadily on every flow line. So having seen the importance of flow of water through soils particularly relevant to the subject heads like environment engineering and construction engineering. Then in the previous lectures we have derived and defined the total stress is equal to effective stress plus pore water pressure.

Suppose if the soil reaches complete equilibrium or complete dissipation of pore water takes place then what will happen is that sigma tends to equal to sigma dash. That means entire water pressure has been transferred to the grains. The grain to grain interaction has been mobilized that we define also as intergranular stresses. Incase of dry soils then the sigma is equal to sigma dash that also we have defined. What will happen now if the water flows through the soil, whether it induces any changes in effective stress or not. If it induces what will happen when the water is flowing for example from top to bottom or bottom to top? Particularly in case of the previous conditions we have considered that hydrostatic conditions, no flow conditions then we have established the relationship like total stress is equal to effective stress plus pore water pressure.

So in this lecture the flow of water through soil has been introduced and we understood that if there is a flow to take place that head should be available and not necessary that down the hill. That means energy at point 1 to point 2, for example if it is energy at 1 is higher, energy at 2 is low then the flow can takes place from 1 to 2. That means for the flow of water through soil to take place there should be some energy dissipation. The energy dissipation occurs because this is spent or transferring in the form of a frictional drag to the soil particles. And the path which is taken by the water through the soil is called tortuous path. But the one with is idealized is taken as a straight line which is not the tortuous path. And we also tried to deduce a relationship between v and i and we said that v is proportional to i and v is equal to k i. This is very important equation in soil mechanics. That is called Darcy's equation. Then we try to deduce the relationship between V_s that is seepage velocity which is the velocity which occurs through the solid grains and v that is discharge velocity or superficial velocity and porosity which is nothing but $V_s = v$ by n.

In the next class we will try to see what will happen when the water flows through the soil, whether any effective stress change occurs or not. In continuation of this we will also see what are the factors affecting the permeability and how this permeability can be measured in the laboratory as well as in the field.