Unsaturated Soil Mechanics
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Week - 04
Lecture – 12
Suction Measurement/Control Techniques – II

Hello everyone, we have been going through several techniques for the measurement of suction. Some of them are useful for both laboratory and field. And so far we have seen some techniques where we control the suction.

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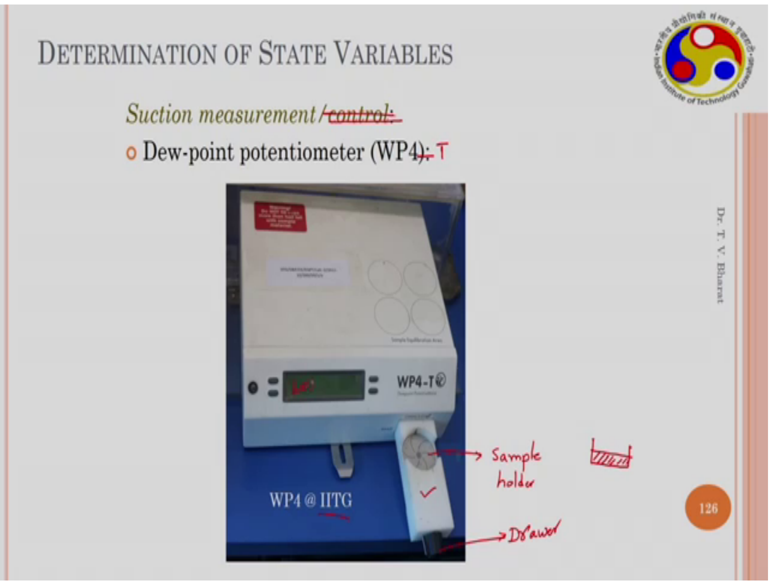

DETERMINATION OF STATE VARIABLES

Suction measurement/~~control:~~

- Dew-point potentiometer (WP4~~):~~ T

Now, we will discuss technique called dew point potentiometer or WP4 which is a laboratory technique. The technique is this particular setup is useful for measuring the suction rather than controlling. So, we do not control the suction in this particular case. Here we can measure the suction rather we estimate the suction indirectly. Let us see how we do it.

So, this is the dew point potentiometer which is called WP4 T which is developed by Decagon, USA. So, this is a set up at IIT, Guwahati, Geotech lab. This setup consists of a sample holder, where you can keep the sample generally a cup you have similar to shrinkage cup, but this is a smaller size where you can fill the soil to half of its height. So, it should be filled only half, half or less than half of the cup height. And this cup can be placed here and this is the drawer using this you can open or when you close it this whole thing will go in. So, it is a LCD display here and these are the operating switches.

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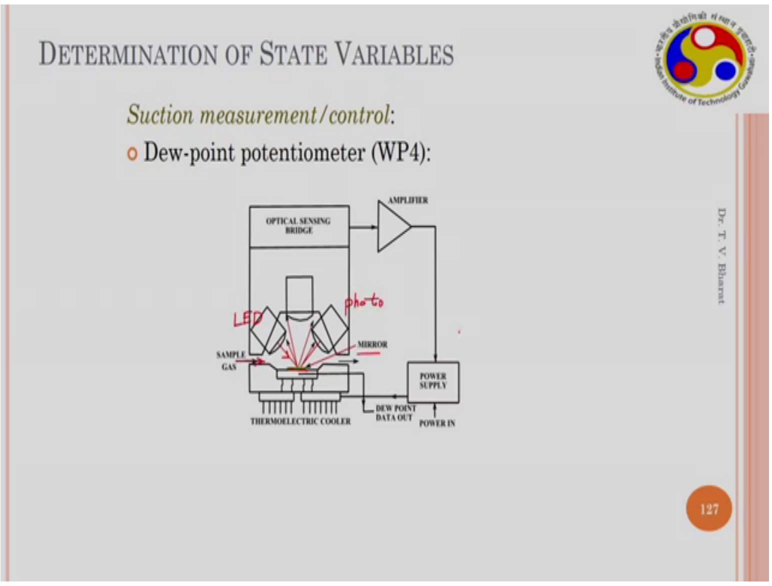

DETERMINATION OF STATE VARIABLES

Suction measurement/control:

- Dew-point potentiometer (WP4):

Dr. T. V. Bharat

And the operating principle of this particular technique is we estimate the suction we estimate the relative humidity of the soil or relative humidity of the pore spacer of the soil and from that we estimate the total suction let us understand how we do it.

So, in this particular technique you have a sample is fed through this and you have a thermoelectric cooler here and you have a mirror here, mirror is placed here and you have and you have a LED here. So, using this LED you have a ray which is going in and you have photo detector. Let us understand the principle behind this particular technique called WP4.

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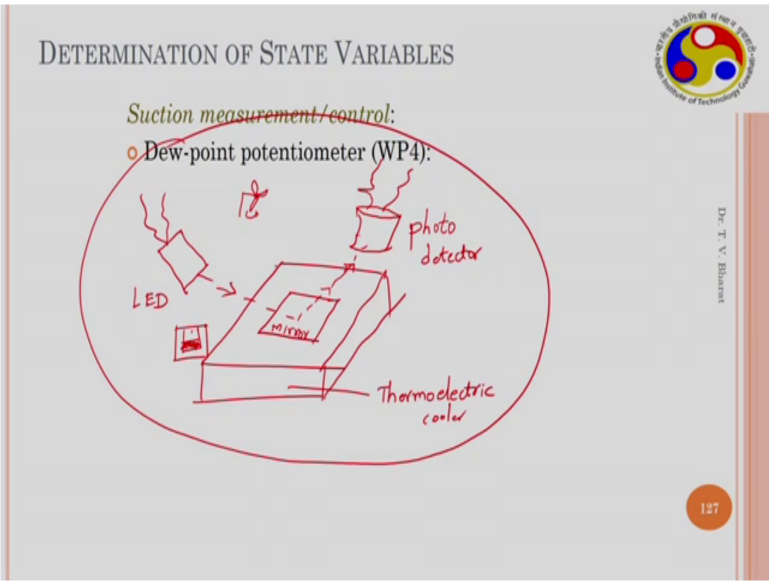

DETERMINATION OF STATE VARIABLES

Suction measurement/control:

- Dew-point potentiometer (WP4):

In this dew point potentiometer you will have a thermoelectric cooler, there is a thermoelectric cooler, on top you will have a mirror this is mirror and you will have a LED. So, wires will be connected like this and LED can send the rays and this can be detected by a photo detector. So, that reflected light can be detected by photo detector, this is LED.

So, the principal is very simple, here you have a LED which sends the rays and which will be reflected on this mirror and that are detected by the photo detector. So, here thermoelectric cooler which can cool down the ambient temperature so that when the ambient vapor pressure reaches the saturated vapor pressure there is a dew formation on this mirror, and the deviation in the reflected light can be detected using this photo detector and that would tell you what is the temperature at which the dew point has occurred. So, the dew point temperature can be obtained using this particular technique.

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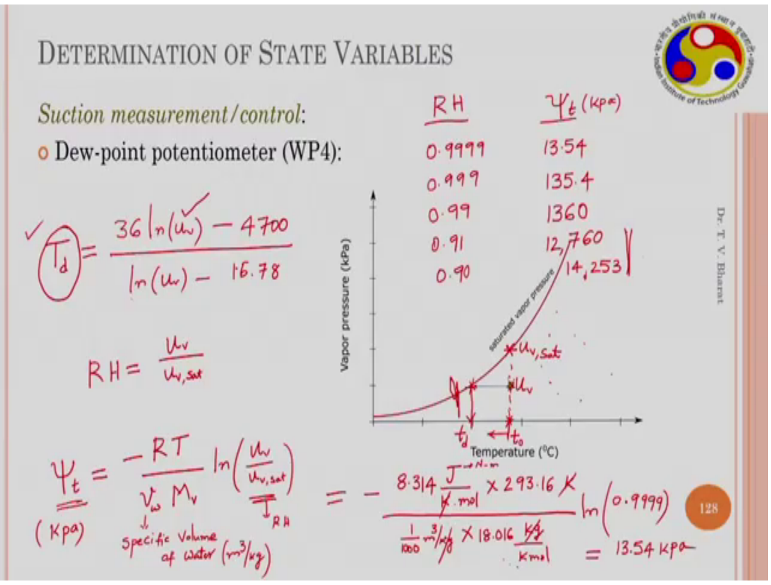

DETERMINATION OF STATE VARIABLES

Suction measurement/control:

- Dew-point potentiometer (WP4):

$$T_d = \frac{36\ln(u_v) - 4700}{\ln(u_v) - 16.78}$$

$$RH = \frac{u_v}{u_{v,sat}}$$

$$\underset{(kPa)}{\psi_t} = -\frac{RT}{\underset{\text{specific volume of water } (m^3/kg)}{v_w} M_v}\ln\underbrace{\left(\frac{u_v}{u_{v,sat}}\right)}_{RH} = -\frac{8.314\,\frac{J}{K\cdot mol}\times 293.16\,K}{\frac{1}{1000}\,m^3/kg \times 18.016\,\frac{kg}{kmol}}\ln(0.9999)$$

$$= 13.54\ kPa$$

RH	ψ_t (kPa)
0.9999	13.54
0.999	135.4
0.99	1360
0.91	12,760
0.90	14,253

As we have seen earlier that the saturated vapor pressure line goes like this. When you plot vapor pressure versus temperature this is the saturated vapor pressure line the vapor pressure of the atmosphere generally lies below this saturated vapor pressure line, it can lie anywhere here. The soil sample which is filled half or less than half of the height of the cup which is placed inside the WP4 operators.

So, inside you will have a fan. So, this fan when it rotates it allows the ambient environment to come to the same vapor pressure as a soil pore water space. When you keep a partly saturated soil inside, so you will have a sample somewhere here soil sample. So, this the soil sample. So, this whole thing is in a closed container or closed environment.

When the fan rotates in the closed small space the ambient vapor pressure and soil vapor pressure would be same or the chemical potential of the ambient and the chemical potential of the soil pore would be same after sometime. So, then assume that the soil pore space is at this particular ambient condition the temperature is say some temperature may be standard temperature and the vapor pressure is say UV, but this vapor pressure would not know we do not know what is this vapor pressure at which the soil pore space exist.

So, what we do is the thermoelectric cooler that reduces the temperature gradually which causes reduction of the temperature from the present temperature ambient temperature is slowly reduced. So, which causes dew formation because this line hits the temperature reduces this line hits the saturated vapor pressure line and which causes formation of the dew. So, this is the t d is a dew point temperature and initial temperature is known maybe that is t naught. So, t d we know there is a dew point temperature and using an expression that is t d that means, the temperature is in Kelvin equals to 36 log UV minus 4700 divided by log UV minus 16.78. So, using this particular expression knowing the t d one can estimate what is UV.

So, when UV can be estimated. So, initial vapor pressure of the soil pore space that could be estimated using this particular by estimating the dew point temperature. And corresponding vapor pressure also we know at that particular temperature what is a saturated vapor pressure we know using the expression that was explained earlier, Tetens equation or any other question you would be able to estimate the saturated vapor pressure. So, by estimating UV and UV sat, one can obtain the RH relative humidity which is UV by UV saturated vapor pressure. So, knowing the relative humidity one can obtain the suction that is total suction using the Kelvin's equation which states that minus RT by V w into M v times log UV by UV sat are simply RH this whole term is simply RH which is substituted in pressure.

So, using this particular expression substituting the value for RH and the temperature you can obtain the total suction. So, the total suction of the soil can be determined by estimating the dew point temperature using WP4. For example, for one particular RH say let us see the sensitivity of this Kelvin's equation. For example, let us input some RH values and then see how the total suction varies. So, this is R is gas constant which is 8.314 Joule per Kelvin mole times temperature maybe you can substitute at standard temperature 293.16 or 15 that is equivalent to 20 degree Celsius which is in Kelvin here, divided by this V w here is the specific volume of water the specific volume of water, specific volume of water is one over the density of water. So, this has units of meter cube per kg.

So, the density of water is 1000 kg per meter cube therefore, we can substitute this value as 1 over 1000 meter cube per kg times the molar mass of vapor is 18.016 kg per kilo mole times log. I will substitute a value of 0.9999; four decimal points are substituting that is 0.9999. Let us see how much value we get. Joule can be converted to Newton meter because this is Newton meter and moles can be cancelled. Here kilo you have that should be taken care so you will get10power 3 here. And kg, kg gets cancelled and when you simplify when you represent the suction in kilo Pascal. So, this value comes out to be 13.54 kilo Pascal. So, let me write the total suction values for some RH values.

Let me give the values of total suction using Kelvin's equation if RH is in ratio 0.9999 that is 99.99 percentage, the total suction would be 13.54 in kilo Pascal which we just estimated if RH is 0.999, three 9s then this value is 135.4. So, similarly if it is 0.99 that is 99 percent then this value is 1360 kilo Pascal, if this value is 0.91 then this is 12,760 kilo Pascal. So, approximately 12.18 pa. If this is 0.9 this value is 14,253 kilo Pascal. If you look at these two values the measured variation in RH is only 0.9 and 0.91.

So, in the second decimal point there is a small change 0.90 and 0.91. So, for that the variation in the suction is nearly 2000 kilo Pascal's such a huge variation. So, therefore, the suction variation at very high RH values is very sensitive, so measurement there are we cannot exactly estimate the relative humidity with a precision of 4 decimals or three decimals. So, therefore, the suction estimation below 90 percent RH it should be avoided that means, the suction which we are going to measure when the soils RH is below 90 percent then only the suction measurement will be accurate.

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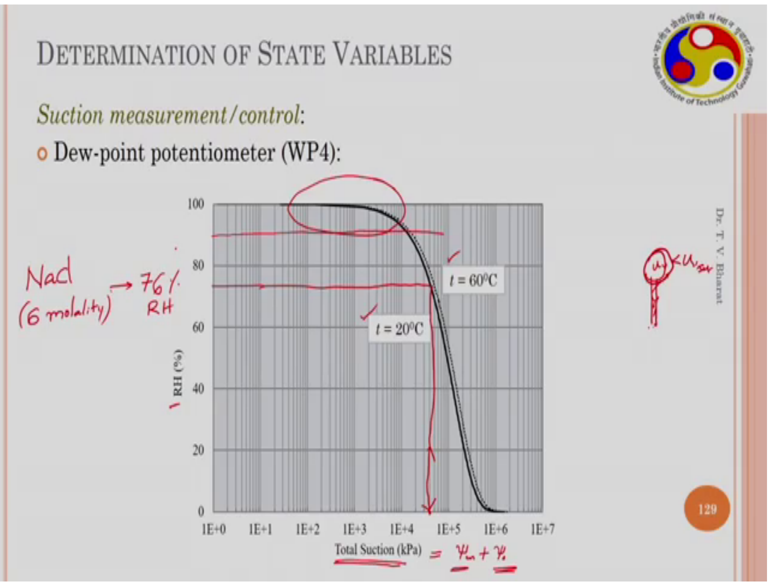

DETERMINATION OF STATE VARIABLES

Suction measurement/control:

- Dew-point potentiometer (WP4):

So, if I plot the total suction whereas, this RH this is how the plot varies for different two temperatures one is a 20 degrees, another one is a 60 degrees, the dotted line is for 60 degrees and the solid line is for 20 degrees.

So, if you look at the variation of total suction with RH. So, your 90 percent is somewhere here in this region in this zone it is very difficult to accurately determine the RH values, because for a small change in RH there is a huge change in the suction. So, generally we obtain the suction values for nearly dry state and especially only for fine grained soils for coarse grained soils. So, the entire soil water characteristic curve hardly varies within probably 100 kilo Pascal or something. So, for fine grained soils especially clays we have seen that it can vary in the range of it is a very small suction like10kilo Pascal to a large suction value nearly at dry state the suction may as high as 10 power 6 kilo Pascal are nearly 1000 mega Pascal's. So, therefore, when the clay soils when their RH is less than 90 percent then this technique is useful for accurately estimating the suction values in the laboratory.

So, far what are the methods we have used I have mentioned that we can estimate the matrix suction, but in this particular case we can estimate the total suction. I hope you understand the difference between matrix suction and total suction. Total suction consists of both matrix suction plus the osmotic suction. Here we are using the technique for estimating the RH relative humidity where we utilize the measurement of vapor pressures of the soil. It can directly measure the total suction because we have seen earlier that capillary condensation concept we have seen where the presence of curvature to the soil water causes develops suction drop or pressure drop across interface, development of curvature at the air water interface causes a pressure drop.

So, because soil has tiny pores they act as capillaries and which develops a matrix suction within the soil pores. Apart from that you also when you have added some salts to the soil pore water that also causes decrease in the chemical potential of the soil pore water, because of which again you have a additional suction which is called osmotic suction.

As we are not using physically arresting particular ions are allowing the water to pass through the way we have done in osmotic control techniques or any other earlier techniques, here we are directly getting the vapors. Whenever there is a change in the air water interface or whenever there is a curvature at the air water interface you have a capillaries. So, this is a capillary that exists within the soil pore, because of which there is a drop in the vapor pressure. So, above this here there is a drop in the vapor pressure which is less than UV sat. That causes matrix suction and addition of some salts here that causes additional drop in the vapor pressure which is corresponding to your osmotic suction.

So, as we are estimating the vapor pressure here in this particular case which is, which caused because of both from the capillary condensation phenomena and also because of the addition of solutes then it can actually estimate the total suction. In case if you do not have salts in your pore water soil pore water then your total suction is equals to the matrix suction. But if you have salts added to your soil then whatever you are estimating is the total suction. If the soil is completely saturated and then you have some salts in it, then also you will get some suction here that is osmotic suction. So, that is how you can actually separate the osmotic suction component and matrix suction component in this particular technique. Because when the soil is completely saturated and when you maintain certain concentration of salts in your particular soil pore water then you will get osmotic suction.

Similarly when the water content decreases, but still you can maintain certain concentration. So, then the variation of matrix suction can be obtained. So, this way you can obtain both and you can separate it out by careful experimentation or you can get a combined values using this particular experimental technique. So, before using this WP4 we need to calibrate it. We can calibrate using known solutions because as I have mentioned already earlier when you add salts to the water the chemical potential decreases which causes decrease in the vapor pressure that means, it decreases the RH value.

So, edition of how much salt you can add how much salt you have added to the water and if that information is known how much RH you can obtain you can find out analytical techniques in physical chemistry and those have been reported earlier. For example, as I have mentioned earlier if I take NaCl of 6 molarity which gives a RH of 76 percent RH. So, 76 percent, 76 percent RH is somewhere here. So, we can obtain corresponding suction and we know that this gives this much of suction value. Therefore, instead of soil you take NaCl solution of 6 molality in a cup and put it in WP4 and obtain what is the suction value it is displaying. If that suction value matches with this particular suction obtained from the Kelvin's equation then your instrument is working well otherwise you need to adjust or calibrated it again.

So, then after that you can place a given soil sample in either with some salt solution or with when it is in partly saturated condition then you can obtain total suction values. So, this is a laboratory technique.

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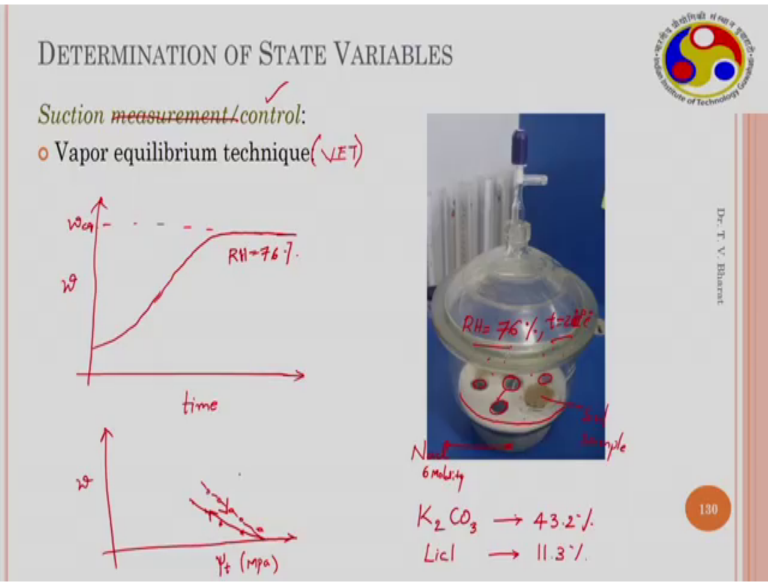

DETERMINATION OF STATE VARIABLES

Suction ~~measurement/~~control:

- Vapor equilibrium technique(VET)

$K_2CO_3 \rightarrow 43.2\%$

$LiCl \rightarrow 11.3\%$

Using similar concept we have another technique called vapor equilibrium technique, VET technique, which is nowadays widely used for estimating the suction at very high suction range. Earlier WP4 technique is also useful for estimating the suction at high suction range. This particular technique is useful for controlling the suction at high suction range. So, here we control the suction.

What we do is we can take a desiccator. So, the desiccator which is generally used for desiccating the soil or desiccating anything, so such desiccator can be taken. And it will have two halves where you have, you can keep one you can separate the lower chamber in this you can separate the lower chamber with the upper chamber using this particular plate which contains several holes.

So, here you can place a given salt solution as I just said the NaCl at 6 molal at molality can be placed here and you can keep a soil sample here, this is a soil sample. Soil sample in a cup can be placed. So, oven dried soil sample can be placed here and then this can be closed tightly. So, that the soil only comes in equilibrium with the vapors of the sodium chloride 6 molality solution. So, therefore, as you have NaCl solution it does not have direct physical contact however, through vapors as you have holes here through vapors of the NaCl.

So, the soil slowly comes in equilibrium with this vapors. So, essentially initially we have taken a oven dried soil sample and RH is very small because there is no water in it. So, NaCl 6 molality has certain RH the RH is 76 percent. So, inside you are maintaining a RH of 76 percent at a temperature. Temperature also should be controlled temperature is this is RH. This whole setup can be kept in humidity chamber where you can control temperature and also humidity also can be controlled anyways this is a closed chamber. So, you do not need to control the humidity you can control the temperature, 20 degree Celsius.

So, you are maintaining a particular humidity and temperature are ambient atmosphere within this desiccator. So, therefore, soil comes to equilibrium with this particular environment. So, slowly because there are some vapors available now, earlier the soil at the initial condition the soil has very less vapors are close to 0. So, soil adsorbs these vapors and hydration of the clay particles the interlayer and the surface cations hydration takes place, so with adsorption of these vapors. So, slowly the water content of the soil increases. So, quickly you can take out the soil sample at a given time and then you can wait and keep it back again without much disturbance.

So, with this way you can actually measure the weight indirectly you are measuring the water content because mass of solids you know because before putting it is oven dried soil sample. So, there is no water. So, you know the mass of solids. So, the increase in the weight of the soil sample is due to the increase in the water content and with time if you estimate you would see that slowly the water content increases and it reaches in equilibrium value, when it reaches in equilibrium value. So, this water content this water content corresponding to one suction value the suction value here is corresponding to RH of 76 percent which may be several Mpas.

So, here which is represented in Mpa, so may be around if you get some value here which is around 100 Mpa also which is four 100 Mpa also some Mpa, some value here and you would get water content here. So, corresponding to this particular this water content is corresponding to 1 equilibrium that is RH is equals to 76 percent. So, corresponding suction is known and water equilibrium water content is also known this is equilibrium water content. So, that equilibrium water content and RH can be plotted on this SWCC, similarly another test can be conducted by changing the solution.

You can use a different solution like a K 2 CO 3 probably saturated solution where it can exert a RH of 43.2 percent which is very high suction. So, therefore, at very high suction again another equilibrium value you can obtain. So, this is another point you will get. And you can also use LiCl little later, similar test with similar test with LiCl also can be conducted. So, then you get which is corresponds to suction of 11.3 percent. So, you will get very small value of water content. So, in the residual portion you get you can establish the soil water characteristic curve in the residual portion using this particular technique. So, WP4 can measure the suction values in the residual portion when the soil is in the residual portion, and this particular vapor equilibrium technique can estimate or can control the suction values of the soil in the residual portion.

So, similarly you can use different solutions to obtain this particular curve, where soil sample initially itself is in saturated condition, then vapor pressure is saturated vapor pressure because the soil is at saturated condition there is no matrix suction and there is no capillary condensation that is existing. So, it is completely saturated therefore, UV is equals to UV sat initially but the solution vapor pressure is smaller than that. So, therefore, now it tries to come to equilibrium by losing the water from the soil. So, that way you can estimate the drying SWCC in the residual saturation path. So, if you plot that also then you may get data like this. This is wetting and this is drying. So, you can also obtain the hysteresis in the residual portion of the soil water characteristic curve, using this particular technique.

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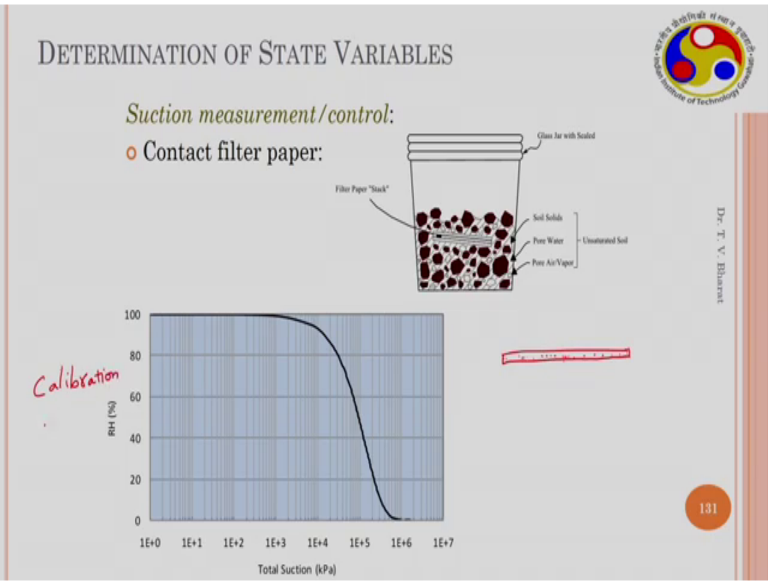

DETERMINATION OF STATE VARIABLES

Suction measurement/control:

- Contact filter paper:

Let us discuss one more test which is commonly used in the laboratory general in the laboratory it is commonly used which is the contact filter paper technique. Filter paper technique is a cheap or very inexpensive technique that could be used for obtaining the soil water characteristic curve or a wide range of suctions. You have two different techniques here, one is the contact filter paper technique which estimates the matrix suction and you have a non contact filter paper technique which estimates the total suction. Technique is very simple the filter papers which commonly used in the laboratory those filter papers have a uniform pores. So, therefore, if you take a filter paper which has a uniform pores the pore size would vary depending on the type of filter paper.

If the soil water characteristic of the filter paper is known then bringing this filter paper in contact with the soil as shown here, you can obtain the moisture equilibrium with the soil then if you measure the water content of the filter paper then the chemical potential of the filter paper and the soil will be same at equilibrium at study state. So, measuring the water content of the filter paper would tell you what is a suction of your soil. So, what we do is we should have a calibration chart like this, this is a calibration chart.

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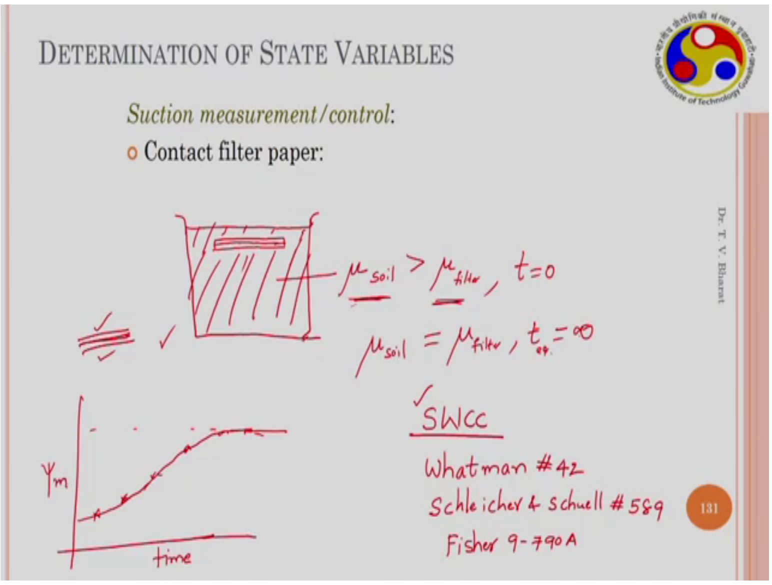

DETERMINATION OF STATE VARIABLES

Suction measurement/control:

- Contact filter paper:

So, in this particular filter paper technique you have contact filter vapor technique and non contact filter vapor technique. Using the contact filter paper technique we can measure or estimate the matrix suction using the non contact filter paper technique we can estimate the total suction. Let us understand how we do it.

Here you take filter paper, we have several filter papers like Whatman size 42 or Schleicher and Schuell 589 or white ribbon or fisher which is supported by fisher scientific. Fisher 9-790 A are the most commonly used types of filter papers. So, for these filter papers the calibration chart should be available or these filter papers the soil water characteristic curve should be known. How do we get the soil water characteristic curve this filter papers? So, generally these filter papers have uniform pore size distribution. So, therefore, it is possible to establish the soil water characteristic curves therefore, this can be used as a standard material to estimate the suction, for other soils other material like soils.

Using access translation technique which I described earlier, so the filter papers will be placed there and suction is maintained to obtain the soil water characteristic curve. That way the soil water characteristic curve of SWCC of these filter papers would be obtained those are already known. So, once the filter papers soil water characteristic curve is known SWCCs are known what we need to do is we need to bring the filter papers in contact with the soil. So, here you have soil we need to place the filter papers here, you may place more than 1, more than 2 numbers because usually we stack three filter papers minimum these two are sacrificing filter papers and middle one is the filter paper which is not soiled so that could be used later on for measuring the water content.

So, now these set of filter papers which are in contact with the soil. So, for good contact you can also place it inside. So, you can place it inside like, you can place the soil. So, filter papers are inside somewhere. So, oven dried filter papers without touching you with your hands carefully placed in the soil. So, that it is in contact with the wet soil. So, this is whole thing is soil. Initially the chemical potential of soil is higher than the chemical potential of the filter papers because this is completely wet. So, the chemical potential of soil is higher than chemical potential of the filter papers. So, therefore, there is a equilibrium that takes place. So, water enters into the filter papers and it may it wets the filter paper until the chemical potential of the soil and chemical potential of the filter paper becomes equal.

So, then there is equilibrium. So, what you need to do is here several duplicate test like this can be performed maybe 10 duplicate test can be perform, so which is called sacrifying method. So, after say 10 days you sacrifice one test you take out the filter papers and (Refer Time: 34:22) filter paper carefully obtained and you wait up to 2-3 decimal points this is a sensitive techniques. So, carefully you should estimate the weight of the filter paper and already we have established the soil what characteristic curve of this particular filter paper therefore, measuring the water content corresponding suction can be obtained the suction indicates the chemical potential.

So, the chemical potential of the soil and the filter paper are same at equilibrium. This is at time t equal to 0, at time t equal to infinity chemical potential of soil and chemical potential of the filter paper both are one and the same, at time t equal to infinity that is equilibrium.

So, therefore, the suction value which you obtain from the first test by measuring the water content of the filter paper can be obtained similarly from the second test you can obtain. So, you can plot the suction values that you obtained from different test with time allowed for saturation or time allowed for equilibration. So, you would see that the again the suction values increase, suction value increase and then reaches equilibrium at one particular value this indicate different test values. So, probably after four test may be 40 days or 50 days or 60 days you would see that the water content does not change in the filter paper. So, you will get a constant suction values.

So, this is the actual suction value of your soil. So, this is how you can obtain the suction value of the soil because when you have solute here the filter paper do not filter any solute like salts or anything. So, therefore, you get matrix suction the suction what you get here is some matrix suction.

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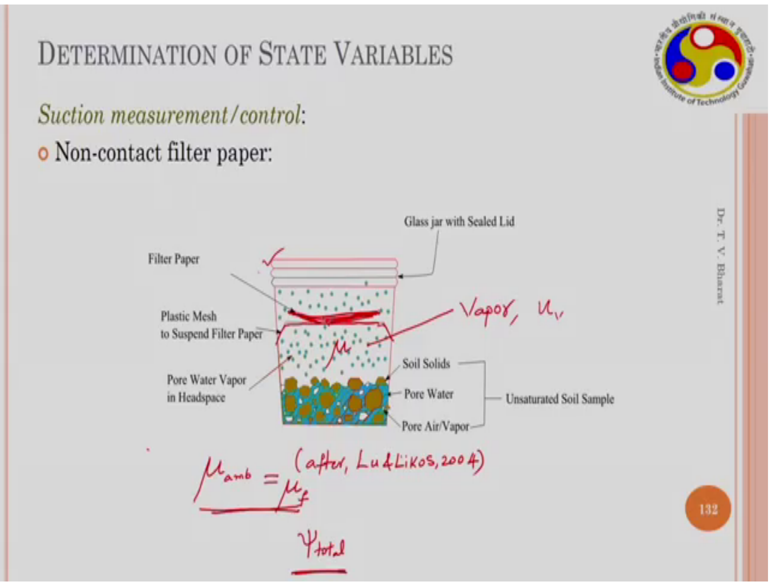

DETERMINATION OF STATE VARIABLES

Suction measurement/control:

- Non-contact filter paper:

(after, Lu & Likos, 2004)

$\mu_{amb} = \mu_f$

Ψ_{total}

You have another technique similarly, you have non-contact filter paper technique where you have the soil sample here figure is redrawn from Lu and Likos. So, I should mention that this is after Lu and Likos 2004. So, in this particular technique you have a one small cup where you have a wire mesh which is placed here, on top of it you have the filter papers stack of filter papers maybe 5 or something or maybe more than 2 I should have.

So, then you have soil here, these are the vapors. So, now, this is a closed, you have a lid with that you have close it so tightly. So, now, the ambient vapor pressure is controlled, ambient conditions are controlled now. Now, the soil the filter paper will come in equilibrium with the vapors of the soil pore water. So, therefore, if you have a salts the vapor pressure decreases the same vapor pressure will be reflected in your filter paper are the same moisture content moisture content correspondent to the same vapor pressure will be will be reflected in your filter papers therefore, in this particular technique you can estimate the total suction.

So, here in this particular technique when the unsaturated soil is placed here there is some vapor pressure. So, maybe vapor pressure UV which is maintained. So, initially when you keep a oven dried filter papers above this without with a physical contact with the soil. Then the filter papers slowly get wet because the vapor the filter papers get hydrated with the vapor that is available. So, the water content of the filter papers will get increase, will increase slowly.

So, therefore, when you conduct the several duplicate test after certain given time, you can sacrifice one test you can take this filter paper and measure its weight, from the weight you can obtain the suction that indicates the chemical potential of the ambience here. So, if it comes to equilibrium the filter paper comes in equilibrium with the vapors ambience chemical potential that is soil pore water potential is same as the chemical potential of the filter paper. So, when that condition is achieved by understanding the variation in water content for different duplicate samples at different time intervals. when the water content does not change that means, this condition is achieved. So, therefore, the corresponding water content from using the soil water characteristic curve relationship for that particular filter paper from that you obtain the suction value and the suction value indicates the suction of the soil sample, but that is a total suction, because here we are using the vapor equilibrium it will indicate total suction.

So, this way you can conduct the test on same soil one is with contact and another one is without contact then you can obtain total suction and matrix suction independently, so that you can understand what is effect of osmotic suction. So, similarly the earlier technique what we have used earlier, in this case also we can control individual suction or we can estimate individual suction value and we can compare what is osmotic suction and what is a matrix suction.

Thank you.