Expansive Soil

Professor Doctor Anil Kumar Mishra
Department of Civil Engineering
Indian Institute of Technology, Guwahati

Lecture: 17

Cyclic Swelling Shrinkage Behavior

(Refer Slide Time: 00:37)

Hello, everyone. Welcome to the course on Expansive Soil. This will be the 16th lecture overall of this Module 5, and it will be dealing with the swelling and shrinkage characteristics of expansive soil. In today's lecture, we will be learning about the cyclic swelling, shrinkage behavior of a soil.

So, far we have learned about the shrinkage and swelling behavior, how a soil swells and how a soil shrinks, but we have learned swelling and shrinkage behavior in a different manner, that means separately. However, a soil when subjected to swell, also shrinks when it loses water. And this process of cyclic swelling and shrinkage goes on in a regular manner, in a periodical way.

(Refer Slide Time: 01:14)

Say, for example, in this picture, we can see this is a part of the soil which is, let us assume this is an expansive soil. And we know that a soil when subjected to a change in the water content can produce the swelling and shrinkage behavior. So, this is an expansive soil, and this is the water table.

Now, this soil will undergo a change in the water content due to wetting, due to the rainfall or drying due to the summer season. So, we say, that one is the seasonal fluctuation in the water content. So, here we can see this is a mean level of the water content. And during the dry season, the water content of the soil will reduce and the water content will be lower in comparison to the mean or average level of the water content, which it should be.

So therefore, the soil in this portion will have a less water content, because the water will get evaporated in a process of evaporation or maybe in the process of evapotranspiration. So, therefore, the water content of this soil will be less. But as we move down from the soil surface, the water content will keep on increasing and at a particular level, the water content will become equals to the average or mean value of the water content of the soil.

Now, if we go to another season, that is a cool or rainy season, there will be less amount of water which will be lost because of the evaporation and more amount of water will be infiltrated into the soil because of the rainfall or precipitation. So, due to this ingress of the water, the water content of the soil will be increased. Here we can see, the water content profile shows that the water content of the soil is higher than its mean or average value of the water content.

So, therefore, during the two seasons, that is the dry season and in the rainy season, there will be a change in the water content of the soil. Similarly, for the rainy season, if we move down, we can see after certain depth, the water content will become constant and it will not vary with depth, and it will become almost identical with the mean water content of the soil.

So that level at which the water content will not change due to the seasonal fluctuation is known as the active zone. Thus, soil between the soil surface and active zone will undergo an expansion and shrinkage due to a fluctuation in the water content. During the dry season when the water got evaporated, the soil will be subjected to shrinkage and during the rainy season when there is an ingress of the water and when there is an increase in the water content, the soil will swell. So, this process will keep on changing regularly. That means, during the dry season the soil will lose water and it will undergo shrinkage.The next, will comes the rainy season in which the water content of the soil will increase and that leads to the swelling of the soil. And again, during the dry season, the water content of the soil will decrease and soil undergoes shrinkage. So, this cyclic process will go on for many years to a soil, and this leads to cyclic swelling and shrinkage behavior. Again, this fluctuation in the water content can be different, if we provide a slab on the surface. Slab in the form of a floor slab or pavement or maybe a foundation.

So, in the presence of this slab or pavement or foundation the water content profile will be different than what it should be in the absence of this. Here we can see, this is the water content profile without the presence of the slab during the dry season, we can see, the water content is less, but due to the presence of slab the water content during the dry season is not equal to this level. In fact, the water content is higher in comparison to this.

In rainy season again, the water content will be more. But now, due to the presence of this slab or the pavement, the change in the water content between the dry and wet season will be less. So, therefore, the soil will undergo less swelling or the swelling and shrinkage phenomena of the soil will be different in comparison to what it should be in the absence of a slab. So, therefore, the change in the or the swelling shrinkage phenomena of the soil will be different in the presence of a slab and in the absence of a slab or a foundation.

(Refer Slide Time: 06:28)

Here you can see one example of how the water content changes along the depth, this is a fluctuation of the water content in different season as reported by Hamberg in 1985. If we draw a line, say for example, at this depth, we can see this fluctuation in the water content at different times of different years. So, here you can see there is quite large change in the water content.

Again, if we draw another line here, we can see there is a change in the water content at different times of year. But if we look into this graph carefully, then we will see that as we move down the change in the water content with the depth will be less or it will decrease continuously in comparison to this one.

(Refer Slide Time: 07:38)

So, therefore, a large number of or a large fluctuation in the water content will take this only at a shallow depth in comparison to the large depth. So, when there is a change in the water content of the soil happens that will lead to the swelling and shrinkage phenomena. When there is an increase in the water content, the soil will be undergo swelling process and when there is a decrease in the water content the soil will be subjected to shrinkage.

Here we can see a movement of the foundation that is the how the foundation has settled or lifted off during the different parts of the year has been plotted here. Here we can see clearly, that the foundation is getting lifted off and again it is getting settled down. This lifting off is due to the swelling of the soil. This swelling is taking place because of the ingress of the water either due to the rainfall or any other reason, but once the swelling stops, then during the dry season, there will be shrinkage, and as the shrinkage occurs, the foundations settles.

Again, during the rainy season, you can see, there will be swelling and again there will be lifting off of the foundation and again there will be a shrinkage, and again swelling. So, this process will take place continuously. This has been reported for four years, we can see from 1974 to 1978. And we can see regularly that the foundation is subjected to vertical upward as well as downward movements due to the swelling and shrinkage phenomena.

So, if this phenomenon occurs continuously then the foundation may crack and it will lead to the fatigue to the structures, which leads to the damage to the structure above it. Therefore, we need to learn how the swelling and shrinkage phenomena takes place in a cyclic manner, and what will be its impact on its swelling and shrinkage behavior.

(Refer Slide Time: 09:38)

Here we can see one example. A structure is located on an expansive soil, this is in dry season. We can see there are cracks available through which the water can ingress. During the rainy season there will be rainfall and the rainwater will ingress into this pore space as a result of which this soil, the soil surrounding the foundation will swell. As the soil will swell, it will lift the foundation in the upward direction.

If the movement of this foundation is uniform, then there will be no problem to the structure, but that seldom happens as we saw that due to the presence of slab that water content will be different. So, therefore, this part of the soil or this part of the foundation will be lifted more in comparison to other parts. So, therefore, the structure will be lifted in a non-uniform way.

Now, during the dry season, again the soil will lose out water. Here we can see due to the evaporation, and as the water is lost from the soil, the soil will shrink and as a result of which this part of the structure will settled. So, as this soil gets settled, this will give a non-uniform or differential settlement to the structure, and because of this, the cracks will start to appear on the structure.

So, this process will goes on regularly, that means, it will swell then shrink, then again it will swell and again it will shrink. And if this process continues for a long time, the structure will be stressed and the structure may collapse eventually. Here we can see this is seasonal wetting. The structure is getting lifted off at this point, because of the ingress of the water and the swelling of the soil surrounding this foundation. And during the dry season as the water moves away the water content will reduce; the soil will shrink.

This is the soil is, water is evaporating and the soil is shrinking on this portion. As the soil shrinks, the structure will undergo settlement here. Whereas, at this portion it will be getting lifted off. So, if this process is continues for a long period of time, then the structure will be under stress, and it will collapse. The water from the soil not only lose because of this evaporation, it will also lose because of the presence of some large trees near to the structure.

As we know that the root can go deep inside to a soil and this root can absorb moisture present next to the foundation. As the water is being moved away the soil here will undergo shrinkage. And as a result of which there will be the shrinkage of the soil and the structure will get settled and that will lead to the cracking on the foundation or on the structure. So, this is how the evapotranspiration brings the shrinkage of the soil.

(Refer Slide Time: 13:27)

So, this swelling and shrinkage phenomena takes place quite regularly and that brings damage to the structure. Here we will be learning how the shrinkage and swelling phenomena controls the swelling and shrinkage behavior of the soil. So, first going by the definition, by cyclic swelling, it is meant that the soil specimen is wetted and allowed to swell, then dry it to its initial water content, sometimes less than its water content, which we will explain later at room temperature.

That means, the soil should be dried under the room temperature or due to the exposure to the sun and then it will be wetted again to swell, and again it will be dried, and this process will go on regularly. So, this is known as cyclic swelling and shrinkage of the soil. You need to remember one thing, if the sequence of drying occurs first, then it will be known as drying-wetting process or shrinkage-swelling process.

If the sequence of wetting occurs first, then it will be known as wetting-drying process or swelling and shrinkage process. And because of this reversible manner the swelling and shrinkage behavior may be different. Here we can see one example. Take an example of this soil. This is in the initial condition. Now what we will do is, we add some water to it. So, as we add water to the soil, the soil volume will increase, so that we say is the swelling stage.

In the swelling stage, the soil will absorb moisture and the volume of the soil will increase. Then when we airdry the soil, the soil will lose out its water because of the process of evaporation or evapotranspiration. And as a result of this removal of the water, the soil will shrink or the soil will get dried. As the soil gets dried, it will shrink and its volume will decrease.

Similarly, again when we re-wet the soil sample by adding water again the volume of the soil will increase, and as the volume of the soil will increase, it will lift the structure in the upward direction. And again, when we re-dry the soil again its volume will decrease. So, we need to remember that, because of this wetting and drying and then re-wetting, re-drying the volume of the soil may not be whatever it should be to the earlier stage.

That means, this swelling volume and this swelling volume may not be equal, this dried sample and this dried sample may not be equal in volume. So, we will learn about those things in later slides. In the process, when the soil absorbs moisture and it will dry it will be known as first cycle of swelling and shrinkage.

And again, when the dried sample absorb moisture and again it will re-dry it this is known as second cycle of swelling and shrinkage. Similarly, there will be a third cycle of swelling and shrinkage, fourth cycle and so on. So, in one cycle, it will be, the soil will be subjected to wetting and drying. Wetting maybe because by addition of the water and drying by air drying.

(Refer Slide Time: 16:53)

Here we can see the effect of initial water content on this swelling and shrinkage behavior of the soil. In this case a soil was taken with an initial water content of 76.6 percent. So, this is the initial stage where the soil was taken, then the soil was dried. In fact, three samples were taken and the soils were dried.

One sample was dried up to a water content of say 60 percent, second sample was dried up to a water content of 35 percent and third sample was dead up to water content of 0 percent. Then after drying the soil sample, it was allowed to swell, that means, water was added to the soil such that the sample were swelled.

Now, if we could see this thing, this graph, then we could see the swelling behavior are different for these three different soils. The soil which was dried up to 0 percent water content is swelling to a large value in comparison to the soil, which has been shrunk to a lower water content. That means, for this case, the swelling was less in comparison to this one, and this one, whereas the soil which was shrunk to 0 percent water content swelled more.

Similarly, when we dried again the soil to 0 percent, and when we rewetted the soil sample again, the increase in the volume was quite high. So, this process is keeps on going like this. And similarly, for the first sample, when again there is a continuous decrease in the swelling state, that means, during the swelling, it will not be coming back to its original position.

So, therefore, we could see from this graph, that initial water content or the water content to which the soil has been dried and again when it become re-wet plays an important role in influencing the swelling and shrinkage behavior of this soil. So, here you can see the effect of drying water content on maximum swelling on repeated drying and swelling is quite large.

So, therefore, we need to understand what is the effect of drying on the swelling shrinkage behavior of the soil. So, this can be achieved by drying the soil into different water content and then re-wetting the soil and see how much the volume of the soil is increasing. Again then, we will shrink the soil to different water content and we will see again on re-wetting how much volume is being taking place.

(Refer Slide Time: 19:42)

So, this process can be taking place in two way in a laboratory. This can be carried out using partial shrinkage, and drying process or full shrinkage or drying process. In partial shrinkage and drying process, the drying process of a swollen soil take place up to its natural water content.

That means, suppose if we take a soil sample with the initial water content say 20 percent then the soil will be first swollen and once the soil completely swells, then it will be dried up to a water content of 20 percent, approximately up to 20 percent. So, that is known as the partial drying. So, after the soil reached 20 percent of the water content, again it will be re-wetted and again it will be dried up to a water content equals to 20 percent. So, this process of drying the soil to its initial natural water content is known as the partial shrinkage and drying process.

In the second case, we will take a soil sample with the initial water content, say 20 percent and let the soil has a shrinkage limit of 10 percent. Now, what we will do is, we will take the soil sample then allow it to swell. Once the swelling is complete, then we will dry the soil sample below its shrinkage limit water content. The soil will be shrunk to a water content below its shrinkage limit. So, that process is known as full shrinkage or full drying.

In full shrinkage or full drying process, a swollen soil sample will shrink to a water content below its shrinkage limit. So, in the laboratory, which process has to be taken that depends on the site experience or the site condition. In the laboratory experimentation, the swell-shrink patterns will be selected based on the knowledge of the field suction or moisture content variation with the depth.

We know that the water content will reduce of a soil due to the dry season. Now, the reduction in the water content of the soil during the dry season may not go up to its shrinkage limit up to 10 percent. Only in case of prolonged drought period, the soil will become fully dried, otherwise it will goes up to generally a above its shrinkage limit.

So, therefore, on the basis of that we need to decide which process of swelling and shrinkage we need to take in the laboratory. Similarly, the top soil experience full swelling and chances of full swelling reduces with depth. So, these three factors, we need to take care of before deciding whether to go for a partial shrinkage drying or full shrinkage drying during a laboratory test.

(Refer Slide Time: 22:58)

When we use some laboratory test to determine the swelling shrinkage cycle, we use different terminology. So, those terminology I will explain here. Generally, when we take a soil sample and wet the soil sample, the soil volume will increase, so that increase in the volume will be measured in terms of the vertical displacement, which will be expressed in terms of, $\Delta H/ H_i$, where ΔH is the increase or decrease in the height of the specimen due to swelling or shrinkage and H_i is the initial height of the specimen.

So, here we can see the first this is the soil is allowed to swell then it is allowed to shrink. So, allowed to swell again and shrink. So, this is a plot which we will get during the swelling shrinkage cycle. So, there are different terminology, which we can use from this graph. The first one is highest swollen level. Highest swollen level is the level to which the specimen will swell in any of the swelling shrinkage cycles. So, this is different cycles and the maximum amount of swelling, which the soil will undergo is known as the highest swollen level. So, in this case, this will be the highest swollen level.

Next comes the equilibrium swollen level. If we look into this graph, we can see that after a certain number of cycles, the change in the swelling or the change in the shrinkage will becomes same, that means, the soil will becomes in equilibrium. This equilibrium level during the swollen is known as equilibrium swelling level or it is the swollen level recorded at the equilibrium state, which usually occurs after a few swell-shrink cycle. This is an equilibrium stage and this is known as equilibrium swollen level.

Similarly, we have equilibrium shrunken level, it is a shrunken level of the specimen at equilibrium state, which usually occurs after a few swell shrink cycle. Similarly, this is the equilibrium swollen, equilibrium shrunken level, and in between this there is a middle line, which will be known as operating displacement or operating middle level. So, operating middle level is the middle level between the equilibrium swollen level and equilibrium shrunken level. So, this is the, this middle line is known as the operating middle level.

Next comes the equilibrium bandwidth. It is the bandwidth of the vertical displacement at equilibrium state between the equilibrium swollen level and equilibrium shrunken level. So, this is our equilibrium swollen level, this is our equilibrium shrunken level. So, this bandwidth between this swollen and swollen and shrunken level at equilibrium is known as equilibrium bandwidth.

Next comes the initial reference level. Initial reference level is the initial level of the specimen with respect to which all the measurements are made. So, this is our initial level from which we are measuring all this change in the height, increase in the height or decrease in the height, so that is why this is known as the initial reference level.

Next is the operating displacement, operating displacement is the level difference between the operating middle level and initial reference level. So, this, this distance between the operating middle level to operating initial reference level is known as operating displacement. So, these are the few terminologies generally are used in a swell shrinkage plot. Now, in order to explain the swelling-shrinkage phenomenon during the partial shrinkage and full shrinkage, I will explain a few of the examples from the literature.

(Refer Slide Time: 27:31)

First, I will talk about the effect of full shrinkage on behavior of the soil. This has been taken from the paper Basma et al, they have used four different soil and named as S1, S2, S3, S4. The soil has different values of liquid limits starting from 53 to 81 and different clay content 38 to 72. This S4 has some montmorillonite in it, that means it has some expansive nature or its expansive behavior is bit more in comparison to the other soils. Then all this soil where undergo the full shrinkage.

(Refer Slide Time: 28:09)

Here we can see the soil are undergoing the full shrinkage, that means, the soil has shrunk to a water content below its shrinkage limit. Here the plot has been plotted between the normalized water content that is the water content at different states to the shrinkage limit water content with the time. We can see here, the time which is taking for the soil to decrease its water. So, we can see here, a large amount of time is taking for the soil to get reduced below its shrinkage limit.

So, this point, the one state says that it is the shrinkage limit water content, and the amount of water content of different soils are different. So first, I will start with one example. In this case, the soil was allowed to swell first, here, and then once the swelling was over the water content was 26.3 percent. Once the swelling is over the soil was allowed to dry below its shrinkage limit. So, this is the, our reference, initial reference level.

When the shrinkage was over, the water content was 4.2 percent. Here the shrinkage limit was 10 percent. So, here, that means the soil were fully dried. Again, the soil was allowed to swell, and once the swelling is complete, the water content was measured as 27 percent. Then again, the soil was allowed to shrink and that water content was 5 percent, so this process was repeated in number of cycles.

Here we have 1, 2, 3, 4, 5, 6 number of cycles. So, if we look into this graph, we could see that the swelling water content keep on increasing with the number of cycles. That means, the swelling volume of the soil is being increased with the number of cycles. But after reaching a certain number of cycles for example in this case is 3, after reaching the third cycle the swelling of the soil stops.

So, here we can see there is a marginal increase in the swelling or the swelling is almost constant over here. Similarly, if we look into the shrinkage behavior, the soil was shrunk up to a water content of 4.2 percent, that means, a large amount of shrinkage has been observed here, then in the next cycle, the soil was shrunk to a higher water content that means, up to 5.5 percent.

Since the soil was shrunk to a higher water content, the shrinkage was marginally less. In the next cycle again, it was shrunk up to 6.7 percent. And again, there is a because of this increase in the water content again the shrinkage was bit less. So, if we look into this shrinkage portion, then we could see that the shrinkage is keep on decreasing with the number of cycles. And after a certain number of cycles, it becomes constant.

From this we can also conclude that during each cycle the final water content will increase continuously. So, therefore, the swelling of the soil will increase continuously. Similarly, on the shrinkage part with each cycle, the final shrinkage water content will keep on increasing, therefore, the total amount of shrinkage on drying portion will keep on decreasing.

(Refer Slide Time: 32:09)

The reason behind the change in the swelling and shrinkage phenomena is due to the orientation of the soil. Due to a higher shrinkage of the soil the soil particles becomes more random leading to a higher flocculated structure. When the soil comes in contact with the water, it absorbs more moisture and swell more.

We have already seen in the previous class that when we dry a soil sample below its shrinkage limit, then the structure becomes more flocculated. And when we add more water, it will absorb moisture and it will swell to a higher extent. So, therefore, we can see when we are drying the soil sample below its shrinkage limit, the structure becomes more flocculated, and when on re-wetting, the volume of the soil is increasing. So, this is an example of the soil which has been taken with a shrinkage limit of 13 percent and 14 percent.

Again, the soil was allowed to swell and the swelling was stopped at a water content of 33.1 percent and then again it was allowed to dry and the drying water content was up to 7.1 percent. Since it was shrunk below a shrinkage limit it is a full shrinkage experiment. In the next stage or in the next cycle the soil again swell to a higher value. So, the final water content becomes 34.9, and the swelling volume was more in comparison to its previous cycle.

If we look into the next cycle, again the water content has increased and the swelling volume has increased. And it will keep on like this until it reaches a final equilibrium stage. At equilibrium stage, there will be no further increase in the volume of the soil due to re-wetting. Similarly, if we look into the shrinkage part, during the each cycle the shrinkage water content is keep on increasing, that means, the soil is being shrunk to a lower value that means the shrinkage volume is being reduced with number of cycles.

And after a certain number of cycles, the soil will reach to an equilibrium stage, and beyond which the soil will not further shrink or the shrinkage will becomes constant. This value of the number of cycle up to which the soil will reach to its equilibrium state depend on the soil to soil.

For example, in this case the soil is reaching its equillibrium stage at fifth number of cycles in earlier case it was 3. And if we look into this case, it will be around sixth cycle. So, depending on the soil type the number of cycles to reach the equilibrium stage will be different. So, here, these are the two examples of the soil which has been shrunk fully.

(Refer Slide Time: 35:12)

So, from this we can conclude that as the number of cycles increase there is a gradual increase of the swelling potential as indicated by a shifting of the curve in upward direction. The amount of shrinkage for the first cycle was the largest, and it steadily decreased in the next cycles. The water absorption capability of the soil is increased with the number of cycles therefore, the swelling also increased.

The water content beyond which no significant shrinkage takes place increases with the number of cycles, this observation implies that there is an increase in the apparent shrinkage limit of the soil. So, these are the few of the observation during the full shrinkage of the soil.

(Refer Slide Time: 36:03)

If we look into the change in the swelling potential, we could see that the percentage increase in the swelling potential is large in the initial few stages. And after reaching an equilibrium stage, it becomes constant and we could see depending on the soil type, that equilibrium stage are quite different, that means, the number of cycles to reach those equilibrium stages are different for different types of soil.

Similarly, if we look into the maximum swell potential versus number of full shrinkage cycles, we could see that with increase of the number of cycles, initially it will increase, initially the maximum swelling potential will increase then, it will reach to an equilibrium stage at a certain number of cycles of swelling and shrinkage, and then it becomes constant.

So, therefore, the maximum swell potential and percentage increase in the swell potential with number of cycles for full shrinkage and swelling will increase in the initial few cycles of the swelling and shrinkage process, and then it remains constant. And beyond that, there will be no further change in its swelling potential.

(Refer Slide Time: 37:26)

If we look into the swelling pressure plot, so, similar observation like the swelling potential can be seen here, that means, the swelling pressure will increase up to a certain number of cycles and beyond that, there will be a marginal or no increase in the swelling pressure takes place. And that number of cycles also again different for different types of soil.

If we see this is percentage increase in the soil pressure again, we can see that depending on the soil type, it will reach to an equilibrium value for different types of soil. Indicating that the soil will reach to an equilibrium stage depending on its soil properties.

(Refer Slide Time: 38:08)

Next, we will discuss about the effect of partial shrinkage on the behavior of the soil. Here I would like to remind you that partial shrinkage means soil is allowed to shrink up to its natural water content. So, here the plot has been plotted between the normalized water content to its initial water content. This 1 means its initial water content. So, the soil was shrunk up to its or near to its initial water content. And this is the time taken to complete the shrinkage process.

Then, if we plot the axial deformation versus the time of swelling and shrinkage, we can see, initially, during the swelling process the soil swells to a water content of 28.3 percent. Then when the soil is dried, it goes up to 11.8 percent. And at this stage, the soil was again allowed to re-swell by re-wetting the soil and here the soil could swell up to a water content of 25.2 percent.

Now, if we compare from the water content or the first two cycles, we can see that the water content is reduced from 28.3 percent to 25.2 percent. That means, the swelling of the soil has reduced from the first cycle. Then again, when the soil is re-dried, then the water content becomes 11.4 percent, 11.8 percent. And again, if we re-wet the soil the water content was 25.1 percent. So, that means after first cycle the soil got stabilized, whereas, the shrinkage was also stabilized after the second cycle.

But if we compare the partial shrinkage to the full shrinkage, we could see that in the full shrinkage with the number of cycles, initially the swelling of the soil was higher than the previous cycle, but in this case, the swelling has reduced. The swelling deformation has reduced from this portion to this portion, and subsequently, it will remain constant for this soil. So, therefore, this soil has reached its equilibrium stage after second cycle.

(Refer Slide Time: 40:51)

Similarly, if we take for other two soils with a shrinkage limit 13 percent and 14 percent, we could see the similar behavior like the first one, where, the soil initial water content gets reduced continuously with the number of cycles. The initial water content has continuously reduced from 33.1 to 30 then 28.2 and 27.5 and then to 26.5 and then it becomes constant. So, that means the soil has reached to its equilibrium stage after fourth cycle.

Similarly, if we look into this shrinkage part, the shrinkage water content keep on increasing that means, the shrinkage is keep on decreasing with the number of cycles, but after a certain number of cycles say third number of cycles, the shrinkage water content remaining same. That means, the shrinkage becoming constant after third number of cycles or the soil has reached its shrunk level at the end of third cycle.

Similarly, for the other soil, we can say the soil is coming to equilibrium after the third cycles. And again, the water content keep on decreasing, that means, the swelling of the soil it keep on decreasing with the number of cycles and the swelling becomes constant after the third number of cycles. Similarly, the shrinkage behavior can also be seen.

(Refer Slide Time: 42:30)

If we compare with the percentage decrease in the swell potential and number of cycles, we could see that initially there is a steep decrease in the swelling potential with the number of cycles, and after reaching a certain number of cycles, which will vary from soil to soil, the percentage decrease in the swelling potential becomes constant or soil has reached to its equilibrium stage.

If we plot between maximum swell potential and number of wetting and full shrinkage cycle number of, sorry this is partial shrinkage cycle, then we could see that after certain number of cycles the maximum swelling potential becomes constant. And again, depending on the soil to soil, the number of cycles will vary.

(Refer Slide Time: 43:34)

So, this is a plot between the percentage decrease in the swelling pressure and the number of cycles. Again, we could see with increase in the number of cycles the percentage decrease in the swelling pressure will be different. And after reaching a certain number of cycles, the soil will reach to an equilibrium stage, and after that a further re-swelling of the soil will not decrease its swelling pressure.

Similarly, if we see the swelling pressure plot versus number of wetting and partial shrinkage cycle then we could see that after a certain number of cycles then there will be no change or no decrease in the swelling pressure is taking place. So, for this case, this is the second cycle, this is for the third cycle. Depending from soil to soil, the number of cycles beyond which no further change in the swelling pressure taking place are different.

(Refer Slide Time: 44:42)

So, therefore, we can conclude from this partial shrinkage that the swelling potential and swelling pressure decreases with increasing the number of cycles. Most reduction in the swelling occurred after the first few cycles. The soil's ability to absorb water upon wetting is reduced with the number of cycles. So, this three, if you could compare with the complete full shrinkage, then we can see these are entirely different for partial shrinkage.

(Refer Slide Time: 45:17)

Now, in this case, the change in the void issue for different number of cycles for partial shrinkage and full shrinkage are shown in here. So, here we can see this is for S4 type of soil. We can say that due to this full shrinkage, the void ratio of the soil is increasing. Similarly, due to the partial shrinkage, the void ratio is decreasing. That means, the soil has been decreasing in its volume.

Similarly, for other three soils we can see with the number of cycles for full shrinkage with the number of cycles for full shrinkage part the void ratio is keeping on increasing after swelling, and for partial shrinkage it keeps on decreasing. So, in this plot we can see that with each number of cycles for a partial shrinkage, the volume of the soil is decreasing, whereas, for a full shrinkage, the volume of the soil is increasing. And again, depending on soil to soil, the amount or the void ratio after each cycle will be different.

(Refer Slide Time: 46:47)

In this plot, it has been shown the effect of overburden load or surcharge load on this vertical deformation of the soil with number of cycles. In this case two load was taken, 6.25 kPa and 50 kPa. So, if we could see this swelling shrinkage behavior and if you could see the bandwidth here, then soil subjected to a lower pressure, the bandwidth will be higher.

That means, the difference between the swelling and shrinkage height will be higher. Similarly, if we compare it with a higher surcharge load, this bandwidth is a bit lower. That means, with the increase in the surcharge load, the effect due to this cyclic swelling and shrinkage behavior of the soil will be decreased.

(Refer Slide Time: 47:42)

This plot shows the effect of initial condition on cyclic swelling and shrinkage behavior of the soil. Three soil samples were taken in this case. The water content and the void, the water content and the dry density was varied.

The soil was compacted at a water content of 21 percent and dry density of 17.05 percent. Here the water content was fixed, but it was compacted to a lower density. Similarly, in this case, the density was kept constant and the water content was increased. Here we can see that soil compacted to a higher density is swelling more in comparison to soil compacted to a lower density.

So, this two we can see the water content is identical, but the densities are different. Therefore, this soil is swelling to a higher value in comparison to this, and the equilibrium bandwidth for soil compacted to a higher density is 14.77. And for this other sample for which it was compacted to a lower density is 14.47 percent. So, therefore, it is marginally higher in comparison to the soil compacted to a lower density.

But if we compare with the change in the volume at the initial stage, we could see soil compacted to a higher density will swell to a higher value. Similarly, if we take to the soil which is compacted at a higher water content, then we can see the swelling of that soil is less and the shrinkage for that soil will be more. So, if we compare with this and this, we can see, there is a decrease in the swelling but there is an increase in the swelling for the soil which is compacted at a higher water content.

But again, the equilibrium bandwidth will be around 14.39 percent, so almost identical. But if we look into all the individual plots, then we can see the swelling and shrinkage will be different for these three different soils. So, here you can conclude that if a soil is compacted at a higher density, then its swelling will be more and its shrinkage will be less.

Similarly, if the soil is compacted to a higher water content, its swelling will be less, but its shrinkage will be more. So, therefore, we can see, the initial condition plays an important role in the swelling and shrinkage phenomena of the soil. But if we look into all this plot, we can see that, after a certain number of cycles all the soils reach to its equilibrium stage. And again, that number of cycles will vary depending on the initial condition.

(Refer Slide Time: 50:57)

Then, we will discuss about the effect of swelling and shrinkage on the bandwidth. So, different factors we will consider here. Again, the bandwidth means, the difference between the equilibrium swelling state to equilibrium shrinkage state. That magnitude is known as the bandwidth. The magnitude of the bandwidth reduces with the decrease in the amount of drying. So, bandwidth can be defined as the vertical movement between the swelling and the shrinkage in the successive stage at equilibrium is known as the bandwidth of the soil.

(Refer Slide Time: 51:36)

First, we will see the effect of liquid limit on bandwidth. Three soils were taken one with a liquid limit of 103 percent one with a liquid limit of 75 percent, another is 64 percent. And soil were compacted for water content between 13 percent to 38 percent, 10 percent to 38 percent, 19 percent to 32 percent. And if we plot the equilibrium bandwidth for all the soils, we can see that soil with a higher liquid limit will have a higher bandwidth in comparison to the soil with lower liquid limit.

But if we compare with the compacted density, then we could see for all the soil, the effect of density on the bandwidth remains less. Therefore, we can conclude over here that soil with a higher liquid limit will have a higher bandwidth, and it will have a more impact on the bandwidth of a soil. And this bandwidth will be depending on the liquid limit and it will be independent of the initial compaction condition, that is initial density or its initial water content.

(Refer Slide Time: 53:04)

Then here we will compare the effect of surcharge load on the bandwidth. Here we could see that with the decrease in the loads, the bandwidth is increasing. So, if we consider for the same soil, but at different load we can see the soil subjected to 6.25 kPa is a highest equilibrium bandwidth in comparison to soil subjected to 200 kPa. Similar trend was observed for soil at different liquid limit. And also, we can see, with increase in the liquid limit this increase in the bandwidth is also increasing. So, from this graph, we can conclude that the equilibrium bandwidth is decreasing with the increase in the surcharge load.

(Refer Slide Time: 53:54)

Next is the effect of shrinkage water content on the bandwidth. The soil has shrunk to different water content 0 percent water content, then 13 percent water content, and 20 percent water content. And here we can see that this is for 0 percent water content, this is for 13 precent and this is what 20 percent water content.

And if we compare here then the soil which is shrunk to a higher water content has a lower value of bandwidth, soil compacted or the soil shrunk to a lower value of water content has a higher value of bandwidth. So, therefore, we can see the magnitude of the bandwidth is influenced by the amount of drying allowed during the each shrinkage cycles. And soil shrunk to a lower value of water content will have a higher value of bandwidth.

(Refer Slide Time: 55:00)

Next, we will discuss about the reversibility of swelling and shrinkage. That means, what will happen if suppose, full swelling and full shrinkage stage followed by the full swelling and partial shrinkage, and that again will be followed by the full swelling full shrinkage and again it will be followed by the full swelling and partial shrinkage state.

Here in the example, you can see the soil is subjected to first a full swelling and full shrinkage process. During this full swelling and full shrinkage process initially, there will be increase in the vertical deformation and with the number of cycles that will get stabilized, and it will reach to an equilibrium over here. Once it reached to an equilibrium, the soil was subjected to a full swelling and partial shrinkage.

During this stage the soil were allowed to dry partially. In this case the soil was allowed to shrunk up to a water content of 4.5 percent, but in this case, it was shrunk up to 28.2 percent.

So, here we could see after a few number of cycles, the soil will get stabilized. Then again, the soil was undergone a full swelling and full shrinkage process, and after reaching the equilibrium again it was undergone full swelling and partial shrinkage process.

Now, if we look into this graph, we can see that due to the full swelling and partial shrinkage, there is no impact on the bandwidth of this soil. That means, because of this, there is no change in the bandwidth. So, bandwidth is remaining constant at 14.4 percent even at this stage. Similarly, for full swelling and partial shrinkage again there is no change in the bandwidth and it is remaining constant at 4.4 percent.

So, here we can conclude that the swelling and shrinkage are not reversible process during the initial cycles. And after equilibrium state is reached and equilibrium bandwidth of the movement is established, the swelling and shrinkage becomes a reversible process. That means, whatever bandwidth we have achieved here that will be achieved in the second full swelling and full shrinkage process.

Similarly, whatever the bandwidth achieved in the full swelling and partial shrinkage state that also achieved in the second stage of full swelling and partial shrinkage process. Therefore, this bandwidth will be a reversible process independent of whether the it is a full swelling full shrinkage or full swelling partial shrinkage process.

(Refer Slide Time: 57:56)

So, the summary of today's lecture are the soil undergoes cyclic swelling and shrinkage behavior regularly due to the change in the water content. So, due to this change, the soil experienced cyclic heaving and shrinkage. The magnitude of heaving or shrink depends on the initial water content from which the soil is swelling or shrinking. Depending on the shrunk water content, the process can be divided as partial shrinkage or full shrinkage.

For the full shrinkage, the axial deformation will increase with the number of cycles and reaches an equilibrium stage. For a partial shrinkage, the deformation decreases before reaching to an equilibrium value. The water content beyond which no significant shrinkage takes place increases with the number of cycles.

Similar to the deformation the swelling pressure and swelling potential increases with the number of cycles before reaching an equilibrium value. With an increase in the surcharge load, the axial deformation decreases. The magnitude of the deformation depends upon the initial water content and the shrinkage water content. And these are the references which I have used for today's lecture. With this, I will conclude today's lecture, and thank you for your attention.