Expansive Soil

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Lecture 16

Measurement of Various Shrinkage Characteristics of Soil

Hello everyone, welcome to the course expansive soil. Today will be the 15th lecture and this will be the module 5 of this course. With continuing this swelling and shrinkage characteristics of expansive soil, today we will be learning about how to measure the different parameters of the shrinkage characteristics of soil.

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When we talk about different parameters which we need to measure during a shrinkage test then we have to think about the five different parameters. These five different parameters are the shrinkage limit, the linear shrinkage, the radial shrinkage, volumetric shrinkage, and the shrinkage curve. These five factors or the five parameters known as the shrinkage parameters need to be determined to know the shrinkage behavior of the soil.

Generally, all these parameters are determined in a laboratory. So in this lecture we will be learning about how to determine all these parameters. But before that I would like to explain few of these terms. A few of the terms I have already explained in the previous classes, so first one is the shrinkage limit. As I discussed in the earlier classes the shrinkage limit of a soil is defined as the minimum water content at which the soil remains fully saturated.

So, if we take a soil sample say for example, in this case and if we air dry the soil continuously then the volume of the soil will decrease with a decrease in the water content, but a particular stage will be reached beyond which further drying of soil sample will not decrease the volume of the soil.

So, that water content at which the volume of the soil remains constant on further drying is known as the shrinkage limit. It has another definition which says that the shrinkage limit is the water content of a soil at which if the soil is dry further no reduction in the volume takes place and this is the water content at which the soil will remain saturated.

So, this is the minimum value of the water content at which the soil remains saturated. On drying further from this water content the air will starts to enter and the degree of saturation starts to reduce from 100 percent and the soil not remains in saturated state it will becomes an unsaturated soil sample.

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Next comes the volumetric shrinkage, it is defined as the decrease in the volume of a soils mass expressed as percentage of dry volume of the soil when the water content is reduced from any percentage to the shrinkage limit of the soil. Say for example, take the soil sample over here, and now suppose the water contained of the soil is W_1 and its volume is V_1 then what we will do is, we will dry the soil sample. When we dry the soil sample to its shrinkage limit the water content will reduce and at shrinkage limit the water content becomes the shrinkage limit water content, and let the volume of the soil at the shrinkage limit be V_2.

Since after reaching V_2, the volume of the soil will not reduce, therefore, this V_2 will be equal to the dry weight of the soil, so V_2 will be equal to V_d. Now, the volumetric shrinkage of this soil will be equal;

$$\text{Volumetric shrinkage, VS (\%)} = \frac{V_1 - V_2}{V_2} \times 100 = \frac{V_1 - V_d}{V_d} \times 100$$

V_d is the dry volume of the soil; V_1 is the initial volume of the soil from which the drying takes place. This water content can be any value that can be liquid limit value; that can be in-situ water content value.

$$\text{Volumetric shrinkage, VS (\%)} = \frac{\text{Initial volume -Final volume}}{\text{Dry volume}} \times 100$$
$$= \frac{\text{Change in the volume } (\Delta V)}{\text{Dry volume}} \times 100$$

So this is known as the volumetric shrinkage.

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Third one is the shrinkage ratio. Shrinkage ratios is defined as the ratio of a given change in the volume expressed as a percentage of dry volume to the corresponding change in the water content and remember this change should be within this zone of shrinkage limit it should be above the zone of shrinkage limit.

Say for example, take a soil sample with an initial water content of w_1 and initial volume of V_1, now we will dry the soil gradually so as we dry the soil gradually the volume will decrease and the water content will decrease; with the decrease in the water content the volume will also decrease.

Now, suppose at any stage the water content is w_2 and corresponding volume is V_2, so as per as the definition;

$$\text{Shrinkage ratio, SR} = \frac{\frac{V_1 - V_2}{V_d}}{w_1 - w_2}$$

That means if we further dry the sample, the volume will decrease like this one and this is the shrinkage limit and on further drying there will be no decrease in the volume of the soil sample take place and this will be the final volume Vd.

$$\text{Shrinkage ratio, SR} = \frac{\frac{V_1 - V_2}{V_d}}{w_1 - w_2}$$

Suppose in second stage, that means, if the V_2 equal to V_d that means a shrinkage limit volume and then the corresponding water content w_2 will be equal to the w_s.

So, in that case the shrinkage ratio will be equal to;

$$\text{Shrinkage ratio, SR} = \frac{\frac{V_1 - V_d}{V_d}}{w_1 - w_s}$$

W_1 is the water content at the initial stage, w_s is the shrinkage limit water content.

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Next, linear shrinkage of the soil; if we dry a soil sample then its dimensions will also change. The linear shrinkage tells about the change in the linear strain of the soil sample due to drying. Going by the definition, the linear shrinkage is expressed as a percentage decrease in the length of the soil mass due to drying to the initial length at a water content equal to its liquid limit. So, here you can see a soil sample has been taken with a length of L_1, the linear dimension is L_1 and its initial water content is approximately liquid limit water content or little bit two, three percent higher than the liquid limit water content.

Then we will dry the soil sample, I will explain about this test later on, so after drying completely the length of the soil sample will decrease. At dry state the length of the soil sample will be say L_d, then;

$$\text{Linear shrinkage (\%)} = \frac{\text{Initial length (L)- Final length } (L_d)}{\text{Initial length (L)}} \times 100$$

$$= \frac{\text{Change in length}}{\text{Initial length}} \times 100$$

Next radial shrinkage, as the name suggests the change in the the diameter of the soil sample due to drying is known as the radial shrinkage. So, going by the definition the radial shrinkage is expressed as the percentage decrease in the diameter of a soil sample due to drying to its initial diameter at a water content equal to a little bit higher than its liquid limit water content. Here we can see a soil sample is there, a circular soil sample with an initial diameter is D and initial water content is approximately equal to liquid limit or little bit higher than the liquid limit. Once we dry the soil sample its volume will decrease, as the soil shrink the volume will decrease and so the diameter of the soil sample will decrease.

Finally, when the soil becomes fully dry, let the diameter of the soil sample be D_d, so this small d stands for the dry soil sample diameter. Then the radial shrinkage will be equal to;

$$\text{Radial shrinkage (\%)} = \frac{\text{Initial diameter (D)- Final diameter } (D_d)}{\text{Initial diameter (D)}} \times 100$$

$$= \frac{\text{Change in diameter } (\Delta D)}{D} \times 100$$

So this gives the the radial shrinkage of a soil sample that means how the soil is shrinking in a radial direction due to drying.

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Another most important parameters or maybe you can say a relationship between the soil water content and void ratio or volume of the soil during drying can be obtained using a shrinkage curve. So, shrinkage curve shows a relationship between the void ratio or the volume of the soil sample with the change in the water content due to drying.

So, remember this drying should be gradually that means it should be air dried. A mathematical representation of the shrinkage curves provides a relationship between the volume and mass of the constitutive surface in response to an increase in the soil suction. Generally, this is one of the most important characteristics of a soil sample during the drying stage. So in this class we will be learning how to determine the shrinkage curve for various soils.

Now, how to determine the different shrinkage parameters in the laboratory? There are various methods available in the laboratory to determine the shrinkage parameters. First of all, the shrinkage limit. Generally, in india we determine the shrinkage limit as far as IS2720 part 6 this is given in 1972 and this is also known as mercury displacement method. So, what we have to do is, you need to take a soil sample about 30 gram which should be passing through 425-micron sieve size. Then we need to add sufficient amount of water such that the soil will becomes a paste and generally the water content will be approximately its liquid limit.

Then we need to take shrinkage dish, here we can see these are the shrinkage dish, then we need to coat the shrinkage dish inside with a layer of silicon grease such that the soil will not be adhered or not be attached with the clay surface while drying. Then once we coat the soil with a layer of silicon grease then we need to take the weight of this shrinkage dish and then we need to measure the volume of the shrinkage dish. The volume of this shrinkage dish can be measured by mercury displacement method.

Here what we will do is, we will fill this empty shrinkage dish with mercury and remove the excess amount of mercury. Then we measure the weight of this mercury which are filled inside this shrinkage dish and from that we can determine the volume of the shrinkage dish. So, once the volume and weight of the shrinkage dish is measured, then we need to fill shrinkage dish with the soil sample. We need to fill the soil samples in layer such that there will be no air bubble form inside the soil sample, so for that we need to tap this shrinkage dish while placing the soil sample. So, we need to fill the shrinkage dish with the soil paste in layers by tapping to prevent the presence of any entrapped air.

Once the soil sample is filled inside the shrinkage dish then we will measure its weight. The volume of this shrinkage this will be the volume of this soil sample. So, now we know the initial volume of the soil sample and initial weight of the soil sample. Then once the shrinkage dish weight and volume is measured then we will air dry the soil sample and that will be followed by drying at 105 to 110 ^{0}C inside an oven for 24 hours. Once the soil is fully dry then we will take out this soil pat. So this soil cake is known as soil pat.

So, we need to take out the soil pat and then we need to measure its weight. So we will know the weight of this dry soil pat. Then we need to determine the volume of this dry soil pat. To do that we need a evaporating dish, you can see this one this is an evaporating dish, then we need to take a glass cup and then we need to fill this glass cup with mercury and then we put this dried soil pat over here and then we will push this dry soil pat using a glass plate with a prongs. Once the soil is go inside the excess amount of mercury will be spilled over here.

Then we need to take this excess amount of mercury and then we measure the weight of this excess amount of mercury or spilled over mercury. That weight of the mercury will give the volume of this dry soil pat. When we divide the weight by the density of the mercury then we will get the volume of this mercury which will be equal to the volume of this soil dry pat. This is known as the determination of volume of the soil by mercury displacement method. Sso this is an indirect method of determination of volume of this soil pat.

Once we know the initial water content which will be known to us before the testing, we will be knowing the volume of the pat, the wet pat that it means here this one is the volume of the initial wet pat, then we will be knowing the volume of the dry wet pat, so this is the volume of the dry wet pat which will get from mercury displacement method.

Then we will know the weight of the oven dried soil pat by measuring the weight of this soil sample. After knowing all this parameters we can use this equation;

$$\text{Shrinkage limit (\%)} = w - \frac{V - V_0}{W_0} \times 100$$

Where, W is the initial water content, V is the volume of the wet pat, V_0 is the volume of the dry soil pat, W_0 is the weight of the oven dried soil pat into 100.

So, that will give us the shrinkage limit of the soil, however there is some demerits of this test that is on the using of mercury. Since mercury is hazardous, it is not recommended to use the mercury and thereof the ASTM standard has now suggesting to use the water displacement method.

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So, this is the ASTM standard which uses the water displacement method to determine the volume of the soil. Again, the procedure is almost identical. We need to take a dry soil pat then instead of using mercury here the dry soil pat will be immersed into a molten wax such that a layer of wax will be coated around the soil sample.

Now, here we have to be careful that there should not be any entrapped air while dipping the soil sample into the molten wax and also the layer of the wax should be very thin. The procedure, if we see it is almost identical to Indian standard method, we need to take around 30 gram of soil sample which should be passing through 425 micron and then we need to add with water to prepare a paste and the water content will be approximately its liquid limit.

Then we need to measure its empty weight, then we need to take shrinkage dish and its empty weight and empty volume will be measured. Then it will be coated inside with a layer of silicon grease to prevent the addition of the soil sample. Then this shrinkage dish will be filled with the soil paste in layers by tapping to prevent the presence of any entrapped air.

Then we need to measure the weight of the shrinkage dish along with the soil sample, then we will dry the soil, first it will be air dried then it will be oven dried at 105 to 115 degree centigrade. Once the soil is fully dried then we need to measure the weight of the shrinkage dish along with the dry soil pat. Once the soil is dry you can see this is a dry soil pat then it will be immersed in a molten wax such that a coat of wax will cover the soil sample.

Then we will cool down the soil sample, after that the weight of the soil pat along with the wax will be measured. Then this soil sample will be immersed in water and the displaced amount of water will be taken and its volume will be or weight will be measured. So, that displaced amount of water will be equal to the volume of the dry soil.

So, the method is almost identical with the Indian standard only thing is instead of mercury method here it uses the water and the volume of the mercury which was taken earlier as the volume of this dry soil pat here will be replaced by the volume of the water which are getting displaced due to the immersion of the dry soil pat coated with wax. So, this gives us about the weight of the dry soil pat and the volume of the dry soil pat with wax.

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Once we know the volume and weight of the dry soil pat with the wax, these are the different steps to calculate the shrinkage limit.

Mass of dry soil pat (m_s) = Mass of dry soil pat and shrinkage dish (m_d) - Mass of shrinkage dish (m)

Then,

Mass of water displaced by dry soil pat and wax (m_{wsx})

= Mass of dry soil pat and wax in air (m_{sxa}) - Mass of dry soil pat and wax in water (m_{sxw})

$$\text{Volume of dry soil pat and wax } (V_{dx}) = \frac{m_{wsx}}{\rho_w}$$

Where, ρ_w is the unit weight of water.

Then,

Mass of wax (m_x) = Mass of dry soil pat and wax in air (m_{sxa}) – Mass of dry soil pat (m_s)

$$\text{Then, Volume of wax } (V_x) = \frac{m_x}{G_x \rho_w}$$

Where, G_x is the specific gravity of the wax.

Then,

Volume of dry soil pat (V_d) =Volume of dry soil pat and wax (V_{dx}) – Volume of wax (V_x)

So, volume of the wax we can get from here.

Then,

$$\text{Shrinkage limit, SL} = w - \left[\frac{(V - V_d)\rho_w}{m_s}\right] \times 100$$

So, this is the different steps which we need to follow to determine the shrinkage limit as per as the ASTM standard is concerned.

Once we determine the shrinkage limit then there are various factors which we can also determine. One is the shrinkage index which is defined as the plasticity index minus the shrinkage limit. Then we can determine the shrinkage ratio, sorry this is the shrinkage ratio SR will be equal to;

$$\text{Shrinkage ratio, SR} = \frac{\text{Weight of oven dry soil pat (g)}}{\text{Volume of oven dry soil pat (ml)}}$$

Then we can determine the volumetric shrinkage which will be equal to;

Volumetric shrinkage, VS

$$=\left[\left(\text{Intial moisture content, } w_o\text{, in \%}\right)-\text{Shrinkage limit, } w_s\text{, in \%}\right]\times\text{Shrinkage ratio}$$

So, these three parameters we can determine once we know the shrinkage limit of the soil.

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Next is the shrinkage curve, in all those experiments generally the volume of the soil we were measuring at a single point that is at shrinkage limit and also at initial stage, but in order to determine the shrinkage curve we need to measure the volume at different time interval and also at different water content and different void ratio. So, here we can see, in order to determine a shrinkage curve of this soil sample we need to determine the water content and void ratio and the volume of the soil at point 1, point 2, point 3, point 4, point 5, and point 6, 7, and 8.

Therefore, we need to measure these parameters at different time interval as well as different water content up to the soil becomes fully dry. Then we can draw a curve between the void ratio or the volume of the soil with the water content to get the shrinkage curve. In two ways we can do that, either we can take a soil sample at initial stage one and we will gradually dry the soil sample to get the different water content, different volume, and different void ratio until the soil is fully dry.

Or we can take several soil samples and we start to gradually dry the soil samples and at different time interval we need to pick up one-one soil sample and we can measure it the volume of the soil and the water content at different time intervals so that we can get a shrinkage curve but the problem is for that we need a large number of soil samples.

So, therefore, we can either we can take a single soil sample and gradually dry it or we can take large number of soil samples, dry it and at different time interval we can take out the soil sample and we can measure its weight and volume. Remember, while measuring the volume of the soil sample or the weight of the soil sample, if you use mercury method or water displacement method that sample cannot be used further for drying the soil sample.

So, therefore, if we are using the mercury displacement method or water displacement method then we need to have several soil samples to get the shrinkage curve. However, if we are going by some other method which will give us the water content and volume at different time interval we can use that method, I will talk about those things later on. But the shrinkage curve we can get by drying the soil sample gradually and measuring its weight, volume, and void ratio during the drying.

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Another test we need to do is the linear shrinkage. The objective of this test is to determine the linear shrinkage of a remoulded soil as far as IS method is concerned. This is a linear shrinkage apparatus which has a length of around 125 mm and width of 25 mm and this depth is around 10 mm. To do the test we need to take a soil sample passing through 425-micron sieve and with an initial water contain 2 percent above the liquid limit.

Then we need to fill that soil sample inside this mould and we need to do that slowly in layers such that there should not be any entrapped air present inside the soil sample and to do that we need to gradually tap the soil sample. Once the soil is filled or this mould is filled by the soil sample then we need to dry the soil sample.

How to do that? This drying should take place gradually; first the soil will be air dried until the soil shrunk such that it will not adhere to the wall of this mould. Once that is achieved then the soil will be dried at a temperature of 60 to 65 degree centigrade till the shrinkage stops that means till we reach the shrinkage limit water content. Once we reach up to this point then further drying can take place inside an oven at 105 to 110 degree centigrade to complete the drying of the soil.

Once the soil is fully dry, you can see this is a fully dried soil sample, we can measure the length of the soil. So the linear shrinkage we can obtain using this equation, that means the linear shrinkage will be equal to;

$$\text{Linear shrinkage} = \left[1\text{-}\frac{\text{Length of oven dry specimen } (L_d)}{\text{Initial length of specimen}}\right]\times 100$$

So, using this equation we can obtain the linear shrinkage of the soil, so this is given by IS2720 in part 20.

There is another method, another way or other shrinkage parameters that is known as coefficient of linear extensibility and popularly known as COLE. In this method, the objective of this method is to determine the linear strain of an undisturbed, unconfined soil sample on drying from an initial state of 5 psi which will be equivalent equivalent to 33 kPa of suction to an oven dry condition which will be approximately a suction value of 15000 psi which will be 1000 MPa.

So, in this method soil will be dried from initial state of 5 psi of suction to a oven dry suction value of 150000 psi or 1000 MPa. Once the soil is dried then we need to measure its density or we need to measure its volume so that can be obtained by a resin method. The undisturbed soil sample will be coated with a flexible plastic resin.

This resin is impermeable to liquid water but permeable to water vapor. So, here what we have to do is, first soil will be taken to an initial state of 5 psi or 33 kPa of suction value then its volume and weight will be measured then the soil sample will be oven dried and once the soil is oven dried its weight and volume will be measured.

How can we measure this one, using a plastic or flexible plastic resin. We will be coating the soil sample inside a plastic resin and then we will immerse in a liquid and will measure the displaced amount of liquid and from that we can measure the volume of this dried soil sample. Then the COLE value can be obtained;

$$\text{COLE} = \frac{\Delta L}{\Delta L_D} = \left(\frac{\gamma_{dD}}{\gamma_{dM}}\right)^{0.33} - 1$$

$\Delta L/\Delta L_D$ = Linear strain relative to dry dimension

γ_{dD} = Dry density of oven dry sample

γ_{dM} = Dry density of sample at 33 kPa suction

So, using this equation we can determine the COLE value of the soil sample, but this method has certain disadvantages like we need to bring the soil sample at an initial stage of 5 psi from that only we need to dry the soil sample. So, sometimes it is very difficult to bring the soil sample to exact 33 kPa water content, therefore it has some limited usability.

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Another method is there that is known as CLOD method that is coefficient of linear drying. This method is almost identical with this COLE method, but in this method we need to measure the volume of and weight of the soil sample at different interval such that it can give us the shrinkage curve. This method, it determines the volume change of a soil using unconfined, undisturbed soil sample coated with waterproof plastic resin. So, here what we have to do is, we need to take a soil sample and then we need to coat this soil sample with a plastic resin.

Generally, Saran resin is used. Here you can see the procedure. This is a soil sample and then it is hanged with a thread and then it is being immersed inside a resin you can see this is Saran resin. Once the soil is dipped inside a layer of resin will coat the soil sample, here you can see after dipping it the soil has been taken out. This method allow us to measure the volume of the soil sample at different water content condition. So, therefore once the soil is coated with the resin then the soil will be taken out and it will be dried.

Once this resin gets dried it will act as a flexible membrane and it will keep intact the soil fabrics and the soil fiber so the soil fabrics and the fiber will not go any change during this drying process. The resin is essentially a waterproof when is exposed to liquid for a short time, but it permeates gradual water vapor flow to and from the soil sample.

Therefore, when we dip the soil sample inside the water to measure its volume the water will not go inside the soil and we can measure the volume of the soil. Once we measure the volume then we will take out the soil sample and then again, the soil can be dried further because this resin will permit the flow of water or flow of moisture from to and from the soil sample so the soil can be dried.

So, therefore, if this is a soil sample now in the first stage we have to coat the soil sample with a resin and then we need to dip inside the water and measure the displaced volume of the water. Since this resin is a waterproof when inside the water no water can enter into the soil sample. Then we can measure the volume of the soil and weight of the soil, then we will take out the soil sample and then we will dry it again. Since the resin allows the outward movement of the moisture, the soil can dry further. Then again at different location different time interval we will take out the soil sample and again will dip inside the water and measure its volume.

So, we can get V_1, W_1, W_2, V_2, W_3, V_3 at different location using a single soil sample. Therefore, we can draw a shrinkage curve using this method. The advantage of this method is the volume of the soil sample of any shape can be measured by weighing the soil clod while it is submerged under water on a balance. Therefore, we can measure the volume of the soil sample of any shape using this CLOD method.

From the clod method, we can determine the CLOD index, you can see this is a shrinkage curve, this is for 100 saturation line. This is the line when the degree of saturation less than 100 percent, so this is a curve, a dryng curve. Now if we take the slope of this curve that is known as the clod index,

$$\text{CLOD index, } C_w = \frac{\Delta e}{\Delta w}$$

So, if this is w_2 this is w_1, this is e_2 and this is e_1,

$$\text{CLOD index, } C_w = \frac{e_1 - e_2}{w_1 - w_2}$$

So, clod index will tell us about the rate at which the shrinkage is taking place inside the soil sample. So, these are the different methods by which we can measure the different shrinkage parameters in the laboratory.

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Next is how to measure all the shrinkage parameters? The various properties of soil need to be measured for determination of sinkage parameters are water content, bulk density, dry density, and the void ratio. Water content of the soil will be measured by measuring the weight of the soil before and after drying.

Similarly, the bulk density can be measured by taking the weight and the volume of the soil before drying, so this will give us the initial bulk density. The dry density we can measure by measuring the weight and the volume of the soil after drying inside the oven. Then void ratio can be determined by measuring the weight and volume of the soil sample before and after the drying and also during the drying.

So, in all these parameters we need to measure two things, the weight and the volume of the soil sample. It is very easy to measure the weight, because weight can be measured using a weighing balance. However, it is very difficult to measure the volume of the soil sample because in order to measure the volume of the soil sample directly we cannot measure the volume.

Therefore, we have to go through some displacement method, whether that is a water displacement method or mercury displacement method, but if we take a dry sample and if we insert inside the water then the water will enter into the soil and the soil will get collapsed, the void will get collapsed.

Therefore, we need to coat the soil sample using wax or resin or indirectly we can measure the volume of the soil sample by measuring its linear dimensions, so that I will discuss here. The first one is the mercury displacement method. So in this I will explain about how to measure the volume of the soil sample. Since it is easy to determine the weight of the soil here we will need to determine the volume of the soil, so first method is the mercury displacement method.

As I have discussed earlier Indian standard has suggested this method. This is an indirect way of measuring the volume of the soil. This we can measure by measuring the displaced amount of the mercury when we dipped a dry soil pat into a glass filled with mercury. Here we need to take a shrinkage dish, then we will fill that shrinkage dish with soil as I discussed earlier.

Then we will allow the soil to dry, so during the drying this is suppose at any stage after drying, after shrinkage the soil got shrunk and you can see it the volume has decreased. So, this is a soil pat then we need to determine its weight and volume weight can be measured using a weighing balance then we need to measure the volume.

Now, as I told you we cannot dip the soil into the water directly to measure its volume, therefore, we need to take the help of mercury. Mercury we can use because the mercury is a heavy metals and it cannot go into the soil pores and it cannot disturb the soil and also it will not stick to the glass, so therefore it will be easier to measure the volume of the soil correctly. So, here we have to take an evaporating dish then we have to take a glass plate, then we have to fill this glass plate with mercury and remove the excess amount of mercury.

Then we will dip this dried soil pat, due to dipping or immersing this soil pat the excess amount of mercury will come out and fall on this evaporating dish. This excess amount of mercury will then be taken and its weight will be measured. So, this weight of mercury will be used to know or calculate the volume of the mercury. So, the volume of the mercury will be equal to the volume of this dry soil pat. Therefore, the volume of the soil pat V will be equal to the weight of the mercury displaced divided by the density of the mercury.

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Another method is the vernier caliper method, so this is one of the direct methods of measuring. The advantage of this method is, we can measure the volume of the soil sample at different stage of drying to obtain a shrinkage curve. In a mercury displacement method once this soil is used for determination of the volume using mercury displacement method then we cannot reuse the soil sample further. Therefore, we cannot use this soil for further drying or to obtain a shrinkage curve. Hence, we have to go with the vernier caliper method.

Vernier caliper method allows us to measure the volume of the soil sample at different stages of drying. Here you can see, soil sample is drying at different interval and correspondingly we are measuring the volume of the soil at different time interval, and from that we can determine the void ratios. In this method what we have to do is, we have to take a vernier caliper and then we have to take the soil sample for which we need to measure the volume, then we need to determine the diameter of the soil sample at 5 or 7 different locations.

Since during the drying this drying process may not be uniform, therefore, we have to take the 5, 6 locations to determine the diameter of the soil sample and from that we need to calculate average diameter. Similarly, we have to take height of the soil sample at 5 or 7 different locations and then we can calculate average height of the soil sample.

Once we know the average diameter and average height we can calculate the volume of the soil using this formula. Then again, we can allow the soil to dry and again after a few time interval we can measure the volume, so using a single soil specimen we can obtain different values of volume of the soil at different time interval to obtain the shrinkage curve.

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So, these are the few of the procedures to obtain the shrinkage curve. The step one is determination of the initial weight and volume and water content of the soil that is before drying. From all this parameter that is initial weight, volume, water content; we can calculate the bulk unit weight. We will be knowing the initial water content from that we can calculate the dry unit weight, and using the relationship;

Void ratio, $e = \dfrac{G\rho_w}{\rho_d} - 1$

we can calculate the initial void ratio of the soil sample.

Then we can calculate the mass of soil solid that is Ms, which will be equal to the dry density, rhod, which we can get from here and multiplying with the volume of the soil. So, before the shrinkage starts we can get all these parameters the initial void ratio, initial bulk density, initial dry density, and the weight of the soil.

In the second stage the soil will be allowed to dry, air dry gradually and at different interval we can measure the weight of the soil and the volume of the soil.

The volume of the soil can be measured as I explained you earlier by measuring the height and diameter at 6, 7 different locations and then taking the average height and diameter. Then from this weight and volume we can obtain the bulk unit weight at any interval time t which will be equal;

Bulk unit weight at any time t, $\rho_t = \dfrac{\text{Mass of soil at any time t}}{\text{Volume of soil at any time t}}$

Then we can calculate the loss of water due to drying at any time t = ΔMt = Initial weight- Weight after time t

So, this difference will give us the change in the weight of the soil sample, since the soil mass is changing only because of the evaporation of the water so that will be equal to loss of water due to drying ΔMt.

Then the water content at any time t can be obtained by using the equation, $w_t = w_i - \dfrac{\Delta M_t}{M_s} \times 100$

So this will give us the water content of the soil at any time t.

Then we can calculate the dry unit weight at any time t will be equal to; $\rho_{dt} = \dfrac{\rho_t}{1+w_t}$

So, ρ_t we can get it from here w_t, we can get it from here, so we can calculate the dry unit weight which will be ρ_{dt}. Using this ρ_{dt} we can calculate the void ratio at any time t. Therefore, by measuring the weight and volume of the soil sample during different time intervals, we can get w, w_t, and e_t. So, by this we can get w_1, e_1, w_2, e_2, that is water content and void ratio at different time interval until the shrinkage stops, which will give us shrinkage curve.

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This is how we can measure; a sample calculation has been shown in here this is before drying. The average diameter was 7.480, average height of the sample was 2.487, then using this two we can find find out the volume of the soil sample. The initial weight of the soil was 223.480 gram, initial water content was this then we can calculate the bulk unit weight, the dry density, and the void ratio. Then the mass of the solid M_s can also be determined using ρ_d and the volume of the soil that is here and that comes out 187.034 gram it will remain constant throughout.

Then during drying at any stage, let the average diameter is 7.337, average height is 2.428 then this is the volume of the soil sample. Then weight will be taken which will come out 208.2, then we can calculate water content using this equation the loss of water during drying will be 223.480. Using these two we can calculate that is 223.480 minus 208.2 that is 15.28 gram of the loss of water has been taking place, and water content will be equal to w_i which will be 19.512 minus ΔM_t, ΔM_t is 15.28 divided by M_s, M_s is 187.034 into 100, so that will be 11.343, so this is the water content at time t.

Then we can calculate the bulk density then the dry density and from the bulk density and water content relationship we can calculate the void ratio. So, this is how we can obtain the water content and void ratio at different time interval. This is one of the example I have shown here, the weight has been measured at different time interval, the diameter, this is the average diameter, at different time interval, average height, volume of the soil sample, the water content, the bulk density, the dry density, and the void ratio.

Now, you can use the void ratio and water content over here to plot the shrinkage curve. So, vernier caliper method is one of the most simplest method for determination of the shrinkage curve, and it do not need a large number of soil sample. By using 2, 3 soil samples we can measure the the sinkage curve and we can take the average of that.

However, the method is has some limitation like the measured volume of the soil will not be uniform if the drying is not uniform. so that that is one of the demerits or limitation of the method otherwise, it is very simple and easy method to determine the the volume of the soil sample during drying. The next method is water displacement method.

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It is similar to the mercury displacement method, but in place of mercury water is used here. So, this method can be carried out by using a wax coating or a resin coating method. Since the dry soil sample cannot be immersed into the soil, so therefore, we need to coat the soil sample using some impermeable membrane. In order to prevent the permeation of the water inside the pore space of dry soil pat, the method is carried out by the following procedure. First, we need to take the soil sample, like this one as I explained earlier, then we dried the soil sample. So this is a dried soil pat.

Once the soil is dried then it has to be immersed inside a molten wax. While immersing we have to be careful that only a thin layers of molten wax has been coating the soil sample, and also we have to be ensure that there is no air bubble present between the coating and the soil sample, otherwise it will change the volume or it will give some error. Once the soil is completely coated with the molten wax, a thin layer of molten wax, then the soil will be taken out and it will be allowed to dry. So here you can see a soil pat coated with a thin layer of wax.

Then this coated soil sample will be immersed inside a glass or beaker filled with water and as the soil is immersed excess amount of water will be spilled out. Then this spilled out water will be taken and its weight or volume will be measured. So, that weight or the volume of this spilled water will give the volume of the dry wet pat, and the ASTM D4943 has suggested this method for determination of the shrinkage limit. So, this is the procedure by which we can measure the shrinkage limit, already I have explained in the previous slides that how to determine the shrinkage limit using a wax method.

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Next is the resin coating method. The demerits of the wax method is we cannot reuse the soil sample, because wax is generally impermeable to water, therefore water cannot enter or it cannot leave the soil. Therefore, in order to determine the shrinkage curve we need to have a large number of soil samples.

In order to avoid that we can use a resin coating method. Resin coating allows the volume measurement of the soil at different moisture condition. Once the resin dries on the soil sample it acts like a flexible membrane and it will maintain the soil fabrics and the fiber intact and also it will be waterproof material when exposed to water for a short time, therefore it will prevent any ingress of water to the soil sample.

However, if we allow the soil to dry, this resin will permit the gradual inflow or out flow of the water vapour from the soil sample, thereby, the shrinking process will or drying process of the soil will take place. You can see here, this is a dry soil sample, this will be immersed inside the resin which will be mostly Saran resin can be used and this is a resin coated pat then we need to take this resin coated pat and it will be immersed in a water then the displaced water will be taken and its volume will be measured.

Similarly, after measuring this the soil will be taken out and again it will be allowed to dry, since this resin will allow the outflow of vapor, the soil will dry further and again at any stage we can dip inside the water and then we can measure the spilled amount of water and to know the volume of the soil sample. This method allows us to measure the volume of any shape of the soil sample using this technique.

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The next method is the balloon method. This is also a method which allows us to measure the volume of the soil sample at different time interval. The different steps involved in this method is, the first one is a sample preparation, then saturation of the soil sample, then placement of the soil sample inside the balloon, and then drying the sample by air pump. Then measure the volume and water the soil and then oven drying the soil sample. Here we can see so these are, the different balloons which are being used and here we have the soil samples which are being dried and this is the inflow of air and this is the outflow of the air.

The air will inflow into the system to allow the soil to dry, I will explain this thing in the next slide. Here we can see this is a soil sample which is kept inside a balloon and it is connected with an inlet pipe, which is carrying dry air and once the dry air moves through this soil, the water will get evaporated, and then this wet air will be taken out. So due to this process the water will get evaporated and the soil will get dried. This is the soil sample, this is the wet air, this is the balloon, and it will be filled with or fitted with a rubber cork, here you can see, this is a rubber cork such that outer air cannot be entered into the system or to make a seal proof system.

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Then we need to measure the volume of the soil at different time interval. To do that what we have to do is, suppose we are drying the soil sample at any time interval we need to measure the weight and the volume. Then we need to take out this soil sample from this stand then we will keep it the soil sample over a weighing balance.

So, that will give us the weight of the soil sample. Then in order to measure the volume of the soil sample, first of all we need to take out the weight or the air which is present inside the balloon. We can use a syringe to remove the air from this balloon such that the accuracy will be quite high.

Then we have to take a beaker filled with water and then we have to dip this balloon along with the soil sample inside the water. Then the change in the volume or the spilled amount of water will give us the volume of the soil sample inside the balloon, so this is how we can measure the volume of the soil sample at different location.

You can see a set up over here, so this is an inlet air, this is outlet air, this is balloon containing soil samples and this is the soil sample inside the balloon, this is the dry air which is entering into the balloon and drying the soil and because of the evaporation, the wet air is being removed here and this is a rubber cork to make this soil as a water tight or airtight and this is the method to determine the weight and the volume of the soil at any time interval.

This is the step one to measure the weight of the soil wi at any stage; then in step two we need to take a bottle then fill this one with water. In step three we need to immerse this balloon along with the soil sample and to measure the displaced amount of water and the weight or the volume of that displaced amount of water will be equivalent to the volume of the soil sample over here. Remember before that we need to take out the excess amount of air present inside the balloon, this can be done using a syringe.

Once this is done then again, we will connect this soil sample with inlet and outlet pipe then again, we allow to dry the soil and again after certain time we can measure the volume and weight of the soil sample. So that will give us water content at any time t and the void ratio at any time t. So, by knowing w_1, w_2, up to shrinkage limit w_s, similarly e_1, e_2 up to e_s we can draw a shrinkage curve. So, this is how the volume and weight of the soil sample can be measured to determine the shrinkage curve or the shrinkage limit.

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So, this is the reference which has been used for this class. In the next class I will explain you about the cyclic swelling and shrinkage behavior of the soil sample. How the cyclic swelling and shrinkage takes place inside a soil and what are the different factors which controls their values and with this I conclude today's lecture.

Thank you for your kind attention.