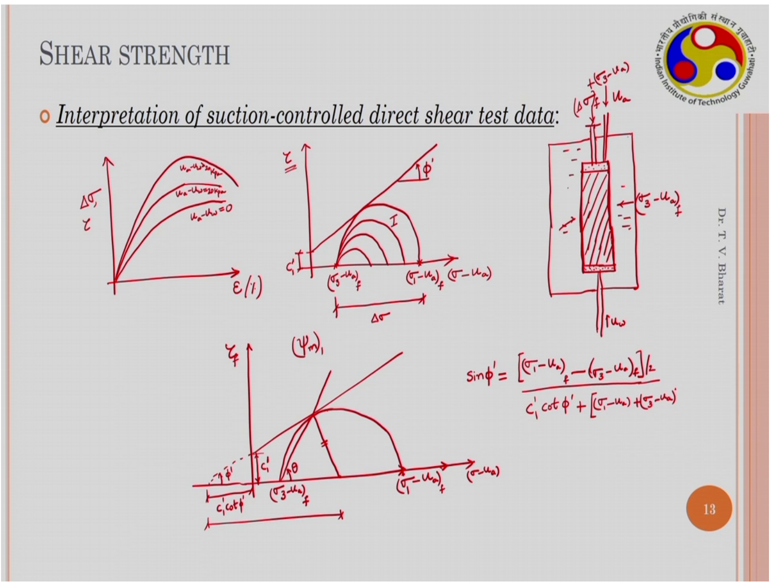
Unsaturated Soil Mechanics
Dr. T.V. Bharat
Department of Civil Engineering
Indian Institute of Technology, Guwahati

Week – 09
Lecture - 25
Suction-Controlled Triaxial Test

Hello everyone. Let us understand how to interpret the Suction-Controlled Triaxial test data.

(Refer Slide Time: 00:37)



So, in Triaxial test we generally get a data of deviatoric stress. So, the deviatoric stress is delta sigma or delta sigma dash depending on the type of test. If you are conducting drain test, then you could say delta sigma dash. This is called deviatoric stress or shear stress this is nothing, but shear stress versus axial strain. We get and this varies in this manner and as the suction increases in suction controlled tests, this is this is increases in this manner and this increase so on so forth.

This is one particular suction so, this is maybe 0. So, fully saturated soil exhibits this behaviour and this is u a minus uw. So, sum value 10 kilo Pascal or 20 kilo Pascal and this is a higher value as the suction increases, the delta sigma failure starts increasing. So, this is because when you interpret in terms of Mohr circle. In Mohr circle term this is sigma minus u a net normal stress and this is tau, then initially you take a soil sample and consolidate and this is sigma 3 minus u a. And, then increase the stress the axial stress the delta sigma is increasing on this.

So, at one particular loading condition it fails. So, this is sigma 1 minus u a at failure. This is sigma 3 minus u a at failure did not becomes sort of a constant all round pressure, when you when we increase the deviatoric stress. So, this is deviatoric stress delta sigma. So, when we increase the deviotoric stress the soil sample fails at one particular loading, and that is sigma one minus u a f there is a major principle stress acting on the soil sample.

So, now when we conduct a different as this is one particular test and if we conduct different tests you will get the critical straight line like this. And, in unsaturated soils we get intercept even for sandy soils. In unsaturated soils, when we do triaxial test, when the soil is completely saturated, then generally we do not get any cohesion intercept we only get phi angle of internal friction, but because this is unsaturated you get a cohesion intercept of c 1 dash c one dash you get right.

And, this is angle of internal friction fine and cause in your triaxial test the sample of 3.8 centimetre by 7.6 centimetre length, there is a standard size of the soil sample, where one coarse porous plate is kept on the top of the sample. And it is fix on a higher inter disk porous plate and the sample is inside a flexible membrane, there is a membrane which covers the soil sample and the porous disc. And, here you can control the pore water pressure inside the sample and this is connected to reservoir.

So, you can control u w similarly this is connected to a u a pore air pressure controlled and this is a coarse disc and the air can enter, and then it can control whatever this u a minus u w you want to maintain within the soil sample. So, and then you have a loading RAM and which is connected to a delta sigma is applied using this. And, this whole setup is contained in a, there is a all run pressure that is acting.

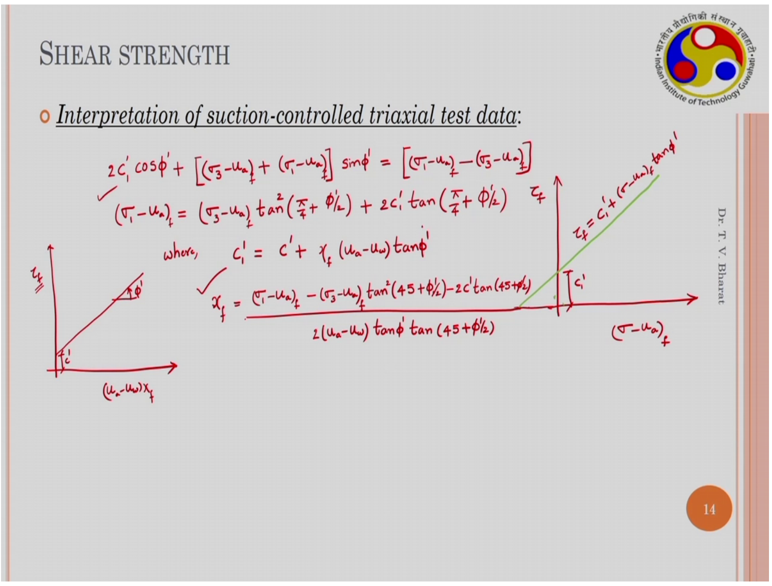
So, there is a u a u there is sigma 3 minus u which is acting all room, on the sample and this 1 plus sigma 3 minus u a, this is sigma 1 minus u a. So, under this stress state soil fails at 1 particular delta sigma f and at that delta sigma f, we get a sigma 1 minus u a f and a sigma 3 minus u a f, we get corresponding tau f or shear stress at failure.

See, if I consider the critical straight line somewhat like this. And, this can be extended to somewhere here, and you have tau f here and you have sigma minus u a. Now, this angle is phi dash and this is this is c 1 dash, c 1 dash because this whole thing is done at one particular matric suction value.

So, this is the critical straight line I got. So, this is my Mohr circle and this is a centre of it and this is failure plane and so, this is theta. So, this value is c 1 dash cot phi if we take sin phi dash, this is equals to this is sigma 3 minus u a at failure, and this is sigma 1 minus u a at failure and this is sigma minus u a on x axis.

So, sin phi dash is equals to sigma 1 minus u a f minus minus sigma 3 minus u a f divided by C 1 dash cot phi plus this is divided by 2 radius. So, this is radius this one that is this quantity and this quantity. So, C 1 dash cot phi plus this is a sigma 1 minus u a plus sigma 3 minus u a by 2.

(Refer Slide Time: 08:11)



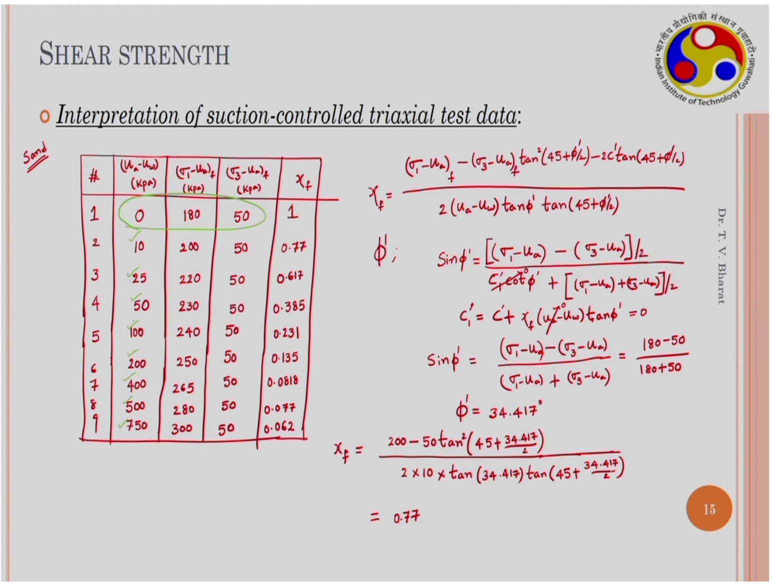
If, we simplify we get 2 C 1 dash cos phi dash, because cot phi times sin phi multiplication will get cos phi dash plus sigma 3 minus u a plus sigma minus 1 minus u a times sin phi dash is equals to sigma 1 minus u a minus sigma 3 minus u a.

So, if we simplify we get sigma 1 minus u a is equals to sigma 3 minus u a times tan square pi by 4 plus phi dash by 2 plus 2 C 1 dash, tan pi by 4 plus phi dash by 2. So, this is the expression you get here C 1 dash is equals to this is a tau f versus sigma 1 minus u a f if you plot this varies in this manner. So, this is C 1 dash and so, this expression is tau f equals to C 1 dash plus sigma minus u a f tan phi dash, this expression that tells you.

So, with increasing the sigma 1 minus u a f the tau f increases in this particular manner. So, this sigma 1 dash is nothing, but C dash plus xi f times u a minus uw tan phi dash. So, if I plot tau f versus u a minus u w xi f I should get an equation something like this. So, this angle is phi dash. So, this is a intercept C 1 dash is equals to that is again somewhat like this that is what you get? So, this expression can be simplified for sub xi of f is equals to sigma 1 minus u a I did not put, if there is a at failure.

So, f minus sigma 3 minus u a at failure times tan square 45 plus phi dash by 2 minus 2 c dash tan 45 plus phi by 2, divided by 2 u a minus u w tan phi dash times tan 45 plus phi dash by 2. So, this is the expression to obtain estimate, how the effective stress parameter varies with matric suction or volumetric water content. So, this expression is similar to what we get for saturated soils except that the C 1 dash the intercept is nothing, but C dash itself. So, when you substitute u a minus u w is equals to 0. This boils down to the equation which we use for interpreting the triaxial test data under saturated conditions.

(Refer Slide Time: 12:45)



Let us understand how to estimate the effective stress parameter from the measured data. Here some synthetic data is provided from that we will understand how to get the xi f estimated. So, in this particular example so, number of tests were conducted suction is controlled and sigma 1 minus u a f is measured and the sigma 3 minus u a f is controlled.

So, in the first test it is the test is conducted on a saturated soil. So, the matric suction is 0 and sigma 1 minus u a is 180 kilo Pascal. This is observed when the all run pressure is maintained to be 50 kilo Pascal. So, this particular test is conducted on sandy soil using modified or suction controlled triaxial tests. In the second test u a minus u w is maintained to a 10 kilo Pascal and the major principle stress is observed to be 200 kilo Pascal, when sigma 3 minus u a at failure is always maintained at 50 kilo Pascal for all different tests.

And, similarly at 25 kilo Pascal slowly the suction is increased, the sigma 1 minus u a at failure started increasing and this is 50, then this is observed to be 230 and this is same and for different suction values. So, this is 240 250 265 280 and 300. So, this is how the data started increasing for different sigma 3 values equal to 50 kilo Pascal, where this first test is conducted by maintaining one particular set of sigma 1 minus u a f and sigma 3 minus u a at f, but it is quite completely saturated state. So, once this test is conducted on sandy soil one can obtain the angle of internal friction value.

So, once the angle of internal suction value is obtained cohesion intercept is not present because this is a sandy soil. So, xi f parameter is of only unknown which varies with suction. So, for different suction values xi f can be obtained. So, that the functional relationship of xi f with other state variables such as either matric suction or volumetric water content can be obtained, and this function is unique for this particular soil and which can be used for any field applications. So, now, let us estimate xi f; xi f for the first case anyways is 1, because it is saturated soil from over effective stress definition xi f will be 1 if the soil is completely saturated.

So, therefore, this is one and if we recall our equation xi f is equals to sigma 1 minus u a f minus sigma 3 minus u a f tan square. So, this is the expression for xi f using triaxial tests. So, here to obtain initially we should get the angle of internal friction for the soil. So, to obtain this we have the expression that is sin phi dash which we have taken earlier is equals to sigma 1 minus u a minus sigma 3 minus u a, this whole divided by 2 divided by c 1 cot phi dash plus sigma 1 minus u a plus sigma 3 minus u a by 2.

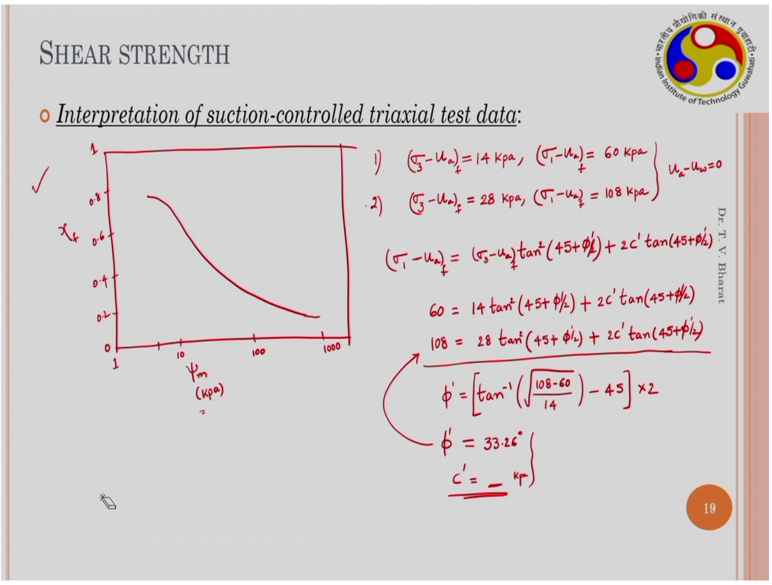
As, C 1 is equals to c because C 1 is equals to C dash plus xi f u a minus u w tan phi v as u a minus u w is 0 because this is conducted at fully saturated state C 1 dash should be equal to C dash. However, this is sand so, cohesion intercept is also 0. So, this whole term is cancelled this is 0.

So, therefore, sin phi dash is simply sigma 1 minus u a sigma 3 minus u a by sigma 1 minus u a plus sigma 3 minus u a. So, this is for the first example. So, this is 180 minus 50, that is 130 divided by 180 plus 50 that is 230.

So, phi dash is equals to 34.4 1 7 degrees. So, this is the phi dash. So, you can estimate xi f had different suction values. At suction value 10 this would become 200 minus 50 tan square 45 plus this 34.417 by 2 minus, then is this term whole term is 0. Because, C is not present divided by 2 times u a minus u w is 10 tan 34.417 times tan 45 plus 34.417 by 2.

So, this value is 0.77. Therefore, xi f values would vary in this manner 0.7 7 and 0.6 17 for suction value 25 and for 50. This would be 0.385 and for 100. 23 1 for 200 this is 0.135. For 400 this is a 0.0 818 for 500 0.077 and for 750 this is 0.0 6 7 6 6 2. So, this is these are the some of the values for xi f for different matric suction.

(Refer Slide Time: 21:33)



So, if we plot xi f and suction maybe varying from 1 to say 1000.

So, this is in log scale so, 1 so, this is a 10 this will be 100 and xi f is varying from 0 to 1. So, 0.2 0.4 it starts from 0.7 onwards and it goes somewhat like. This is how the xi f is varying with matric suction, there is a semi log graph. And, in case if we have test silty soil where you have cohesion and angle of internal friction then the data is interpreted in this particular manner. So, you need to have at least 2 data sets or 2 tests conducted at fully saturated state.

So, that the expression can be utilized directly to obtain the angle of internal friction and cohesion term so, once these 2 are obtained then you vary the matric suction by maintaining the all run pressure. So, that the sigma 1 minus u a at failure would be found from the tests and using this data. We can interpret how the effective stress parameter varies with matric suction.

So, let us take an example the same triaxial suction controlled triaxial test is conducted on a silty soil so, where it may have some cohesion so, then at least 2 tests need to be conducted. In the first test the sigma 3 minus u a is maintained to be at 14 kilo Pascal and sigma 1 minus u a you may obtain some value like 60 kilo Pascal. And, another test by with varying the sigma 3 minus u a say this value is 28 kilo Pascal.

So, then sigma 1 minus u a at failure may be 108 kilo Pascal. So, this is the measured data or observed data from the triaxial test when u a minus u w is maintained to be 0. So; that means, the tests are conducted at saturated state. So, when you conduct these tests at saturated state. So, you have the standard equation for the Mohr circle that is sigma 1 minus u a is equals to sigma 3 minus u a tan square 45 plus phi by 2 plus 2 C dash tan 45 plus phi by 2.

So, if we substitute the data this is 14 is equal to 60 tan square. So, this is sigma 1 is 60 is equal to 14 tan square 45 plus phi dash by 2 plus 2 C dash tan 45 plus phi by 2. And, other test data is second one is 108 is equals to 28 tan square 45 plus phi dash by 2 plus aims to C dash tan 45 plus phi dash by 2.

So, if we simplify these 2 equations. Then, you get phi dash is equals to tan inverse 108 minus 60 by 14 minus 45 times 2. So, this value comes out to be 33.26. So, if we substitute the phi dash value into any of these equations, then you get C dash.

Once, these C dash and phi dash are available, then other tests can be conducted at different matric suction values by perhaps you can maintain the sigma 3 u a constant and conduct tests by changing the u a minus u w, then you get different values of sigma 1 minus u a at failure, then using the expression shown earlier, you get the xi f at any given u a minus u w. So, therefore, once xi f is known we can obtain the relationship between xi f and u a minus u w that is psi m in this manner.

So, this relationship is unique to this particular soil. You can also alter the sigma 3 minus u a and u a minus u w and then the sigma 1 minus u a at failure can be obtained and based on that also you can interpret the results. So, either way you can get xi f value and then this could be used for the modelling. However, there are some shortcomings observed in this approach, because the xi f regionally believed that this is bounded by 0 and 1.

However, it is seen for some soils this is not bounded by 0 and 1. It may cross 1 for some soils moreover, if we observe the effective stress principle that is given by bishop that is sigma dash is equals to sigma minus u a plus xi f into u a minus u w.

So, for example, if we take some soils like, some compacted samples from the triaxial test setup can be taken. If, we take and this sample initially subjected to some stress conditions. And, after that the stresses are released and once the test is over are in between once the comes at once the soil is completely saturated. This specimen, when it does not have any stresses on the soils, then if use the effective stress principle it states that there is no sigma minus u a, because there is no stress that is acting on the soil and the u a minus u w is 0 if the soil is fully saturated if the soil is completely saturated.

So, then ua minus uw is 0 and this is also 0. So, accordingly the effective stress within the soil should be 0. So, a major limitation with this particular the bishop effective stress the model requires so many number of tests need to be conducted at different suction values, continuous distribution of xi f with respect to matric suction or volumetric water content can be obtained.

However, especially for fine grained soils conducting tests over a wide range of metric suction is not possible, because of the limitations associated with different test procedures. In the access translation technique the maximum range of matric suction is limited to from 0 to 1500 kilo Pascal. And, the osmotically controlled tests will have another limitation based on the pore size of the semi permeable membrane and molecular size of the pg polyethylene glycol solution.

So, therefore, as many number of tests required to estimate the xi f and moreover the xi f is not a unique relationship for different soils. So, it is difficult to conduct these tests and difficult to obtain the xi f parameters for given soils. So, people started looking for alternative interpretation of these test data and we will discuss one of such test data in the next class.

Thank you.