Soil Mechanics
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Lecture – 21
Flow of water through soils-II

Welcome to lecture number II for flow of water through soils. In the previous lecture we have understood about the concept of flow of water through soils and we discussed about Darcy's law which relates discharge velocity and coefficient of permeability in the hydraulic gradient, a parameter which is defined as i = h by L. The h is the head loss which is taking place between say two points A and B separated by a length L. So in this lecture we will be seeing when water flows through soils, how these effective stresses change whether it remains constant or increase or decrease. So in the previous class we have understood about fluid flow through soils and we introduced the Darcy's law, after Darcy's 1856 and introduced the very important parameter in soils mechanics called coefficient of permeability. And we have tried to introduce relationship between seepage velocity and discharge velocity which we also named as superficial velocity.

In this lecture we will concentrate, when flow of water takes place through a porous media, then what are the changes in geostatic stresses with flow of water through soils. Let us concentrate this particular effect in the case when water flows through soil. So before discussing that in this slide as we have seen in the previous lecture the soil is assemblages of particles. In this particular slide the granular particles are shown like solid grains which are possible in course grain soils. But in case of clayey soils depending upon the structure it can have a flocculent structure or a disperse structure or semi flocculent or disperse structure. So depending upon the flow shell takes place across the plates that is the particles are perpendicular to their plane.

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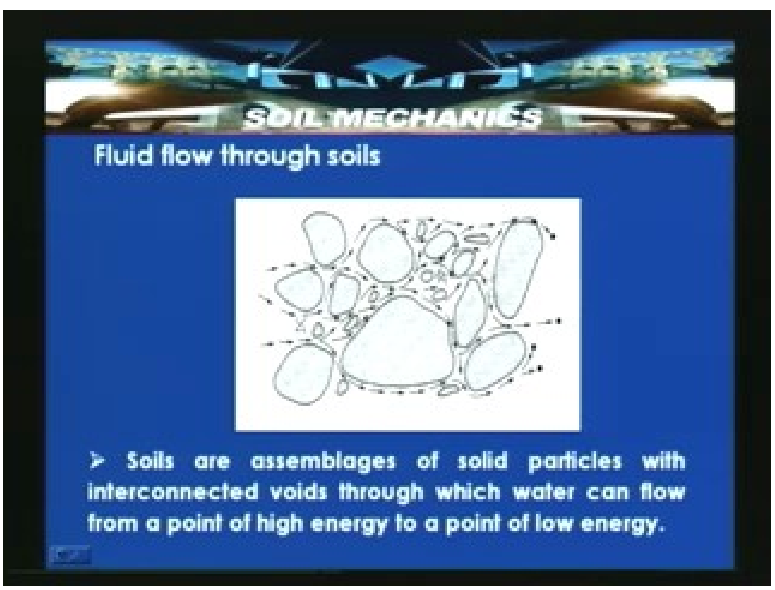

So here the soils are assemblages of solid particles with interconnected voids through which the water can flow from a point of higher energy to a point of low energy. That means for the flow to takes place we said that higher energy should be there at point and lower energy should exist at another point. Then the flow can takes place from a point of higher energy to a low energy. This concept we have already seen but let us look once again, very important concept which we should remember in flow of water through soils.

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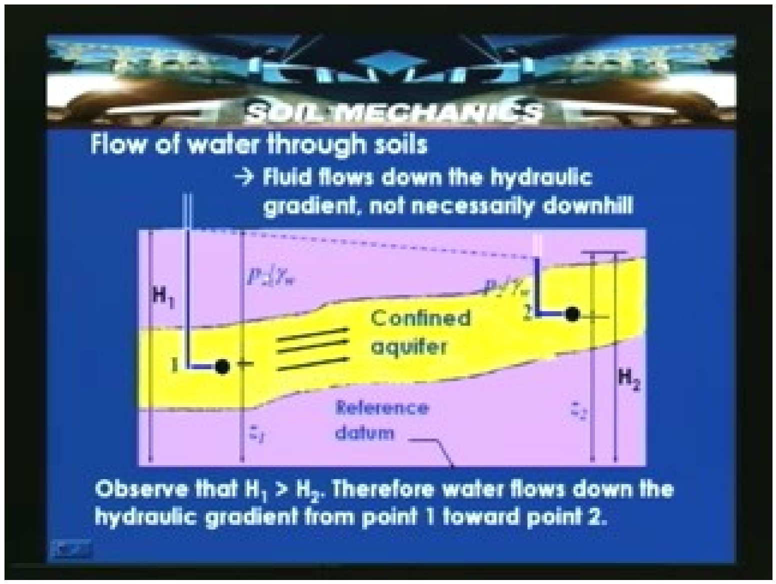

Here total head is H_1 and the reference datum which is shown here and the elevation head is z_1 and pressure head is P_1 by gamma w. So total head is equal to $H_1 = P_1$ by gamma w + z_1 at point one. At point two total head is H_2 that is summation of P_2 by gamma w + z_2. If you observe that when H_1 greater than H_2, not necessary the down the hill, the flow can takes place from one to two in the confined aquifer conditions like the one which exists below the ground level.

So for the flow to take place the energy which is spent by the water in flowing through the soil is the $H_1 – H_2$ that is delta H over a distance which takes place say L is the length between two points. Then hydraulic gradient is set to be here as H_1- H_2 divided by L. Now while introducing the concept of flow of water through soils we said that and we assumed that the soil is assumed to be completely saturated and assuming frictionless boundaries are there. We also assumed that the flow is in the laminar regime.

That means for soils when the flow takes place through soils the Reynolds number will be less than one. So we discussed except for some coarse sands and gravelly soils the Reynolds number will be very much less than one that means that the flow will honor the laminar regime. That means that it will be under the laminar regime.

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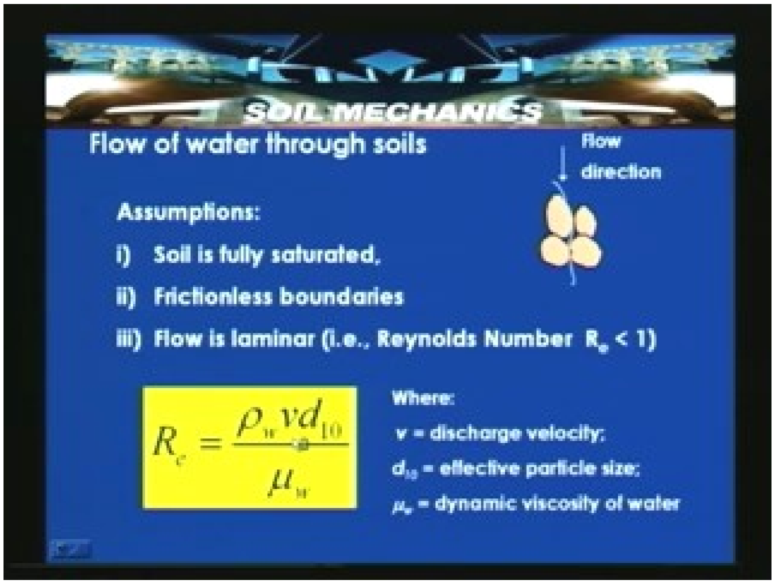

Then we defined here Reynolds number is equal to row v d_{10} by mew, where d_{10} is the effective particle size, v is the discharge velocity or superficial velocity over which that is the velocity through which the water is flowing through particular area of cross section. And we also discussed that the flow cannot take place particularly passing through the contact points. So it can actually take a winding path and we described that path as a tortuous path. We idealized that at a macroscopic level as a path which is indicated called as a flow line. When you look in to this flow of water through soils and we introduced the concepts like permeability one parameter which indicates that is with which the water flow through soil.

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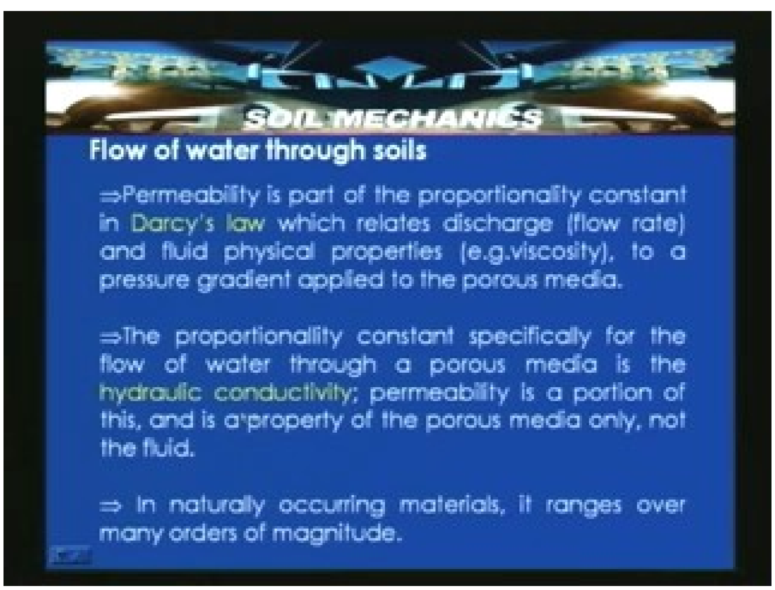

So permeability is a part of the proportionality constant in Darcy's law. As you all know that Darcy's law is equal to v = ki and v is proportional to i. So as long as the flow is in laminar regime it satisfies this particular Darcy's law. Once accept in gravelly soils rest of the other soils this particularly Darcy's law remains valid. So Darcy's law which basically relates the discharge that is the flow rate and fluid physical properties like viscosity of the permeant under consideration to a pressure gradient applied to the porous media. That means at what head the flow is taking place that is the head loss or a pressure gradient.

So the proportionality constant specifically for the flow of water through a porous media is hydraulic conductivity. So permeability is a portion of this, and is a property of the porous media only, not the fluid. In naturally occurring soils, this particular permeability can range from different magnitudes. That means for fine grain soils it can have particular value very low value and for a coarse-grain soils it can have very high value. So this value of the permeability depends upon the type of the soil and it depends upon many other factors like its gradation, its denseness and its structure, which we are going to discuss in forthcoming lectures. In naturally occurring materials this permeability ranges over many orders of magnitude. For clayey soils and sandy soils more than million times of magnitude difference will exist. So that indicates how difference is the behavior when we consider a clayey soil and sandy soil.

So let us consider like we did in the previous class. In the flow direction consider two points A and B which are separated with a head loss by distance L between A, B and total head at A is H_a total head at B is H_b. So the difference in head between A and B is H_a- H_b that is delta H. So the hydraulic gradient can be set as H_a- H_b by L, where L is the distance between two points A and B where the flow is taking place.

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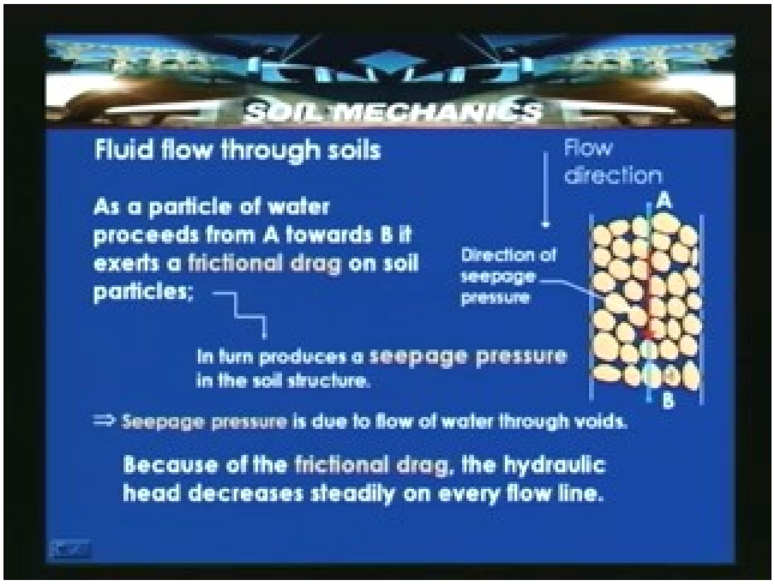

So as a particle of water proceeds from A towards B it exerts a frictional drag on soil particles. So when the flow is taking place from A to B it exerts some frictional drag on to the soil particles. While inducing the frictional drag whatever the energy it has to flow through the soil it will try to dissipate. In the process what will happen is the water which is actually flowing with certain energy will be losing the energy as the water is flowing through the soil. Once it comes to the exist point the complete energy loss will occur. That indicates the complete dissipation of the energy which was there at the entry point is said to be dissipated.

So in turn produces a seepage pressure in the soil structure. That means these frictional drag when it is taking place produces seepage pressure which can use changes in the effective stress. For example it depends upon the direction of the flow, if it is say downward then it can push the particles into the denser packing positions. If it is an upward position so there is an upward direction, then the seepage pressure acts in the direction of the flow and can agitate the particles. That means this influence of this seepage pressure, the seepage pressure always acts in the direction of flow and can change or influence the effective stress.

So that we will be seeing very shortly. So seepage pressure is due to the flow of water through voids that is what we have just now discussed. And because of the frictional drag the hydraulic head decreases steadily on every flow line. For a particular cross section can have innumerable number of flow lines. So through this flow line what will happen is that a gradual or a steady dissipation of the energy takes place. Because of the frictional drag the hydraulic head decreases steadily on every flow line.

So let us look in to the concept once again. Before looking in to the flow of water through soils, let us look as we defined earlier that Terzaghi’s concept of effective stress sigma s that is total stress = sigma dash + u_w where sigma dash is the effective stress and u_w is the pore water pressure. So let us see the changes in geostatic stress with flow of water through soil. So when water flows through the soil it exists the drag force called seepage forces. That is what we just now discussed that when the water flows through the soil it spends energy in the form to induce a frictional drag on to the soil particles.

So it exerts drag forces called seepage forces on individual grains of the soils. So the presence of the seepage forces which cause changes in the direction of flow will cause the changes in the pore water pressure and effective stresses in the soil. When these seepage pressures act then they finally influence the effective stresses. So now let us consider three different cases. In the first case like what we did before, when we discussed about hydro static conditions when no flow is taking place.

Let us consider the same case again as a case one. So case one, when no flow takes place through soil that means the hydrostatic condition. So consider a container having water head which is H_1 and H_1 is the level of the water above the top surface of the soil. This portion is filled with a soil of height H and it is connected to a stem and this water level is maintained.

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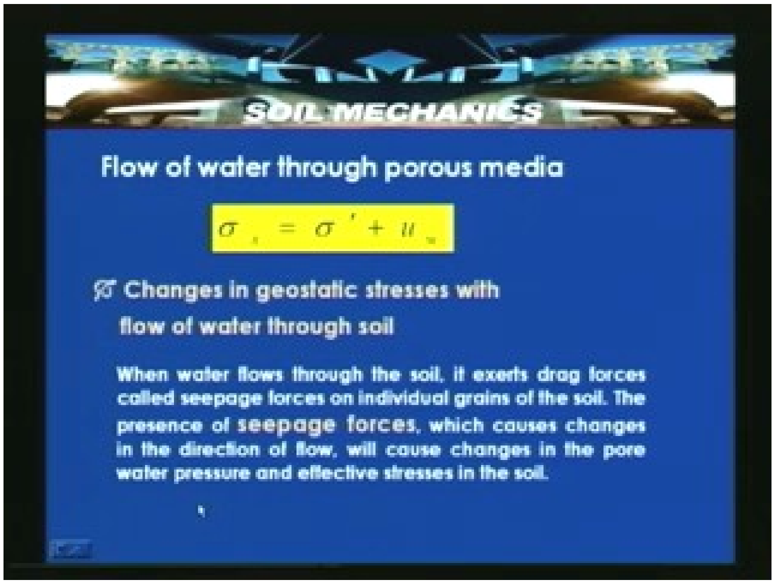

So this is the water source here a continuous source and this particular head is maintained by taking this water out. Assuming that this particular portion of the soil is completely saturated and interconnected here from the stem. Then this particular portion is filled with water and maintained at this level and extra water is collected outside. So if at all flow to take place then water flows either depending upon the location of the stem. So here this location is maintained such a way that the level of the water in the stem is equal to the level of water in this main container.

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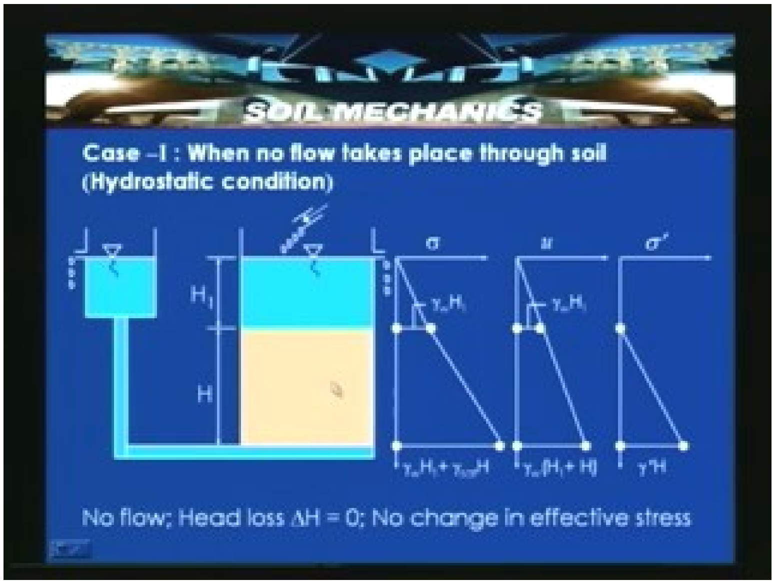

Let us look into that particular case if the soil is completely saturated, then gamma sat saturated unit weight of the soil, gamma w is the unit weight of the water. So the total stress variation with depth can be given as, at particular point of the atmospheric surface that is the top surface where the water surface is there, so pressure is equal to zero. That is here it is zero and at this particular point it is gamma w H_1. That is the water pressure here is gamma w H_1, (Refer Slide Time: 14:46) if you call this as point B and this as point A, at this point it is gamma w H_1 + gamma sat H. Because gamma sat H is the saturated unit weight of the soil and gamma w H_1 is the unit weight of water which is acting. So the total stress acting is, suppose this is having a unit area then gamma w H_1 + gamma sat H.

So the pore water pressure distribution with depth for this case can be given like this. At top surface it is zero. So here the total stress is zero, here the pore water pressure is zero because of the atmospheric surface and here the water pressure is gamma w H_1 and at this particular point it is the ordinate here is gamma w H_1 + H (Refer Slide Time: 15:18-15:40). What it has is that because of the same water, the slope of this line is same. But here there is water and then soil so there is a change in the slope of the line can be noted. So here gamma w H_1 and here at this point is gamma w into H_1 + H. So the effective stress is nothing but total stress minus pore water pressure. So that is obtained here is zero and zero at this point that is gamma w H_1 minus gamma w H_1 is set to be zero here. And at this point when you subtract gamma w H_1 plus gamma sat H minus gamma w H_1 minus gamma w H is reduced to gamma sat minus gamma w into H that is nothing but gamma dash H that is submerged unit weight of the soil plus submerged unit weight of the soil times H.

So this indicates we have seen that when no flow takes place, particularly there is no head loss between point one and two. So if you look into it, if this is taken as a datum total head at this point is H_1+ H and at this point it is also H_1+ H. So because of that there is no head loss. So in the process the delta H is equal to zero. So no flow can takes place between points A and B because of this particular condition. So in the process like which we discussed in the previous lectures, now the effective stress that is the distribution is zero at the top of the solid surface and then the bottom of the solid surface it will be around gamma dash H also. That indicates what ever may be the height of the H_1, this is independent of the height of the water resting on the soil bed. So this we have already discussed. Once again we are discussing this as a case one for this condition. So no flow can take place because head loss delta H = 0, so no change in effective stress. So what ever may be the height of the H_1 value here, the effective stress will remain unchanged.

Now consider a case two where a particular arrangement is shown in this slide. When flow takes place through the soil but a downward flow. Why downward? Let us look into it. Let us consider now this stem has been lower by a vertical distance or by small h. And similarly here it is H_1 and here it is H. So the total stress which is in the main container is gamma w H_1 and at this particular point it is gamma w H_1 plus gamma sat H. so this is nothing but H_1 and the thickness of the soil specimen within the container is H.

So here is gamma w H_1 plus gamma sat H. So like the previous case and this case the total stress remains unchanged. The total head which is available here will be like, for example here the u will be gamma w H_1 and if no flow to take place then the gamma w into (H_1 + H) is the water pressure. It is suppose to be, you should get at the bottom portion when the no flow to take place. In the previous case what we got is that gamma w into (H_1+ H).

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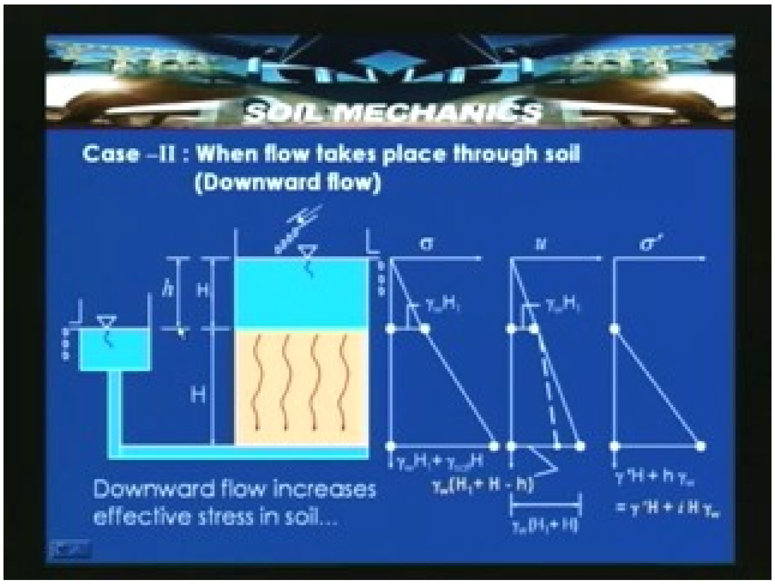

In this case because of this position there is head loss which is taking place between point A and point B. So that head loss is nothing but indicated by small h and thickness of this soil bed here is capital H. So the hydraulic gradient is set to be small h by capital H. What is happening is that having the head which is driving the flow is small h which is here and then it is said to be zero here. That that means the water will have energy of small h. So at the 50% of the height, the 50% of the head loss will occur at somewhere around 25% of the height from the top surface, so 25% of the head loss will occur. At three fourth of the distance from the top surface, so 75% of the energy will be lost.

So after crossing the full thickness of the soil specimen, the head loss is supposed to be zero that is H=0. By eventuality of that we will be seeing in the next slide. But because of this particular phenomenon the pore water pressure which is available at top of the soil sample will now get reduced to gamma w into H_1 plus capital H minus small h. So that is the reduced pore water pressure because that much is transferred in the form of a seepage pressure to the soil grains. Now if you look at the effective stress at this point the ordinate is here, total stress is gamma w H_1 and here it is gamma w H_1 that means the effective stress is zero and at this point it is zero, so in this zone it remains unchanged. But when you come to the bottom, because of the change in pore water pressure the effective stress increases. Why? Let us look into it. So that is nothing but total stress is equal to gamma w H_1 plus gamma z H, this particular ordinate if you consider here minus gamma w into H_1 plus H minus small h.

So if you simplify this it reduces to gamma dash H + H gamma w. When the no flow is taking place we do not have this term H gamma w. Now this H gamma w is adding. So this is actually a component which is actually being spent in the form of a seepage pressure. So because of this total head loss available at this point and at this point, the head loss is occurring from top to bottom. The flow takes place from top to bottom that is the downward direction. So when the flow takes place from top to bottom that is in the downward direction then the effective stress increases. So downward flow increases the effective stress in soil that is what we have seen the downward flow increases the effective stresses in soil. That means because of the frictional drag this particles will be pushed to the denser positions, in the process more effective stress is generated because of this decrease in the pore water pressure. The total stress remains same but decrease in pore water pressure occurs because of the loss of the energy when the water tries to flow through the soil.

Consider the same case two again and let us try to understand once again the mechanics, why the flow is taking place in the downward direction. At different levels, how exactly we can determine the pore water pressure? So the same case what we discuss is that the arrangement is shown here which is nothing but the similar arrangement but positions has been made to show these stand pipes.

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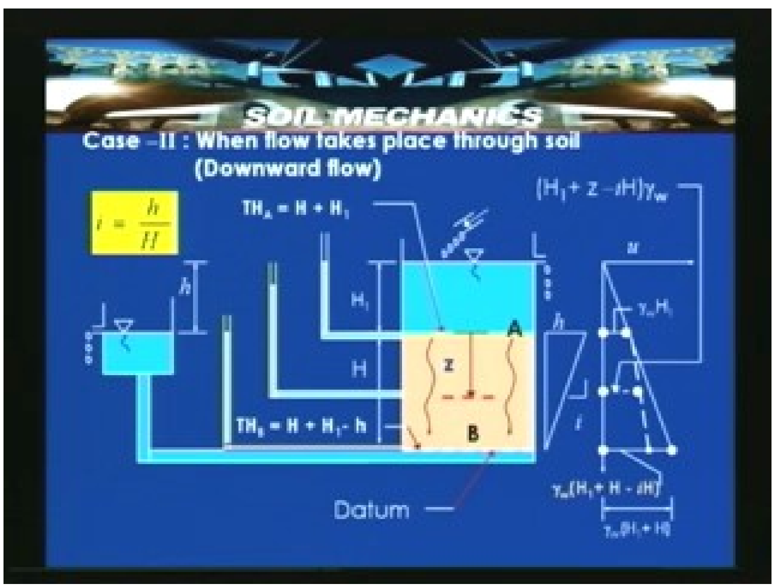

Let us assume that it has got the water level H_1 like in the previous slide and H is the thickness of the soil bed and this is the top surface with the point A and the bottom surface is a point B. And assume that there is a constant source of water and this head H_1 is maintained by collecting the surplus water and it is connected to a stem which is h units below this particular upstream water level. So in the process because of this the water flows in the downward direction. When the steady seepage conditions are established then the amount of water flowing through this soil which is collected here that is nothing but the discharge which is the amount of water flowing through the soil.

So we can estimate the amount of water collected in a given time. So based on that we estimate the coefficient of permeability value which we are going to see in the next lecture about how to determine these coefficients of permeability of a given soil in the laboratory as well as some field methods to determine this particular parameter. Let us consider if this particular portion is treated as a datum that is the reference datum then total head at point A is H+ H_1 because the pressure head is H_1 and elevation head A is H meters above the datum. So the total head is equal to, the pressure head is H_1 elevation head is H so the total head at A is H+ H_1.

When you come to the portion that is the point B which is at the bottom of the sample, the total head at B is equal to H+ H_1-H. This is because here the elevation head is zero the pressure head is H+ H_1- H, because that much head loss is already occurred. That means H is the energy which is available that is the head loss which is occurring from upstream end to downstream end. Over a length h, the slope of this line is nothing but the hydraulic gradient i. So at this point A it has got the full head which is yet to dissipate. At this point at a certain depth there is a certain head component so i= h by H, so h is equal to iH. For example z = h by 2 then we say that 50% of the head loss has already occurred. When this z is say h then complete head loss occurs. So at this particular point, when z = small h. So total head at B is, because pressure head is H+ H_1-H that is this level and elevation head is equal to zero. Because of this the total head at B is equal to H+ H_1- H. The difference between total head at A and B is small h, that is the one which is driving the water to flow in the downward direction. So similarly whatever the pressure distribution we got can be interpreted like this.

So at this particular point because of the atmospheric pressure the water pressure is zero. At this point A it is gamma w H_1. So here what we said is also gamma w H_1 that is H_1 is the pressure head which is available at point A and H is the elevation then the total head at A = H+ H_1. So here at a certain point from the top surface say from A that is at a certain point within the soil say z, then that ordinate can be given as H_1+ z- iH. So this z is equal to full soil depth then it changes to gamma w (H_1+ H-iH). So this iH is written as i= h by H. So previously what we wrote is that H_1+ H-iH, the small h is now written in terms of hydraulic gradient times thickness of the soil specimen. So if no flow takes place this ordinate is gamma w into H_1 + H. So because of this flow which is taking place, this much particular portion of the pore water pressure is lost from point A to point B. So that is transferred to the soil grains in the form of an effective stress. So that actually results as an effective stress. So similar mechanism can be explained when the flow is taking place in the upward direction.

So let us look into it as a case three. When the flow takes place through the soil in the upward direction. That means assume similar arrangement but what we did is that this stem has been taken h meters or h units above this level. So this serves as an upstream surface and this serves as a downstream surface. So when I am actually having a continuous source of water when this head is maintained here in the stem which is provided here.

And when extra water which is collected here is nothing but the one when the steady state seepage conditions are established then the amount of water flowing through the soil can be collected here. That is actually can be measured as a discharge and then to reduce permeability. But in this case because of this difference in head between this point and this point and head at this point is more than head at this point, in view of that the flow takes place in the upward direction.

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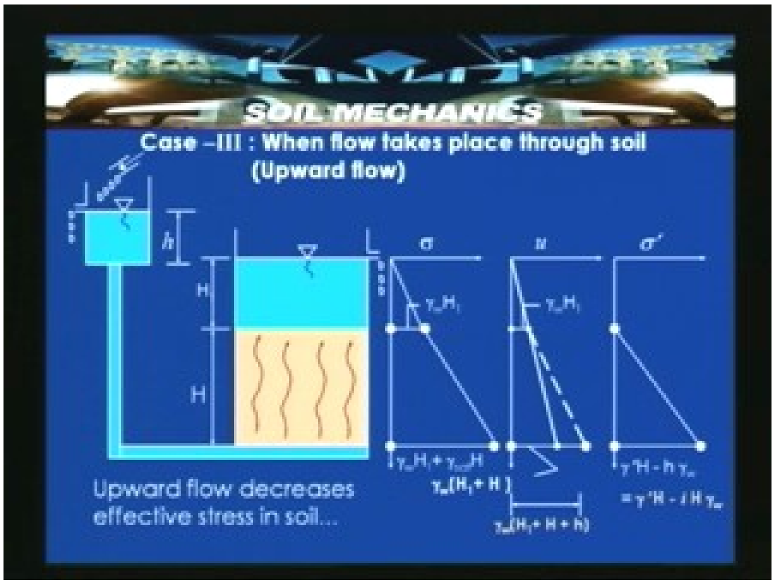

So what will happen to this geostatic stresses when the flow takes place in upward direction? Let us look into that in detail. So if you look into the total stress distribution with depth it remains same because same height H_1 and H. So which reduces to gamma w H_1 and gamma w H_1 plus gamma sat H which remains same like in the previous case. Which is also same when the flow is not taking place. But the only difference is that the flow which is taking place and also depends upon the direction of the flow. So here in this case the pore water pressure is obtained like this. At this point it is zero and at this point it is gamma w H_1 which is same as this. And when the flow is not taking place we have actually said that gamma w into H_1+ H is the pore water pressure. But here because of this difference in head the flow takes place in the vertical direction.

So in the process the head which is driving the flow, the total head is nothing but if this is taken as a datum H+H_1+h which is nothing but gamma w into H_1+H+h. So the total head at this point is H_1+ H+h and here because the dissipation of the energy occurs the head at this particular point will be H_1. So gamma w into H_1+ H+h that is now the pore water pressure is increasing in this particular case. Let us look what will happen when this is subtracted from the existing total stress. So at this point the pressure is zero, so in this case there is no change again like in the previous case. But here what exactly happening is that the total stress is decreasing because there is an increase in the pore water pressure.

So at this particular point the pressure is gamma dash H- h gamma w. So in the previous case we got like gamma dash H plus H gamma w, when the water flows in the downward direction. So in the upward direction the effective stress decreases. So when this particular head is say increases then at one certain point the effective stress can even reduce to zero. Further if it increases then the effective stress reduces to a negative value that means that all particles are agitated and there is no interaction between particles. It represents something like most fluid situation or a boiling situation. So gamma dash H minus iH gamma w, where i =h by H. So by writing h is equal to i times capital H then we can write this effective stress at this particular point as gamma dash minus H gamma w.

So upward flow decreases the effective stress in soil. So in the previous case when the flow is downward there is an increase in effective stress. When no flow is taking place there is no change in effective stress, when the flow is taking place in the downward direction then there is an increase in effective stress. When the flow is taking place in upward direction then there is a reduction in the effective stress. So this particular upward flow condition which can occur because of the some natural existing features, can create failures for the geotechnical structures.

Now let us look once again into the explanation for the case three. Here the same situation is explained where you will see that the H is the thickness of this soil specimen and H_1 is the head of the water which is resting here. So the extra water which is collected here is after establishing the steady seepage condition that is the one which is actually when flow is taking place in the upward direction. That is the direction of the flow is this. So the head loss between these two points is the small h, the length of the soil specimen which is subjected to flow is capital H.

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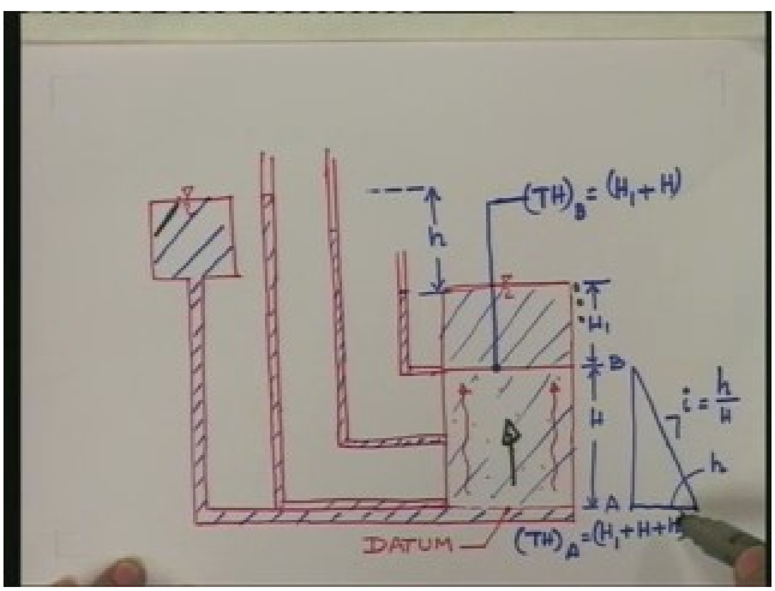

So the hydraulic gradient head which is driving the flow is small h which is here and zero at this particular point. The slope of this line is nothing but the hydraulic gradient i=h by H. If you put at different points say at this point and at this point and this point and if this point is called as A and this point is termed as B which is shown here, then if this particular plane is taken as datum, then elevation head is zero, the pressure head if the water tapped here then it will raised to a head which is equivalent to $H+H_1+h$ (Refer Slide Time: 35:28-36:03). That means the head which is there is this much. That means at this particular point elevation head is zero.

So the total head at point A= H_1+H+h. When you come to this particular point B, already this h is now reduced to zero. So the head which is available now is pressure head which is H_1+H. So the total head is equivalent to H_1+H. In the process we can say that the head loss which is occurring between these two points, which are the difference between the total head at point A to the total head at point B is nothing but $H_1+H+h-H_1+H$ gives rise to that h which is taking place over a length H.

So like this there is a pore water pressure and by the time it comes out which decreases. So in the process that means there is an increase in pore water pressure here that means at this particular point where this head is maintained, there is a decrease in the effective stress. At this point again it remains unchanged. So having seen the effect of seepage or flow water through this effective stresses. The effect of seepage on effective stresses, so seepage is the flow of water through soil that is what we have discussed. It exerts a frictional drag on the soil particles in the form of a force called seepage forces.

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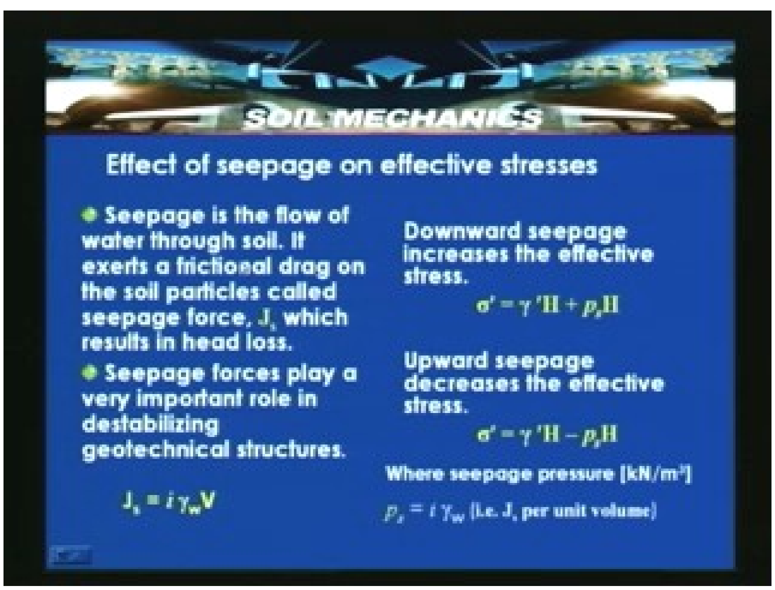

And which results in head loss because of the mobilization of the seepage forces it results in that head loss which is actually driving the flow. And seepage force plays a very important role in destabilizing geotechnical structures, like we discuss it just now. Particularly the seepage process play a very important role in destabilizing geotechnical structures which we are going to see very shortly. So here to summarize, the downward seepage increases the effective stress. So when the flow is taking place there is an increase in the effective stress which is nothing but sigma dash is equal to gamma dash H+ P_s times capital H. So this P_s is nothing but i gamma w, which now we have written gamma dash H plus i gamma w H. This i gamma w is seepage force per unit volume which has got the units as that of unit weight like kilo Newton per meter cube in SI units.

So seepage force which is nothing but the seepage pressure per unit volume and seepage force is indicated as J suffix s and defined as i gamma w V, where V is the volume of the soil where the flow is taking place, A is the cross section area and H is the height. And this i can reach to a certain head where it can reach a maximum value. Then in that case it can reduce the effective stress to a zero value. So that particular hydraulic gradient at which this particular effective stress reduces to zero is called quick condition or boiling condition which we are going to see.

So seepage is the flow of water through soil, it exerts a frictional drag on the soil particles called seepage force J_s which results in head loss. So let us consider geotechnical structure where you are retaining water which is shown at this particular point. So in this force when the water is flowing in the downward direction. In this particular zone there is an increase in the effective stress. Similarly when the same water when it is flowing in this direction there is a decrease in the effective stress. So this particular portion where particularly in this zone it can create destabilizing effect and it can reduce the stability of this structure and then can lead to a collapse.

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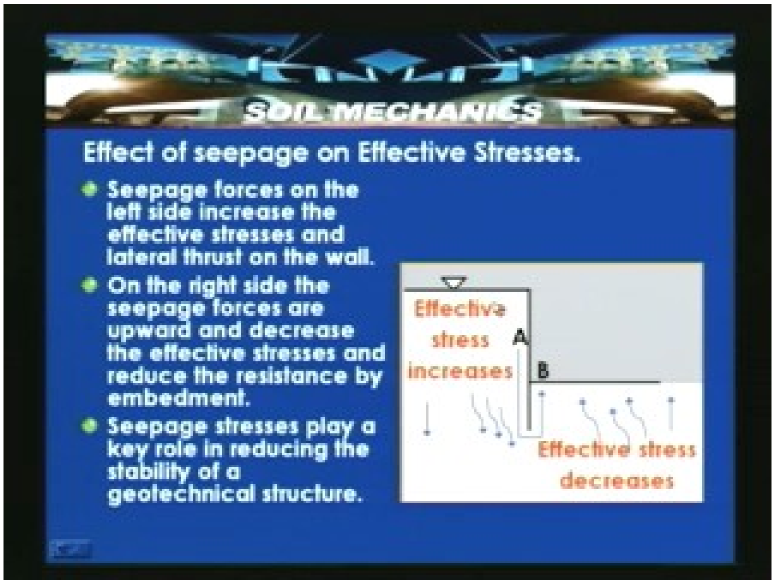

So seepage forces on the left hand side increase the effective stress and the lateral thrust on the wall. So with an increase in the effective stress it exerts also and in lateral thrust on the wall. On the right hand side the seepage forces act in the upward direction, because the flow is in the upward direction and decreases the effective stresses and reduce the resistance by embedment. Whatever the embedment resistant it is giving, it destabilizes that. So seepage stress plays a key role in reducing the stability of a structure. So seepage stresses play a key role in reducing the stability of a particular geotechnical structure.

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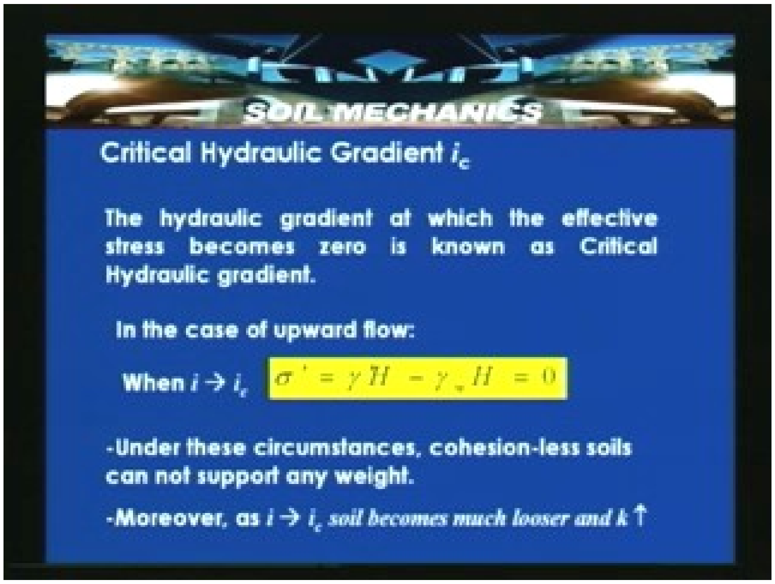

What is this critical hydraulic gradient? We have defined that the hydraulic gradient at which the effective stress become zero is called the critical hydraulic gradient. That means if you maintain particularly for upward flow condition, if you increase the head constantly, at a certain head it reaches the critical head where it can lead to a critical hydraulic gradient and lead to an effective stress zero in the soil. That means the soil loses all its supporting capacity to support the load.

So before the occurrence of the quick condition, the soil might be supporting the structure. But when the quick condition takes place it can create a destabilizing effect and reduce the effective stress to zero. So the hydraulic gradient at which the effective stress becomes zero is known as critical hydraulic gradient. In the case of upward flow, when i changes to i_c, that means head is increased such a way the H value reaches say H_c, if that is termed as a critical hydraulic gradient then i intends to i_c that is H_c by L, when L is the length of the soil in which the flow is taking place. Then that is nothing but a critical hydraulic gradient. So in the previous case when the flow is taking place in upward direction, we have derived an expression called sigma dash =gamma dash H - gamma w H.

So if gamma dash H i gamma w H =0. So under these condition if you substitute then the effective stress tends to become zero. In the process at i =i_c, so i_c is equal to gamma dash by gamma w. So if you take for a saturated soil then we can express this in terms of i_c = g_s - 1 by 1+A also. If you know the specific gravity and then packing of the soil particles we can even determine the critical hydraulic gradient.

For sandy soils we are having the specific gravity equivalent to 2.65 or so. The critical hydraulic gradient will be equal to 1 that is i_c =1. Under these circumstances cohesion less soil cannot support any weight. Because when i tend to i_c, then i_c is equal to gamma dash by gamma w. That means whatever the weight which is acting at that particular point is suppressed by this pore water pressure. So that means the stress which is acting at the top which is equivalent to the one, which is countering that. In the process the effective stress reduces to zero.

So particularly this critical hydraulic gradient is very severe for cohesion less soils or particularly for sandy soils or fine sands or silty sands or silty soils. It is not possible for gravelly soils or pebbles because, there is a weight which is required to be lifted will be very high. So in the process, it gets suppressed. But in the process for a fine sandy soils or silty sand this can agitate the soil particles, can also have this upward flow or agitating effect. Whereas particularly for clayey soils again this quick condition cannot exist because in the clayey soils there is an apparent cohesion which can determine this particular behavior.

So more ever, as i become i_c the soil becomes much looser and coefficient of permeability increases. Basically this is very severe for sandy soils and cohesion-less soil because there is a binding cohesion because of the metrological properties are so. Clayey soils posses that, so because of that it cannot have a quick condition to take place. But whereas in sandy soils or fine sandy soils this ought to take place. So quick condition or boiling condition in cohesion- less soils that is what we are discussing.

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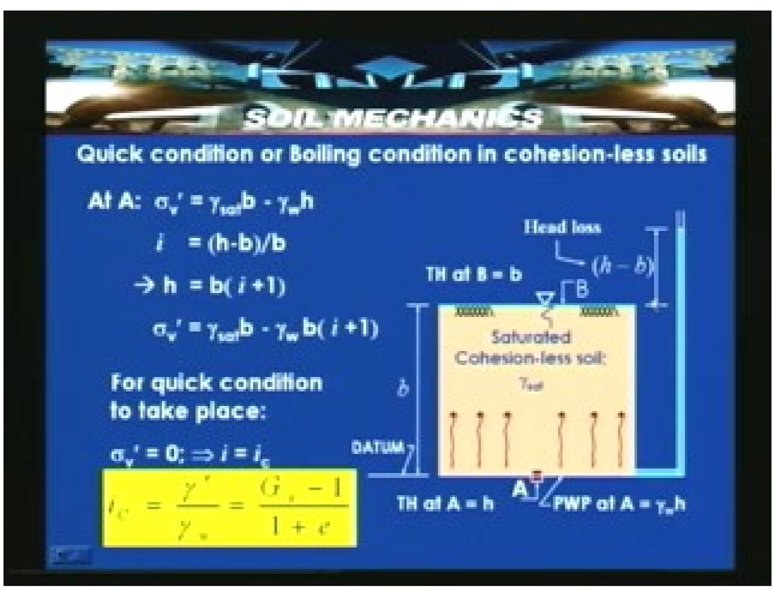

Now let us consider in this slide a thickness of a soil bed which is undergoing upward flow is b and h- b is the head loss taking place between these two levels. And total head at point B is small b and total head at A is h. So the difference is nothing but h - b, that is the head loss. Hydraulic gradient here i= h- b by b.

So the pore water pressure at point A here is gamma w H and if you look at point A sigma v dash that is vertical effective stress is equal to gamma sat b- gamma w H. The gamma sat that is saturated unit weight of the soil times the thickness of a soil specimen minus gamma w H, that is the pore water pressure at this point. So that is nothing but h-b+ b that is the head which is available and elevation head is equal to zero. So the total head is equal to h and the pore water pressure head is also equal to h.

So the pore water pressure at A is equal to gamma w H. So because of these the effective stress can be written as gamma sat b minus gamma w H. So hydraulic gradient i = (h- b) by b. So h is equal to we can write like b (i+1). So substituting here for h in the previous equation at A, sigma v dash is equal to gamma sat v minus gamma w h. Then after simplifying it reduce to sigma v dash is equal to gamma sat b minus gamma w b into i +1. For quick condition to take place, if you look into it sigma v dash is equal to zero. That is for quick condition to take place or boiling condition or agitating condition to take place this i has to become critical hydraulic gradient. That means this particular value of h - b has to be increased, so that this head becomes the critical head causing boiling condition. So in this particular case when it becomes $i = i_c$ then i_c is equal to gamma sat by gamma w. So i_c is equal to gamma dash that is gamma sat minus gamma w by gamma w which can be written as gamma dash by gamma w. Which can be further simplified by considering the saturated soil, G_s-1 by 1+ e. So i_c= G_s- 1 by 1+ plus e.

What are the conditions favorable for this quick sand or boiling condition to occur? So quick sand or a boiling condition is a flow condition not a type of sand that is require to be noted. Quick sand is not a type of sand but a flow condition occurring within cohesion less soil. That is the reason we said that fine sands or silty sand soils or so, when its effective stress is reduced to zero due to upward flow of water. So quick sand is not a type of sand but a flow condition which occurs in cohesion-less soils when its effective stress is reduce to zero due to upward flow of water.

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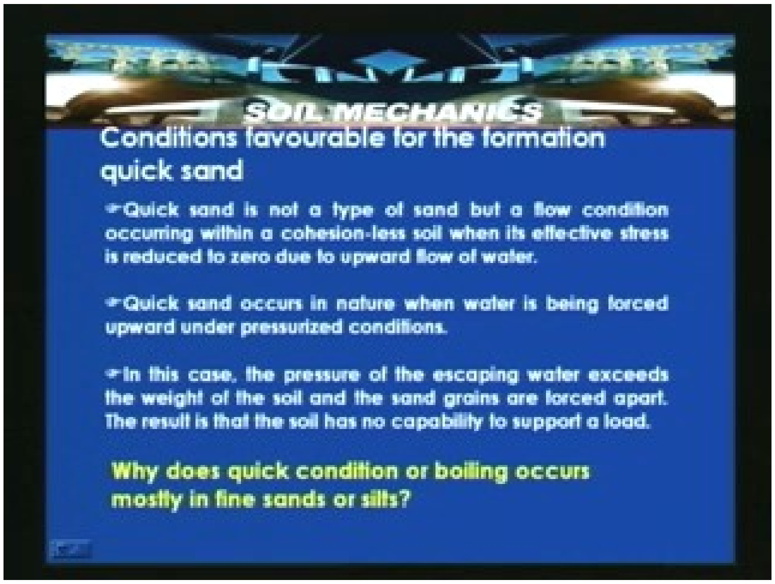

Then the quick sand occurs in nature when water is being forced upward under pressurized conditions. This is possible when there are some artesian conditions say a pervious layer is beating with a head of water because of the source of the river or so. In the process water tries to develop very high head at that particular point and drives the flow in the upward direction. So in this case the pressure of the escaping water exceeds the weight of the soil and the sand grains are forced apart. The result is that the soil has no capability to support the load. That is the reason why in the particular quick sand condition, the pressure of the escaping water exceeds the weight of the soil. That is the reason why when we said that pebbles or gravelly soils cannot have because it has to exceed the self weight of those materials.

But whereas in fine particles like sandy soils or so it can separate them, totally part them and then can create this particular condition. The condition that we discussed is why does quick condition or boiling occurs mostly in fine sands or silts? Because they are absence of having cohesion because of that it cannot have this particular capability to sustain this. So they are prone for quick condition. What are the practical examples of quick sand condition or boiling condition? Generally excavations in granular materials behind cofferdams alongside rivers. So whenever the excavations are taking place water tries to flow from a higher head to the lower head can create a quick sand condition or a boiling condition.

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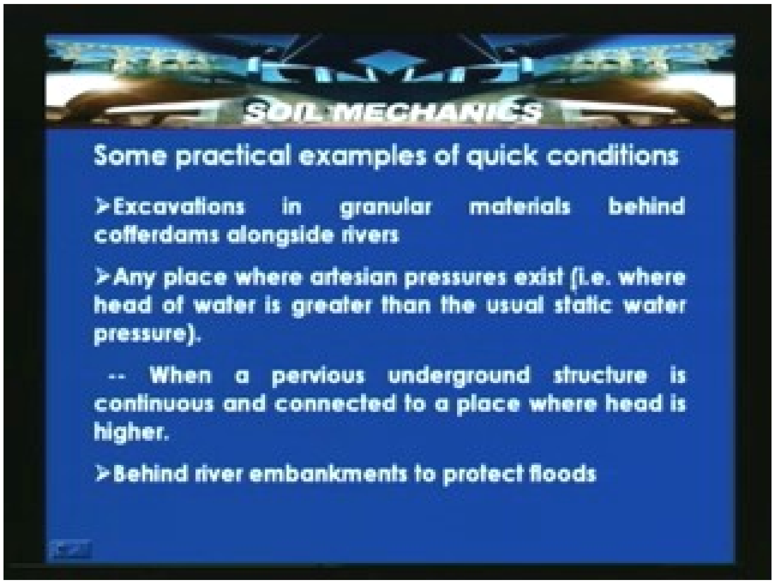

Any place where artesian pressure exist that is where the head of the water is greater than the usual static water pressure. So when a pervious underground structure is continuous and connected to a place where the head is higher. So the artesian condition means the definition can be defined like this, when a pervious underground structure is continuous and connected to a place where the head is higher. Then it can be subjected to artesian condition then flow can be upward.

And behind the river embankments where to protect the levees, basically in the river embankments, we used to protect the floods when you construct then there it can be prone for the quick condition or boiling condition which can have this particular failure. So some practical examples in the sense, we generally come across these quick conditions. But one popular belief is that one cannot survive in the quick sand condition when somebody drowns into it. But if you look into this slide here, contrary to the popular belief it is not possible to drown in quick sand because the density of the quick sand is much greater than that of the water.

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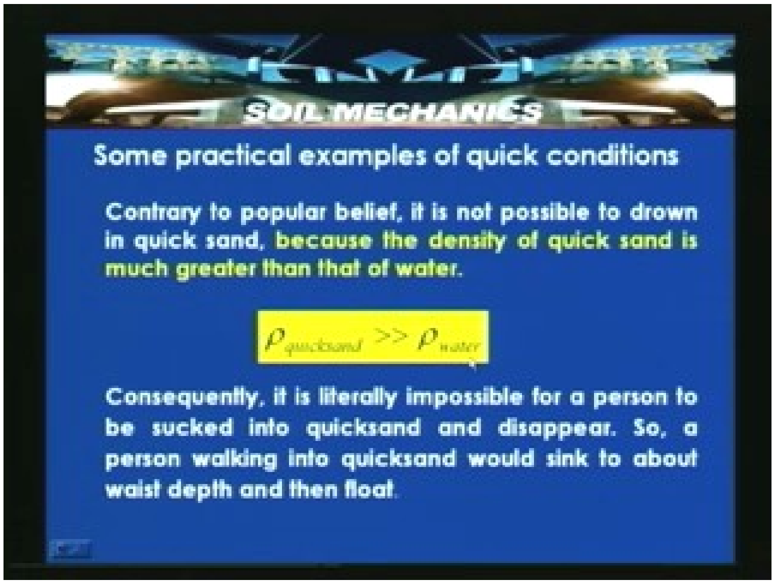

As the density of the quick sand is much greater than the density of the water because it is with the particles and then the one in which water has got certain unit weight. Because of that if a person is stay a float rather than unless we work on it and becoming panic they can lead to a disaster situation. Otherwise scientifically if you look into it is literally impossible for a person to be sucked into quick sand and disappear. So a person walking into quick sand would sink to about waist depth and then float that is because of this particular reason.

So in this lecture what we have seen is that, what will happen to this effective stresses when water flows say in the downward direction and then upward direction. And how these effective stresses are changing? And we also consider a no flow condition, downward flow condition and upward flow condition. Then in the case of upward flow condition when the head which is creating upward flow say reaches a critical head then we said that particular head which is driving the flow can yield to hydraulic gradient called critical hydraulic gradient and that can create an condition where an effective stress is equal to zero that means that the soil can no longer support the structure.

So in the next lecture we will be looking into some practical problems and then we will try to solve some problems with an application of this technique and then we will try to discuss the factors affecting the coefficient of permeability as well as some laboratory and field methods for determining this permeability or coefficient of permeability.