Expansive Soil
Dr. Anil Kumar Mishra
Department of Civil Engineering
Indian Institute of Technology Guwahati
Lecture 11
Determination of Swelling Properties

(Refer Slide Time: 000:37)

Hello, everyone. Welcome to the course Expansive Soil. Today we will go through the fourth module of this course and it will be the lecture number 10. The module will be the swelling behaviour of expansive soil. We will be continuing with this module. And in the last few classes, we learned about different kinds of mechanism in which the water molecules get attracted towards the clay surface, the swelling phenomena of expansive soil, how the soil expands.

In this lecture, we will learn about how to determine the swelling properties of an expansive soil. So, in this chapter, we will be learning about different tests, what has been conducted to determine the swelling pressure and swelling potential of the soil.

(Refer Slide Time: 01:25)

When we talk about the swelling, the first things come to mind is a free swelling test. The free swelling test is one of the simplest and quickest tests available to determine the free swelling of the soil. The term free swelling means, in this test the soil is allowed to swell freely without putting any overburden weight on it. That means the soil will be submerged in the water and no load will be put over the soil such that it can swell freely. So, that is why the term called free swelling comes.

So, free swelling by definition is a test to determine the swelling capacity of an expansive soil without any overburden pressure and in the presence of a liquid. This liquid can be water, or any salt solution, for which we need to determine the free swelling. There are two methods available. One is Indian standard method, which is IS: 2720 Part XL (1977). And the second method is ASTM standard, that is ASTM D 5890 (2019).

So, both the standards are widely used, particularly Indian standards is used in India, whereas, ASTM standard is mostly used around the world. So, we will learn about the procedure involving in this two methods.

(Refer Slide Time: 02:48)

First of all, the Indian standard method. In Indian standard method, we need to take 10 grams of expansive soil and it should be passing through 425 microns sieve and the soil should be oven dry. That means there should not be any moisture present in the soil. And then, we need to take two 100 ml measuring cylinder, then we will take two different liquids.

First of all, we need to take water, or salt solution, for which we need to determine the free swelling. In another tube, we will need to take a non-polar liquid such as kerosene. Here I would like to tell you that, if the soil is expected to swell to a large extent, then in that case, instead of 10 gram we can take 5 gram of the sample, or maybe we can increase the size of the tube from 100 ml to 250 ml.

So, after taking the water, or the salt solution, and kerosene in another tube, or any other non-polar liquid, then we will submerge the soil here. What we will do here is, we will add this expansive soil slowly with a 0.1 gram increment and then we will completely fill this tube up to 100 ml mark with this water or salt solution. Similarly, in other tube we will fill this one with kerosene or any non-polar liquid. Then we will not disturb these two tubes and we will allow the soil to expand for 24 hours.

After 24 hours the volume of the soil inside the tube will increase. Mostly it will increase in the water or salt solution, but in kerosene it will not increase. Since kerosene is a non-polar liquid, the dielectric constant of kerosene is various less in comparison to water or salt solution. Therefore, the swelling in kerosene will be very, very less or almost negligible. So, that is why in kerosene the swelling will not be taking place.

We take kerosene in order to determine the volume of an expensive soil in non-expansive condition. So, you can see in this diagram, this is in water. Here we can see a large amount of volume change has taken place. But in this case, this is with kerosene, we can see a less amount of swelling has taken place. So, what we will do next is, we will measure this volume, by noting down this marking on the tube and that will give you the volume of the expanded soil.

So similarly, we will measure for this one and then we will determine the free swell index using this equation. That is the ratio between the swollen volume in water minus swollen volume in kerosene divided by swollen volume in kerosene multiply by 100. Sometimes this is also called as differential free swelling test or DFS test. So, this is all about the Indian standard method.

(Refer Slide Time: 06:06)

But in ASTM standard method, we do not need to take any non-polar liquid, all you need to take the soil as well as the solution for which we need to determine the free swelling test. And also, the major difference in this test is instead of 10 grams, here we will be taking 2 grams of oven dry sample. And the soil, which we have to use should be 100 percent passing through 150 micron seive, and at least 65 percent should be passing through 75 micron sieve.

After taking this soil, then we will put it into oven for 24 hours for the sample to be drying, then after that, we will take 2 gram of this soil sample. Then we will fill this tube with this either water or salt solution, up to half mark, then we will add this soil in 0.1 gram increment. And we have to take care such that the soil should not stick to the surface of this tube.

Once we completely put all the two gram of the soil into the tube, then we will fill this tube up to 100 ml mark. And then we will keep it undisturbed for at least 16 hours. So, after 16 hours, we will measure the reading here and that will give you the swollen volume of this soil and the unit will be in millilitre per 2 gram.

The main difference between ASTM standard and Indian standards are in Indian standard, we need to take 10 gram of the soil. And also, we need to take two tubes, where in one, we have to put water or salt solution, in another tube, we need to put kerosene and then we will allow this soil to be expanded and then we will measure the volume and then we will measure what is the difference in the volume between these two condition and then we will find out the free swell index.

Whereas in ASTM standard, only we need to take one 100 ml measuring cylinder and then we will put 2 gram of the soil and then allow it to swell for 16 hours and we will measure the volume after 16 hours to tell what is the free swelling index of this soil. So, this is one of the simplest method and that will give you a good indication of how the soil will be swelling in presence of water or salt solution.

(Refer Slide Time: 08:44)

The other few parameters like swelling pressure and swelling potential is one of the most important two parameters of a soil, which needs to be determined for any engineering application. So, going by the definition of the swelling pressure is, when a soil swells then it try to expand in upward direction. If it is suppose, if this is soil and if it is literally constrained and then if we allow the soil to absorb moisture, then it will try to expand in its volume.

If we put some additional load over here and if we not allow the soil to swell, then it will start to exert a pressure over here. So, again we need to increase the pressure at this point and at particular point, we will reach to that pressure, which will totally prevent the soil from being swollen. So, that pressure is known as swelling pressure.

In other way also, if we take a soil sample and if the soil is allowed to swell, then it will start to exert a pressure over here. So, that pressure is known as swelling pressure. So, swelling pressure is defined as the pressure that needs to be applied over a swelling soil to prevent its volume to increase. A swelling pressure of less than 20 may not be regarded as much as of consequence to the any structure.

Similarly, there is another term the swelling potential, which defines as the how much soil has been swollen. So, for example, if we take a soil and if we allow the soil to swell, let this be the final height of the soil. Here, I am not allowing the soil to swell in this direction that means, I am constraining in the side. So, this is the increase in the height of the soil. So, this is can be ΔH and this was the initial height of the soil.

Now, this ΔH by H ratio is known as the swelling potential of the soil,

Swelling potential = $\Delta H/H$

or by definition, it can be defined as the magnitude of the heave of a soil for a given final water content and loading condition. We need to remember this terms and this terms. Because if we apply some load, the total increase in the volume will be different. So, therefore this $\Delta H/H$ also depends on the loading conditions.

Similarly, the water content also plays an important role. So, therefore it should be for a given final water content and loading condition.

(Refer Slide Time: 11:26)

We will see one by one how to determine the swelling potential and swelling pressure. First, go with the swelling potential. Swelling potential is defined as the percentage swelling of a soil sample submerged in a liquid. This can be water or any salt solution, there are several methods using which we can measure this swelling potential.

The four different methods generally, which are being used are number one, under a minimum surcharge load; number two, under a given surcharge load; third is potential volume change and the fourth one is an expansion index test. Generally, these four tests are used and mostly, the first two tests are used to determine the swelling potential of a soil.

(Refer Slide Time: 12:13)

We will go one by one about all these tests. The first one is under a minimum surcharge load. This represents what the soil volume will be, or increase in the volume will be when the load on the soil is minimum. Or in other words, when there is no over burden is there or no structure is present. What will be the increase in the volume of the soil? That is the swelling potential under a minimum surcharge load.

So, mostly we use a consolidation test apparatus to determine the swelling potential using this method. First, we will take a soil sample, like this one this will be soil sample. We know a consolidation ring of 6 centimetre diameter and 2 centimetre in thickness. But here what we will do is, we will not put the soil sample up to entire depth, we have to compact the soil up to this volume. Generally, this is around 1.5 centimetre to 1.7 centimetre.

Then we have to apply a minimum value of surcharge load over here, that surcharge load can be 1 to 5 kPa. This is known as seating load. So, first what we will do is, we will take a soil sample, then we will compact it in a required density and moisture content and then the compacted soil will be placed in a consolidation apparatus, then a seating load will be applied after that the soil will be submerged in the water or any testing liquid for which we are going to determine the swelling potential and we will allow the soil to swell.

Soil will swell slowly and depending on its swelling tendency, it can be over within 24 hours or it can take up to 7 days. After the end of the swelling, we will measure the final height of the soil sample. Let that be ΔH. This $\Delta H/H$ will give us the swelling potential.

(Refer Slide Time: 14:34)

Here we can see in this diagram. This is a plot between the void ratio and pressure. We took the soil sample in its initial condition, where the initial height was H_i and initial void ratio was e_i. Then at this point, minimum surcharge load of 1 to 5 kPa was applied. Under this load, the sample was submerged and the soil was allowed to swell. After this swelling is over, the soil swells to the final height of Hf and the final void ratio of e_f. This value will give us the change in the thickness or change in the void ratio of the soil.

So, we can calculate what is the change in the height of the sample by knowing H_f and H_i that will be ΔH and when we divide ΔH by Hi that will give us the swelling potential. Similarly, from void ratio also, if we can calculate what will be the e_f and e_i, we can use this equation to find out the swelling potential of the soil. So, this equation can be used to determine the swelling potential.

$$\text{Swelling potential (\%)} = \frac{\Delta H}{H_i}\times 100$$

$$= \frac{\Delta e}{1+e_i}\times 100 = \frac{e_f - e_i}{1+e_i}\times 100$$

(Refer Slide Time: 15:51)

I will solve an example for better understanding. One initial water contained and the void ratio should be representative of the in-situ immediately prior to the construction in case where it is necessary to use disturbed soil samples, the soil samples should be compacted to the required field density and water content in a Proctor compaction mold. So, we need to remember this.

Suppose a soil sample was taken whose initial water content was OMC was 27.1. Dry density was 1.28 and specific gravity was 2.81. Now, we need to prepare the soil sample, then we compacted the soil into the consolidation ring with an initial height of 1.5 centimetre, as I told you that we need to give some allowance such says that the soil will swell. Diameter of 6 centimetre so, final volume will be 42.41.

Weight of the ring, we will measure is 128.85. The final weight plus weight of this ring plus soil 193.48 gram. Then weight of the soil will be 64.63. Then, water content of the soil 27.3, although we had targeted 27.1, but in laboratory, it is difficult to achieve what is the target.

So, generally it should be something around plus minus 0.5 percent. Then we can calculate the bulk density, dry density and from this we can calculate what is the initial void ratio and degree of saturation.

(Refer Slide Time: 17:37)

Then we will apply a seating load of 5 kPa initially. Initial dial gauge reading was 1200 unit and the initial void ratio was 0.534. Then at this point, we added water or we submerged the soil in water. So, as we submerge the soil in water, the soil starts to swell. Finally, the volume increase which was measured by the dial gauge reading was 1500. Initial height of the sample was 15.

So, change in the height= (1500-1200) x Least count of dial gauge =3 mm

Final height of sample = 15 mm + 3mm = 18 mm

The initial void ratio was this one and then we can calculate Δe. So, Δe becomes 0.307, that means increasing the void ratio by 0.307. Finally, the void ratio becomes 0.841. So, other things I will explain in the later when I explain about the swelling pressure. So, here the swelling potential, we can calculate by knowing e_f, e_i. So, e_f is our 0.841, then e_i is 0.534;

$$\text{Swelling potential (\%)} = \frac{e_f - e_i}{1+e_i}\times 100 = \frac{0.841-0.534}{1+0.534}\times 100 = \frac{0.307}{1.534}\times 100 = 20.01\%$$

(Refer Slide Time: 19:16)

If we draw this one on e-log P graph, this is the void ratio plot, this is a pressure plot, this is initial condition before swelling and at this point water was added. So, there was an increase in the volume, or with the swelling process starts over here, and finally the swelling stops at this point. So, this is the swollen volume or ΔH or maybe Δe. This will indicate the swelling potential of the soil.

Since we are applying a minimum surcharge load of 1 to 5 kPa. So, this method is known as swelling potential under a minimum surcharge load. Generally, this method is applicable when there is no surcharge present on the soil.

(Refer Slide Time: 20:10)

If there is a surcharge load present on the soil. Then how to determine the swelling potential? In that case, we need to go by this method. This is known as swelling potential under a given surcharge load. The objective of this test is to determine the swelling potential of a soil subjected to a surcharge load, which is equivalent to the weight of the structure above it.

Again, we will be using the consolidation test apparatus for determination of this one. The procedures are first, the soil sample should be compacted to the required density and the moisture content. Then the sample will be placed in a consolidation apparatus, then a vertical load will be applied until the load will reaches to the surcharge load for which we are going to determine the swelling potential.

And here we need to remember the thing is the load which will be applied should be applied gradually. And also, we should not give much time between two loads or two increments, because if we give some more time, then the soil will gets dry and the initial water content will change and that will change the swelling potential.

In this method, first we will start with some initial load and gradually, we will increase the load. In increment wise, we have to increase the load and this will be the load for which we need to determine the swelling potential or this is equivalent to the surcharge load for which we are going to determine the swelling potential.

Once we reach to that load, then the sample will be submerged in the water or testing liquid and it will be allowed to swell. So, after the end of swelling, we need to determine the final height of the sample or final void ratio. From that we can calculate the swelling potential.

(Refer Slide Time: 22:07)

So, here we can see, this is the initial condition, then we started to apply load gradually in increments and we reached up to this value. So, this is the surcharge load for which we need to determine the swelling potential corresponds to this load. Once we reach to this value, then we will submerge the specimen in water or any salt solution. So, this P value is a surcharge load for which swelling potential is to be measured.

Once we submerge the sample, the sample volume will increase and the height becomes increased from H_{p1} to H_{p2}. Similarly, the void ratio has been increased to e_{p1} to e_{p2}. So, knowing H_{p1} or e_{p1} and H_{p2} and e_{p2}, we can calculate the swelling potential using this formula,

$$\text{Swelling potential (\%)} = \frac{e_{P2} - e_{P1}}{1 + e_{P1}} \times 100$$

where e_{P1} is the stabilized void issue under the load P, e_{P2} is the swollen void ratio under the load P. This method is applicable, when we need to determine the swelling potential under a given surcharge load.

(Refer Slide Time: 23:26)

Next method is potential volume change method or this is known as PVC method. This method is mostly used for the remolded soil. In this method the remolded soil sample is placed inside a consolidometer ring with a modified compactive effort of 2600 kg per meter cube. So, soil should be compacted using a modified compactive apparatus and sample should be compacted at its natural moisture content. Then the sample will be submerged.

(Refer Slide Time: 24:01)

Before that I will explain you the methodology here. This is a soil sample, compacted soil sample and this is inside a consolidometer ring. There will be an adjustable rod and this will be attached to a proving ring. Here we will submerge the soil. Once the soil is submerged, it will start to absorb moisture and the volume will start to increase.

As the volume starts to increase, the soil will start to apply a vertical pressure over here and that will push this rod in upward direction and that will exert a force over here in the proving ring. And from the proving ring, we can measure how much pressure is being applied by the soil.

Going by the methodology. Soil is then submerged and allowed to swell against the proving ring. The swell index is reported as the pressure in the proving ring and it will be correlated with a range of potential volume change.

Once we know the pressure on the proving ring, we will correlate this one with the potential expansiveness of the soil. We can determine from this graph by knowing the swell index. Suppose if the swell index is 2000 and if the soil is in initially dry and moist condition, then we can say, there will be a marginal potential volume change can occur to the soil, if the pressure exerted on the proving ring is around 5000 for example, so, here we can say that the soil will be very critical in terms of its expansiveness. So, using this test and this diagram, we can determine the potential expansiveness of the soil. So, that is why it is called potential volume change method.

(Refer Slide Time: 26:02)

Next is the expansion index test. In the expansion index test, the soil will be taken which should be passing through 4.75 mm sieve size and then the water will be added to the soil to bring its water content to its optimum moisture content. Then, we will allow the soil to be equilibrate for 6 to 30 hours and then it will be compacted into a mold of diameter 4 inch.

Then will check its degree of saturation. If the degree of saturation is less than 50 percent, we will add some amount of water to bring its initial degree of saturation up to 50 percent. Once the degree of saturation is up to 50 percent, we apply a overburden pressure of 6.9 kPa and then the sample will be submerged for 24 hours in water. And the volume change will be monitored for 24 hours. And finally after 24 hours, the percentage swell of the soil sample will be measured.

Suppose, if the percentage swells of the sample is Δh, then the expansion index can be calculated using this equation.

$$\text{Expansion index (\%)} = \Delta h \times F \times 100$$

Where, Δh is a percentage swell, F is a fraction passing through 4.75 mm sieve size.

(Refer slide Time: 27:34)

So, based on the expansion index, we can know what will be the expansion potential of the soil. If it is in between 0 to 20, the expansion potential should be very low, 21 to 50 it will be low, 51 to 90 it will be medium and if it is more than 130, then it will be very high. In this method, we can determine expansion index and this expansion index can be correlated with the expansion potential using this table. So, this is all about the different methods, which are available for determining the swelling potential of the soil.

(Refer Slide: 28:16)

Next is the swelling pressure. As I defined earlier, the swelling pressure is the external pressure required to stop the swelling of a soil. There are a few methods available. One is known as Oedometer method and second one is known as a Constant volume method. These are the two methods generally which are used to determine the swelling pressure.

(Refer Slide Time: 28:35)

So, we will go one by one. Oedometer test method. So, there are several methodologies available using oedometer test. First one is under a minimum surcharge load and this is also same as IS 2720, Part XLI, 2016. The objective of this method is to determine the pressure required to consolidate a soil sample to its original volume.

The apparatus which is required is a consolidation test apparatus. The methodology is, first the soil will be prepared to its moisture content, which can be its in-situ moisture content or its optimum moisture content. Then, the soil will be compacted into a consolidation ring of 6 centimetre diameter and the height of the samples can be kept around 1.5 centimetre. Then a seating load of 1 to 5 kPa will be applied.

As I told you earlier, this is the minimum surcharge load which you can expect in the field. After applying 1 to 5 kPa of surcharge load, the sample will be submerged in water or testing liquid and it will be allowed to swell. After the completion of the swelling, the soil will be consolidated at various pressure. This method we have already learned for determination of swelling potential.

After end of the swelling, then different amount of consolidation pressure will be applied in increment to consolidate the soil sample. The external pressure required to consolidate the soil to its pre-swollen volume will be known as its swelling pressure.

(Refer Slide Time: 30:28)

To better explain this one, I will use the graph over here. This is the soil sample. This is in the initial condition. The soil has been compacted to its initial water content almost any density, the density can be in-situ density or MDD. And similarly, the water content can be in-situ water content, or it can be its OMC. Once we apply a minimum surcharge load of 1 to 5 kPa, then the sample will be submerged in water or testing liquid.

So, once the soil is submerged, the volume will increase to here. After the end of the swelling we will measure what is H_i, what is e_i, H_f and e_f. Once the swelling part is over, then we will start consolidating the sample by applying different amount of pressure in increments. This is the different amount of loads we will apply. And for each load, we will determine what is the void ratio corresponds to each load, maybe we can write e_1, e_2, e_3, e_4, e_5, e_6. So, we can determine what are the different void ratio corresponds to different pressure. Once we know the void ratio corresponds to different pressure, we will plot this e-log P graph. Then we will draw a horizontal line, which will be parallel to this pressure axis and the point at which it will cross this e-log P graph, the pressure corresponds to that point will be known as the swelling pressure.

This also can be defined as the pressure which will be required to compress the soil to its initial void ratio. At this point, the void ratio was equals to or will be equals to its initial void ratio e_i. That means this amount of pressure is required to compress a swollen soil to its initial state. So, that is known as the swelling pressure of the soil.

(Refer Slide Time: 32:42)

We will solve a problem. We will be using the earlier problem, which I have explained. So, this is the initial condition, the soil was compacted inside a consolidometer ring, the thickness was 1.5 centimetre, diameter is 6 centimetre, weight of the ring was 128.85 gram, weight of the soil plus the ring is 193.48 gram. So, the weight of the soil is 64.63 gram, the water content was 27.3, bulk density we can calculate, the dry density from water content we can determine. Then we can calculate what is the void ratio and degree of saturation. So, this corresponds to our e_i.

(Refer Slide Time: 33:31)

Then, from the different pressure and void ratio graph, we will get the load and the final void ratio plot. For each load, we can know what will be the final dial gauge readings. So, that will give us the change in the height ΔH. So, here plus means there is a swelling happening, minus means the sample is getting consolidated. So, that means the volume of the soil is decreasing. Here we can calculate what is the Δe, and then we can calculate what will be the final void ratio.

And then we will plot the e-log p graph, then we will draw a horizontal line which will be starting with e_i which was the initial void ratio, the point at which it will cross the e-log p graph, then we will drop a vertical line to the x-axis and the pressure corresponds to that point will be the swelling pressure. So, in this case, it will be the swelling pressure will be 80 kPa.

So, by this method, we can determine the swelling pressure under a minimum surcharge load. So, using this method, we can determine the swelling potential and the swelling pressure under a minimum surcharge load. So, we just need to do one experiment to determine both the parameters.

(Refer Slide Time: 35:01)

The next method is under a given surcharge load, what will be the swelling pressure? So, in this case, the main objective is to determine the swelling pressure subjected to a surcharge load, which will be equivalent to the weight of the structure above it. Again, we will be using a consolidation apparatus. The sample will be compacted to its required density and moisture content, then the sample will be placed in a consolidation apparatus and then the sample will be loaded gradually till it reaches to a value for which we need to determine the swelling pressure.

And when we apply the load, we have to apply the load in increment. And also we need to remember that the difference, the time gap between two loading should be minimum, such that there will be will be no evaporation of water from the soil. Once we reach the surcharge load value, then the sample will be submerged in water or testing liquid, and the sample will be allowed to swell.

Once the swelling is completed, then the consolidation load will be applied and the void ratio corresponding to this load will be determined and then a load and void ratio curve will be plotted and the load corresponding to the void ratio before the swelling will be determined as the swelling pressure.

(Refer Slide Time: 36:29)

So, here we can see, we took the soil sample in its initial condition, then we started loading it and we reached up to this point. So, here we need to apply the load gradually. So, here we are applying two increment in between there are two increments and remember the gap between them should be minimum. At this point, this pressure represents the surcharge load for which the swelling pressure needs to be determine.

Once we reach to this point, then we will submerge the soil over here. Once the soil is submerged, it will start to swell. And this will be the final void ratio after swelling. Then, once the swelling is completed, then we will gradually apply the load to consolidate the soil sample. Then we will get a graph like this, this is e-log p graph. Then we will draw a line from here the point at which it will cross the e-log p graph will be the swelling pressure corresponding to that surcharge load.

So, this is the method or this is a way by which we can determine the swelling pressure of a soil under a given surcharge load.

(Refer Slide Time: 37:55)

This is a third method, here also we have to apply a surcharge load, but here that the difference between this method and the other method is, here we will be applying a load such that the volume of the soil will remain constant, or we will keep on applying a surcharge load to keep the volume of the soil constant.

Again, here we will be using a consolidation test apparatus. The soil will be first compacted to its OMC and MDD or any other in-situ density. Then the sample will be placed in a consolidation apparatus and vertical load will be applied until it reaches up to the load for which the swelling pressure needs to be determined, then the sample will be submerged in water, then the volume will starts to increase.

Here what we will do is, we will apply some additional load such that the soil will not swell, or we will apply the load to prevent the soil from swelling and we will gradually increase that load, such that the volume will not increase further. But once we reach a certain point or certain pressure, the soil starts consolidating. So, that pressure is known as the swelling pressure of the soil.

(Refer Slide Time: 39:28)

So, this is better I can explain in this e-log p plot. First, we will take the soil sample. The initial condition was like OMC or MDD or in-situ density. Then we will apply the gradual loads up to this point, for which we need to determine the swelling pressure. Then once we reach to this pressure, then the soil will be submerged. Once the soil is submerged, it will start to swell, but immediately we will start to apply the load, such that the volume will remain constant. That means the e will should not change or changing the height should be 0 and we will gradually increase this load.

So, after reaching a certain amount of load, if we further apply a load, the soil will start to consolidate. So, here you can see the e is decreasing from this point onwards. So, this maximum amount of pressure after which the soil starts to consolidate is known as the swelling pressure of the soil. This is known as a constant volume method, since the volume is being kept constant at this portion, or by applying this amount of pressure, the volume of the soil is remaining constant. So, this is the swelling pressure corresponds to this surcharge load. So, this is all about different methods.

(Refer Slide Time: 41:00)

Going by ASTM standard, ASTM also has three techniques. So, we will go one by one about those techniques. Mostly ASTM D 4546-21 deals about the swelling pressure and swelling potential of a soil sample by using one dimensional swell or settlement in apparatus. The first method which is method A, also known as wetting after loading test. Here, 3-4, soil samples will be taken and the initial conditions can be like in-situ density, or it can be like compacted OMC or MDD, that means soil can be undisturbed or can be a re-molded soil.

Then different amount of vertical loads corresponding to different depth of the load will be applied and specimen will be submerged and allowed to swell or compress. Here we will take 3-4, samples. So, this is say, for example, 1st sample, 2nd sample, 3rd sample and 4th sample. So, after taking the 4 samples, we will compare the soil to its initial condition, whether it is MDD or OMC or any in-situ density. And in this soil, we have to apply different amount of loads, which will be corresponds to their overburden pressure.

In this method generally what happens, this represents from which depth we were taking the sample. So, if we are taking the sample from different depth, the overburden pressure on the samples will be different. So, we have to apply different amount of overburden pressure on these samples. So, if the sample number is this 1, is this 2, 3, 4, we have to apply the corresponding overburden pressure on this soil. And we have to apply this overburden pressure gradually and incrementally and also time between two increment should be kept minimum such that there will be no evaporation of water.

Once we reach to this overburden pressure that means, if suppose this is P_1, P_2, P_3, P_4, then the soil will be submerged inside the testing liquid or water. So, here we can see different vertical loads corresponding to different depth of the load will be applied and specimens will be submerged and allowed to swell or compress. The vertical load applied to a soil is equals to the overburden pressure plus the stress due to any structural load if present. The final swelling or compression will be measured.

(Refer Slide Time: 43:51)

Then we will plot a graph like this one. Say in this one, this is a first sample. Here, this corresponding to the total overburden pressure present on this soil overburden pressure which will be like weight of the soil plus any structural load if it is present. Then we will allow the soil to swell. So, from this to this the soil got swollen.

Second one, second sample, we will apply an additional amount of load, which will be more than this first one. Again, this second load will be corresponding to the overburden load which are present on this sample and this point the soil will be allowed to swell. So, soil swells from this point to this point. Similarly, third one, we applied another overburden pressure and then we will submerge the soil, but in this case instead of swelling, the soil will start consolidating or getting compressed.

Similarly, at this fourth sample, we will apply a different amount of overburden load and then we will submerge the soil, then again like sample number 3, sample number 4 also starts to consolidate. So, in these two cases, the soil is swelling, this is 1, this is 2, this is soil is consolidating and this is also consolidating.

Now, we will plot a compression strain and swelling strain plot at different vertical stress, this corresponds to sample number 1, sample number 2, sample number 3, and 4. Now, the pressure corresponding to 0 strain, or this pressure will be known as the swelling pressure. By this method, we can determine the swelling pressure of the soil.

The data from this test can be used to estimate one dimensional ground surface heave or settlement that can occur due to the full wetting after a fill has been constructed. So, this is the method, method A, which is also known as wetting after loading, that means first we will load then we will wet the sample or submerge the sample.

(Refer slide Time: 46:28)

The second method is single point wetting after loading test. In this also we can use remolded soil sample, the seating pressure of 1 kPa will be applied to an undisturbed soil sample to evaluate the disturbance, the load on the sample will be increased up to in-situ vertical stress in step wise. Since it will be, it will be carried out for an undisturbed soil sample, when we take out the soil sample there will be some amount of disturbance.

Initially, what we will do is, we will apply 1 kPa of seating load, then to evaluate the disturbance of the soil sample, we will increase the load on the samples up to its in-situ vertical stress. And again it has to be in step wise. And also each load increment will be kept for 1 hour not more than that. Then, once we reach to that in-situ vertical stress, then the sample will be unloaded. So, that means, if this is the soil sample, once we reach here, then the sample will be unloaded and then again it will be reloaded in increments.

(Refer Slide Time: 47:50)

This is a soil sample for initially, it is at 1 kPa, then it will be first loaded to its initial in-situ stress. From 1 kPa the soil will be loaded to its in-situ stress. Once we reach to this value, then the soil will be unloaded like this one. So, after reaching this the soil will be loaded again. So, the difference between the void ratio, or the compression before and after this loading-unloading will give you the disturbance of the soil samples.

So, after reaching to this value after unloading and reloading, the soil will be submerged over here. And then we will allow the soil to swell and determine how much swelling or compression is being taking place.

Then the sample will be unload and reload again in increments after reaching to its initial state, where the vertical pressure equals to in-situ pressure, sample will be allowed to stabilize for 30 to 60 minutes, then the sample will be submerged in water and allow it to swell and the swelling potential will be measured.

So, this value will tell you about the swelling potential of the soil. To determine the swelling pressure of the soil, the test will be repeated on different samples at different pressure, such that few of them will swell and few of them will compress. Say, this test is conducted at P1. Similarly, another test will be repeated at a pressure of P2. Then another one will be repeated at P3, another will be repeated at P4. Say for example for P1 and P2, sample will swell and for P3 and P4, it will compress.

Now like the earlier case, we will plot a graph between compression strain and swelling strain, for this is corresponds to P1, this corresponds to P2, since there will be a swelling. So, this is on swelling strain. Now, this is P3 and this is P4, this is a compression strain, because the volume of the soil is decreasing. Now, the pressure corresponding to 0 strain or 0 volume change will be known as the swelling pressure.

Using this method, the single point wetting after loading test, we can determine the swelling potential as well as the swelling pressure of the sample.

(Refer Slide Time: 50:36)

The next method is loading after wetting test. This method has two steps involved, this test can be conducted on undisturbed as well as remolded soil. This testing can be carried out in two steps, the first step will be identical with method A and B. But the second step is bit different. After this one, the soil will be allowed to swell or compressed.

So, after reaching to this state on completion of swelling or compression, additional load will be applied in stepwise, the vertical stress corresponding to zero deformation will give the swelling pressure value.

(Refer Slide Time: 51:23)

So, if we look into this one, we will take the soil sample, which will be should be disturbed or undisturbed one. Then we will load the soil sample to its in-situ or any stress for which we need to determine its swelling pressure. So, let this be the that pressure. Once we reach to this value, then we will wet the sample or we will submerge the sample. After submerging the sample, the volume of the soil will increase, say the volume increase to this one. After the increasing to this, we will start to apply load to compress the soil.

So, this is the different loads are being applied, like simple consolidation procedure. And then we will find out at which pressure this e-log p curve is crossing the 0 line or 0 strain line. So, the pressure corresponding to that line is known as the swelling pressure. So, this is the third method which is also known as loading after wetting test. So, this is a three methods described by ASTM depending on the situation we can choose any of these method to determine the swelling pressure and the swelling potential.

(Refer Slide Time: 52:49)

There is another method also available that is known as constant volume method, this is described by IS 2720 Part XLI 2016. As the name suggests, in this method, the volume of the soil sample will be kept constant. So, objective of this test is to determine the external pressure required to keep the volume the soil constant. Again, the apparatus is a consolidation test apparatus, or a loading frame and proving rings are required, the soil sample of required density and moisture content will be prepared, then sample will be placed in a consolidation apparatus on loading frame.

So, maybe first I will show you the diagram. This is a soil sample, which has been compressed into a consolidation ring. Then this is placed over here and there is a proving ring here, which has been connected using a piston over here. And these are the platen of loading anvil. There are also dial gauge will be there to measure vertical strain and also the dial gauge is there to measure the pressure on the proving ring.

Then what we will do is, we will submerge the soil sample and then we will fix this anvil such that the volume of the soil will keep constant. Now, when we add water, the soil will try to swell and it will exert a pressure over here. So, that will be recorded on this proving ring. Since the volume is constant, it will try to exert a pressure on this. A proving ring and a strain gauge will be attached. The sample will be submerged in water or testing liquid. The volume will not be allowed to swell by adjusting the platen.

The proving ring reading will provide the value of the swelling pressure. So, that can be calculated using this one. The final dial gauge reading on the proving ring and by knowing this initial dial gauge reading and by knowing the area of the soil specimen and by multiplying with the calibration factor of proving ring, we can calculate the swelling pressure.

Before the swelling will note down the initial dial gauge reading, then after the swelling, we will note down the final dial gauge reading. The area of the soil specimen will be known to us, the calibration factor of the proving ring will also be known to us and then we can find out what will be the swelling pressure of this soil.

So, these are the few methods by which we can determine the swelling pressure and swelling potential of the soil using various parameters such as, free swelling, swelling potential, or liquid limit or its plasticity index.

(Refer Slide Time: 55:42)

And thank you very much.