Unsaturated Soil Mechanics
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Week - 05
Lecture - 13
Summary: Suction Measurement and Control Techniques

Hello everyone. So, far we have seen several techniques for the estimation of water content suction, it includes matrix suction and total suction. Let us summarize the techniques that we have discussed so far. Initially we discussed about negative column or hanging column technique.

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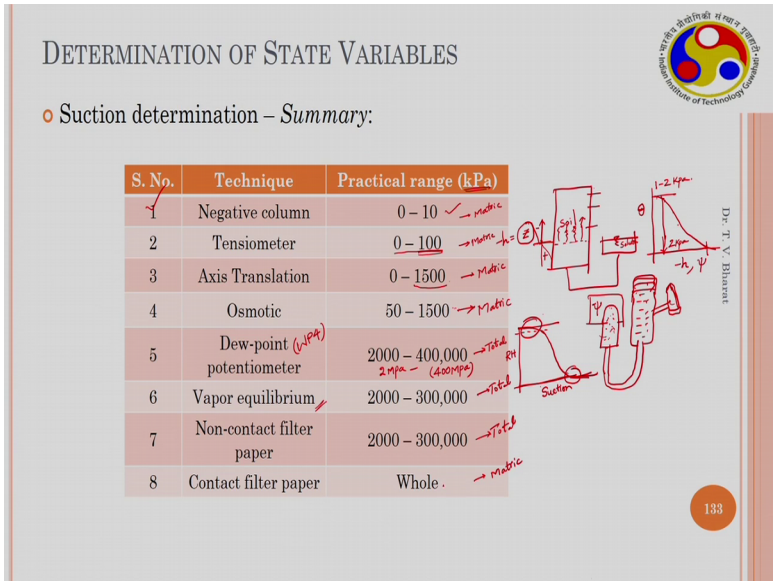

In particular technique we have a soil column which is connected to a reservoir the reservoir level can be adjusted. So, this is a soil. Now, the water level would be here in the soil at equilibrium, now at equilibrium there is a capillary rise there is a water that goes up into the soil column which creates a negative pressure within the soil pore system.

So, here above this level say z we can estimate what is the pressure that exists within the soil pores because that include that is nothing but this is this itself is the negative head. You can estimate the pressure also by multiplying with gamma w. So, that is a negative pressure that exist and below this you have a positive pressure and above this is your you

have a negative pressure. So, this pressure are negative head can be estimated and by connecting or by inserting at different locations the water content measurement sensors you can estimate how the moisture content varies with the negative head. So therefore, you can establish the negative head, the moisture content theta and negative head or the negative power pressure or suction. So, this way you can establish the soil water characteristic curve. We can also raise the water level so that you can vary the head value and water current value or you can lower the values so that you can get number of points on this soil water characteristic curve. So, this how we can establish.

However, the practical range is 0 to 10 kilopascal because, 10 kilopascal represents divided by gamma w gives you around 1. So, you can have only 1 meter height of the soil column and beyond that it is very difficult. Even though you can if you can raise to 1.5 meter soil column you can estimate up to the range of 15 kilopascal beyond that it becomes very difficult to maintain the soil column and do the experiment. It is also laborious to do the test because you need to wait for equilibrium to come. You need to put several sensors at different locations to establish the soil water characteristic curve. So, therefore, the practical range I have given is 0 to 10 kilopascal, all the suction ranges are given in kilopascal.

This particular technique is very useful for establishing the soil water characteristic curves of sands core sands, medium sands, etcetera because for sands generally the air entry value would be around 2 kilopascal, 1 to 2 kilopascal in fact. For core sand it may be around 1 kilopascal or 0.9 kilopascal and for fine sands you may have around 2 to 0.5 kilopascal. So, therefore within 10 kilopascal you would be able to estimate establish the entire soil water characteristic curve. So, therefore, this is a wonderful technique to establish soil water characteristic curve for sand sandy soils.

Other techniques the sensitivity maybe higher compared to air entry value of the sand. For example, if you consider tensiometer when tensiometer works in the same range I mean in the low range also like 0 onwards however, the sensitivity maybe question or the least count of the tensiometer values maybe hindrance for establishing SWCC in the lower range like 1 to 2 kilopascal. Because a minimum value you can establish by tensiometer is maybe 1-1.5 kilopascal or something. So, in that such conditions the negative column or hanging column method is a wonderful technique.

So, coming to the tensiometer we have seen, we have a higher disk and which is connected to a flexible tube and you have a water column here and which is connected to a gauge to measure any pressure that that is observed due to equipment between soil pore water and water column here, you will a screw here, so this a gauge, right. So, here when the soil comes in contact with this particular high air entry porous disk, so especially when the soil has a negative pressure that is it has certain suction then water will be it tries to suck the a water from the column. So, that pressure can be measured using the gauge. So, there is what we have seen.

And this technique is a wonderful technique for using it in laboratory or in the field directly because you can place this high air entry disk in contact with field in situ therefore, you can establish how the suction varies with time or how the suction varies with moisture content if you also keep moisture content sensor along with this. So, the maximum suction range is that it can measure is 100 kilopascal because nearly at mean sea level beyond this particular suction value cavitation takes place.

And therefore, we cannot establish continuity between soil pore water and then the water reservoir therefore, beyond that we cannot establish. We have also seen that at higher altitudes we have seen that as a atmospheric pressure decreases therefore, the measuring range of the tensiometer also decreases. So, if the atmospheric pressure drops considerably and then it can only estimate the suction values maybe up to maximum 80 or 85 or something, 85 kilopascal depending on atmospheric conditions and vapor pressure of the atmosphere.

Other thing as you continuously use a tensiometer, so maybe the accumulation of solute on the high air entry disk are of soil particles maybe is entering into the high air entry disk are certain conditions, the range of tensiometer again decreases. So, as you when as and when you start using it the maximum range of measure measurable suction value decreases for the tensiometer. So, as I said the atmospheric pressure plays an important role in the maximum measuring range of suction using tensiometer. The axis translation techniques uses similar principle where the air pressure is increased to certain value and water pressure is maintained at atmospheric. So, that required suction value that is u a minus u w could be maintained and you can establish the SWCC to a greater value.

As a high air entry disks capacities may vary those are nomenclatured as 5 bar, 10 bar, 15 bar etcetera. So, the suction range of the measurable suction range also varies in the same manner like 500 kilopascal, 1000 kilopascal or 1500 kilopascal. So, beyond 15 bar generally we do not get the high air entry disk. So, therefore, the maximum range of measurement by axis translation technique is 1500 kilopascal. In the osmotic technique we maintain equilibrium between solution and soil pore water solution, by separating with a semi permeable membrane.

So, in the semi permeable membrane separates the solution and soil pores pore water as you are not allowing the solute to move through the membrane from the soil pore water the water will be drawn out of the soil and it moves to the other side to dilute the solution or solute. So, which creates a osmotic head and you would be able to control the osmotic heads that would be equivalent to your matric suction head in this particular case. Using a osmotic technique you will be establishing you can using the osmotic technique you can control the matric suction and by controlling the matric suction you can establish the SWCC of any given soil.

Here again depending on the membrane size and the solute particle size the suction values vary and also the concentration also plays an important role. So, generally the osmotic technique workable or practical range of measurement is between 50 and 1500 kilopascal. So, using this particular technique you get matric suction. So, I forgot to mention the negative column technique would give you the total suction because if you have solutes here instead of water if you have some solution say NaCl solution if you have the raise would be different or if you change sorry this also gives sorry.

So, these negative column technique would give matric suction tensiometer also gives matric suction axis translation also matric suction. So, all these techniques would give you matric suction because here they cannot control or they cannot filter the movement of inorganic solute for example, Nacl or something and Na or Ca or K ca 2 plus or k. So, therefore, it gives matric suctions. So, as a range the suction range of clays especially plastic clays are highly plastic clays vary over a wides range for example, it can vary from 0 kilopascal to 1000, 1000s maybe 10 power 6 kilopascal range. So, we require more techniques to establish the entire soil water characteristic curve therefore, the dew point potentiometer which is often used which utilizes the concept of measuring the

vapor pressure of soil pore water or above the soil pore water based on that we can estimate the suction value using Kelvin's equation.

So, dew point potentiometer as we have seen at very high value of humidity the suction values are very sensitive therefore, we cannot establish the suction values when the humidity is very high, when the humidity falls this maybe suction, this maybe RH, and this is RH, and this is suction. So, at very high value of RH may be up to say 95 etcetera it is difficult to measure the suction value accurately. Similarly here at very low value of RH, RH the measurement of suction is again difficult. So, generally the suction value by dew point potentiometer are which is also called WP4 which is a instrument name provided by Decagon could work very well between 2000 to 400,000 kilopascal range. So, 400 Mpa, this is 400 Mpa, range 2 Mpa to 400 Mpa range.

This is useful in establishing of soil water characteristic curve in very high suction range. So, this is useful for especially very high plastic clays. So, this gives the total suction, and the dew point potentiometer we cannot control suction, but we can measure the suction. In the vapor equilibrium technique where you can control the vapor pressure within the soil pore system so you can establish the SWCC by controlling suction values soil tries to come to equilibrium with the ambience and finally, when it achieves the equilibrium it has certain value of moisture content corresponding to the given vapor pressure in this pore system or suction value. So, using this we can and establish the SWCC.

Similarly, we have discussed non contact filter paper. Here also the concept is similar where the filter paper is not in direct contact with the soil sample which is in equilibrium with the vapor of the soil sample. So, therefore, it absorbs moisture initially when you take a oven dried filter papers placed in the same ambience as the soil, then it absorbs moisture and comes to equilibrium and based on the moisture content and existing calibration curve one can establish the suction value of the soil. So, at the equilibrium the chemical potential of the soil and chemical potential of the filter paper would be same. So, at that particular equilibrium one can establish the suction value.

So, here also you will get total suction, here also you establish total suction. And in contact filter paper technique where the filter paper directly is in contact with the soil there is a moisture equilibrium that takes place and if you have any solute also can

exchange or which can also flow through the soil and there is no filtering mechanism therefore, it establishes matric suction. This can be used on the whole range however, when the water content in the soil system is very small then amount of moisture that exchanges into the filter paper will be very less, and it is very difficult to accurately measure the moisture content if a small error that is made in the measurement of moisture content of the filter paper. So, then that decreases the accuracy significantly for the established suction value. So, even though theoretically this can be used for whole range, but very dry states or when the suction is very high the accuracy comes down.

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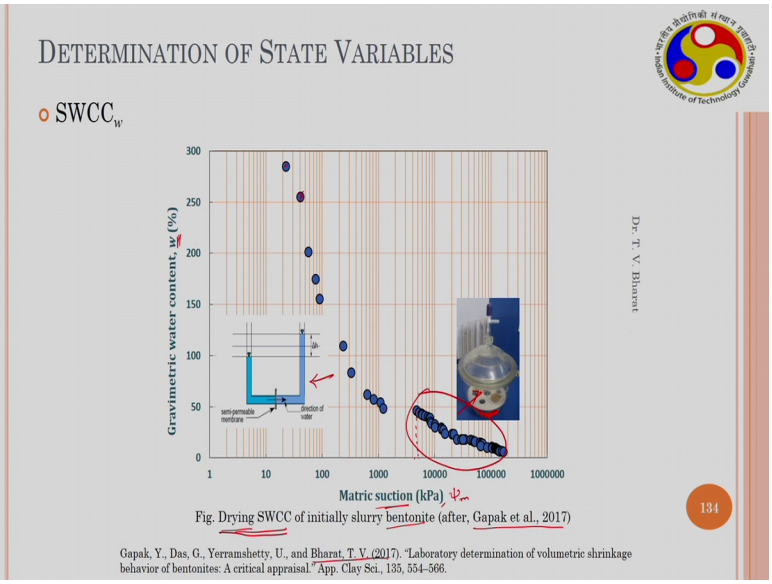

There is some data which is available in the literature are presented here the soil water characteristic curve in terms of gravimetric water content w and matric suction psi, maybe you can write psi n is established for bentonite clays drying SWCC which is presented. Here this is data from Gapak et al, our lab. So, here the soil sample initially was taken at slurry state by mixing the sample with 1.5 times liquid limit water content, then after making the slurry and keeping it in a small container which is brought in equilibrium with the peg solution polyethylene glycol, by placing a semi permeable membrane in between.

So, there is a osmotic technique that is used. So, we maintain certain peg solution concentration initially. At equilibrium there is a water transport that took place. The water is a drawn from the soil because initially the soil is at fully saturated state

therefore, it has more chemical equilibrium compared to the peg solution. So, as a peg molecules are not allowed to enter into anyways the peg molecules are not allowed to pass through the semi permeable membrane, now the water will be drawn out of soil will move towards the peg solution. So, the peg solution concentration decreases with time. And at equilibrium you have one particular concentration for the peg solution if you can measure the peg solution concentration, using brix index or the refractometer.

Then you can understand: what is the osmotic suction head that is created and the soil water content also can be measured at equilibrium. That way you will get the water content and suction value matric suction value for the first point on this curve. Here initially the soil is completely saturated, at equilibrium the moisture content within the soil must decreases therefore, this is a drying SWCC core. So, other points also obtained in the similar manner by initially the slurry sample was taken and after that soil is brought in equilibrium with different concentration of the peg solution, and now the as the concentration of the peg solution increased more water will be drawn out of the soil and you get a point at somewhere here as the suction increases and moisture content drops. So, you get different point

Similarly, the points are established up to nearly slightly above 1000 or 1500 kilopascal, and beyond that the vapor equilibrium technique was utilized where the slurry sample was placed in equilibrium with some solution say KCl solution or NaCl solution at different concentrations. At regular intervals the moisture content of the sample was measured when it reaches the equilibrium the moisture content will be same, the moisture content will not change. So, at that particular instance at equilibrium the suction value can be estimated by directly measuring the vapor pressure of solution using WP4 because the vapor pressure also might change slightly after equilibrium with soil.

So, therefore, vapor pressure of the solution can be directly measured in WP4 and that gives the suction and the soil moisture content can be estimated using oven dry technique that way we establish the data in this range using vapor equilibrium technique. So, in this range we established using osmotic technique. So, here as we measure the water content by oven drying technique, we got the water content, we got the gravimetric water connect. This is a data for compacted bentonite in wetting condition.

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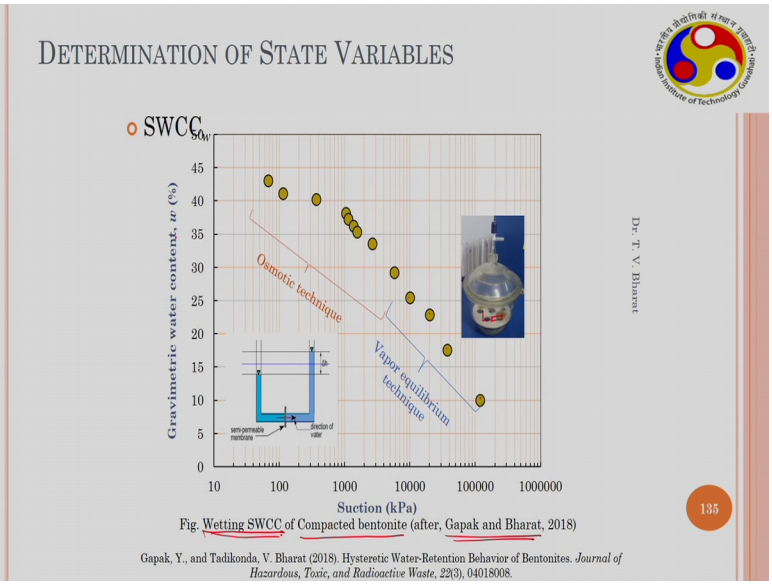

In wetting condition initially the sample was compacted and also brought in equilibrium with peg solution by placing at semi permeable membrane, and as initially the sample was at dry state completely air dry state. So, moisture from the peg solution went into the soil to saturate it or to improve the chemical potential. So, due to that the water content increases in the soil therefore, it is affecting SWCC. So, this way we established wetting SWCC using osmotic technique, and similarly here this is not representative here we have shown slurry sample here, but actually the compacted sample was used here and which is it brought in contact with vapor solutions.

It is brought in contact with vapor equilibrium of different soil solutions, at the equilibrium the vapor pressure was measured and from that the suction was established. So, the vapor equilibrium technique is used for these 4 points, because the sample is at in compacted state it is very difficult to get the data because it takes very long time for equilibrium. So, this is again from our lab work. So, here also the water content was measured by oven drying technique therefore, we got gravimetric water content.

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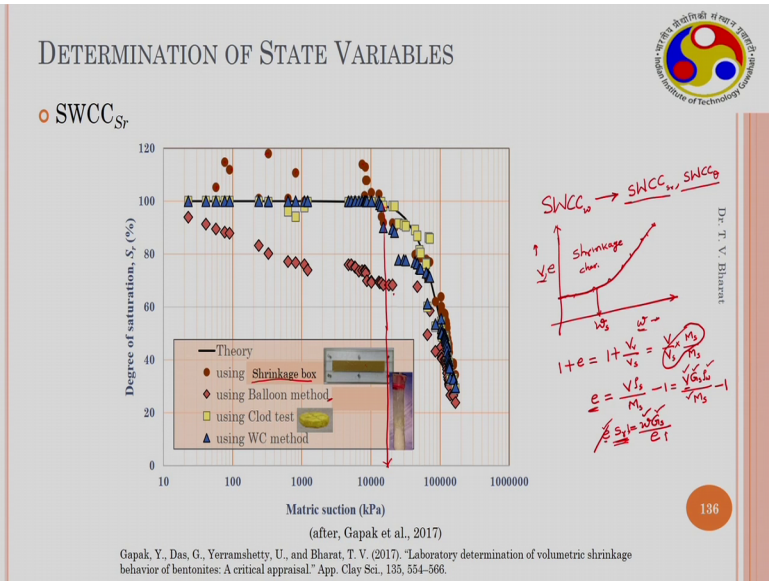

So, generally the soil water characteristic curve either required in terms of degree of saturation that is S r or volumetric water content. The dependent variables in the flow equations contain volumetric water content and some equations contain degree of saturation. Therefore, we required to establish in terms of degree of saturation verses suction or volumetric water content versus suction. So, to establish gravimetric water content based SWCC which is represented with SWCC w into convert to w, SWCC in terms of S r or SWCC in terms of theta. So, to establish either SWCC S r or SWCC theta we require the knowledge of how the volume changes with drying or how the volume changes with wetting.

So, in case of the slurry sample when it is subjected to different suction values by using osmotic technique or vapor equilibrium technique the volume of the sample decreases as water content decreases the volume of sample also decreases. Therefore, the shrinkage characteristics using different techniques we already discussed earlier. So, where the water content, gravimetric water content and total volume of soil sample these are plotted. So, initially this may be the state of soil and it decreases and it the volume does not change beyond certain value which is called shrinkage limit water content we require all data points on this particular curve if we know the volume; So, the 1 plus void ratio that gives 1 plus volume of voids per volume of solids which is nothing, but total volume by volume of solids.

So, therefore, void ratio can be written as total volume if I multiply M s here and M s here this is the density of solids. So, so this can be written as V rho s by M s minus 1 or simply V rho s can be written as G s rho w by M s minus 1. So, if total volume is known specific gravity of the solids can be determined and rho w is 1 gram per centimeter cube. Mass of solids also can be determined because at the end of the test we oven dry the sample, so we get the mass of solids so which is also known. So, therefore, if you know volume you can also plot in terms of void ratio versus w here instead V you can also plot in terms of void ratio versus w.

So, when void ratio is also known using the expression e S r equals to W G, W G s, W is known water content at any given point is known and G s is known void ratio is known. So, S r can be obtained. So, here S r was obtained in this particular manner and using different tests to establish the shrinkage characteristics of the clay sample established using different techniques the techniques which I discussed earlier. So, here if you see using shrinkage box where you have a shrinkage box, where the sample was initially at slurry state the same state as it was for establishing the SWCC in terms of gravimetric water content. So, the same slurry state it was brought into then sample was subjected to natural drying; so, then the water as the water content decreases the volume and weight was taken regular at regular intervals so that volume and water content could be obtained.

Here the volume could be estimated by Vernier Calipers. So, this may not be accurate because the volume measurement by shrinkage box is in the beginning it was little difficult because of soil was in a slurry state and using the calipers, the measurement of volume was little difficult because the change in the volume was very small initially. But later on when it becomes where shape of the sample also cannot be maintained the same. So, therefore, it is very difficult using shrinkage box test. So, if you see using that particular data when you establish the SWCC. So, S r value was more than some, so more than 100 percent before the air entry value. So, the air entry value of the sample is somewhere. So, the air entry value of the sample was nearly 20 Mpa, 20 megapascal. So, before this the sample the data showed that the degree of saturation would be more than 100 percent which is inaccurate.

So, due to the measurement errors in the volume the degree of saturation went above hundred percent, and using balloon method even before air entry value the degree of

saturation at any given point appear to be less than 100 percent. So, here because the balloon volume was also considered as the volume of the sample as a measure volume was higher. So, void ratio was also higher and when the void ratio was higher degree of saturation when the e is taken that side higher void ratio is measured. So, therefore, lesser degree of saturation was estimated even suction was closed 0 it exhibited smaller degree of saturation values.

Using clod technique the data was fine. So, mostly the data showed very close to the theoretical value. So, this was a very good technique to use however, the clod technique is also difficult to use when the soil consistency was close to slurry because you cannot apply the PVA glue around the soil sample at that particular stage, it has to come to one particular consistency where you can handle the sample and apply the PVA glue. So, initial few data points you would miss for soils. So, after it is brought to one particular consistency only you can apply the glue and do the test.

Wax coating method; so, here for this particular soil the data was good up to near air entry value and beyond that there was slight deviation, but other soils also there was a huge deviation that is because for each data point we have we were utilizing different different soils. So, many number of duplicate samples were required for establishing the SWCC S r in this particular case. So, it was very difficult and also sometimes it is not that accurate.

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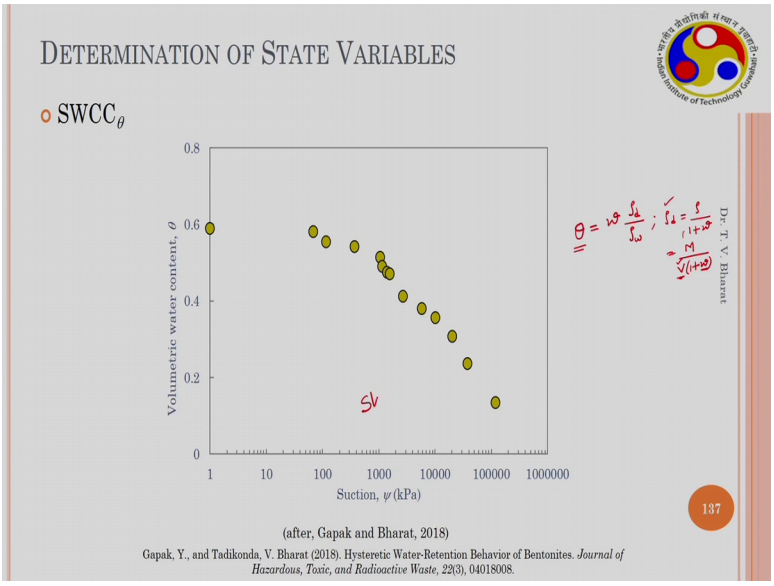

Similarly, here the SWCC was established in terms of theta where theta was estimated using this particular expression gravimetric water contents times rho d by rho w. So, the rho d the dry density of soil sample at any given moisture content can be obtained knowing the total volume. So, rho rho d can be written as rho divided by 1 plus w yeah rho divided by 1 plus w, using this expression one cannot turn rho d, here rho is obtained by getting a total mass by total volume of the soil sample. So, the volume once we can establish using shrinkage characteristics, we can establish the volumetric water content from the gravimetric water content converted to SWCC theta.