Unsaturated Soil Mechanics
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Week - 11
Lecture – 32
Summary: Shear Strength of Unsaturated Soils and Introduction to Volume Change

Hello everyone. We have been discussing the summary of different Mohr coulomb failure envelopes extended for Unsaturated Soils.

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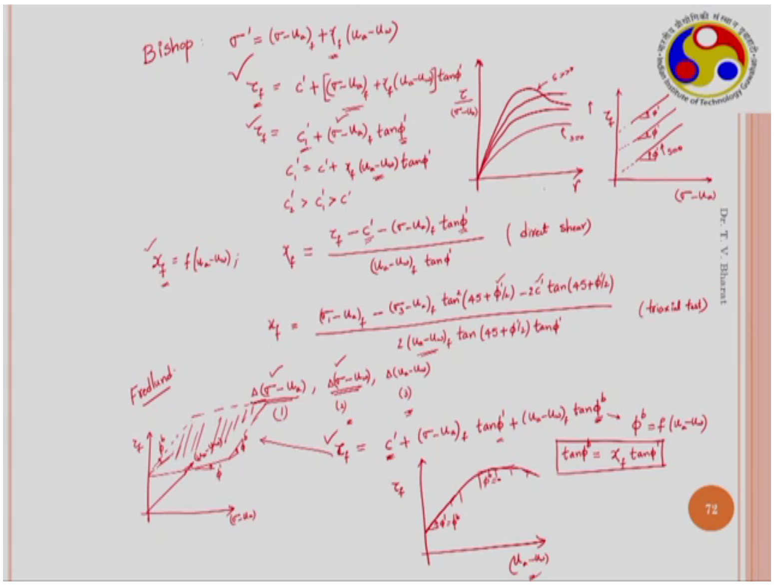

As, we have seen for the Bishops approach the effective stress principle becomes sigma dash is equals to sigma minus u a plus xi times u a minus u w. So, this xi f is a effective stress parameter this provides the contribution of matrix suction to the shear strength of the soil.

So, therefore, here as the xi f parameter becomes 1, then this turns out to be terzaghis effective stress principal, if xi f is equals to 0 and it reference state are at guaage pressure sigma dash is equal to sigma. So, this is nothing, but coulombs principle coulombs equation. So, the total stress is equals to effective stress. So, as bishop has identified 2 stress state variables such as sigma minus u a and u a minus uw, several tests were conducted by controlling the suction interracial and direct shear operators.

So, therefore, several data were obtained in direct shear where you get the stress ratios tau divided by sigma minus u a and gamma. So, this the stress ratio gets increased with increase in the suction. So, this is for suction equals to 0 that is for saturated state and as a suction increases the stress ratio gets increased. So, this is how it increases? Even as the soil is normally consolidated or the soil is loosely compacted, as the suction value increases interestingly at very high suction values it exhibits a peak behavior, such as over consolidated clays or densely compacted soils.

So, this is at very high suction value may be large suction value. So, therefore, if you plot tau f versus sigma, what we get is the failure envelops with different intercepts, this is for suction s equals to 0 and this is for higher suction and this is a much higher suction. So, as a profiles go up if the angle of internal sorry the intercept value keeps on changing increasing. However, the angle of internal friction value nearly same. Except that the, whatever the small difference we find in the angle of internal friction due to experimental errors, apart from that the angle of friction remains same.

So, therefore, this expression could be the tau f equals to sigma minus u a that is net normal stress plus sigma dash tan phi c plus c dash plus. So, the effective stress is this. So, this is sigma minus u a plus xi f u a minus u w times tan phi dash. So, if this expression tau f versus sigma minus u a is plotted. So, this could be written as some c 1 dash plus sigma minus u a, f tan phi dash. So, this c 1 dash is equals to c dash plus xi f u a minus u w tan phi dash.

So, therefore, when tau f and sigma minus u a these 2 are plotted here, the angle of internal friction remain same phi, but c 1 dash varies as u a minus u w changes. So, as u a minus u w varies the c 1 dash becomes c 2 dash. So, c 1 dash becomes c 2 dash and it keeps on increasing as u a minus u w increases.

So, this is what is observed. So, therefore, this expression could be used to understand or to analyze the test data we obtained from suction control test. So, then we have utilized this particular expression to determine the xi f from measured test data.

So, using this expression for direct shear test data for direct shear and for triaxial the xi f is determined from this expression. So, this is the expression for Triaxial test. So, in direct shear test we require c dash and phi dash to be determined as c dash and phi dash or the strength parameters of the soil, at saturated state and phi dash anyways remain same for even unsaturated soils phi dash does not change.

So, we conduct 2 tests 2 at saturated state. So, that we can determine c dash and phi dash when we vary u a minus u w then we get xi f. So, that xi f variation with respect to u a minus u w can be obtained. If the test is on sands as at saturated state the cohesion intercept is 0 one test can be conducted at saturated state. So, that we can obtain angle of internal friction value, and then we can obtain the functional form of xi f. In triaxial test also when we conduct 2 test at saturated state we can obtain c dash and phi dash, then once these 2 are known. The principal stress at failure can be determined by varying the u a minus u w as it is a suction control test we can control the u a minus u w and we can obtain the xi f variation with respect to u minus u w.

Once the xi f is known, a functional form is known for us. So, the effective stress is known for that particular soil and entire stress state of the soil can be determined in un saturation. So, this is a approach given by bishop and several modifications were suggested by Fredland Morgenstern and Fredland Et Al. Essentially they Fredland has conducted several null type test, where he has controlled u a the air pressure, water pressure, and the all round pressure independently. And, then he increased these values independently such that when the variation in sigma minus u a and delta sigma minus u w delta u a minus u w.

So, these values he started varying independently. So, then he checked the variation in any of these 2 stress variables are kept constant, and then he observed that the volume changes are 0. So; that means, he has kept these 2 parameters 1 and 2, the variation in 1 and 2 are kept constant and other can other thing can be varied then the volume remain same. Similarly, the 2 and 3 variation in the 2 and 3 parameters are second and third stress state parameters are kept constant.

So, then similarly the volume is constant. Similarly, even 1 2 1 3 and different combination of these stress state variables when they are maintained constant the variations, so, the volume does not change. That means, any of these 2 stress state parameters qualify for independently defining the stress state of the soil. So, therefore, he validates the Bishops approach and confirms that the sigma minus u a and u a minus u w these 2 stress state variables can be independently used for defining the soil state in unsaturated un saturation.

So, further he proposes a new shear strength equation new failure criterion, where tau f is written as c dash plus sigma minus u a, f tan phi dash plus u a minus u w times tan phi b. So, this particular expression is the very advantageous to represent the failure envelope clearly, when it is plotted in 3 dimensions tau f in 3 dimension tau f sigma minus u a and u a minus u w, or plotted. So, then the failure envelop can be clearly seen. So, this is how the failure envelope is obtained?

So, this angle with respect to u a minus u w is phi b and with respect to sigma minus u a is phi dash this is again phi b and this is the failure envelope. So, the equation defines this particular failure envelope. Initially it was thought that the phi b is constant. So, therefore, we do not require a huge data sets for determining the variation of xi f with u a minus u w. When phi b is constant only 1 set of data in saturated state and another set of data in unsaturated states are required.

So, that in using 1 set of data in saturated state we can determine sigma and c dash and phi dash. And, in unsaturated state we can determine phi b when u a minus u w is varied. So, this is what initially thought and then this I was considered to be a simplified and this is more advantageous, but later on it was realized that the phi b is not constant, phi b itself is a function of u a minus u w. And, as this was plotted tau f was plotted with respect to u a minus u w. It was observed that, initially this is nearly equals to phi dash when near saturation region of SWCC and later on it started decreasing and becomes 0 and even becomes negative.

So, here phi dash is phi b sorry this is phi b. And, this phi b is 0 and phi b even becomes negative for some soils this was observed experimentally.

So, therefore, as phi b itself is not constant and which varies with u a minus u w or amount of water that is present in the soils. So, we do not draw any additional advantage. This is just similar to the Bishops approach except that a new variable is given here. So, this is similar to when you compare this expression and bishop’s expression.

So, here the tan phi b is equals to xi f tan phi xi f tan phi dash as xi f is not vary not constant. So, therefore, phi b is not constant.

So, therefore, phi b anyways whatever we are obtaining phi b from either considering several set of data, at different matrix suction values to determine phi b this approach will be similar to obtaining xi f using set of several sets of several set of data. From suction control direct shear and suction control triaxial test.

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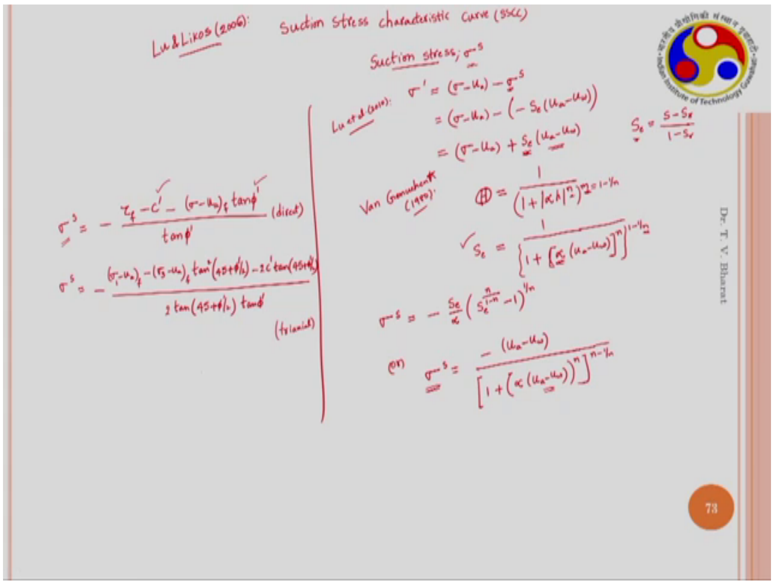

Later on Lu and Likos in 2006 have come up with suction stress characteristic curve called SSCC.

So, in the suction stress characteristic curve if defined suction stress as, as stress a stress which takes care of all the chemical potential that has decreased due to presence of electrostatic potentials, capillary suction force, capillary forces due to surface tension and van der wall attraction forces between the particles. And all are cementation all any other forces that that can come into soils in un saturation and even at saturated state. So, therefore, they introduced suction stress, in the suction stress approach they have in the expression that is sigma dash is written as sigma minus u a minus sigma s.

So, this is suction stress. So, suction stress should absorb all different components of all different types of physico chemical capillary force effects in this particular parameter, but later on this equation got diluted by introducing in Lu Et Al 2010. This expression in Lu and Lu and Et Al 2010 later on this expression got reduce to simply minus se times u a minus u w, which was similar to bishops approach. So, if you write the substituted sigma S as minus se times u a minus u w. So, this is simply se times u a minus u w.

So, this se is a degree of saturation, but this is a normalized degree of saturation degree of saturation itself got normalized S e is equals to S degree of situation at any given point minus residual degree of saturation at residual point divided by 1 1 minus S r.

If, S r equals to S equals to S r this becomes 0 if S becomes 1. So, then this whole thing becomes 1 so, S e varies from 0 to 1. So, then they have substituted they expressed se or u a minus u w in terms of in terms of other they expressed S e terms of u a minus u w, or they expressed u a minus u w in terms of se using interrelationship proposed by Van Genuchten equation. So, as Van Genuchten in 1980; he has given expression for volumetric water content normalized volumetric water content that is 1 by 1 plus alpha times he essentially says h over n whole power m. And, later on he related m and n and m is related to n by this particular formula.

For simplification so, that you have only 2 parameters to estimate. So, similar expression is used by Lu Et Al in 2010, they have used this particular form and they have used alpha and u a minus u w power n power 1 minus 1 by n. So, this expression they used then the effective stress equation is written as in terms of S e, this can be written as se power n by 1 minus n minus 1 whole power 1 by n or in terms of u a minus u w this becomes 1 plus whole power n minus 1 by n.

So, these 2 expressions were given and again the estimation of this is a continuous form. So, if you have the data of SWCC then you can fit to this particular expression Van Genuchten expression and you can obtain alpha and n parameters. So, if you know the alpha and n parameters you can obtain the suction stress characteristic curve by plotting sigma s versus u a minus u w, if you do not have this data again using the same expression similar to bishops.

So, the sigma S can be written as minus tau f minus c dash minus sigma minus u a f tan phi dash tan phi dash, this is for direct shear and for triaxial. So, this becomes sigma minus u a sigma 1 minus u a at f minus sigma 3 minus u a f tan square 45 plus phi dash by 2 minus 2 c dash tan 45 plus phi dash by 2 by 2 tan 45 plus phi dash by 2 tan phi dash.

So, here similar to bishop the c dash and phi dash can be determined, if the tests are conducted at saturated state, and then beyond that after that when the direct shear test is conducted at particular u a minus u w. Then sigma S can be determined at different u a minus u w S, and sigma S and u a minus u w can be plotted to obtain the Suction Stress

Characteristic Curve SSCC. Similarly, this is with triaxial test, triaxial shear stress data is analyzed in this particular manner.

So, essentially all these approaches are similar to bishops approach, where either to determine xi f if xi is known the tan phi b. The phi b parameter in Fred land and Morgenstern can be obtained and the suction stress characteristic (Refer Time: 21:48) can also be derived if xi f is known.

So, therefore, essentially all these approaches are same and still so, to determine the effective stress of unsaturated soil we require xi f or phi b are sigma S. So, therefore, we can determine effective stress and we can understand the failure envelopes in unsaturated soils. Let us discuss a new topic that is volume change in unsaturated soils. In our basic soil mechanics we study the volume change behaviour of soils in consolidation.

So, when the load is applied on saturated soil mass either isotropically applied load or under k naught condition isotropic load is applied in triaxial tests on saturated soils and under k naught condition this is conducted in odometers. When, this loading is applied the excess pore water pressure that is generated in the soil mass soil pore system, we will get dissipated through the boundaries and once this has got dissipated the volume changes.

Because, there are only 2 phases that is water and soil solids as water goes out the volume of the sample decreases. So, this decrease in volume is called consolidation and the volume changes are very important in the field problems. Especially, when you have expansive soils located and when you are constructing a building or any building or when you are constructing an embankment the consolidation settlements are very important.

Often we theoretically determine the coefficient of consolidation in the laboratory by take collecting the sample from the field and conducting odometer test, under field conditions and the coefficient of consolidation is obtained. And, this coefficient of consolidation is utilized in the field for obtaining the rate of consolidation settlement. Similar to estimate the consolidation settlements, we load the sample and let it consolidate and again we increase the load and let it consolidate, similarly we obtain in e log p curve that is e versus sigma dash effective stress effective stress relationship. This constituent relationship is similar to stress strain relationship. From this you get bulk modulus that is mv are 1 over mv and you get hydraulic conductivities at any given point. And, similarly using the entire constituent relationship you will obtain coefficient of compression CC.

So, from this we can obtain the consolidation settlement or using the bulk modulus that is one over mv you can estimate the settlements. Often this terzaghis 1 dimensional approach is criticized and for highly expansive soils or when the soil is highly plastic, or when it is slurry state like mine tailings etcetera. A large strain consolidation approach is used because terzaghis consolidation consolidation approach uses small strain approximation.

So, large strain consolidation approaches are also available. So; however, all these considerations are based on soil state to be at saturated completely saturated.

However, when the soil is unsaturated, then the change in the volume how to determine the change in the volume or how to analyze the change in volume?

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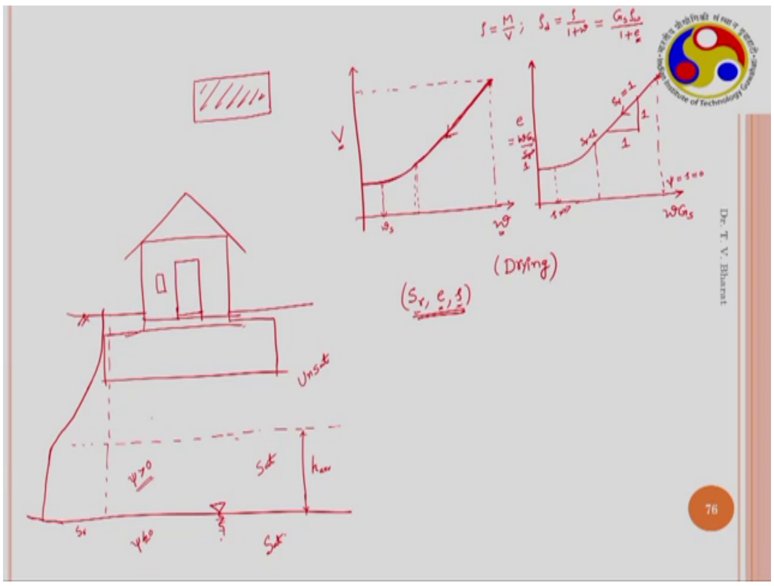

So, we have often seen that, when initially a saturated or slurry state soil is kept in a small container, this is slurry sample and when this is exposed to the environment. So, slowly the evaporation takes place, due to this evaporation from the soil mass. So, the water content of the soil decreases. So, soil enters into unsaturated state. So, this is often seen as the volume of the sample and water content are plotted.

So, initially the sample state is somewhere here sample water content is at may be slurry state or at equilibrium state. So, this is done in shrinkage test shrinkage limit test. So, this is the initial state, where it has particular volume and particular water content. So, when the soil is subjected to drying, because when the soil is kept in atmospheric conditions.

So, due to the rh and temperatures there is a some suction load that is applied on the soil mass. So, because of which soil volume decreases up to certain water content and beyond that this is non-linear and the change in the volume ceases to be exist at one particular water content, which is called shrinkage limit. So, up to one particular water content this is linear.

So, the volume decreases linearly with water content. So, this also can be plotted as degree of saturation sorry void ratio. So, because the volume of the soil is known and water content at any given point are known. So, we can obtain what is the total mass is also known mass of the soil sample is known, because when the water content measurement is taken the soil is weighed right. So, therefore, the density of soil bulk density of the soil is known because total mass and total volume is known.

So, knowing the bulk density the dry density of the soil can be obtained using this particular expression knowing the water content the dry density can be obtained. Knowing the dry density, knowing the specific gravity, we can obtain the void ratio.

So, that is how the void ratio can be obtained and which is plotted on y axis and on x axis instead of w if we plot with w G s, w G s we see that there is one is to one line. There is a one is to one line exists up to certain water content; that means, the degree of saturation of the soil remains same. And, beyond that degree of saturation becomes less than here degree of saturation is one and here degree of saturation is less than 1 beyond this and here degree of saturation may remain same constant.

Because, the decrease in water content is nearly constant and it almost ceases to sorry degree of saturation slowly becomes close to approaches to 0. So, the volume see here it approaches one is to one. So, therefore, if the what e is equals to w G b s r. And as s r equals to 1 up to here this is this follows one is to one line.

So, s r is equals to 1 so, w G and w G. So, therefore, it plots 1 is to 1 line. So, as the soil is subjected to drying. The degree of saturation remains same up to one particular water content and beyond that the degree of saturation decreases. And, volume of the sample continuously decreases from the beginning itself and what happens to the suction; suction of the soil increases. Here the suction maybe 0 the suction either psi or s smallest is equals to 0, the suction is very high. Suction becomes very very high may be in terms of MPa you may be able to measured depending on type of soil also.

So, this particular thing happens in expansive soil or soils which exhibit volume change during drying and wetting. So, this is a drying process. So, soil exhibits a volume decrease during this particular process. Similarly, when the soil is subjected to wetting the soil volume starts increasing.

So, how much it increases or how the suction varies here the suction volume the degree of saturation the volume. So, which can be represented with void ratio and suction 3 different parameters are changing, when the suction is increased the volume maybe decreasing and degree of saturation will be decreasing.

So, similarly these 3 parameters are dependent on one and each other. So, to understand the soil behaviour we need to conduct the tests under controlled environment by controlling suction and how these parameters are changing this is what needs to be done? Similarly, this is this particular tests are conducted when there is no external load, but similar tests may also exists when we are constructing a building or any other structure on soils. So, this may be foundation and you may have a groundwater table (Refer Time: 31:47) somewhere as here.

So, this is a groundwater table and this is ground surface. And, you may have a fully satruated region, that is capillary region may be up to here. So, this is equal to the air entry head height or capillary height. So, beyond that this is unsaturation. So, if you see the profile. So, if you see the variation. So, the water content varies in this particular manner, water content nearly same or degree of saturation is same, but beyond that it decreases decrease in this manner.

So, when the water content decreases in this particular manner. So, this is may be degree of saturation and this is height. So, the degree of saturation may decrease in this manner. So, essentially when you are constructing some particular building in unsaturated region this is unsaturated region, and this is saturated region and this is saturated region, but here the suction component exist suction is more than 0 here suction is 0 or suction is less than 0. So; that means, this is a there may be positive pore, water pressures exist below the ground water table, but here you will have suction value more than 0 and here the suction value will be very high.

So, when you are constructing such building or when you are exerting some loading due to construction activity. How the soil volume changes is our important question that need to be addressed. For that some suction controlled consolidation tests are also conducted.

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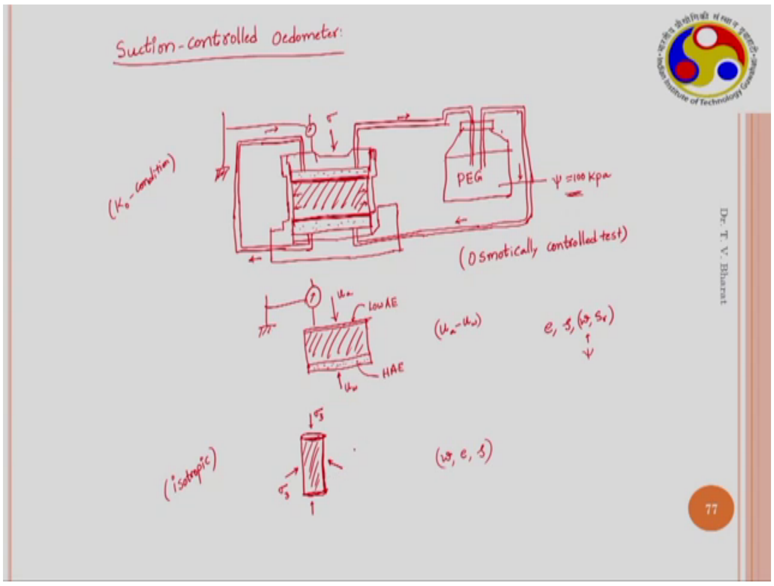

Suction controlled odometer tests are conducted. In the suction controlled odometer tests, we have odometer similar to what we have seen earlier we have 2 porous plates, look at it on top and bottom of the soil sample, if this is your soil sample. And, here if this is a ring which keeps the soil sample intact, this is a ring, and this is a loading plate, and load is applied on this, and there is a pipe are connected to circulate the peg solution. So, this is osmotically controlled odometer.

So, these are connected these are peg solution which is circulated into the around the soil sample boundaries. So, that the peg solution comes in contact with the pore water of the soil, there is a semi permeable membrane, which is kept here and again here. So, due to the semi permeable membrane in the peg molecules are not allowed to enter into the soil sample.

So, therefore, as a peg solution concentration is high on at the boundaries. So, the water will leave from the soil and the water content of the soil decreases. So, when the peg solution concentration which provides a suction value of say hundred kilo Pascal due to this 100 kilo Pascal suction it is exerted on the soil. So, the water content decreases due to decrease in the water content. So, under the either the applied load or even without the load the soil volume will decrease.

So, similarly this is osmotically controlled test and similarly using the access translation technique. So, where at the top and bottom of the clay sample are soil sample, you will have higher entry disk here H A E disk. And, you all have low air entry disk low air entry disk located at the top. That means, course porous stone is located at the top and higher entry disk is located at bottom. So, this is connected to a gas pressure gas chamber. So, the air pressure can be applied and through which the water pressure can be applied and this air entry higher entry disk is always kept saturated.

So, this is it maintains a very good hydraulic contact with the soil pore water. So, then the pore water pressure is maintained through this chamber and from the bottom and air pressure is maintained from the top. So, this way given u a minus u w is maintained within the soil sample. And, so, the volume of the soil sample can be obtained by connecting to a by measuring the height of the soil sample using dial gauge.

So, here also you will have a dial gauge, which is located and which measures the change in the volume you will have a dial gauge. So, which measures the change in the volume of the soil sample. So, this way void ratio can be measured suction can be controlled and the water content of the soil can be obtained by having independently established soil water characteristic curve. Therefore, the knowing the suction the water content or knowing the suction either water content or degree of saturation can be obtained.

So, this way to independently or these 3 parameters can be obtained from these particular tests and the constitutive relationships can be developed for different soils. Similarly, this is the K 0 condition because when you apply a load soil exerts pressure on the boundaries. So, this is K 0 condition, but in triaixal similar test can be conducted where we isotropically. So, this is the soil sample where we isotropically consolidate.

So, we exert an all round pressure of sigma 3 on the soil sample. So, therefore, soil can be isotropically consolidated. So, this is isotropic consolidation. So, therefore, in suction control triaxial tests the isotropic consolidation test can be connected. So, therefore, here the total volume that can also be measured.

So, amount of water that is leaving that can be determined. So, therefore, water content or degree of saturation and the void ratio because change in the volume is also known, and suction which is controlled all these 3 parameters can also can also be obtained in suction controlled triaxial tests; if you look at different data that we get from these tests.

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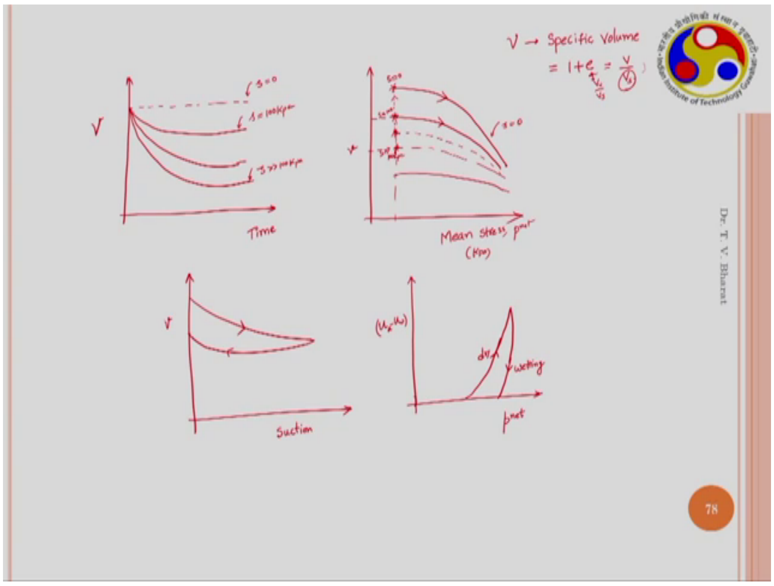

So, these are either plotted with void ratio or often this is plotted with specific volume. The, specific volume which is nothing but 1 plus e, 1 plus void ratio because void ratio is volume of volume of voids volume of solids. So, this is nothing, but total volume by volume of solids. As, volume of solids anyway is constant how the total volume changes with by apply a different suction and mechanical loading can also be can be obtained. Therefore, specific volume is often used.

So, the specific volume versus time for different applied loading, if you see so, when the suction is 0. So, not much change, but as a suction is increased you would see that the specific volume will decrease with time. So, this is equilibration time. So, with equilibration time the specific volume decrease for different suction higher than, 100 kilo

Pascal. Similarly, specific volume is plotted with the mean stress under different suction conditions.

Mean stress so, that is p net when it is plotted. So, when the soil is completely saturated. So, this is what we get this is typically a e log pico similar to e log pico this is a test equals to 0 this is a test equals to 0. So, that is purely saturated soil and for other soils a dry condition, because if the soil is expansive soil, the initial volume of the soil sample may be here. Due to saturation initially under this particular seating load, when you saturated the volume total specific volume becomes this and when you consolidate this is the curve that exhibits.

So, initially for example, under 100 kilo Pascal, for initially the sample may be somewhere here specific volume maybe somewhere here, when you saturate it upto 100 kilo Pascal. So, the initial state of the soil may be here. So, this is at s equals to 0 this is at S equals to 100. So, then if I consolidate so, it may consolidate somewhat like this. The slope of the curve change, because there is a suction because of which the, it does not consolidate as much as it does not compress or volume does not change significantly as it happens when the soil is completely saturated.

So, as my suction is increasing I obtain different profiles. So, here the initial state of the soil sample is different because my suctions are different here this is much higher than 100 kilo Pascal right. So, initially when the soil sample which is taken at dry state probably, it has a suction of may 1000 may be 1000 kilo Pascal. So, then the specific volume may be somewhat here when I reduce the suction within the soil into hundred kilo Pascal then; that means, some wetting takes place, because of which the specific volume becomes this much then I can consolidate.

Similarly, if I want to consolidated saturated state I allow the soil to completely saturate or wet it at seating load then it comes to say S equals to 0 and then after that they consolidate. So, I get different profiles like this for different loading conditions this may be at completely dry state. So, such kind of a profiles you can obtain. Similarly, the specific volume can be plotted with suction for drying and wetting. So, when the specific volume is when the suction is increased the specific volume will decrease, because the specific the increase in the suction the water content decreases.

So, due to decrease in the water content those specific volume will decrease. So, when you wet it, the specific volume increases, but it does not increase as much as we obtain in drying state. Similarly, when you draw u a minus u w, that is suction versus pnet net normal stress. So, during the drying process the net normal stress on the soil sample increases, which decreases as you wet it. So, this is drying and this is wetting.

So, the hysteresis behaviour can be studied very well and while studying the hysteresis behaviour the specific volume changes and the drying and wetting that hysteresis can also be studied very well in this particular suction controlled odometer test.

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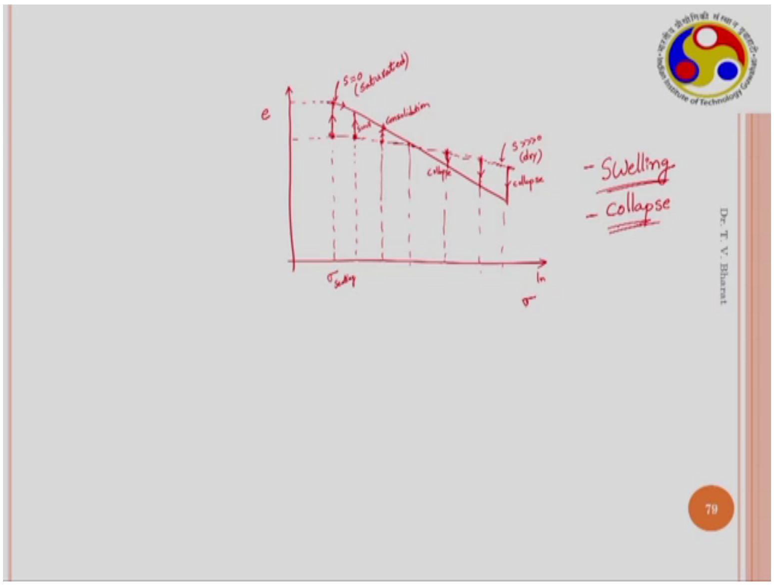

Further, further the void ratio versus log sigma can be plotted when you plot this void ratio versus sigma or sigma dash the effective stress what we see is the suction value when it is 0. So, this is a typical consolidation, test result when S equals to 0. If you assume that the e versus log p dash relationship is a linear, then this is what we obtain. And, when the soil is expansive soil, when the soil is expansive soil assume that this is the consolidation curve, when the soil is dry completely dry.

So, the initial state of the soil maybe somewhere here. The void ratio will be less than, the void ratio of the saturated soil under the same load; under this particular load the soils void ratio will be smaller than the void ratio, that we obtain for the completely saturated soil.

So, for the under the complete dry state, when you load it. So, this is compression this is not called consolidation when you compress the soil. So, the change in the volume will be negligible. So, which changes in this particular manner right.

So, because this is a dry soil when you are compressing by applying the loading so, change in the volume are the void ratio is not significant therefore, this is the curve you get or this is the relationship you get. And, this is at s equals to much greater than 0 or nearly dry state and this is completely saturated.

So, now when the dry soil at any particular loading, if you subject to wetting how does it behave? For example, at this particular loading, if I wet the soil sample for example, the soil sample is now initially compacted to one particular density. And, I will explain this one again initially the soil sample in a dry state which is taken in compacted and kept in odometer.

Now, this is under seating pressure, this is a seating pressure. Now, this is completely saturated. So, when this is completely saturated this is the void ratio the soil obtains at fully saturated state. Now, when we consolidate this is the curve we get. So, this is a consolidation curve. So, at each load increment at each load increment, we wait for soil to consolidate. And after it consolidates this is equilibrium void ratio and again we put next loading and that is how we consolidate the soil sample. So, this is what happens? Now, if you take dry soil sample with the same density and which is at this particular state where the void ratio is e.

Now, if the soil is compressed by applying loading and this is what we obtain dry state. So, now, at any given loading if the soil is subject to wetting. So, what is expected is the soil will swell or the volume of the soil sampling increases, which is called swelling. Similarly, another soil sample is taken which is again compacted to the same level, and again which is subjected to this particular loading, and again which is allowed to wet which is wetted, then it exhibits swelling and then it shows this behavior.

And, similarly here a small swelling is exhibited. Similarly, here when the soil this is in this condition, which is wetted which exhibit such decrease in the volume which is called collapse.

Similarly, the soil when it is here initially when it is allowed to wet when it is wetted it exhibits a collapse. Similarly, here also it exhibits a collapse. So, even swelling soils are expansive soils, when the soils are subjected to wetting under different confining stress or applied stress it may swell or collapse, or the volume may increase or the volume may decrease depending on the stress state of the soil.

So, therefore, the swelling and collapse behaviour of soils can be determined or studied very well by conducting several tests swelling and collapse behaviour of soils can be studied by analyzing their behaviour under suction controlled environments. So, swelling and collapse behaviour we detailedly see in the next class.

Thank you.