Geology and Soil Mechanics
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Lecture - 26
In-situ Stresses - A

Welcome back to the course Geology and Soil mechanics. So, in the last lecture we have seen or we have discussed rather the concept of effective stress, total stress, and pore water pressure and then we discussed about the critical hydraulic gradient and then we talked about the filter design issues and other related details for the filter design. So, now today we will be talking about the capillary rise in soils.

So, it is very important phenomena. Say basically what happens when you have the water table at the ground deposit or soil deposit. Basically, what happens just I mean on top of the water table some soil will be saturated due to this capillary rise in the soil. So, this capillary rise will follow the phenomena of the capillary rise in some tube so the same thing whatever we have seen in our different courses in fluid mechanics as well as physics.

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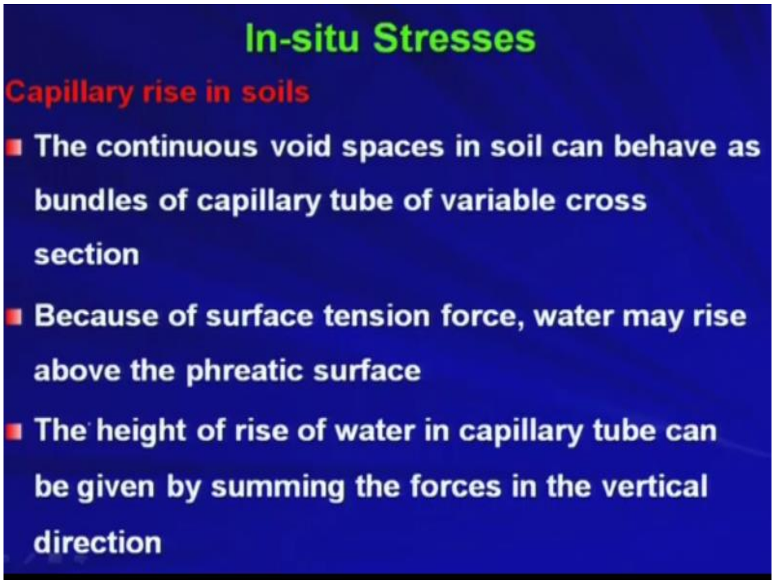

So, basically the continuous void spaces in soil can behave as bundles of capillary tube of variable cross section okay. So, that means as we have already discussed that the void spaces in the soil they are interconnected and they are continuous so rather they will form some kind of tube okay so if you if you idealize that thing a kind of tube so that tube will be having different diameters or the different size okay different cross section of those tube will try to suck or try to get the water inside the void space okay on top of the water table due to the capillary suction. Because of surface tension force water may rise above the phreatic surface. So, phreatic surface already we discussed or we know that what is phreatic surface? Phreatic surface is nothing but the free water surface that is the top level of water deposit or the water level or water table and basically which is exposed to the atmosphere. So, that means on top of the phreatic line you have the atmospheric pressure.

So, the height of rise of water in capillary tube can be given by summing the forces in the vertical direction and we know from our physics or the fluid mechanics concept that how to calculate this capillary rise, the height of capillary rise. So, this is very important that because say suppose you are constructing some underground structure okay in the soil.

Now if you do not consider the capillary rise and if you consider the I mean soil will be always in the dry situation because you are constructing something on I mean above the say ground water table then basically you may be proven wrong because the water will rise on top of the water table okay and it will reach the underground structure. So, that means if you do not consider the capillary rise then sometimes you may face some problem okay.

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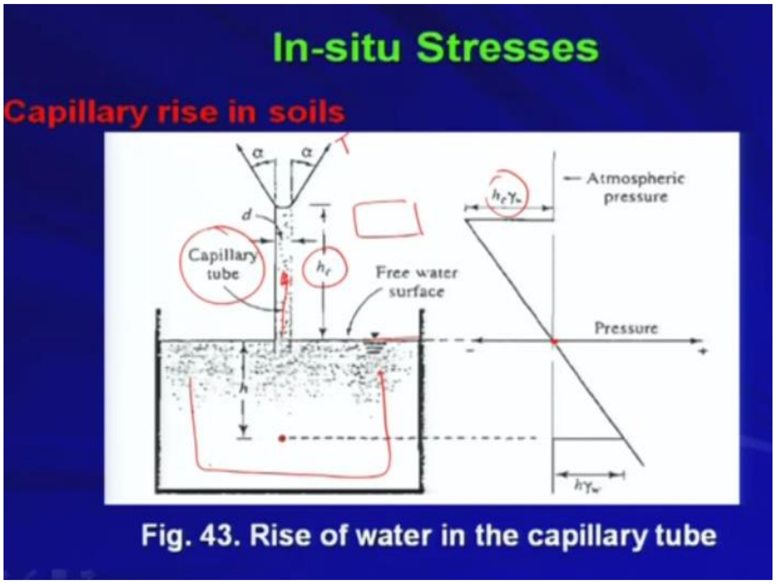

So, I mean this figure is very well-known figure. So, suppose I mean if you idealize that thing this tank say, in this tank you have water. So, this is you have water inside the tank. This is the free water surface that means the phreatic surface that is the top surface of the water table so this tank okay filled with water and it can be idealized as soil deposit which is under water table okay that means submerged soil deposit.

Now you have the continuous void space which will act as capillary tube okay and through this capillary tube basically water will I mean rise in the upper zone basically okay and this height of capillary rise you need to calculate to find out that how much depth will be saturated okay due to this capillary rise because otherwise if you do not consider this then maybe you will be thinking that if I consider some structure here so that structure will be completely under dry situation but it may not be there because due to capillary rise you will be getting some water which will be reaching to that structure okay.

So, now as I told you so from this top surface of the free surface of the water you know how the pressure distribution happens right I mean the pressure distribution due to the water only so that is h into gamma w where h so at any depth say h if you consider below the free water table okay free water surface okay so basically the pressure will be the linear distribution. Already we have seen that there is pore water pressure kind of thing. So, that is coming as h into gamma w and when you reach the free surface of water then basically your pressure will be atmospheric pressure right.

So, that is represented by this point. So, at this point you have the atmospheric pressure. Now on top of that so due to your capillary rise you will be having some suction some tension and that tension will be equal to h c into gamma w where h c is nothing but the height of capillary rise which needs to be calculated needs to be determined okay. So, the pressure distribution one thing is very clear that if you go below the water table your pressure is say compressive kind of thing right all round say water pressure whatever you generally obtain or generally see on any kind of body right if you take any body inside the water whatever pressure you will be getting so all round hydrostatic pressure.

So, that is coming below the water table whereas if you consider on top of the water table that means if you consider the capillary rise then you will be getting the suction or the tension kind of stress okay. So, now in this figure so this is your say surface tension. Now this surface tension T will be equated to the weight of the water inside the tube right so in that way basically you calculate the capillary rise.

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So, let us see. So, pi by 4 into d square that is nothing but the cross-sectional area of the capillary tube into h c, h c is nothing but your height of capillary rise and gamma w. So, gamma w is the unit weight of water. So, this whole term will give you the weight of water inside the capillary tube whatever has been raised from the free water surface okay is equal to so that weight will be I mean that weight is taken care of by the surface tension of the water right.

So, that is given by pi d, pi d is nothing but the I mean peripheral periphery of the water I mean this capillary tube okay into T, T is nothing but the surface tension into cos alpha that is the component in the vertical direction. So, that will give me h c is equal to 4Tcos alpha by d gamma w where alpha is the angle of contact as it is seen here okay and capital T is the surface tension that is the unit is force per length.

Now for pure water and the clean glass we can think of alpha is equal to 0. So, that comes from your physics or from your say hydraulics or the fluid mechanics concept that if alpha is becoming 0 then h c is simply is equal to 4T by d gamma w right. So, if you know T okay if you know the diameter of the capillary tube, if you know the unit weight of water, you can find out what will be the depth of or the height of capillary rise. So, that much I mean up to that zone basically the soil will be saturated.

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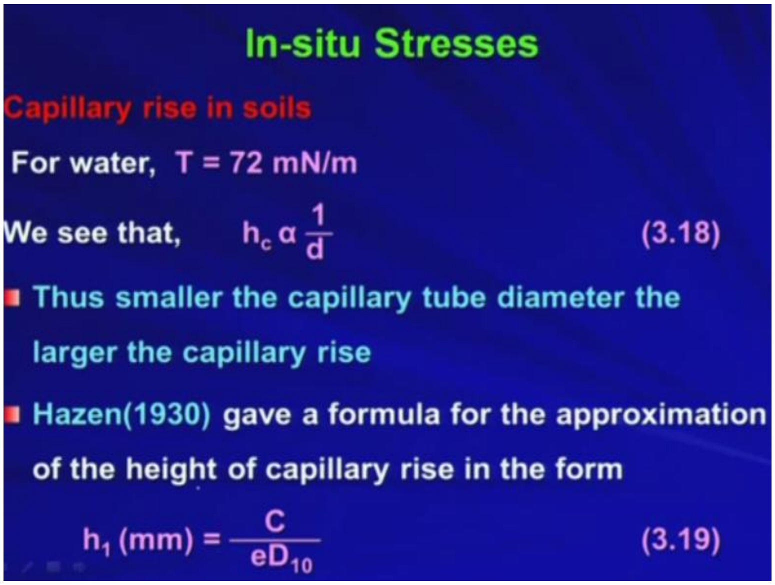

So, for water the surface tension T is equal to 72 mN/m okay and we see that h c that is the then in case of say if T is any particular kind of fluid say T is a constant and if h c that is the height of capillary rise is proportional to 1 by d that means the smaller the capillary tube diameter that means if you consider smaller diameter of the capillary tube the larger the capillary rise. So, h c will be larger. So, this is inversely proportion right.

So, h c is proportional to 1 by d. So, if d increases h c decreases or if d decreases h c increases. So, that means what does it mean basically? So, if you consider or if your pore space that the void space right continuous void space if the continuous void space cross sectional area is less okay so you will be getting higher capillary rise and if your I mean void space cross sectional area or the diameter is less or the I mean less then you will be getting higher capillary rise but if diameter is more then you will be getting lower capillary rise.

So, it depends on the size or the cross-sectional area of the pore space or the void space right. So, Hazen in 1930 gave a formula for the approximation of the height of capillary rise in the form h 1 in millimeter of course is equal to C some constant divided by e into D 10 where e is the void ratio and D 10 of course you know that is the effective size. So, if you this is the constant so I will give you the magnitude of the range of this constant and if you know the void ratio of the soil if you know that D 10 from the gradation curve if you know the gradation of I mean D 10 of that particular soil then you can find out the capillary rise from this equation 3.19.

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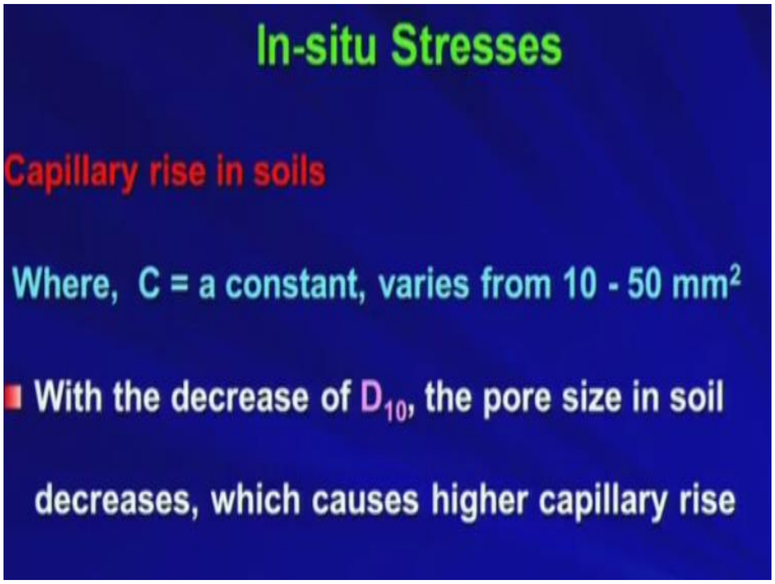

So, where C is a constant and it varies from 10 to 50 mm square okay. So, now with the decrease of D 10 okay as already we have discussed with the decrease of D 10, earlier when we talked about the grain size distribution all those things at that time we discussed or we talked about this thing. So, with the decrease of D 10 the pore size in soil decreases. Do you agree with this or not? So, if you decrease or if you make D 10 I mean reduced further then your pore size in the soil will be also reducing right.

So, now if D 10 decreases your pore size in the soil decreases which causes higher capillary rise because the I mean the more your pore size the lower your capillary rise or other way your lower your pore size okay the higher will be the capillary rise from the I mean relation of whatever we have seen just now h c is proportional to 1 by d right. So, this is very important. So, if D 10 increases your I mean pore size also increases so capillary rise decreases.

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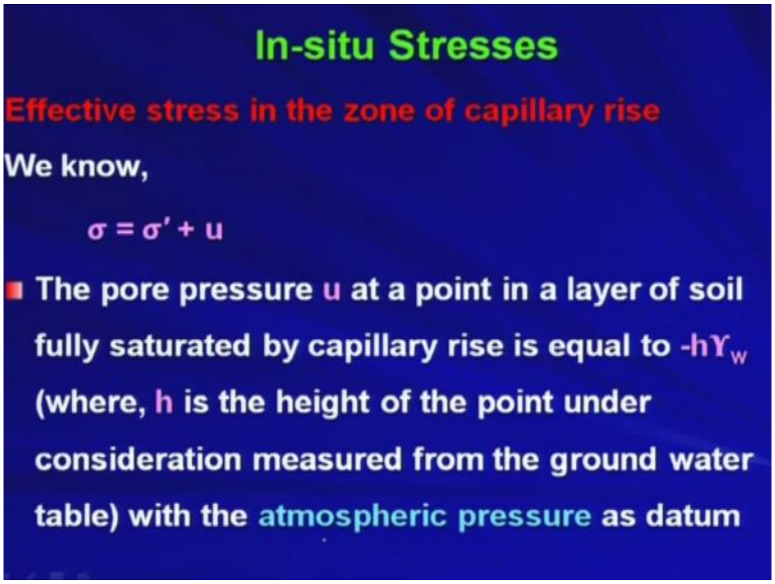

Now coming to the concept that if we want to find out or we want to calculate the effective stress in the zone of capillary rise then how we can do that. So, we know that sigma is equal to sigma prime plus u. What is sigma? Sigma is the total stress. What is sigma prime, that is the effective stress and what is u, u is the pore water pressure. So, this is the fundamental relation already we have established and already we have seen that and discussed in detail in the last lecture right.

So, the pore pressure u at a point in a layer of soil fully saturated by capillary rise is equal to - h into gamma w right, h into gamma w is the pressure or the water pressure above the I mean your water table right, your free water surface. Now why the minus sign is coming? Because the negative sign stands for your tensile nature right, the your I mean now you are getting some suction in the capillary zone.

So, this is your pressure, pore water pressure in the capillary zone. The zone means the zone which is situated above the free water surface to the maximum level of your capillary rise. Now where h is the height of the point under consideration, any height measured from the ground water table. So, please try to remember it is measured from the ground water table. So, now at the ground water table your what is your pore water pressure that is zero right.

So, if you go beyond that towards the capillary zone basically you will be getting some tensile kind of pore I mean pore water pressure. So, that kind of suction you will be getting. So, now this I mean h - h gamma w this is obtained with the atmospheric pressure as datum. Already of course we have seen that. That is the free water surface will be exposed to the atmosphere and that will give me the atmospheric pressure. That is the I mean datum basically. This is my basis on which we can calculate the pressure.

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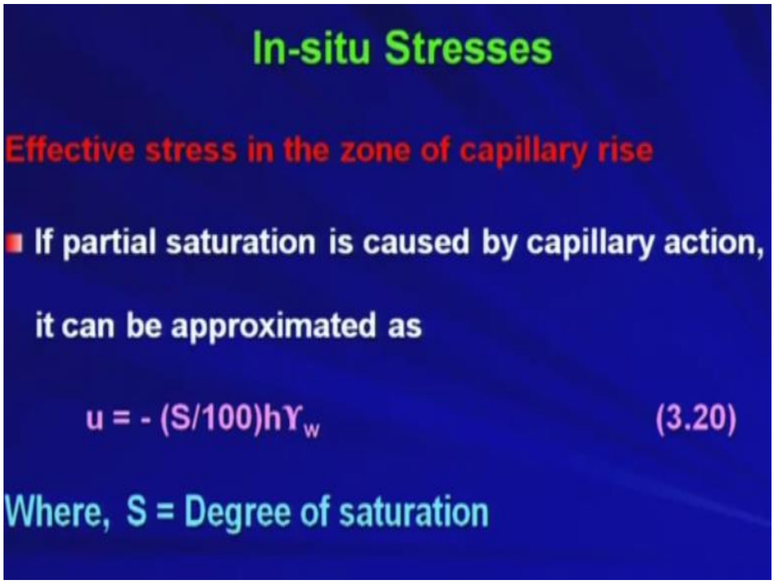

If partial saturation is caused by capillary action already whatever we are talking about say - h by gamma w that will be the capillary I mean that will be the pressure in the capillary zone okay if the soil is completely saturated or fully saturated but if you get some partially saturated soil so that means if partial saturation is caused by capillary action it can be approximated as u that is the pore water pressure is equal to minus of course the negative sign will be there because that will cause the tensile or the suction kind of pressure.

So, - S by 100 into h into gamma w where S is your degree of saturation. So, that means if S becomes 100 that means if the soil is fully saturated then your pore water pressure in the capillary zone is - h into gamma w whereas if S is lower than 100 then I mean accordingly your pore water pressure should be calculated from equation 3.20.

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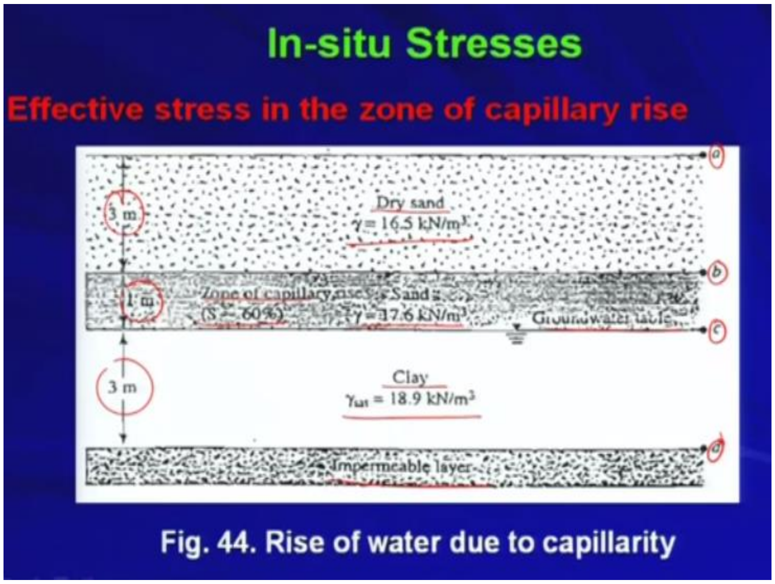

Fig. 44. Rise of water due to capillarity

Now we will take one kind of numerical small numerical example problem, so to understand this pore water pressure calculation and the effective stress calculation in the capillary zone. Now this if you see this deposit the top point is say a then b then c then d okay. From a to b you have dry sand which is having the unit weight 16.5 kilo Newton per meter cube. Then from b to c basically that is also sand but now let us talk in the other way say the bottom deposit say this is your impermeable layer okay.

Then on top of that you have the clay layer which is having say gamma saturated is 18.9 kilo Newton per meter cube because that is under the ground water table. So, ground water table is here. Now on top of the ground water table whatever soil is there so that is nothing but the sand but it is saturated sand right due to the capillary rise. Now this zone is capillary rise zone so it has been calculated and this say 1 m is the capillary zone or the capillary rise okay and for that you and your degree of saturation is say 60% that means partially saturated zone in the capillary zone and your gamma of course already we have seen that.

Gamma prime is your 17.6 kilo Newton per meter cube okay and the depth of clay layer is 3 m whereas the depth of say capillary zone is 1 m and depth of dry sand zone is 3 m because above the capillary zone you will be having the dry sand because there is no water in that zone. So, the maximum water you can find out up to the capillary zone okay. So, now we would we would like to find out the effective stress, total stress, and pore water pressure in different location of this deposit. Let us find out.

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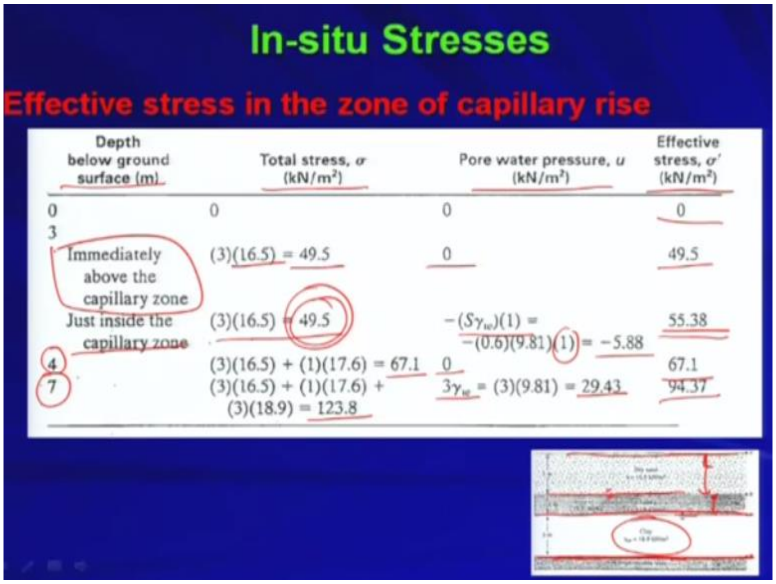

So, depth below the ground surface then we are calculating total stress then you are calculating pore water pressure and total stress minus pore water pressure will be giving you the effective stress right. So, this relation we know from our earlier discussion. Now depth below the ground surface if we consider 0 that means we are on the ground surface, we are just on the ground surface then what is the total stress? The total stress obviously is equal to 0.

That means you are along this line, the total stress obviously equal to 0. So, pore water pressure is obviously equal to 0 and therefore the effective stress is 0. There is no issue okay. Now you are coming below the ground surface and you are reaching the 3 m depth okay. So, that means you are reaching along this line. Now this line is having very interesting characteristics. So, just on top of the line you will be having completely dry sand.

Just below the line you will be having the capillary saturation or the capillary zone, am I right. So, this line will be differentiating will be separating 2 zones basically one zone is capillary zone another zone is dry zone. So, that is why at 3 m you will be having 2 different stresses. One immediately above the capillary zone right, immediately above the capillary zone. At that time what is your total stress? 3 that is the depth of soil deposit multiplied by the dry unit weight of the soil that is dry sand unit weight 16.5, so 49.5 your total stress.

So, what is the pore water pressure? Just on top of the line of this line basically of this line at b okay. So, your there is no water at all. So, if there is no water, so pore water pressure is simply 0. I hope you are understanding this thing right concept. So, if total stress is 49.5 and the pore water pressure is 0 then of course your effective stress will be 49.5 - 0 is nothing but 49.5 itself. So, your effective stress is 49.5. So, and the variation is 0 to 49.5 the variation is linear right. So, this is the linear variation.

Now just inside the capillary zone but still you are at depth 3 m below the ground surface. So, that means one point is just above the line and just below the line okay but you are still at 3 m depth below the ground surface. So, just inside the capillary zone your total stress is 3 into 16.5 that will be remaining same right. There is no problem because the soil which is lying above that line is nothing but the dry sand and the unit weight of the dry sand is 16.5. Now what is the pore water pressure?

What is the pore water pressure at that particular zone that means just inside the capillary zone but you are at depth 3 m below the ground surface the pore water pressure is S into gamma w into 1 right. So, S into gamma w into 1. So, just I mean that basically will give you the pore water pressure at 5.88 right 5.88 or the negative sign is I mean basically for the suction right. So, now why I am saying 1 why it is not 3.

So, already we have discussed or we have told that when you are considering the capillary zone basically your datum is the ground water table. So, what is your datum now, this is your datum. So, from there you have to find out what is the depth. The depth is 1 m. So, and S, S is the degree of saturation so S into gamma w into 1 will be giving you the pore water pressure at this line but just inside the zone so that is coming as - 5.88.

Now what is the effective stress? So, 49.5 is total stress minus the pore water pressure and the minus the pore water pressure and the minus of pore water pressure is minus of minus 5.88. So, it will be additive and you are getting the effective stress as 55.38. So, what does it mean? Because of this capillary rise you are getting some enhancement in the effective stress. So, if you design with the total stress basically right so basically if you do not consider the capillary rise if your design if you are designing something some underground structure based on some total stress then basically you are under utilizing the strength or the effective strength of the soil.

That means actually you are supposed to get 55.38 kilo Newton per meter square as the effective stress whereas this is the total stress you are designing with right. So, now coming to the depth below the ground surface when the depth is 4 m. So, when the depth is 4 m that means you are along this line. So, that means along the ground water surface. So, at that time your total stress is 3 into 16.5. That is coming from this zone plus 1 into 17.6 that is coming from this zone, 17.6 is the unit weight of the moist sand in the capillary zone. So, that gives me 67.1 that is the total stress.

Now what is the pore water pressure? The pore water pressure is 0 because that is the free surface of water okay. At that time, it will be exposed to the atmospheric pressure. So, the pore water pressure is 0. Now if the pore water pressure is 0 and the total stress is 67.1 then effective stress will be simply 67.1 right. Now we are considering the depth below the ground surface is 7 m. That means you are coming to this surface okay. At 7 mr what is the total stress, 3 into 16.5 that is coming from the top dry sand plus 1 into 17.6 that is coming from your capillary zone plus 3 into 18.9 that is coming from the clay part right.

So, 3 into that is the 3 is the depth 3 m is the depth of the clay layer and 18.9 is the unit weight gamma saturated of the clay layer. So, total stress is coming 123.8. Now what is your pore water pressure? Pore water pressure is simply 3 into gamma w where 3 m is the depth. So, h into gamma w. So, 3 into gamma w that comes as 29.43 so 123.8 - 29.43 will give you the effective stress at that level. So, 94.37 is the effective stress at the bottom surface of the clay layer. So, I hope you have understood how we have calculated this thing. Now we are going to plot this thing the distribution the pressure distribution like this. So, let us see now the pressure distribution.

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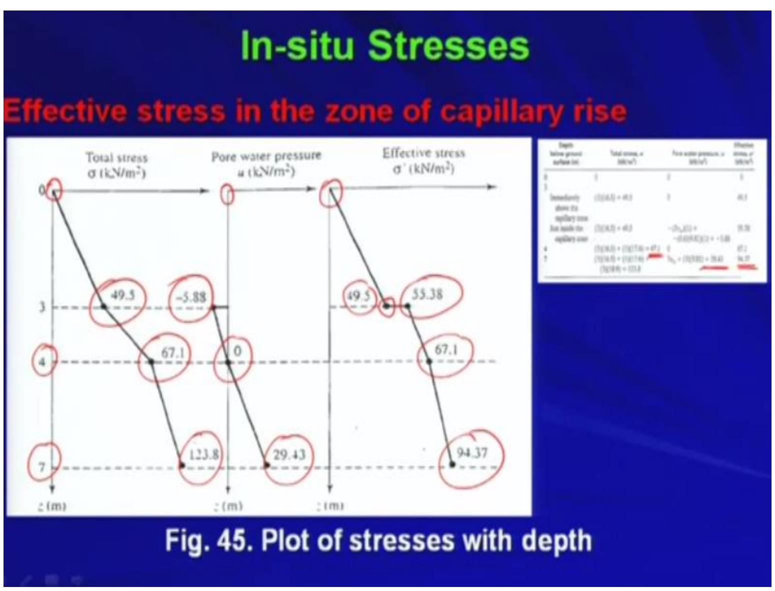

So, from at the ground surface the total stress was 0 okay the pore water pressure was also 0 and the effective stress was also 0 okay. Now at 3 m depth you had the total stress is equal to 49.5. At that time what is your pore water pressure? The pore water pressure was just on top you had the pore water pressure 0. Just below the line you had pore water pressure - 5.88 right okay. Now at the same time you are you will be getting 2 different effective stress that already we have seen.

Just on top of that line your effective stress was 49.5 given by this point. Just below that line okay because of this negative pore water pressure you will be getting some enhancement in the effective stress that is coming as 55.38. So, this is the variation and then from that point to 4 m depth the total stress was 67.1. So, already we have seen that here pore water pressure was 0 because that was exposed to the atmosphere and that is nothing but the ground water table.

So, therefore we are getting the effective stress as 67.1. Now at depth 7 m the total stress was obtained as 123.8 okay and the pore water pressure was 29.43 and therefore the effective stress was 94.37. So, this is the pressure distribution okay at different depths of the deposit okay. So, I hope you have understood this complete concept of the capillary rise as well as the effective stress or the pore water pressure developed due to this capillary rise.

So, I will stop here today. So, in the next lecture we will solve some numerical problems and we will talk about or we will see that how the problems of this flow net and seepage and all those things can be I mean solved. So, thank you very much.