Soil Mechanics
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Lecture – 22
Flow of water through soils-III

Welcome to flow of water through soils lecture number III. In the previous lecture we have introduced what will happen to the effective stress when water flows through soils. And we discussed 3 cases, one is no flow condition and other case is when the flow is taking place in the downward direction and finally we discussed about an upward flow condition. Then we said that depending upon the direction of the flow whether it is upward or downward there will be a change in effective stress. In case of downward flow we have said that there will be increase in effective stress, incase of upward flow we said that there will be a decrease in effective stress.

In case if the head loss which can reach to a critical head then we said that particular head can be called as critical hydraulic gradient at which effective stress is equal to zero. And that condition we have defined as quick condition or boiling condition. There after we have discussed about the practical problems or places where the quick conditions can occur. And we also discussed about quick sand is not a type of sand but a flow condition where water flows in the upward direction. So the submerged weight of the sand is balanced by the upward thrust exerted by the water and that condition simulates a case where sigma dash is equal to zero.

So in this present lecture we will try to understand much about the seepage pressures and then we will try to deduce an expression for seepage pressure. And thereafter we will try to solve some problems in the effective stresses, particularly when the flow is taking place in upward direction. How excavations in the soil, when it is having a layer under artesian conditions can create problems? So this is our previous talk where we discussed about the fluid flow through soils and flow of water through porous media. Then we said that the changes in geostatic stresses with the flow of water through soils and quick sand condition or boiling condition that we defined and tried to discuss. So when you consider the case 3 that is upward flow condition, when flow takes place through soil in the upward direction that means if h is a head loss then that drives the flow in the upward direction.

So in the process when the flow is taking place from this point to this point because to enable the flow to take place it loses the energy which is driving that. So the energy which is available here will be lost here. So in the process there will be a decrease in the pore water pressure. In the process when you take the difference of total stress and pore water pressure then we said that yields as something called, there will be an increase in the pore water pressure because of these there will be a decrease in the pore water pressure. You can see the increase is compared to the one with no flow condition.

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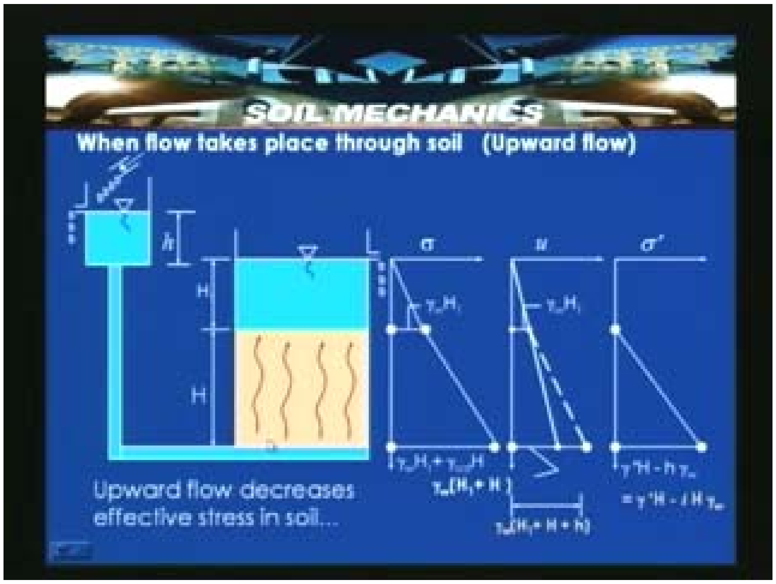

So consider like seepage forces, these are the forces which are responsible because when the flow is taking place through the soil that is exerted onto the grains in the form of a frictional drag as well as viscous drag because of the permeant under consideration. So when water flowing past a soil particle exerts a drag force on the particle in the direction of the flow. So you consider in this slide which is shown here a container having frictionless boundaries, having a surface area perpendicular to the plain of this figure. The surface area is around A, length of the sample is around L. Then it is under saturation assuming that sand which is under saturation with certain density and a water level is maintained here it is connected to a stem and placed at height h above this level.

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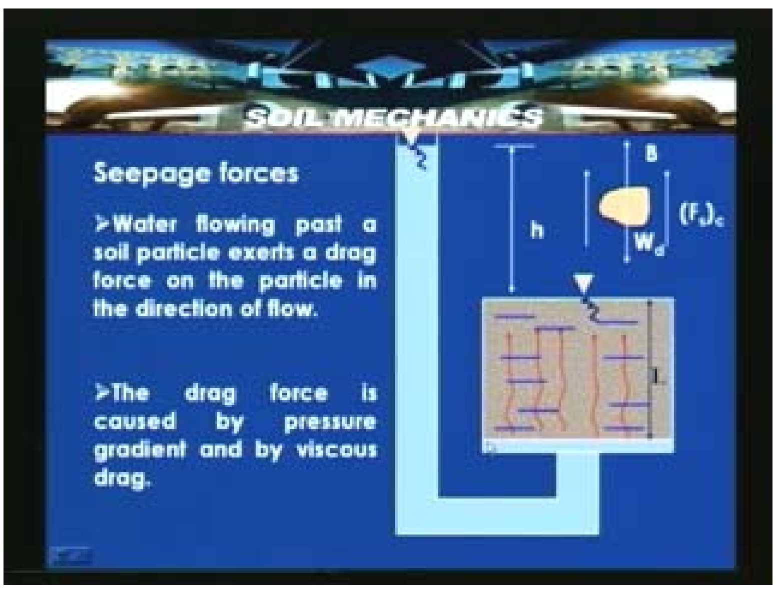

So the hydraulic gradient in this case is h by L that is the hydraulic gradient. So the flow takes place in the upward direction. So in the direction of the flow, if you pick a grain from here and then consider its equilibrium then this W_d is the weight of the dry solid grain and $(F_s)_c$ are the seepage forces acting on both sides of the grains because of the frictional drag as well as the viscous drag imposed on the particle and B is the buoyant weight. If you consider the equilibrium then we will able to achieve an expression for the seepage force. So the drag force is caused by the pressure gradient and viscous drag that is what we are discussing the drag force which is here shown caused by the pressure gradient in the form of a frictional drag and by viscous drag. So water flowing past soil particle exerts a drag force on the particle in the direction of flow.

So it depends for example, if it is happening in the direction of the flow. If it is downward direction then there will be increase in the packing of these particles, because they are tucked in the closer position so there will be increase in the effective stress. In the case of upward flow the particles will be disturbed and in a way there will be a reduction in the effective stress. So if the head is increased continuously then at particular head when it reaches $h=h_c$ then a critical condition can exist. That we call as the quick condition. So in connection with this we will try to solve some problems also, with that we will be clear about this concept.

So considering this free body diagram of soil mass as well as the soil grain let us try to derive an expression for seepage force. So considering this is the direction of the flow which is in the upward direction and seepage force acting in this direction. So this is the base of the sample where the water pressure is acting because of the head which is causing the flow. The w is the saturated unit weight of the entire soil mass. So now if you consider this at critical condition when h is increased gradually such a way that h attains h_c.

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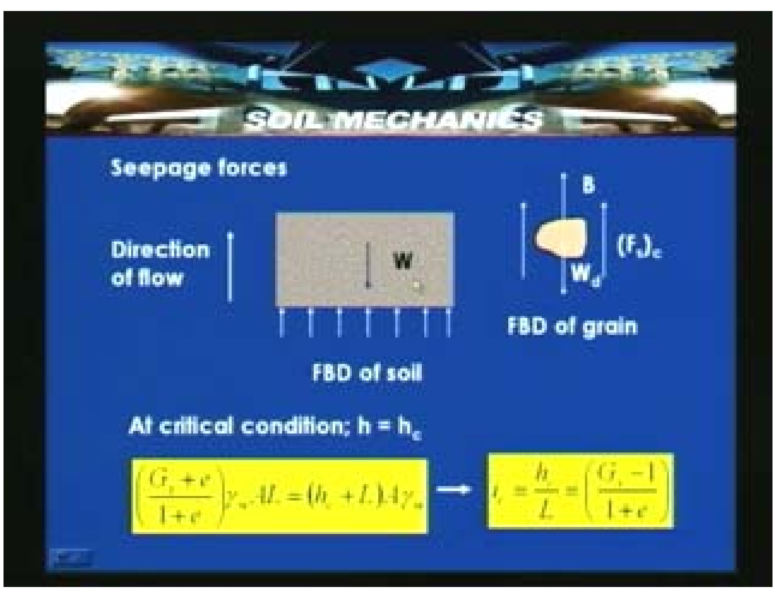

So h_c here is defined as a critical head. So G_s+ e by 1+e gamma w AL indicates something like the saturated unit weight of a soil mass. The expression we know for a two phase system under saturated conditions, gamma sat can be written as G_s+ e gamma w by 1+e, A is the area of the cross section over which the flow is taking place, L is the length of the sample.

So this is the saturated weight of the soil mass that is W which is resisted at the base by h_c + L where h_c is the head which is causing the flow, L is the length. The pore water pressure head which is there at the base of this sample is h_c + L. So that is u which is h_c + L into gamma W where gamma w is the unit weight of water. When you equate this, then we get i = h_c by L which is equal to G_s -1 by 1+ e. So this indicates that h_c by L is the critical hydraulic gradient at G_s -1 by 1+e. We have discussed that the critical hydraulic gradient is mostly equal to 1 for most of the soils and typically for sands G_s = 2.65 then i_c =1.

So it depends upon the packing density at which this particles are there. So in loose sands and silty sands, this particular condition is ought to occur. Particularly for clayey soils this will not occur because there will be a permanent cohesion which keeps the particles binded together. So in the process this quick condition cannot be created to a great extend. Whereas in case of boulders where they have very high self weight because of that again they will not be able to get lifted up or they will not be able to be segregated, such a way that they cannot be agitated in other means, so that this quick condition cannot occur. So considering this free body diagram of the grain alone, let us try to derive the expression for seepage force.

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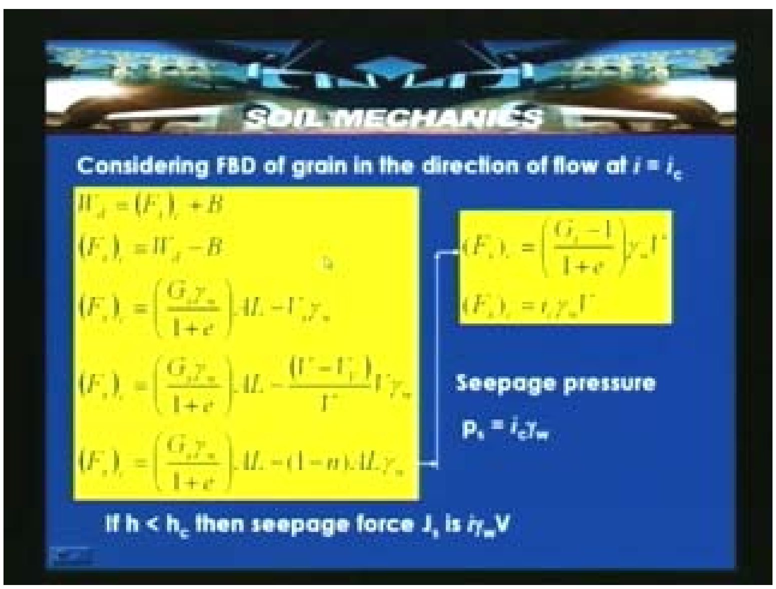

So considering the free body diagram of the grain in the direction of the flow at i = i_c. So we will derive for i=i_c an expression for seepage force. Then we will try to deduce a general expression for a condition which is other than critical hydraulic gradient condition.

So as we have seen the weight of the particle that is dry particle acting downwards and frictional drag which is acting in the direction of the flow and the buoyant weight is opposing the self weight of the particle. So by taking vertical equilibrium we can write $W_d = (F_s)_c + B$ by rewriting this $(F_s)_c = W_d - B$. Now by writing the expression from the two phase system G_s gamma w by 1+e that is nothing but the gamma d that is the dry density or dry unit weight of the soil into AL, A is the area over which the flow is taking place, L is the length of the specimen. So this yields to G_s gamma w by 1+ e into AL minus, the buoyant force is the volume of this solid grain into gamma w. So V_s gamma w is the buoyant force. Simplifying this further G_s gamma w by 1+ e into AL minus, now this V_s can be written as V minus volume of voids that is total volume minus volume of voids divided by total volume into volume.

So the V_s is written here as $V - V_v$ by V into V. So that can be simplified as 1- n where n is the porosity into AL, which is because of the volume it is equal to AL into gamma w. So the frictional force or drag force acting in the direction of the flow is (G_s gamma w by 1+ e) AL- (1- n) AL gamma w. If you further simplify this we will get $(F_s)_c = G_s$-1 by 1+e gamma w V, because n =e by 1+ e, by substituting that we will be able to get frictional drag force $(F_s)_c$ in the direction of the flow is equal to G_s- 1 by 1+ e into gamma w V. So here this G_s- 1 by 1+ e can be written from the previous deliberation as i_c that is the critical hydraulic gradient. So seepage force is equal to i_c gamma w V. So this is also called or indicated by seepage force J_s and also termed as weight of the fluid face undergoing this particular flow phenomenon.

So the seepage pressure is again nothing but the seepage force per unit volume. So in that case P_s seepage pressure is equal to i_c gamma w. So for the cases when head is less than h_c that is when the head is less than critical hydraulic gradient, then F_s continues to be in terms like J_s= i gamma w V where V is the volume of the soil where the flow is taking place and gamma w is unit weight of water, the i is the hydraulic gradient. So if h is less than h_c then seepage force J_s is i gamma w V. So what we tried to derive is that an expression for seepage force and seepage pressure. The units for seepage pressure are same as that of the unit weight units like kilo Newton per meter cube in SI units.

Let us see the critical hydraulic gradient and a quick condition. The quick condition occurs at a critical upward hydraulic gradient, when the seepage force just balances the buoyant weight of an element of soil. That is what we had in the previous slides where we tried to use this concept and derive an expression for critical hydraulic gradient and seepage force. So the assumption is that the shear stresses on the sides of the elements are neglected. So we can write in terms where i_c can also be like G_s- 1 by 1+e when 1+e is termed as a specific volume then we can write like $i_c = G_s$-1 by specific volume.

So the critical hydraulic gradient is typically around 1 for many soils. This condition apart from creating problem or affecting the stability of the geostatic structures, they are also used effectively in particular other discipline like chemical engineering. So fluidized beds in the chemical engineering system rely on the deliberate generation of quick conditions to ensure that the chemical process can occur most efficiently.

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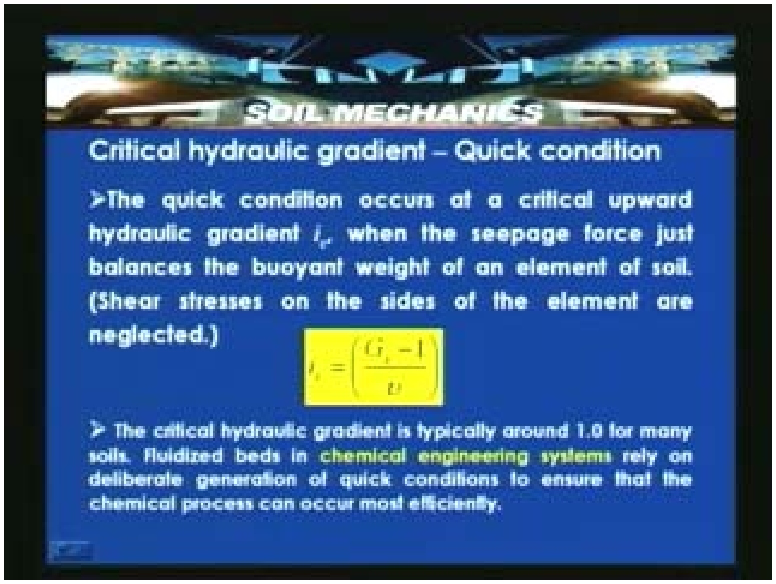

So the fluidized beds are designed in such a way that this quick sand condition occurs and creates this adjacent to the particles. So that the chemical process can occur more efficiently. So it has got merit in terms like it can create or accelerate efficiently the chemical process to take place for fluidized beds. So having seen the theory, now let us look into some problems particularly the example problem which is shown in the slide below. It is the similar arrangement but assuming that there is a saturated sand with unit weight gamma sat= 20 kilo Newton per meter cube and which has got water which is resting above the top surface of the sand. And this is the level which is maintained here and the stem is connected and above that at a height h there is a water level maintained.

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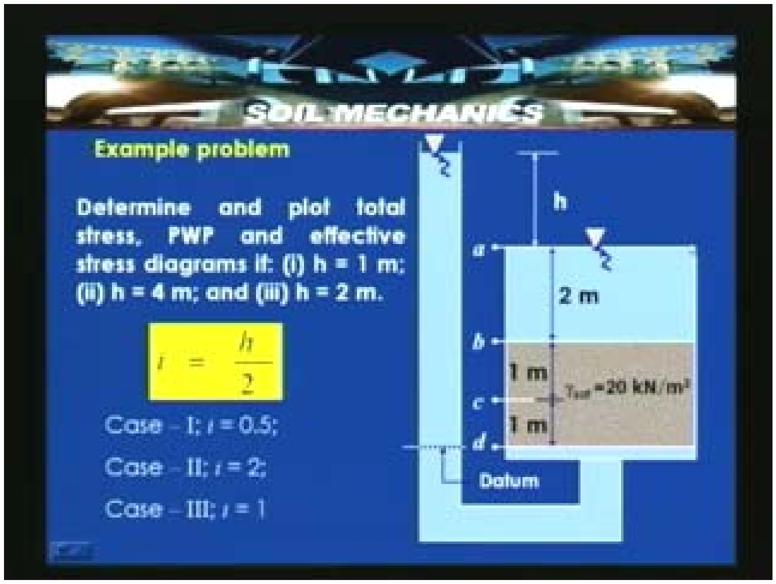

The example problem runs like this. Determine and plot total stress, pore water pressure and effective stress diagram at a b c d. If h=1 meter that is we call it as case 1. Case 2, h= 4 meter and in case 3, h= 2 meters. So if you look into the generalized expression i= h by 2 because L, length over which the flow is taking place is 2 meters, so i= h by 2. For the case 1, the hydraulic gradient i= 0.5 that is because h= 1 meter, 1 by 2 which is equal to 0.5. In case 2, i=4 by 2 that is 2 and in third case i =1. Let us see how this problem can affect the solution with different hydraulic gradient conditions. So the plane passing through the point d is considered as a datum uniformly throughout for all the cases. So c is a point which is at the mid point of b and d vertically.

Let us look for case 1, i=0.5. At point a the elevation is 4 meters, that means point a is 4 meters above this point. So the elevation head is 4 meters and pressure head which is raised about this point is zero. So the total head at this point is pressure head plus elevation head, pressure head is zero so total head is equal to 4 meters. What will happen is that the elevation head is 2 meters and the pressure head is 2 meters. So total head is equal to pressure head plus elevation head that is equal to 4 meters. Now when you come to this point, if you take h=1 meter which is 2+2+1 that is 5. It has got a pressure head of 5 meters, elevation head is zero because it is at the datum. So the total head will have to be 5 meters.

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Point	PH [m]	EH [m]	TH [m]
a	0	4	4
b	2	2	4
d	5	0	5
c	3.5	1	4.5

If the head loss is 1 meter, the total head has to be 4 meters so that the total head loss which is occurring that means here we will have a triangle which is zero, so with a hydraulic gradient of 0.5 the flow takes place. So that is what has been discussed here. The b which is having pressure head of 2 meters, elevation head of 2 meters so total head will be 4 meters. We will come to c later, in case of d where pressure head is 5 meters because this d is at a datum so elevation head is zero, so total head is 5 meters. In case c the total head will have to be 4.5 meters because already at the midpoint 50 % of the head loss would have already occurred.

That means the head loss which is taking place between the points d and c or d and b is around 1 meter. That means mid point around 50 % of the energy will be lost. So the total head will be somewhere around, at d it is around 5 meters and at the mid point c, when the 0.5 meter head loss is already occurred then the total head is 4.5 meters.

Now elevation head is 1 meter because this c is 1 meter above the datum. So the pressure head has to be 3.5 meters that means that much pore water pressure has got dissipated. So in the problem the total head is 4.5 meters, elevation head is 1 meter so the pressure head is 3.5 meters. So let us try to construct total stress, pore water pressure and effective stress diagrams. If you look into this for case 1, i=0.5 that is h=1 then if this is the datum d and b if the flow is taking in the upward direction and with a hydraulic gradient of 0.5 then a is the top most point, d is the point at the datum and b is the top surface of the soil Then the total stress here at this point is zero, at this point is 20 kilo Newton per meter square, at this point it is 40 kilometer per meter square (Refer Slide Time: 22:55). Because 20 + 10 into 2 that is 40 kilo Newton per meter square and then here it will be 60 kilo Newton per meter square.

When you come to the pore water pressure we have discussed the head which is there is 5 meters. So the pore water pressure is 50 kilo Newton per meter square where gamma w=10 kilo Newton per meter cube is considered here. So 35 that is 3.5 meter is the pressure head which is available because 0.5 meter head loss has already occurred when the flow is taking place from d to c. So in the process what will happen is that at this particular point the pore water pressure is 35 kilo Newton per meter square and at this particular point it is 20. So when you determine effective stress that is difference of total stress and pore water pressure. So effective stress at this point it is zero, at this point it is zero and here it will be 40-35 that is 5 and here 60-50, 10.

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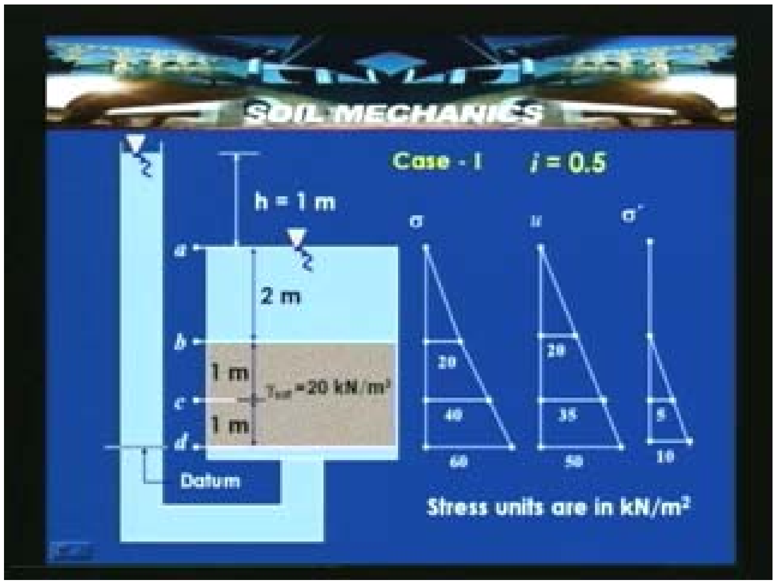

That means at this particular point effective stress which is maintained here is still positive. So for this condition of case 1, based on the total heads and elevation heads and pressure head we try to determine the effective stresses at different points and then we try to use d as the datum in this particular case.

Now let us consider a case 2 where i=2 meters. That means i=2 that is h is equal to around 4. So when you maintain h=4 so i=4 by 2 where 2 is the length of the flow in this present case 2. So a which remains same, as the pressure head is zero, elevation head is 4 meters so total head is 4 meters. And b where pressure head is 2 meters, elevation head is 2 meters. So total head is equal to pressure head plus elevation head which is equal to 4 meters.

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Point	PH [m]	EH [m]	TH [m]
a	0	4	4
b	2	2	4
d	8	0	8
c	5	1	6

But when you come to d, there is a head of 4 meters plus 4+2+2 so around 8 meters pressure head. So elevation head is zero because it is at the datum so the total head is equal to 8 meters. So if you compare d to b there is a 4 meter head loss is occurred. So 4 meter head loss is occurring over 2 meters that means hydraulic gradient is equal to 2. So at d the head which is available for driving the flow is around 4 meter, at b it is zero. When the flow is taking place then the energy is lost in the form of frictional drag transferred to the solid particles.

Now let us see what will be the head at c which is the midpoint of d and b in the direction of the flow. So at d like in the previous case we have got a head of around 8 meters. That means at b it is now the head of around 4 meters. So at c, 50 % of the head loss will occur that means the 2 meters will be already lost. So in the process what will happen is that the total head which is available now is 6 meters at c. Because already 2 meters has been lost, elevation head is 1 meters so the pore water pressure head will be around 5 meters. So the pore water pressure available now here is around 50 kilo Newton per meter square if you consider gamma w =10 kilo Newton per meter cube.
Now let us look into the similar case 2, h=4 meters, the total stress remains same and pore water pressure changes accordingly and it is 20 at this particular point. Now at this particular point it is 50 because the head loss is occurred and 80 here because the head which is driving now is 4+2+2 is around 80 kilo Newton per meter square. Now the difference of total stress and effective stress sigma dash so it is zero here and zero at this point and here total stress minus pore water pressure where it is something called effective stress is negative. So here 60-80 is around minus twenty. So this negative effective stresses they do exists particularly in the condition where the quick sand condition which has already occurred.

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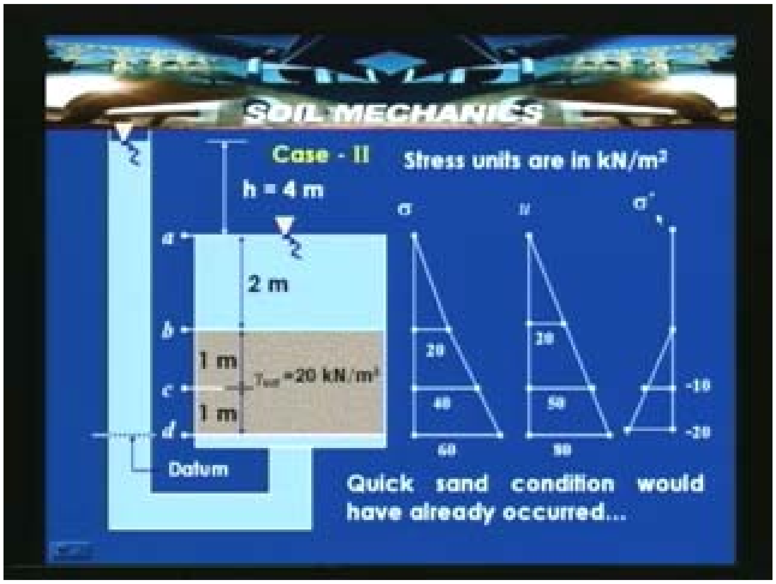

So this is a condition where the quick condition has already occurred, because the negative stress indicates that the particles are in agitated motion and no interaction. So such a way that the pore water pressure is very high and they are not able to generate any intergranular stresses. So this negative effective stresses they do exists particularly in case of agitated or boiling condition. So this particular case 2 demonstrates a condition where quick condition would have already occurred.

Let us now consider case 3. Having seen case 1 and case 2 let us see case 3 where the hydraulic gradient is equal to 1. That means i=1. So for that length of the flow is 2 meters so head loss is around 2 meters. So in the case two by two where i=1. If you look into the same deliberation again at different locations a, b, d and c the pressure heads will be same here at a and b but the only difference here is at d it is 2 meters which is above the upstream level above the point a. That means now the total head available here is 6 meters. So elevation head is zero so the pressure head is around 6 meters. At c because the head driving the head loss which is 2 meters. So at c 50% of the loss would have already occurred that indicates the pressure head will be around 4 meters, total head will be around 5 meters. So elevation head is 1 meters so the pressure head will be around 4 meters.

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SOIL MECHANICS

Case - III $i = 1$

Point	PH [m]	EH [m]	TH [m]
a	0	4	4
b	2	2	4
d	6	0	6
c	4	1	5

So now if you look into this condition like h=2 meters, case 3 where the hydraulic gradient equal to 1. So here total stress remains same and the pore water pressure now at this particular point it is 2+2+2, 6 and that is 6 into 10, 60 kilo Newton per meter square and here it is 40 and here it is 20 (Refer Slide Time: 29:35). So in the process if you take the difference of total stress and effective stress at all points, you will see that effective stress is zero. That means this particular condition just attained quick condition. So just attained quick condition is the case where sigma dash is equal to zero. So this head which is h= 2 meters can be said as critical head which is causing the flow to take place in the upward direction and imposing an effective stress equal to zero.

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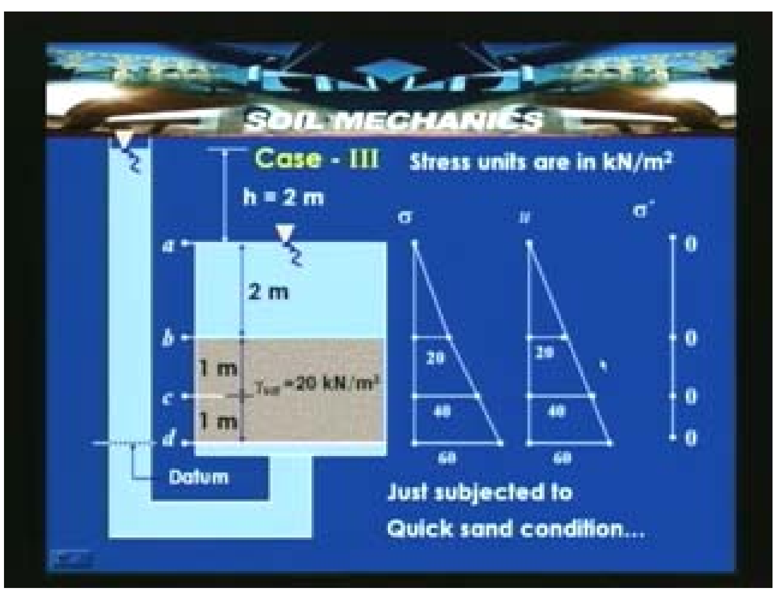

So having scene a particular case and how to determine and ascertain the pressure heads and by using the principles what we discussed from the total head is equal to pressure head plus elevation head. And then we tried to discuss about the case where the hydraulic gradient gradually changes to a critical hydraulic gradient. A case where even negative effective stresses can occur, even for case where the quick condition would have already occurred.

So let us now consider from this example problem where the boiling condition generally occurs in geotechnical structures, when excavation takes place in a particular soil. So in this case stiff clay is underlined by a sandy soil. Suppose this sandy soil due to some reasons if it is subjected to additional head of water. This condition is also called as artesian condition if it has got a source of water which is trapped inside, can impose upward forces on to the soil. So as long as this excavation is not there, so this pressure is not adequate to induce a failure. But when we excavate for installing some underground utilities or so then these failures are ought to take place in 3 hours time. So here this problem says that the sand layer of this soil profile is shown in the figure under artesian pressure.

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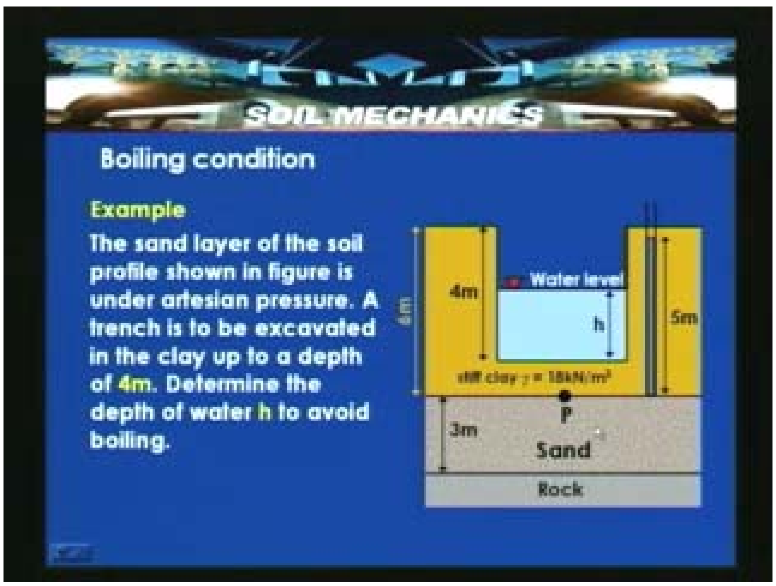

That means here the artesian pressure which has been determined is around 5 meter. That means if investigation has been done carefully then this type of failure can be prevented by adopting suitable remedial measures. Let us consider a case where we know that there is an artesian head of 5 meters which is occurring here. So entire sand which is here is saturated and which is under artesian head conditions. A trench is to be excavated in the clay up to a depth of 4 meters. So the depth of the 4 meters is defined here which is in the stiff clay having the unit weight gamma is equal to 18 kilo Newton per meter cube. Determine the depth of the water h to avoid boiling. So incase if the boiling phenomena occurs then what is the height of the water I should maintain to prevent any boiling failure?

So let us see the solution. This excavation takes place so this much soil will be removed. At P, so at this particular point, interface of the stiff clay and sandy soil. So consider a point P where total stress is equal to gamma w h. So this h is unknown to us. Let us term that the height of the water which is required to be determined in this problem as h. So gamma w h plus 6, the 6 meters is the thickness of the soil layer above the sand layer.

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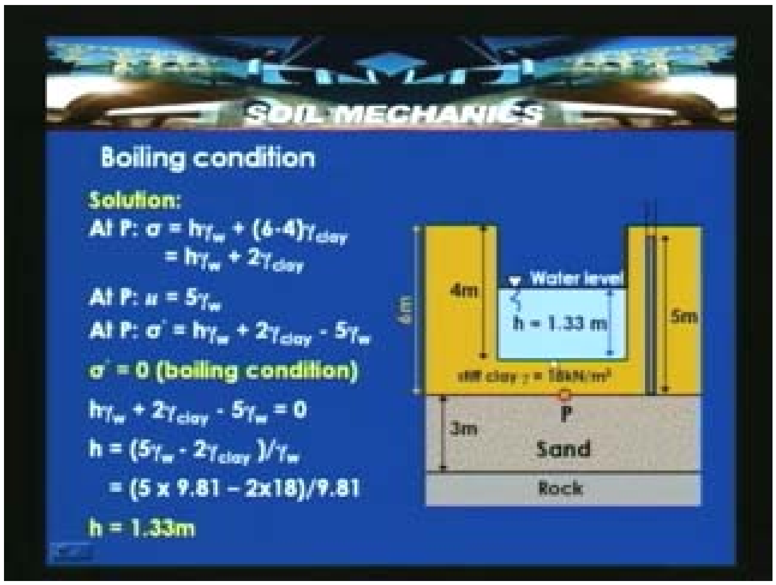

So 6-4 that is 4 meters is the depth of the excavation. So 6-4 that means that much clay has already been removed. So 4 meters already has been removed so 2 meters is still remaining there. There is a decrease in the total stress because of the excavation. So gamma w h which is required to be determined plus 2 into gamma clay. At P for example if this is the area over which this upward thrust is exerted at the point P over a plain area a then u = 5 gamma w. That is nothing but 5 meters is the head which is causing the flow and gamma w is the unit weight of water.

So at P effective stress is equal to total stress minus pore water pressure. So by equating now gamma w h plus 2 gamma clay minus 5 gamma w. So for boiling condition like in the previous case we can impose a condition like sigma dash is equal to zero. So by imposing this condition here we can determine that h =1.33 meters. So this indicates that, to prevent the boiling condition we have to maintain minimum around 1.3 meters of the height of the water in the trench. Otherwise there is an eventuality of occurrence of boiling condition.

In the similar lines let us look into this example problem. A large open excavation was made in a stratum of clay with a saturated unit weight of 17.6 kilo Newton per meter cube. When the depth of the excavation reached 7.5 meter, the bottom rose in the sense heaved up, gradually cracked and was flooded from below by a mixture of sand and water. So subsequent investigation showed that the clay was underlain by a bed of sand with its surface at a depth of 11 meters. So the clay thickness was around 1l meters.

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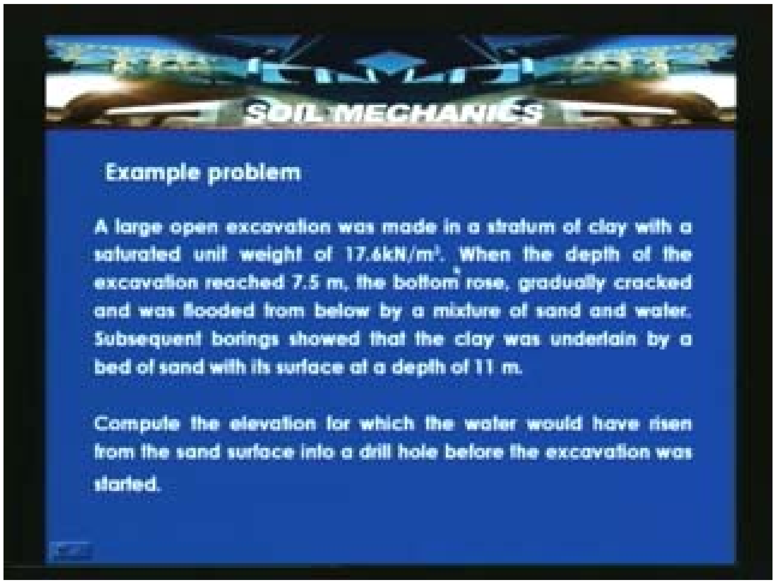

Compute the elevation for which the water would have risen from the sand surface into a drill hole before the excavation was started. So the solution works out like this. We have got a thick clay layer which is around 11 meters having a saturated unit weight equal to gamma sat= 17.6 kilo Newton per meter cube. So the excavation which has been taking place here is that 7.5 meters. So after reaching a 7.5 five meter from depth then it was observed that, the bottom of the excavation heaved up and undergone a failure which has reflected in the form of a collection of sand and water.

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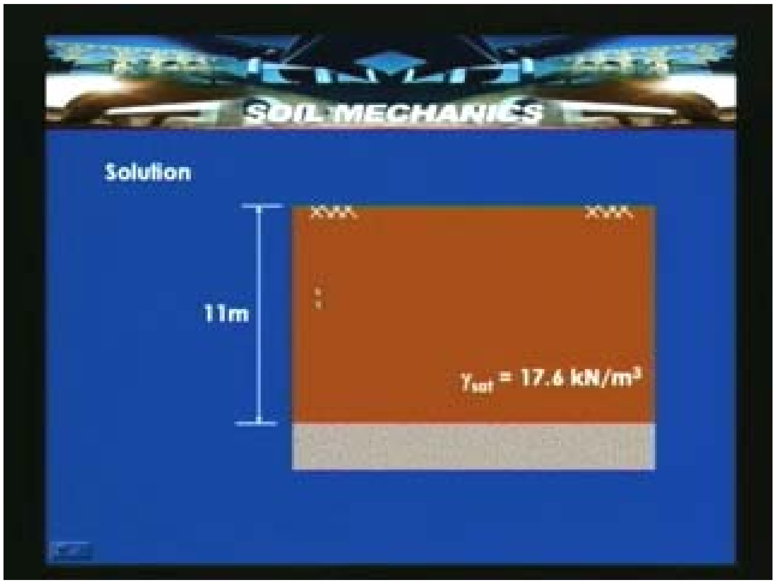

So subsequent investigations have shown that the thickness of the clay layer in which the excavation is carried out is around 11 meters. That means at the end of the 11 meters the sand surface is starting. So if this particular sand layer would have caused this type of hued failure means it would have been under artesian conditions. So the investigations or calculations can be carried out. What would have been the height of the water it would have risen in the stand pipe before excavation, if suppose it would have been measured. So if the excavation is carried out at 7.5 meters, we need to calculate that elevation h to which the water would have risen into the stand pipe.

So here again consider point a which is the interface between clay layer and sand layer. So at this particular portion say area a perpendicular to the plane of this figure is subjected to n upward thrust which is say gamma w h. So in this case gamma w is equal to consider here at 10. So it is 10 h kilo Newton per meter square acting over area a in the upward direction. Now here at this particular point the net total stress which is remaining is nothing but 11 meters minus 7.5. So around 3.5 meters of soil which is resting at that particular time when the excavation is reached around 7.5 meters.

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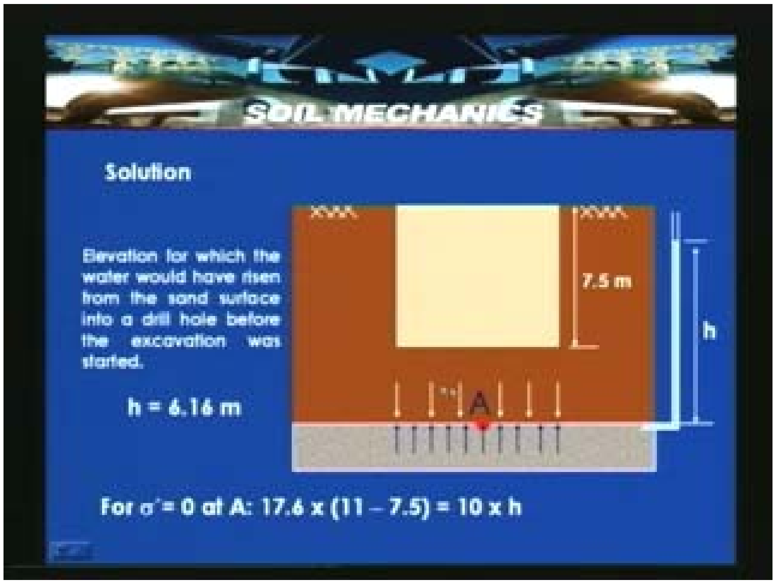

So for the boiling condition or quick condition we say sigma dash is equal to zero. So for that equating total stress is equal to the pore water pressure at this particular base of the soil layer that is the interface here. So 17.6 into 11 -7.5 into10 into h, by equating that we get h is around 6.16 meters. So the elevation for which the water would have risen from the sand surface into a drill hole before the excavation was started will be around h is equal to 6.16 meters. So having seen this now let us try to consider another problem which is again under artesian conditions. But here we are required to determine the effective stress distribution profile at point a, c and b where c is at a point 1 meter above this datum, b is the datum level. So the soil strata which is shown here. The d is the plane called as datum which is passing through b. And c is 1 meter above datum, a is 3 meter above datum.

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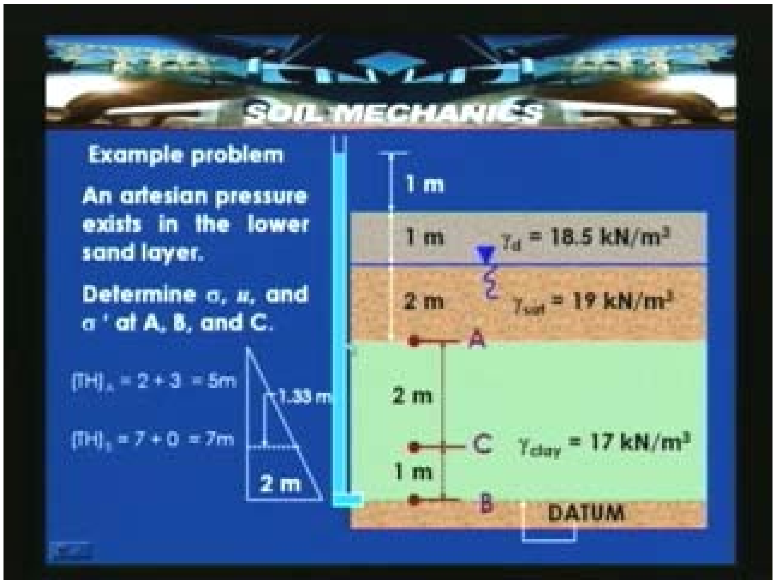

So thickness of the clay layer is around 3 meters and gamma clay is around 17 kilo Newton per meter cube. The ground water table is located here which is 2 meters above point A. Then above 1 meter there is a sand which is dry, gamma d = 18.5 kilo Newton per meter cube and because of the artesian conditions it is having a water head 1 meter, total head is around 1 meter above this ground surface. So this is the existing ground surface. So if you look into this now the head loss which is nothing but difference of levels between this level and this level is around 2 meters (Refer Slide Time: 40:17). So if we consider only the flow, which is taking place in the clay soil ignoring this sand, then if you consider this flow which is taking place from B to A in the upward direction. Because the flow occurs in a flow direction because of the head which is driving the flow from this level point B to A.

So here now the hydraulic gradient is somewhere around which is nothing but 2 is the h and L is around 3 meters. So hydraulic gradient is around 2 by 3. So if you consider at this particular point the total head which is available is around 2 meters. Then afterwards here that head energy which is the total complete loss of energy occurs, by the time it reaches point A. So at this particular point if you look into it then there will be a certain loss of the energy takes place and further loss of energy take place, once the water passes point c and which is traveling towards point A. So here total head at A, if this is taken as a datum so we can say total head at a if I put a stand pipe here it will rise to 2 meters because already when the water traveled from B to A, then complete head loss has already occurred.

So at this particular point only it will raise to 2 meters that is because of the standing ground water table. So here this elevation head is now 3 meters. So if you consider pressure head is 2 meters, elevation head is 3 meters and the total head at this point A is 5 meters. The point B is at the datum so elevation head is equal to zero and total head is 3+2 that is 5+ 2 that is 7 meters.

So here it is subjected to around 70 kilo Newton per meter square that is pressure head is around 7 meters, because elevation head is zero. The total head is also equal to 7 meters. So the difference of total head H_b is around 7 meters, H_a is around 5 meters. So H_b-H_a is 2 meters that is the delta h occurring over a length which is 3 meters that is 2 by 3 that is the hydraulic gradient in this problem. At point c is the total head which is available, energy delta h available is H_b- H_a is around 2 meters. At this particular point already 0.67 meters of the head is already lost. That means 1.33 meter head is available to be spent while enabling the flow to take place through the soil. So by the time it reaches this point A the head loss will be equal to zero. So here at this particular point c it is around 1.33.

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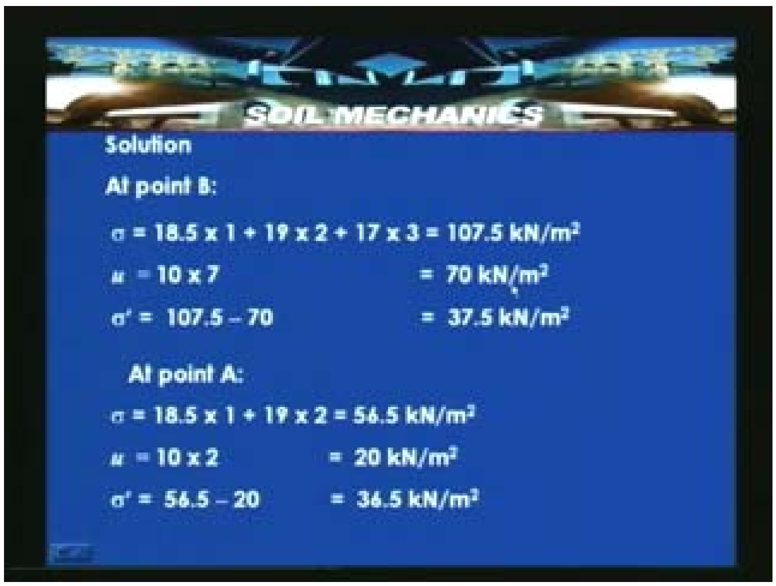

Further we look into this problem in determining the effective stresses at a, c and b. So from the discussion at point b the total stress is equal to 18.5×1+19×2+ 17×3 which yields to around 107.5 kilo Newton per meter square. The pore water pressure is around 10×7 that is 70 kilo Newton per meter square. So effective stress is nothing but the total stress minus pore water pressure. So that is equal to around 37.5 kilo Newton per meter square that means we have tried to determine this total stress and pore water pressure at this point B and effective stress at this particular point B. Similarly at point A we get sigma, u and sigma dash.

Let us consider at point c. At point c which is 1 meter above the datum, sigma is equal to 18.5 ×1+19×2+17×2 which is around 90.5. We have this 10 which is gamma w which is considered as a unit weight of the water around 10 kilo Newton per meter cube into the pressure head at point c is 5.33. How? We are going to see and it is around 53.3 kilo Newton per meter square. And the sigma dash which is total stress minus pore water pressure yields to be around 38.2 kilo Newton per meter square. So the total head at c is determined like this, total head at b – iZ. So z in the direction of the flow that is at z=0 that means the full head is available. So 7 meters is the head which is available there.

So at this particular point i = 2 by 3 and z is equal to around 1 meter so the total head at c should be around 6.33. That means 0.67 meters of the head is already lost. So that is what actually we are discussing while introducing this problem.

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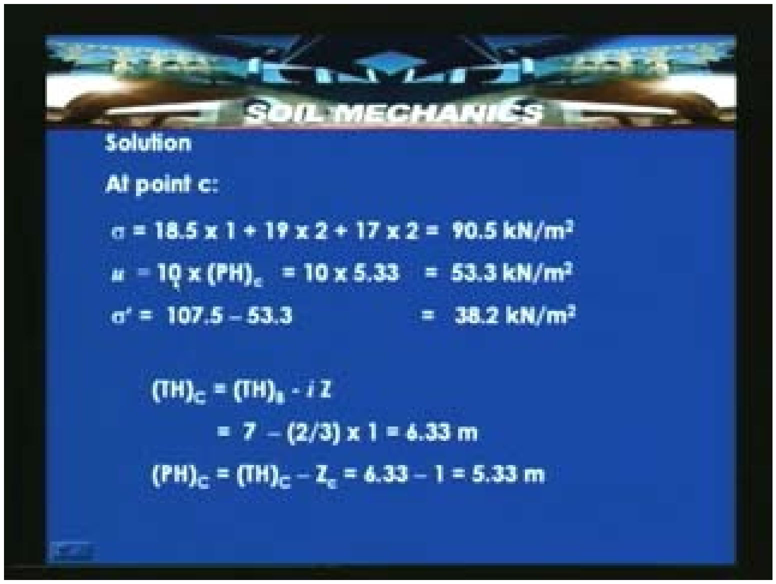

So now the pressure head available at point c is equal to total head at c minus elevation head at c. So elevation head at c is 1 meter so by subtracting 1 from 6.33 we get 5.33. So that is how we determine the pore water pressure at c when the flow is taking place from b to a and c is 1 meter above the datum. So now let us try to plot whatever we have determined for this case. The b is the datum and c is the point where 0.67 meters energy is already lost that is head loss has already occurred. And at this point complete head loss has already occurred. Here the full head of 2 meters which is driving the flow is available.

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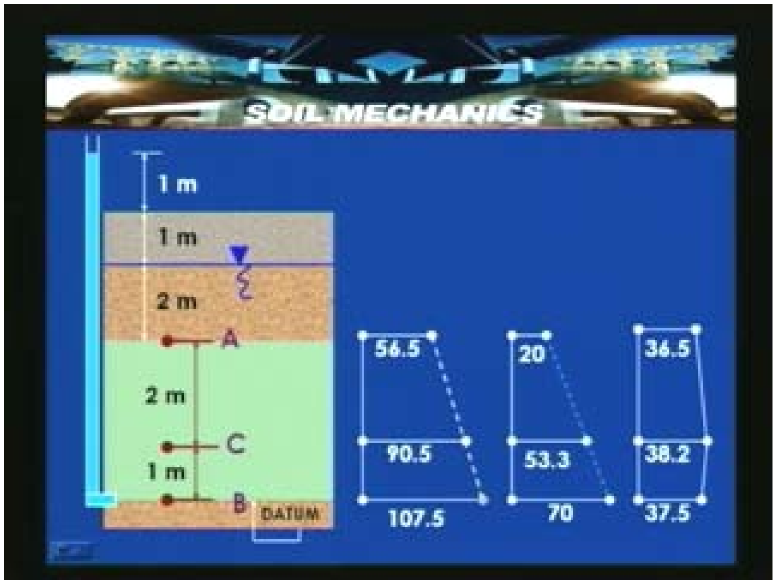

Now in this case the total stress which is 56.5, 90.5 and 107.5, this is because of the self weight that is the geostatic stresses. And here these are the pore water pressure which is 20 at this particular point because here if I put a stand pipe it will raise to 2 meters here. Because of the virtue of the ground water table existing at this particular point 2 meters above point a. So here at this particular point because there is an energy which has been lost from b to c. So because of that the total stress is 90.5, the pore water pressure is 53.3. The difference of total stress and pore water pressure yield an effective stress which is around 38.2.

So this is the effective stress distribution sigma dash and this is the pore water pressure distribution and this is the total stress distribution (Refer Slide Time: 47:36). So in the given problem a stratum has been given and we have tried to understand based on the concept and we have tried to determine the distribution of the total stress and pore water pressure and effective stress when the flow is taking place in upward direction because of the some artesian conditions of underlying sand layer below the clay layer.

So here because of this particular clay by knowing its relevant property even we will be able to estimate seepage pressure or seepage forces within the clay soil also. So like seepage velocity can be estimated by calculating when you know the coefficient of permeability value. So this coefficient of permeability value which is also called as Darcy's coefficient of permeability is an important parameter which can be determined either in the laboratory or in the field test. In the laboratory we also have direct and indirect methods. Indirect methods involve, from the grains and distribution one can determine or as well as indirectly from the consolidation test data we can also determine the permeability.

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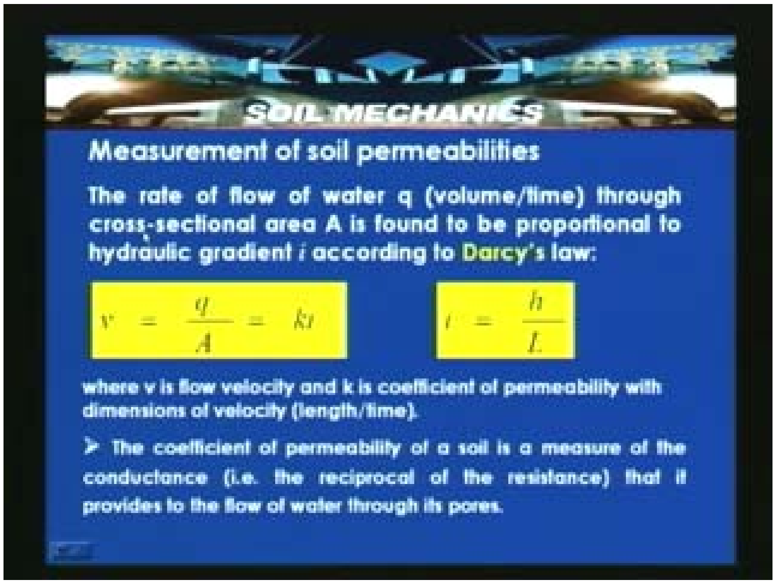

So the measurement of the soil permeability's where the rate of flow of water q that is volume per time through a cross sectional area A is found to be proportional to hydraulic gradient i according to Darcy's law. This is what we have discussed, so v= q by A where A is the area over which the flow is taking place perpendicular to the direction of the flow. A is the cross sectional area perpendicular to the direction of the flow and k is the coefficient of permeability at Darcy's permeability and i. So according to Darcy's law the rate of flow water q that is volume per time through cross sectional area A is found to be proportional to hydraulic gradient i according to Darcy's law, i= h by L. So where v is the flow velocity which is also called as discharge velocity or superficial velocity occurring over an area A. So the coefficient of permeability of a soil is a measure of the conductance which is nothing but the reciprocal of the resistance in electrical terms that it provides to the flow of water through its pores. So the conductance that is it provides to the flow of water through its pores. The coefficient of permeability of soil is a measure of the conductance that it provides to the flow of water through its pores.

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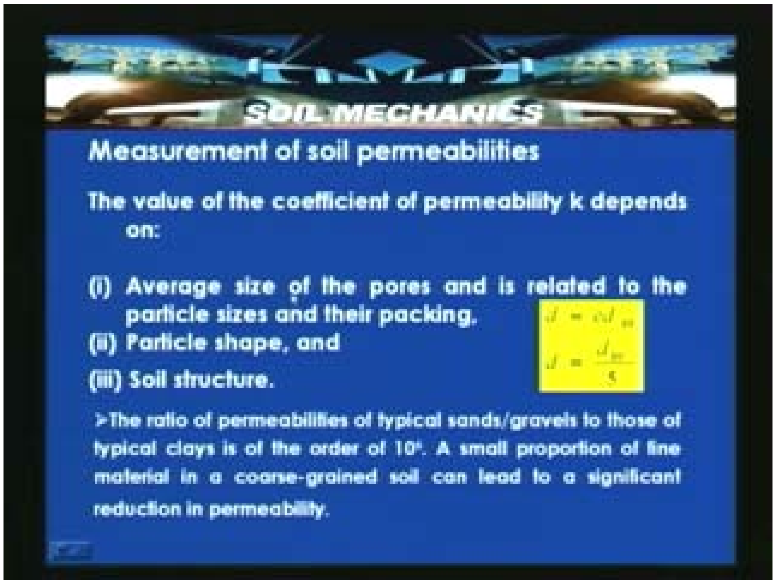

So as we have now different types of soils like sandy soils and clayey soils, then they are different in the soil structure they differ in the type of a soil and composition. So all these factors will affect in having a difference in the permeability values. So the measurement of the permeabilities for example if you look into it, the volume of coefficient of permeability k depends upon average size of the pores. The pores space is very important here, the smaller the pore space then slower is the flow which can take place. So average size of the pores is related to the particle sizes and their packing. So the value of the coefficient of permeability k depends upon the average size of the pores and is related to the particle sizes and their packing. So we have discussed during the capillarity condition or capillarity phenomena we said that d which is nothing but the pores space is approximated as ed_{10} where e is the void ratio and d_{10} is the effective particle size.

So if the effective particle size of a clayey soil is very small then we can expect very minute or miniature pore spaces for clayey soils. So it has got a different value for permeability for clayey soil. The particle shape depends upon particularly for gravely soils or sandy soils this particle shape has got an influence in the permeability. That is in the form of a shape factor which is taken that we will be discussing in detail in the next class. In the soil structure or the soils fabric and arrangement like which arrangement for sandy soils either the loose or dense that is the packing which will effect or in case of a clayey soil whether it is a flocculent or disperse, so that can influence the permeability value. So the ratio of the permeabilities of the typical sands or gravels to those of typical clays is of the order of 10 to the power six.

As we already discussed and mentioned, the ratio of the permeability of typical sands gravels to those of typical clays is of the order of 10 to the power six. A small proportion of the fine material in a coarse grained soil can lead to a significant reduction in the permeability. A small proportion of the fine material that means that if you have got any gravelly soil, a clay which is making the gravelly soil to behave like gravelly clay or so.

Then it can change its permeability characteristics and can impose impervious characteristics to the particular soil. So a small proportion of the fine grain material in a coarse grained soil can lead to significant reduction in the permeability. So that is the reason why it is very important to know about this permeability value and its effects. Because ill effects induce in effecting the performance of the geotechnical structures like parking lots which are designed for drainage where the particular facility will not achieve market yards or different types of structures which do effect and required to be designed with due consideration.

In the next class we will discuss about how to measure this permeability. There are two methods like laboratory methods we do for highly permeable soils, we use constant head per meters and this called constant head test and for relatively impermeable soils like clayey soil or fine grain soils we use falling head test or variable head test. And indirect methods as we discussed like computation from the grain stress distribution or from the oedometer while performing a consolidation test. So in the field also this permeability is require to be estimated like from the pumping methods or bore hole methods. So these test will try to yield permeability value, particularly the packers test are very famous in determining the field permeability values in legons in the field that we will discuss in the forthcoming class.

So here in this what we introduced is that the measurement of the soil permeability's likes laboratory methods and field methods. So we start with laboratory methods and then we also discussed the methods which are available in the filed. And then we will be introducing the factors affecting the coefficient of permeability particularly like what are the different types of soils and how and why a sandy soil and a clayey soil is set to have a different permeability. How for this mineralogy and the soil structure coming into the picture in effecting the permeability.