Unsaturated Soil Mechanics
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Week - 09
Lecture - 26
Extended M-C Criterion – I

Hello everyone. So, far we have gone through the Bishop's Effective Stress Principle, which is modified after Terzaghi's Effective Stress Principle for the Unsaturated Soils. Bishop introduced one more strength parameter called effective stress parameter xi f which is function of matrix suction. The estimation of xi f function from the suction control direct shear test and suction control tri axial test are seen.

So, today will understand the development there were some more developments that took place later on because the xi f parameter estimation is a very difficult especially for fine grained soils where the estimation of xi f over a wide suction range is very difficult. So, independently there were some more test that were conducted by other researchers, further to evaluate whether the independent stress state variables that were used by Bishop are valid or not. So, such test are called null type test, so which will discuss today.

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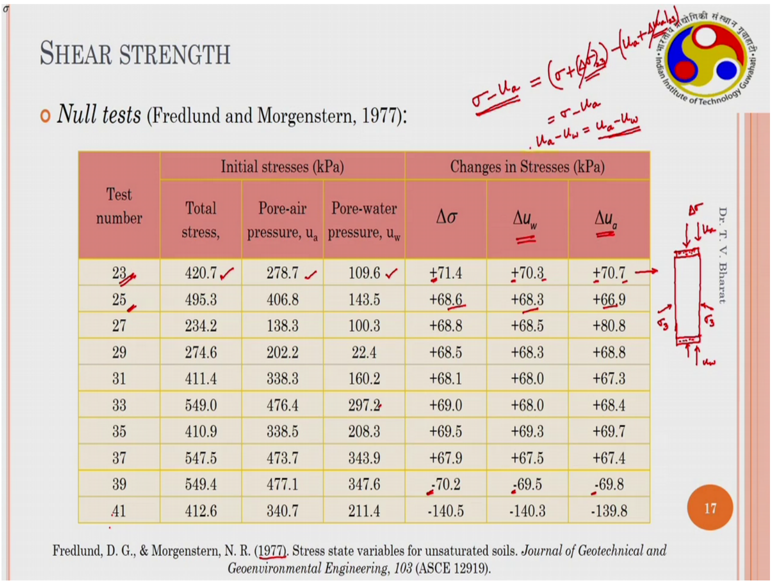

Test number	Initial stresses (kPa)			Changes in Stresses (kPa)		
	Total stress,	Pore-air pressure, u_a	Pore-water pressure, u_w	$\Delta\sigma$	Δu_w	Δu_a
23	420.7	278.7	109.6	+71.4	+70.3	+70.7
25	495.3	406.8	143.5	+68.6	+68.3	+66.9
27	234.2	138.3	100.3	+68.8	+68.5	+80.8
29	274.6	202.2	22.4	+68.5	+68.3	+68.8
31	411.4	338.3	160.2	+68.1	+68.0	+67.3
33	549.0	476.4	297.2	+69.0	+68.0	+68.4
35	410.9	338.5	208.3	+69.5	+69.3	+69.7
37	547.5	473.7	343.9	+67.9	+67.5	+67.4
39	549.4	477.1	347.6	-70.2	-69.5	-69.8
41	412.6	340.7	211.4	-140.5	-140.3	-139.8

So, the null type test these tests are to understand the validity of different the stress state variables. So, it is based on manipulation of different combination of stress state variables. Changes to whether total volume are degree of saturation is observed are used as the measure for understanding whether they are independence stress state variables or not. So, null tests are conducted by Fredlund Morgenstern in 1977, this is very popular work and the concept are used even till date. So, this is published in A.C. geotechnical and geo environmental engineering in 1977.

So, in this work they have conducted more than 19 null test on compacted cerulean soil, cerulean clay by controlling different stress parameters. So, as in tri axial cell one can control the deviatoric stress, the all-round pressure, the pore air pressure and pore water pressure, of course, we have coarse for (Refer Time: 03:20) here and then you have higher entry porous disk located at this location. So, therefore, the u a within the soil mass and a u w within the soil mass can be controlled independently. So, therefore, they have changed these parameters such a way that whether all the parameters are increased to the same extent or decrease to the same extent.

So, here if you observe the test number 23 from their work, so, this is a initial conditions of the soil, where the soil was at equilibrium, total stress was 420.7 and pore air pressure is 278.7 and pore water pressure is 109.6. You can assume some units a kilopascal. Now, the delta sigma is increase to plus 71.4 by changing the water pressure to plus 70.3, and changing the air pressure to plus 70.7, the want values of these parameters to be the same.

So, while doing this experiments slight deviation was there; however, nearly changes in the values are constant. So, due to these changes, the sample dimension the sample volume did not change, or the water content did not change during the testing. Similarly, there is a another test 25 number, this initial condition and so the changes and stresses is same in delta sigma delta u w and delta u a. Similarly, several other test data are shown here. Either you increase this you increase all of them plus or you decrease all of them.

So, in the same direction they have been applied, and when these changes are made the sample volume did not change; that means, the shear stresses are not initiated within the soil sample. So, this is because the sigma minus u a, that is a effective stress the that net normal stress we use; which is equals to sigma plus, there is a small increment delta sigma in the test number 23, minus u a. Here, u a is increased the small value delta u a test number 23.

So, as this delta sigma and delta u a are maintained to be constant, so they get cancelled. So, essentially you get sigma minus u a. Similarly, if you take u a minus u w the increase u a plus delta u a and u w plus delta u w. This delta u a and delta u w both are one and the same. This remains u a minus u w. Due to increase in the stresses as shown here. So, therefore, these 2 variables can be used as independent state variables for defining the shear in the soils. Because earlier Terzaghi's had showed that it is effective stress that defines the state of the soil for shearing.

And here Bishop has propose that sigma minus u a, the net normal stress and u a minus u w these 2 should be used as stress state variables and they are independent to each other. And that is proven by these null test by Fredlund and Morgenstern. So, sigma minus u a and u a minus u w when they are kept constant. There is no shear induced in the soil sample.

So, therefore, there is no change in the volume, or degree of saturation. So, these are confirmatory test for Bishop's effective stress equation for unsaturated soils.

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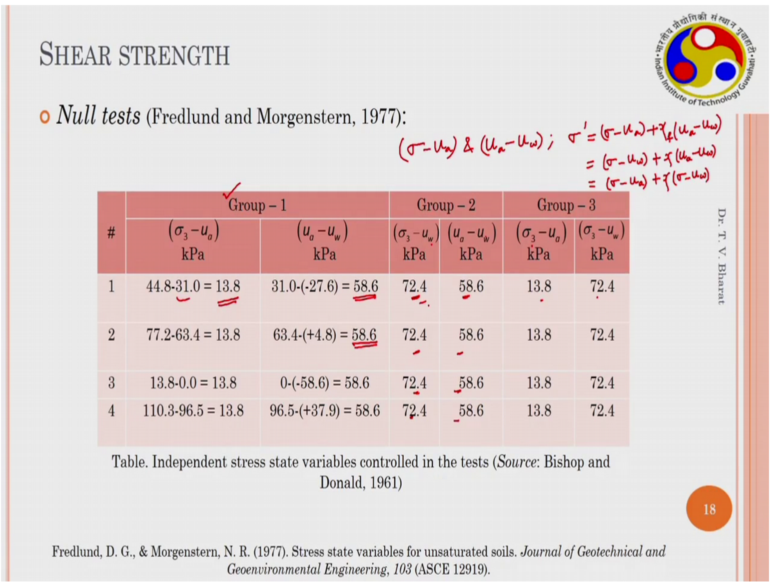

Further their observation states that, it is not just one combination of sigma minus u a and u a minus u w to use as 2 independent state variables, stress state variables. They further say that even if we use combination of this is one set sigma minus u a and u a minus u w. Another combination sigma minus u w and u a minus u w, and a other third combination is sigma 3 sigma minus u a and sigma minus u w. Any of these 3 combinations can be used for defining the stress state in soil.

So, here the sigma minus u a or sigma 3 minus u a, and u a minus u w are maintained to be 13.8 and 58.6 changing from the initial value like this 44.8, so 13.8 and 58.6 are maintained. And in the second test same values are maintained, but different values of sigma 3 and u a are given. And similarly different values of u a and u w are given, but the u a minus u w remains constant.

So, in this all 4 test the sigma 3 minus u a and u a minus u w are kept constant, then the volume of the sample did not change. So, group one that is sigma minus u a net normal stress, and u a minus u w this combination qualifies as independent stress state variables. Similarly, the group 2 is analyzed there is sigma minus u w and u a minus u w.

So, here the same combination is maintained for all different test by varying sigma 3 u w u a independently. So, then the sigma 3 minus u w and u a minus u w these 2 combination kept constant for all these 4 test and we will now the volume remains constant. Similarly, in group 3 the sigma minus u a and sigma minus u w are maintained to be constant for all these 4 test then the volume remains constant.

So, therefore, the effective stress equation that is given by Bishop, that is sigma dash is equals to sigma minus u a plus xi f are simply xi, u a minus u w. This is what we used as effective stress principle, modified effective stress equation from Bishop's proposal. And here the effective stress also could be used as sigma minus u w plus some xi times u a minus u w. Or this could be a sigma minus u a plus xi sigma minus u w.

So, any of these 3 combinations can be used to formulate the effective stress principle, and it could be used to define the shear strength of the soil at any given stress state. So, therefore, this test reveal that Bishop's independence stress state variables indeed valid for the unsaturated soils. And moreover any of these 3 combinations are group one group 2 group 3 could be used as independent stress state variables.

Fredlund and Morgenstern after their stress state variables definitions and stress state variable confirmatory test by in null type test in suction control tri axial and suction control consolidation cells, they are come up with new form of modified column failure criterion for unsaturated soils. Before going into that, let us understand how the stress can be represented graphically so that the Fredlunds extended more coulomb theory can be very well understood.

So, here the stress representation for unsaturated soils can be understood by solving some problems. Here there is one particular problem there is taken; that is some example.

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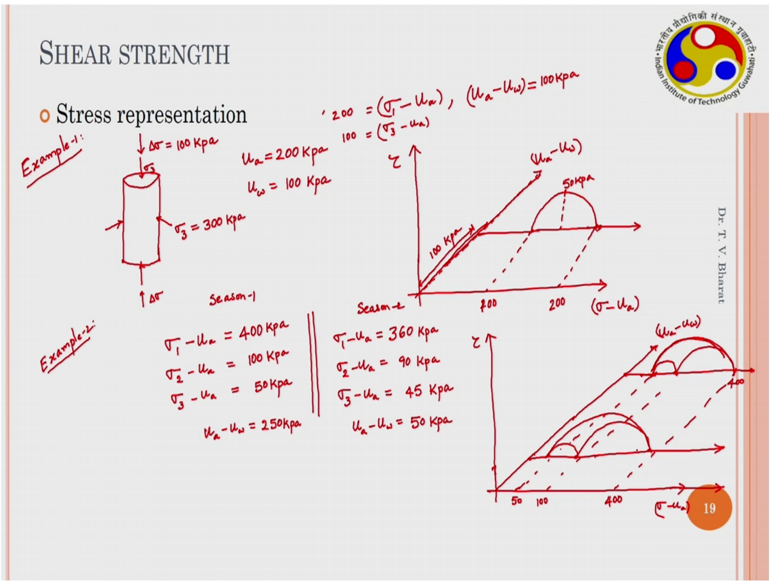

So, one shear testing is conducted on clay soil using tri axial setup. So, soil sample which is at equilibrium with an all-round pressure sigma 3 is equal to 300 kilopascal. So, this is a all-around pressure, and a deviatoric stress of 100 kilopascal is acting. So, this is sigma 3 and that is delta sigma, and there is a pore air pressure on the sample is 200 kilopascal. And pore water pressure is 100 kilopascal. This soil state can be represented graphically as we know the stress state variables for unsaturated soils we can chooses net normal stress there is sigma minus u a and u a minus u w.

So, they as this is tri axial test you will have sigma 1 and sigma 3. Therefore, we can draw the more circle. So, this can be plotted as tau on y axis and sigma minus u a on x axis. But as we have suction also, matrix suction also. So, that can be plotted on third axis.

So, this is third axis, so z axis for u a minus u w. So, if that is represented on y z axis. Now the stressed of the soil can be represented on u a minus u w is 100 kilopascal. So, this is located at 100 kilopascal here. So, this is 100 kilopascal. The more circles stress circle can be drawn on this axis, so which is at 100 kilopascal on the z axis. So, here the sigma 3 minus u a and N sigma 1 minus u a can be obtained. Sigma 1 minus u a that is a net normal stress in the y direction on the soil sample is 300 plus 100, that is 400 minus u a is to 200.

So, therefore, this is 200 kilopascal sigma 1 is 400, minus u a is 200. So, therefore, this is 200 kilopascal, and sigma 3 is 300 and u a is 200 therefore, this is 100 kilopascal. So, therefore, there is 100 kilopascal here, and there may be 200 kilopascal somewhere here. So, this is this is 100 kilopascal and this is 200 kilopascal, sigma 1 minus u a is 200 kilopascal. So, maximum stress is at the centre, that is 50 kilopascal and maximum stress exist at 45 degrees from the major principle stress and this is a maximum values 50 kilopascal.

So, this is how the state of the stress can be represented graphically on a 3 dimensional plot. Similarly, let us take other example. So, there is a soil mass a which is located at on a slope. So, therefore, it has the 3 stresses acting major principle stress, and the net normal stress along with major principles is sigma 1 minus u a is 400 kilopascal. And intermediate stress is 100 kilopascal, and minor principle stress is 50 kilopascal.

So, if this stresses vary during the monsoon state. The stress state changed from one season to another season. This is season one and in the season 2. The stress state changed to sigma minus 1 u sigma 1 minus u a is 360 kilopascal, and sigma 2 minus u a is 90 kilopascal. And sigma 3 minus u a is 45 kilopascal. And in the season one the matrix suction in the soil is 250 kilopascal.

So, this is relatively dry season. And in the season 2 the matrix suction decrease to 50 kilopascal. So, how to represent the change in the stress state of soil? This can be again drawn on the 3 axis plot, sigma minus u a on x axis, and tau on y axis, and the third axis for u a minus u w.

So, here the on the suction axis at 250 kilopascal somewhere here, you draw horizontal line. So, this is sigma minus u a parallel to the sigma minus u a axis. So, here on this the sigma 1 minus u a is 400, say 400 and sigma 2 minus u a is 100, and sigma 3 minus u a is 50. So, you have one stress so this is how it is plotted.

So, this is so this value is 50, and this value is this goes parallel to this axis. So, this is 100 and this is 400. Similarly, in other season 2, in the matrix suction decrease to 50. So, assume that this is 50 and horizontal if you draw and here this became 360. So, slightly decreased this value and here it is 90 and here it is 45.

And this is how it can be plotted stress state of the soil.

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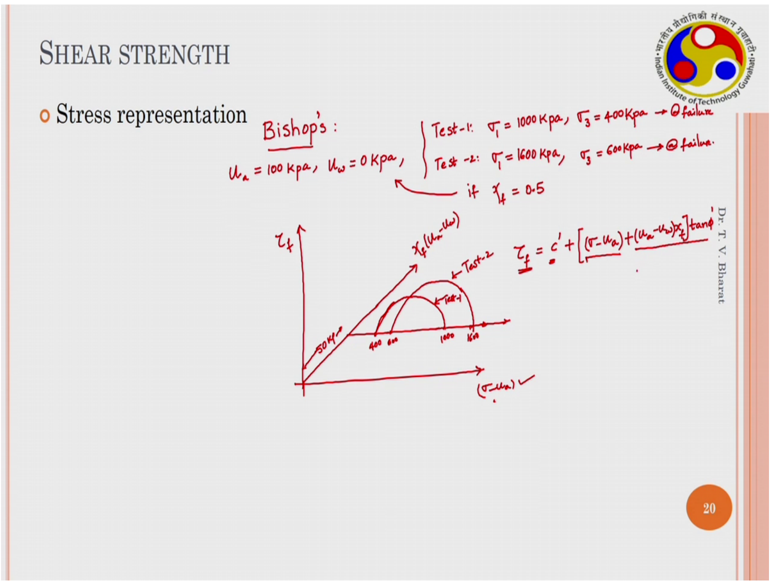

So, in case of Bishop's effective stress principle we have a one test data. So, that is u a is 100 kilopascal and u w is 0 kilopascal. So, in axis translation let us understand how the Bishop's modified more coulomb equations can be represented graphically. So, let us assume one problem where u a is 100 kilopascal and u w is kept at atmospheric, so this is 0 kilopascal.

And in one test in test one sigma 1 is 1,000 kilopascal and sigma 3 is 400 kilopascal at failure; these are observed data. And in test 2 when the sigma 3 is maintained 600 kilopascal, the soil field at sigma 1 of 1600 kilopascal at failure. If xi f is known is equal to 0.5, because it depends on matrix suction. So, matrix suction is constant in these 2 test. So, xi f will be constant for these 2 test is xi f is known there is 0.5, then how to represent this? Here in the same way you can represent on wax is sets the tau an x axis is sigma minus u a.

So now this is third axis, now in this case because the equation is tau f is equals to C dash plus sigma minus u a plus u a minus u w time xi f times tan phi. So, this is intercept plus this whole thing, the one axis is sigma minus u a another axis is tau f, and other axis could be xi f times u a minus u w. So, this xi f u a minus u w. Then at one particular xi f into u a minus u w, u a minus u w is suction is 100 kilopascal, xi f is 0.5.

So, this 50 kilopascal, xi f times u a minus u w that is 50 kilopascal. Then in one test the soil failed at sigma 3 400. And sigma 1 is 1,000 kilopascal. So, this the test one 400 and 1,000. In the test 2 when the sigma 3 is 600 kilopascal, it failed at 1600 kilopascal somewhere here.

So, this is test 2 and this is test 1. This is how it can be represented because we have when we have all of 3 axis defined one is tau f another one is sigma minus u a. And another one is u a minus u w times xi f as third axis then the stress state of the soil can be very well defined using graphically, by graphically.

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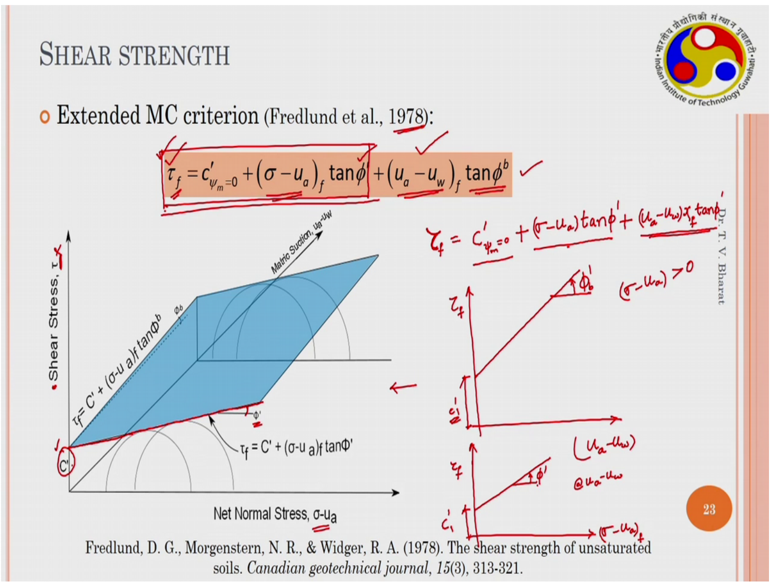

Now, we can understand how graphically this stress state of the soil can be represented.

So, that Fredlund Fredlund Morgenstern and Widger in 1978 proposed extended more coulomb criterion according to this criterion. The tau f is equals to C dash that is a cohesion intercept at suction is equals to 0. That is saturated state, plus sigma minus u a at failure times tan phi dash plus u a minus u w, this is matrix suction at failure times tan phi b. So, here as they came up with Fredlund and Morgenstern in 1977 came up with 2 stressed parameters that can be defined independently. And they confirm Bishop's a modified mc criterion.

So, similar same stress state variables are used in this extended mc criterion area. So, in this extended mc criterion which is nearly similar to the Bishop's modified more coulomb criterion; which I can write it for you here, tau f is equals to C dash. This is same at xi m is equals to 0, plus sigma minus u a tan phi dash plus u a minus u w times xi f tan phi dash; because it is at any sigma 1 sigma minus u a plus xi f u a minus u w that is effective stress times tan phi dash.

So, when we write as 2 terms by multiplying tan phi dash, then you get this. First term is same, second term is same, third term is there is slight difference. The xi f tan phi dash is modified it to be tan phi b. Even though it appears to be a small difference between these 2 equations, there is a significant advantage in writing this Bishop's expression into this particular equation; that is, when you draw shear stress on x y axis, that is tau f or tau and net normal stress on x axis, then the extended mc criterion says that the shear stress for unsaturated soils can be defined with the surface or plane.

So, this plane represent this particular equation. So, if it is tau f versus sigma minus u a. So, then these 2 terms on the right hand side this particular expression is valid. So, as C at x at psi m is equal to 0, so here that the C dash this particular z axis on u a minus u w this is 0. So, then this particular thing is not there then you plot sigma minus u a and shear stress. So, when you plot, so the linear relationship is this. This angle of internal friction phi dash and this sigma minus u a axis and this is tau f axis. This is a cohesion intercept.

So, this is cohesion intercept, and this is angle of internal friction, so this equation is valid. And if you happen to plot tau versus u a minus u w, that is when you look at this 3 dimensional plot from this direction, then net normal stress will not appear for you, and then this can be plotted as this. So, that is tau f versus u a minus u w, this versus u a minus u w. Then you have sum C dash and a this angle is phi v dash tau f versus u a minus u w this is how it is plotted. Because on this tau f versus u a minus u w, the sigma minus u a is 0, because on this 2 dimensional plot or 2 axis plot this sigma minus u a is 0. Therefore, this is simply tau f versus u a minus u w can be plotted in this manner. You have an intercept and you have a phi b.

So, if this is plotted at one particular sigma minus u a; which is more than 0, then the intercept becomes some intercept C 1 dash. Similarly, if tau f and sigma minus u a are plotted, at one particular u a minus u w, then you have some intercept. So, this is not equals to C 1 C dash, this equal to C 1 dash or C 2 dash or something. So, this angle is phi dash. So, the graphical representation of stress state of the unsaturated soils can be very well defined using this particular form of more coulomb criterion, given by Fredlund at all.

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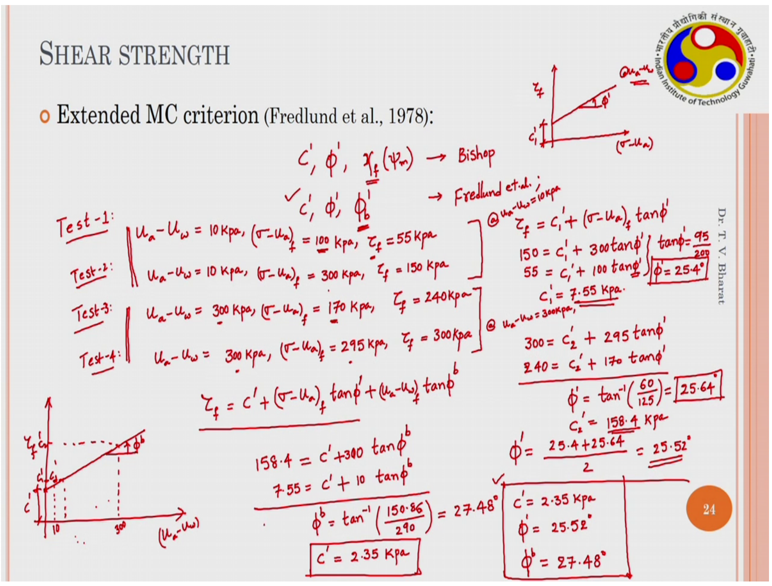

Let us the understand how to estimate the shear strength parameters. We have C dash and phi dash as the shear strength parameters for saturated soils. In case of unsaturated soils, you have C dash phi dash and xi f C dash phi dash and xi f of say psi matrix suction using Bishop's more coulomb criterion.

So, this is called a modified more coulomb criterion given by Bishop. In case of Fredlund at all 1978, this is C dash phi dash and phi b dash, this is single value is not a functional form, but however xi f is a functional form. So, because this is only one particular value phi b dash just like phi dash, so estimation is easier. So, let us understand how to estimate the shear strength parameters? C dash phi dash and phi b dash from the suction controlled direct shear test data.

We have 4 test conducted. In test one the u a minus u w in test from the u a minus u w is maintain to be 10 kilopascal, and sigma minus u a at failure is equal to 100 kilopascal maintained. And tau f is shear stress at failure is observed to be 55 kilopascal. This is a direct shear test data. And test to u a minus u w is 10 kilopascal, and sigma minus u a at failure is equals to 300 kilopascal, and tau f is 150 kilopascal.

In test 3, u a minus u w is 300 kilopascal, sigma minus u a is 170 kilopascal, and tau f is 240 kilopascal. And test 4 u a minus u w equals to 300 kilopascal, and sigma minus u a at failure is 295 kilopascal, and tau f is equal to 300 kilopascal.

So, this is how the direct shear test by controlling the suction is conducted. So, here in 2 test the matrix suction is constant which is maintained to be 10 kilopascal, then the net normal stress is changed from the first test 100 kilopascal, it is changed to 300 kilopascal in the second test. And 2 more test are conducted, by maintaining different value of matrix suction in these 2 tests, that is 300 kilopascal and 300 kilopascal, but the net normal stress is now changed from 170 in the third test to 290 kilopascal in the 4th test.

So, we have this observation, tau f is value there is a shear stress at failure for all these 4 test. So, using this simple data, if you conduct for different test, then you will get all these strength parameters estimated. But in case of Bishop's more coulomb criterion to obtain the Bishop's strength parameters, we need to conduct series of tests for getting a smooth variation of xi f with respect to matrix action.

So, if you have wide range of matrix suction values that may vary in your soil, at all these different matrix suction data points, at all these different matrix suction values the xi f need to be estimated by conducting so many number of test and then xi f can be estimated. Because here the phi b is a single value and this is not a function form. So, therefore, just simply 4 different test if you conduct you get all those 3 Fredlund strength parameters estimated.

So, using the first 2 tests using Fredlunds equation when u a minus u w is constant, so, under particular u a minus u w, so then the plot is between if you recollect. So, the plot is between tau f and sigma minus u a. So, this is at one particular u a minus u w, this u a minus u w is not 0. So, it is at one particular matrix suction so then the angle is phi dash at one particular u a minus u w, the angel is phi dash and the intercept is C 1 dash some values because if the u a minus u w is 0 then intercept is C dash. But this C some other intercept, because we are plotting at one particular u a minus u w.

So, therefore, this equation is simply tau f is equals to C 1 dash plus sigma minus u a at failure and tan phi dash. So, if we substitute from this from this 2 test, this is 150 is equals to C 1 dash plus sigma minus u a is 300 tan phi dash. And here this is 55 is equals to C 1 dash plus 100 tan phi dash.

So, if you solve these 2, that is if you take difference of this, then this is tan phi dash is equal to 95, 95 by 200. So, phi dash is 25.4, phi dash is 25.4 degrees. So, already got one strength parameter. So, from this if you substitute this value here, you can get C 1 dash as 7.55 kilo Pascal.

Similarly, if you solve this 2, so here at a 300 kilopascal this is at u a minus u w is 10 kilopascal. Here this is at u a minus u w of 300 kilopascal. So now, tau f is 300 is equal to this is C 2 dash, because this a different matrix suction value. So, the intercept will be different. So, therefore, C 2 dash is C 2 dash is different from C 1 dash, plus sigma minus u a is 295 tan phi dash this is 240 C 2 dash plus 170 tan phi dash. If we solve these 2, by subtracting from one to another, we get phi dash is equals to tan inverse 60 by 125, which is equals to 25.64 degrees. And if you substitute this value, and you get C 2 dash as 158.4 kilopascals.

So, as phi dash we generally assume that it is constant it does not vary even with change in the matrix suction. So, phi dash we can average root. So, phi dash is equals to average of 25.4 plus 25.64 divide by 2. So, you can consider this to be 25.52. So, this average value we can use. So, coming to the first intercept, 7.55 kilopascal and second intercept is 158.4 kilopascal. From the equation tau f is equals to C dash plus sigma minus u a f tan phi dash, plus u a minus u w at failure times tan phi b. So far we have utilized only this part. So now, when this is plotted as tau f versus u a minus u w, you get some intercept here and here this is phi b.

So, this intercept changes. So, this intercept is C 1 dash and where u a minus u w is equals to 0 this becomes C dash. And at different u a minus u w say, initially u a minus u w is 10 kilopascal, 10 kilo Pascal this is C 1 dash, and at u a minus u w of 300 kilo

Pascal somewhere here. This is C 2 dash so this is C 1 dash, this is C 1 dash and C 2 dash.

So, therefore, now C 2 dash which is equal to 158.4 kilopascal, the expression is C dash plus u a minus u w that is 10 kilopascal times tan phi b. Sorry, 300 and the other expression the C 1 dash is 7.55 is equal to C dash plus 10 kilopascal is a suction times tan phi b dash phi b. If we solve this, we get phi b is equals to tan inverse of 150.86 divided by 290. This is 27.48 degrees. So, if you substitute this value here, then you get C dash is equals to 2.35 kilopascal.

So, the strength parameters are C dash equals to 2.3 kilo Pascal, and phi dash is equals to 25.52 degrees and phi b is equal to 25.48 degrees. So, these are the Fredlund all strength parameters from the extended mc criterion. So, this is how the direct shear test data can be analyzed for understanding the shear strength parameters from the extended mc criteria.

So, here same expression can be used only 4 test data are required to analyze the whole data. And then if this is available this set of data is available. So, entire surface can be plotted and at any given point. At any given matrix suction value at any given net normal stress the shear stress at failure can be obtained; a very easy to do because you already analyze graphical technique of representation of stress earlier.

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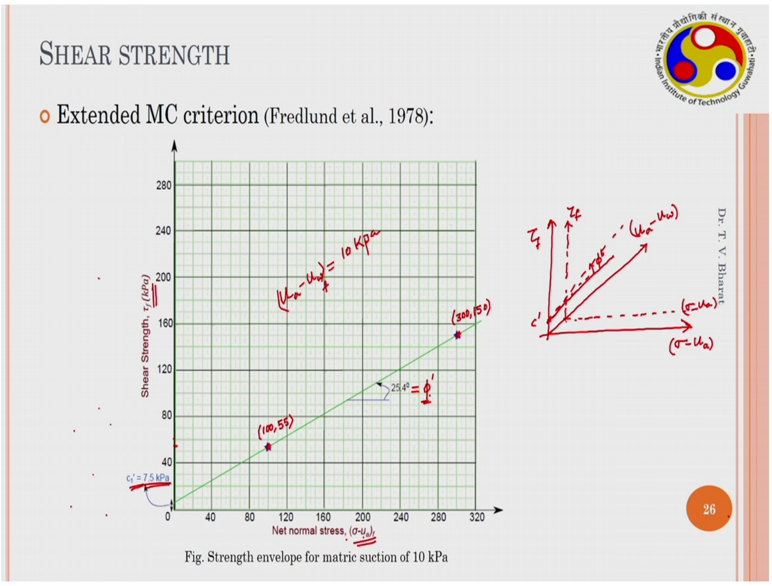

Fig. Strength envelope for matric suction of 10 kPa

So now this will be easy to do it graphically. So, once you take a graph sheet and then give proper dimensions for the x axis and y axis. So, here the x axis dimensions are varied upto 320 kilopascal, because net normal stress in our case where is up to nearly 300 kilopascal. So, similarly the shear strength, tau f is also varied in this particular manner. And here the initially the net normal stress sigma minus u a at failure and tau f are plotted. So, because the matrix suction is not 0, you do not have any test conducted fully saturated strait.

So, the matrix suction varied for 2 different test one is at 10 kilopascal and another one is at 300 kilopascal. Therefore, you have an intercept which is a C 1 dash not C dash. So, how to obtain the C 1 dash. Now one particular test data there is at u a minus u w is equals to 10 kilo Pascal, you have 2 test from this 2 test, the sigma minus u a that is a net normal stress is 100 kilopascal, this is 100 corresponding to the shear strength of soil is 55 kilopascal, so 55 is here.

So, this is 60 and this is 55, so this is the point. And second test at the same matrix suction is conducted. So, because tau f sigma minus u a on x axis and u a minus u w on y axis z axis, then had one particular u a minus u w. So, when you plot at one particular u a minus u w that is 10 kilo Pascal, this is what we are plotting. So, here if the u a minus u w 0, then intercept is C dash. But here this u a minus u w is not 0 therefore, the intercept is slightly higher than that, because in this angle is slightly different. So, if C dash same then this is a thing and if it is slightly C dash is increasing with increase in the suction. So, this angle is phi b, that is what we got.

So, therefore, here one particular net normal stress at u a minus u w corresponding tau f is given here. And another point at the same matrix suction value; that is at 295 kilopascal, the tau f is 150 kilopascal. This x axis is x axis is 300, and y axis is 150. And here x axis is 100 and y axis is 55. So now, if we join this line with a straight line, the angle is phi dash and intercept is C 1 dash.

So, this is intercept, this is same as what we got by solving those 2 equations.

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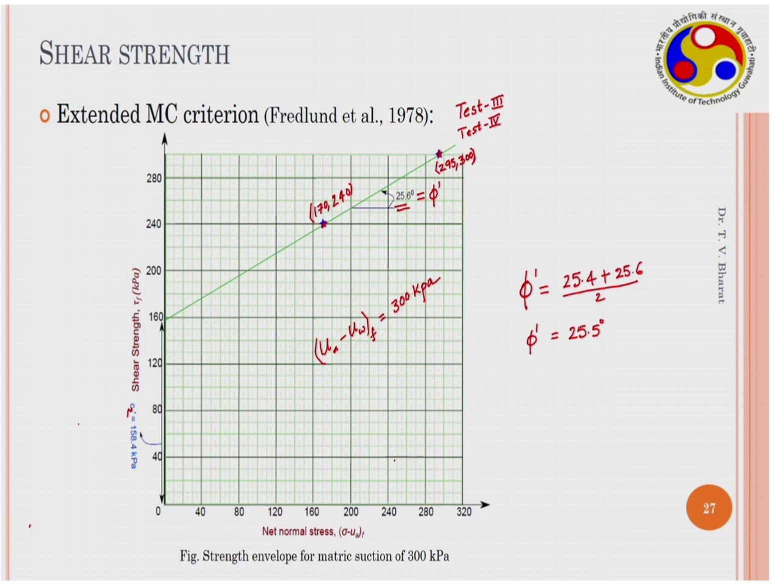

Fig. Strength envelope for matric suction of 300 kPa

Similarly, other 2 test data that is test 3 and test 4 are taken. So, another graph sheet is taken and the axis are noted down on x axis and y axis. X axis an again this is sigma minus u a at failure, and y axis is tau f. Now when this is plotted, one particular value of a sigma minus u a that is 170 and tau f at failure is 240 is plotted and another point. Sigma minus u a from the 4th test is 295 and tau f is 300 kilo Pascal on y axis.

So, when these 2 are connected with a straight line, you get C 2 dash, you get C 2 dash that is intercept at u a minus u w of this is at u a minus u w of 300 kilopascal. So, the intercept is 158.4 kilopascal and the angle this is again phi dash is 25.6 degrees. So, in the earlier, earlier this is u a minus u w is 10 kilopascal. And we got one C 1 dash and phi dash. And when at u a minus u w at failure equal to 300 kilopascal, and you get 158.4 kilo Pascal intercept. And phi dash is 25.6, so when we take a average, we get the angle of internal friction, average value that is from earlier 25.4 plus 25.6 here. If you take average you get 25.5, so this is phi dash.

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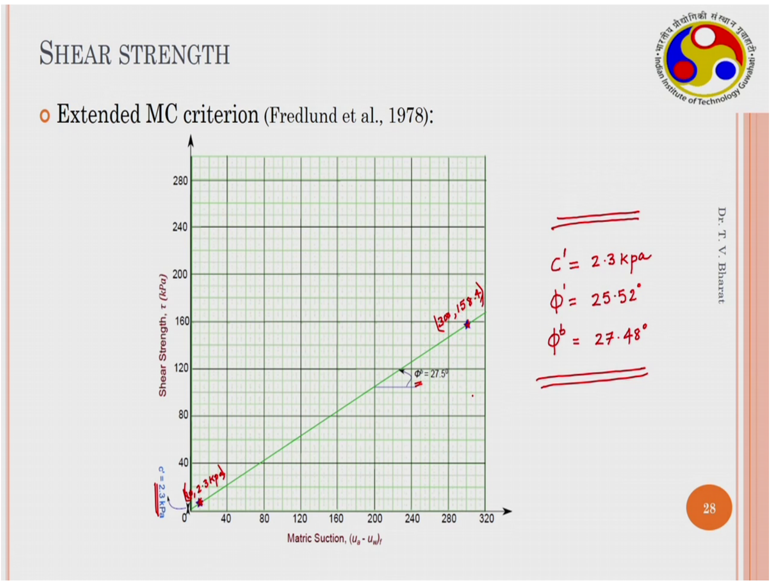

Now, we have the other axis the ratio shear stress, tau on y axis and matrix suction u a minus u w on x axis then the first intercept there is C 1 is 2.3 kilopascal. And other intercept that is 158.4 kilopascal. This is y axis for the matrix suction of 300. And here 10 is matrix suction therefore, x is this one and y is this.

So, from this if you join these 2 points you get phi v angle and the intercept which is 2.3 kilopascal. So, the C dash that is cohesion intercept is 2.3 kilopascal, and a phi dash which is already an average data which is which we used from the 2 4 test, from the first 2 test we got one value and the other 2 test we got another value. So, from this average we got 25.52 degrees and phi b which we got from these to intercept values at 2 different suction.

So, that is 27.48 degrees. This data is same as what we got analytically by solving those equations. So, this particular problem can be solved using with a graphically, or by simply solving those equations by substituting test data from 4 independent test, so.

Thank you.