Unsaturated Soils Mechanics
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Week – 10
Lecture - 30
Concept of "Suction Stress"- II

Hello everyone. Let us understand the suction stress characteristic curve. Lu and Likos in 2006 have proposed the Concept of Suction Stress to consider the physicochemical forces and capillary forces due to surface tension in the air water interface. And any other forces that are not considered in the previous study are included as suction stress into the effective stress principle.

So, the advantage of suction stress is that, it is valid for any given soil and all different forces are considered into the suction stress. Now let us understand how the suction stress characteristic curve varies for different soils and how this is related to the soil water characteristic curve.

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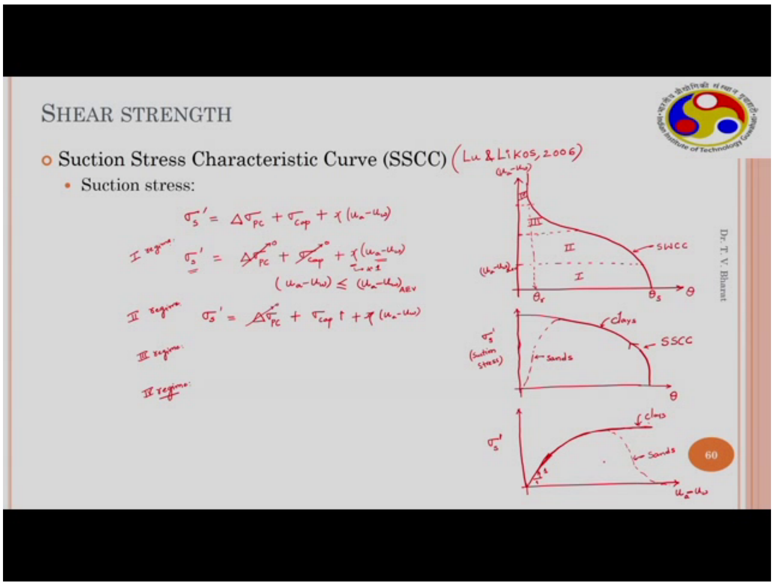

So, the suction stress characteristic curve, a how it varies etcetera we will define based on how the soil water characteristic curve regimes change. So, if this is the soil water characteristic curve for a given soil, here y axis is u a minus u w that is a matrix suction and a or x axis, volumetric water content is given. Now the (Refer Time: 02:01) curve varies in this particular manner. So, this is theta s, saturated volumetric water content and the air entry suction value of this particular soil is somewhere here so, this is a u a minus u w AEV.

So, this is a u a minus u w, Aev air entry value and beyond that, the water content decreases drastically with increase in the matric suction and the change in the water content starts decreasing with increasing in suction after certain pressure. And beyond certain suction value it is very difficult to draw the water by increasing the suction in the soil.

So, if this is a residual water content theta r, so if different zones are considered in this particular manner in the first zone. So, this is a saturated state of the soil even though, the pore water pressure is negative. And this is a second stage where drastically the water content decreases with increase in the suction and this is the third stage where the rate of the decrease in water content will start decreasing and fourth stage which is a residual stage where, water is held around the particles in hydration.

So, this is a hydration stage where water is available as a thin film around the clay platelets. So, this is a SWCC Soil Water Characteristic Curve So, now, the suction stress characteristic curve can be drawn, here the x axis has theta volumetric water content so, on the y axis sigma s dash. So, the sigma s dash is suction stress so, how this suction stress should vary know. So, as we have the equation and for the suction stress that is sigma s dash is equals to a change in the stresses due to physicochemical forces PC plus sigma capillary plus xi u a minus u w this is one of the expression which was given by Lu and Likos.

So, this is not found in the textbooks So here in the first stage of soil water characteristic curve or the initial first regime, so the change in the physicochemical aspects of clays are insignificant because, the change in the volumetric water content is very small water content decreases very insignificantly. The change in the physicochemical aspects become 0. So, this aspect for the I regime the PC is negligible, changing the physicochemical aspects of the soil are negligible and the capillary phenomena is also negligible in the I zone or I regime where the water content is nearly equal to the saturated volumetric water content or the soil is saturated state.

So, then you have xi into u a minus u w. So, here xi is also approximately K is equal to 1. And whatever the variation in u a minus u w, you will see it in suction stress. So therefore, whatever the change you see here, similar change you will see in suction stress. So, in the beginning, so in the first regime, so beyond that, as in this case this is u a minus u w is less than or equals to u a minus u w AEV Air Entry Value.

In the second regime, so in this expression where, u a minus u w is more than u a minus u w is AEV, so soiled desaturates quickly and capillary forces would start increasing. And the electrostatic repulsion will start decreasing in the soil and attractive force are nearly constant, provided the soil grains would not come close to each other or the change in the pore size distribution does not change significantly, but if the soil desaturates quickly then the van der Waals forces remain nearly constant, but then the repulsive pressures within the soil mass will start decreasing.

So, this is insignificant which is close to 0 but the capillary forces are significantly higher, they start increasing. So, their effect is nearly negligible. So, as this desaturates, the capillary forces would shoot up and the contribution is essentially from the capillary forces. So, beyond this in the third regime where the repulsive pressures diminishes and the attractive force if inter particles distance decreases, due to desaturation.

So, the overall increase will reduce because of this and capillary effects also start diminishing, this starts approaching a constant value. And for sands this value starts decreasing because, the capillary forces effect is also getting reduced because the amount of moisture that is available in the soils is getting reduced and the physicochemical force anyways are not significant in sands.

So, therefore for sands this will starts decreasing in the third regime, so, this is third regime. And in the fourth regime, water is held as thin film surround clay platelets, the amount of water that is available in the soils is only available for a hydration of exchangeable cat ions and a hydration of layers of different inner layers of clay platelets. If it is you will have multi layer hydration, that is the water equivalent to multi layer hydration is available in clays and single layer of hydration may be available around sand platelets.

So, the suction stress essentially the capillary force are 0 and a sigma PC is anyways 0. And xi reduces to very small value until approaches close to 0. In case of sands, this goes to 0, but in case of clays because, it attractive forces are the van der Waal forces still exists, which gets a constant value somewhere like this. So, this is the suction stress characteristic curve of a given soil, this is for sands and this is for clays. So, it approaches a constant value somewhere here.

Similarly, this same graph can be drawn for u a minus u w that is matric suction on x axis, u a minus u w on x axis and a suction stress on y axis. So, initially, the suction stress increases at the same rate as the matric suction value, it follows 1 is to 1 linear relationship. And beyond that, the increase in the suction stress decreases with increasing in the suction and which becomes nearly constanted for particular time. But in case of sands this suction stress decreases and becomes 0 at one particular matric suction.

So, this is for sands and this is for clays. So, initially there will be 1 is to 1, linearly it increases and beyond this, this is a non-linear behaviour and it starts decreasing in suction stress becomes constant because of the contribution of only van der Waal forces and such short range forces are dominated at that particular suction value.

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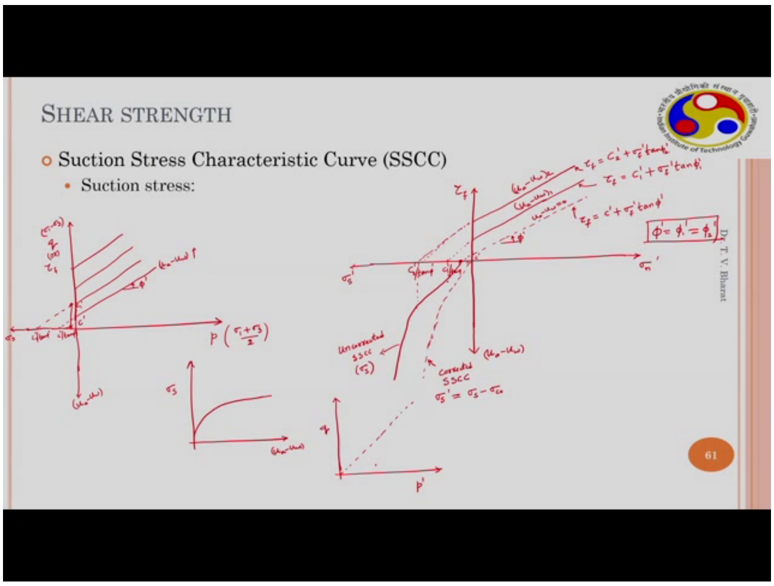

So, how to understand this suction stress characteristic curve? When we plot the strength the more column envelopes tau f versus tau f versus sigma n, normal stress, we get a failure envelope for saturated soil somewhat like this. And for unsaturated soils the cohesion intercept the intercept value increases, it increases in this manner. This is the observation from the experiments, suction controlled direct shear stress or suction controlled tri axial test these are the observations I have a discussed earlier, this is a failure and overlap saturated soil that is, tau f is equals to C dash plus sigma f dash tan phi dash.

So, this is angle of internal friction this is phi dash and this is C dash. And similarly, this is the envelope for tau f equals to some C 1 dash plus sigma f dash tan phi 1 dash we can write and a this is another failure overlap C 2 dash plus sigma f dash tan phi 2 dash. So, however, we have observed that the phi dash is equals to phi 1 dash is equals to phi 2 dash from the experimental data that, the all these lines are parallel to each other.

So, this is external observation. So, the angle of internal friction is a metal constant it does not vary or it does not depend on the suction and which is constant. So, when we extend these lines back on to sigma n axis, so back on to this negative axis, this is a this negative axis is your tension. So, when you extend this tau f is 0 at this particular point, so therefore, the sigma s dash is C 2 dash by tan phi dash and here the point is C 1 dash by tan phi dash and here, this point is c dash by tan phi dash.

So, if this becomes your matric suction, u a minus u w that is a representation of negative pore water pressure within the soil. So, this particular value when you are drawing for a given matric suction, this is done for one particular given matric suction u a minus u w of set 2 and this is u a minus u w of say 1 and this is u a minus u w is equals to 0.

So, this is for 0 and a u a minus u w some particular value and this is u a minus u w some particular value here. So, then the profile that you get is somewhat like this. So, this is uncorrected suction stress characteristic curve, suction stress characteristic curve and this is corrected and a made it to go from origin, then this becomes somewhat like this. So, this is corrected SSCC, Suction Stress Characteristic Curve.

So, this sigma s dash is this is for sigma s and this is sigma s dash which is equals to sigma s minus sigma c naught. So, this is how the corrected suction stress characteristic curve can be obtained for any given for suction stress characteristic curve or the effective stress can be determined for a given suction value using the measured data from suction controlled tests.

When the data of deviatoric stress q, that is a sigma 1 minus sigma 3 deviatoric stress or it could be tau f, if it is a direct shear test. q is a deviatoric stress into tri axial tests, which is equal to sigma 1 minus sigma 3 in tri axial tests and tau f phase, the shear stress applied on soil indirect shear. And on x axis, you can either show sigma the net normal stress or it can be represented with p which is a mean stress. So, the mean stress represented here is sigma 1 plus sigma 3 by 2 and here this is sigma 1 minus sigma 3 so, there is deviatoric stress.

So, when this is this is plotted then, you get series of straight lines with a nearly the angle of internal friction is equals to phi dash, but different intercept, for different matric suction values. So, this is a u minus u w increasing up so, the strength is increasing for any given mean stress. So, this test data can be interpreted by computing the obtaining the cohesion intercept; say for example, C 1 and for this 1 is a C 1 dash, once this is obtained and a phi dash is anyways is available.

So, this particular point is C dash by tan phi dash and this is C 1 dash by tan phi dash. So, these values are available. So, therefore, these are the suction stress values, sigma s values. The matric suction at which, these tests are conducted is also known, so therefore, u a minus u w axis is known and a this y axis values are obtained from cohesion intercepts and therefore, the sigma s is known and u a minus u w is known. So, therefore, they can plot sigma s versus u a minus u w.

This is essentially the variation is somewhat like this and also we can plot q, the deviatoric stress versus p dash, that is a effective mean stress. So, as we know the effective stress values, so therefore, we can compute the mean effective stress values, then you get a unique straight line, this itself is a failure envelope. As we could determine the true effective stress from the SSCC, we can obtain the unique failure envelope for different matric suction ranges. Let us understand by example problem.

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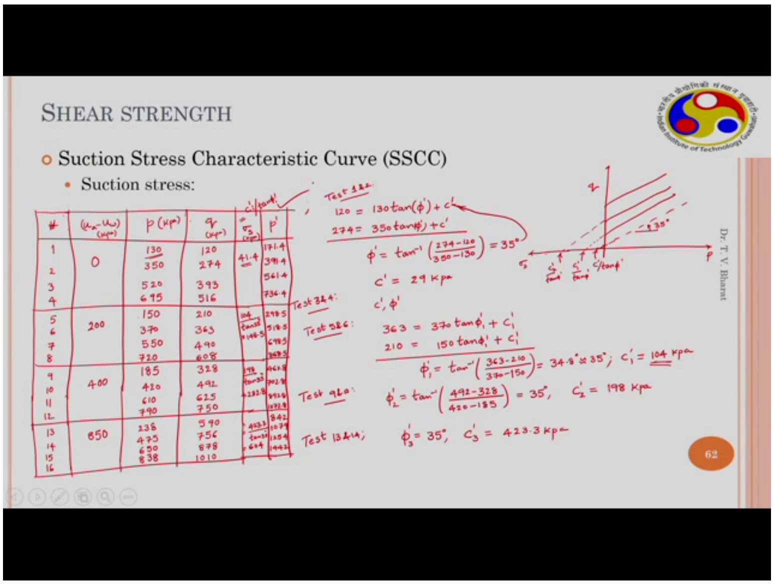

So, in this example we have a data of this is a synthetic data. A number of tests are conducted, test number under the matric suction, how this is varied are controlled. And this is a mean stress and this is deviatoric stress, which is observed at failure.

So, this is test 1 2 3 4, 4 tests are conducted at 1 matric suction that is, 0. So, that means, at saturated state these tests are conducted. So, p values varied, 130, 350, 520 and 695, this manner they varied, under the 0 matric suction or saturated condition and when the p net normal stress varies in this manner then, the q value varies as 120 274, 393 and 516. And another set, under a matric suction value of 200 kilo Pascal are conducted. So, the value of p varied in this manner. And another set of data, the matric suction value of 400 kilo Pascal are conducted the p value varied as and last set of data, the matric suction is 850 kilo Pascal and the p dash varied as 238, 475, 650 and 838 then, the q deviatoric stress varied as 590, 756, 878 and 1010.

So, these are the observations from the suction controlled tests on a given soil. And here, 4 different matric suctions are maintained and the tests are conducted. Then this data if you plot it on y axis q and x axis p, so it is saturated state you may have data somewhat like this and this is what you obtain here.

So, this is the data, that is given to you and we need to obtain c phi, the cohesion intercept and angle of internal friction for all the four sets of data's. So, from the first set of data, that is a test 1 and 2 if you take, so 130 120 is equals to 130 tan phi dash plus c dash and 274 is equals to 350 tan phi dash plus c dash, when you solve this, we get phi dash is equals to tan inverse of this is 35 degrees.

So, when you substitute this into any of these equations, we get c dash is equals to 29 kilo Pascal. So, this is a 29 and the angle is 35 degrees. From the test, when test 3 and 4 if you take, you should get the same data you should get same c dash and phi dash and a test 6 and 6, if you consider, so you have a 363 370 tan phi dash, r phi 1 dash, we do not know whether it is phi dash is same as phi 1 dash. So, we can show it is different then, a when you compute the phi 1 dash we can compare with phi dash.

So, this is C 1 dash and 210 is equals to 150 tan phi 1 dash because, these are all conducted at the same matric suction values C 1 dash. When you solve this, phi 1 dash is equal to tan inverse of which is equals to 34.8 degrees, which is nearly equals to the phi dash that is 35 degrees, when you substitute the above equations, you get C 1 dash as, 104 kilo Pascal. Similarly, from test 9 and 10, phi dash is 35 degrees and C 2 dash is equals to 198 kilo Pascal. And test 13 and 14, phi dash is 35 degrees again that is, a phi 1 dash, phi 2 dash, phi 3 dash, 35 degrees and C 3 dash is 423.3 kilo Pascal. Now, knowing the intercepts at for different matric suction values for the data under control matric suction values now, we can obtain the suction stress the suction stress values sigma s. So, let me write this somewhere here test 1 and 2.

So, sigma s values we can obtain. Sigma s is is equals to nothing, but C dash C i dash by tan phi i dash. So, this is a sigma s axis and a when this is extended on the negative axis, this point is this point is C dash by tan phi dash. So, C dash by tan phi dash for this value is 41.4 kilo Pascal. And for the second set of data, this is a C 1 dash by tan phi dash. C 1 dash, C 1 dash is 104 by tan phi dash is 35, this is 148.5.

And for the next set, so this is again C 2 dash by tan phi dash. So, this data is 198 by 10 35. This is equals to 282.8 kilo Pascal and similarly, for the last set of data cohesion intercept is 423.3 by tan 35, this is 604 kilo Pascal.

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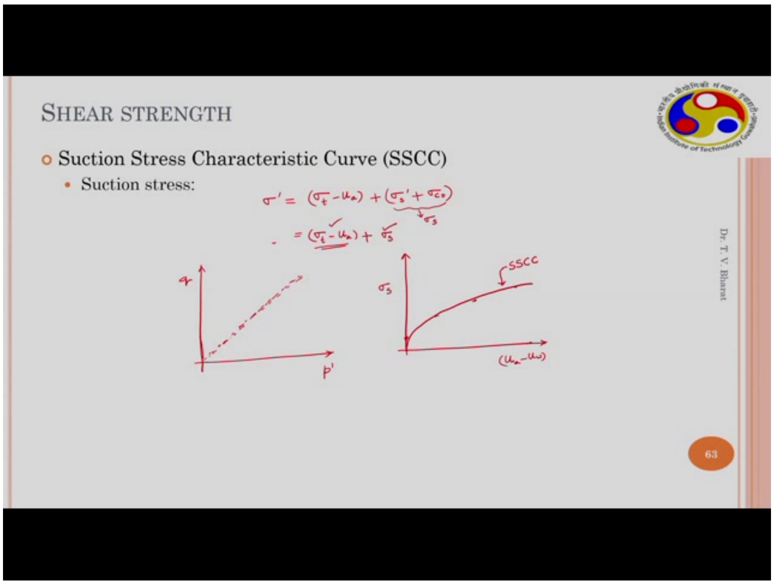

So, we have the sigma s data therefore, now sigma dash effective stress is equals to sigma t minus u a, this is net normal stress plus sigma s dash plus sigma c naught.

So, this is initial cohesion, this together is sigma s that is what we got now. So, therefore, the effective stress is sigma total minus u a plus sigma s, these values we have and net normal stress values we have therefore, effective stress values we can obtain. For the previous data, we can write here itself the sigma dash are here effective mean stress therefore, this is simply p dash So, p dash value is 130 plus 41.4, so this is 171.4 and this is a 350 plus 41.4. Therefore, this is 391.4, 561.4, 736.4 for other values.

So now, we have mean effective stress and a q, so that is deviatoric stress, we can plot deviatoric stress versus mean effective stress if you plot, you will get a data like this, a unique failure envelope using different data. And a similarly, we can plot sigma s and u a minus u w so, we get data somewhat like this.

So, this is the SSCC, suction stress characteristic curve. So, here the 2 effective stress for a given unsaturated soil can be determined from the routine suction controlled tests, in the once the suction stress characteristic curve is obtained from the deviatoric stress versus net normal stress data, from the suction control tests we can compute the cohesion intercepts and angle of internal friction values. And from the cohesion intercepts, one can obtain the suction stress directly. From the suction stress, one can compute the effective stresses are effective mean stress, so the deviatoric stress versus effective stress can be drawn and a unique failure envelop can be obtained.

Thank you.