Expansive Soil
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Lecture 14
Shrinkage Behaviour of Soil

Hello everyone welcome to the course Expansive Soil. Today we will start a new chapter, this will be the fifth module of this course and this will be about the Shrinkage Behavior of the Soil and this will be the thirteenth lecture of this course. Before that, we have learned about the swelling behavior, the factors which controls, the swelling, the swelling mechanism, the measurement of the swelling, and before that we learn about the soil classification, and the engineering behavior of the soil.

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In this chapter we will learn about the shrinkage behavior. We know that a swelling soil undergoes an increase in the volume when there is an increase in the water content. If the same soil undergoes a decrease in the water content, its volume will decrease, that is known as the shrinkage. So, shrinkage and swelling phenomena takes place side by side. A clay soil typically undergo change in the volume when the water content is decreased, so we can see in here, there are four different stages of a soil.

First take the case of the first soil which is a fully saturated soil. In fully saturated soil, the soil has two phases, the water phase and the solid phase, so it is a two-phase diagram. When we decrease the water content of this soil, volume of the soil will decrease and this decrease in the volume of the soil is equal to the decrease in the volume of water. So, here you can see, when we dry the soil from stage 1 to stage 2, there is a decrease in the volume of the soil, and this decrease is equals to the decrease in the water content of the soil and until here the soil will be fully saturated soil.

If we keep on drying the soil, a stage will reach beyond which the volume of the soil will not change. Here we can see the volume of the soil is remaining constant even after drying, so at this stage the air will starts to enter into the soil, and the soil becomes unsaturated soil. Here we can see, the soil has three phases; the solid, water and the third phase air will enter into the system and the soil becomes unsaturated and the water content corresponds to this boundary line is known as the shrinkage limit of the soil.

If we keep on drying the soil, the amount of the water will keep on decreasing, the amount of air will keep on increasing, but at the same time the volume of the soil will remain constant. On further drying up to the whole entire water is displaced or removed air will replace all the water and the soil will have in two phase system that is the air and solid. Since no water is present here the soil will be known as dry soil. This is the way in which a soil generally gets dried and as the soil is getting dried the volume of the soil will keep on decreasing. This phenomenon in which the volume of the soil will decrease is known as the shrinkage behavior or the shrinkage of the soil.

Therefore, the shrinkage of a soil can be defined as the reduction in the volume of the soil due to a reduction in the water content of the soil. All kind of soils shrinks but mostly an expansive soil which undergoes a large increase in the volume also undergoes a large decrease in the volume when there is a decrease in the water content. So large volume change occurs in a climate with alternate wet and dry seasons. Say, for example, during the wet season the volume of the soil will increase to a large extent, but in dry season the volume of the soil will decrease further.

This decrease in the volume of the soil will be of not concerned if the decrease in the volume of entire soil mass is uniform, but if there is a change in the pattern of the swelling or shrinkage then there will be a differential settlement or differential heaving that will cause the damage to the structure.

Now, when a soil shrinks it will be associated with cracking and particularly in embankment or dam this cracking will bring the instability to this kind of structure. But this cracking will be beneficial for agriculture purpose because due to the cracking, the air and water can enter into the soil, and the plant roots can get proper aeration and the growth of vegetation can be faster.

The shrinkage of the soil is generally confined to the uppermost layer of the soil, and this decrease in the water from a soil can be because of this reasons. The soil shrinks due to the reduction in the moisture content and this moisture contained reduction can be due to the evaporation of the water from the soil, due to the lowering of the ground water table due to the absorption of water by roots plant. So, any of these three causes may be simultaneously or maybe individually can bring about a decrease in the water content of the soil, and therefore bring a shrinkage behavior of the soil.

A large amount of shrinkage occurs when water deposited clays are first dried. The amount of re-swelling in the presence of free water depends on the type of minerals present in the soil. If we take, say for example, montmorillonite, generally we will get a reversible amount of swelling and shrinkage behavior due to re-wetting or drying of the soil, but if we take the clay minerals like illite or kaolinite we will get an initial large decrease in the volume of the soil due to drying, but if we re-wet the soil sample the change in the volume will be not that much.

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Talking about again the change in the volume of the soil, if we plot a graph between the void ratios or maybe the volume of the soil, with the water content we can get a distinct curve like this one. Initially we assume the soil is fully saturated and may be the the water content is approximately equals to its liquid limit. When we dry the soil sample from point 1 to point 2 there will be a change in the volume of the soil. This change in the volume of the soil or this decrease in the volume of the soil will be equal to the decrease in the volume of the water from the soil.

So, here you can see, this is the change in the volume of the soil and this change in the volume of the soil will be equal to change in the volume of water of the soil sample. Again, when we dry the soil sample we will reach to a point 3. At point 3, again there will be a decrease in the volume of the soil due to the removal of the water from the soil and again this change in the volume will be equal to the change in the volume of the water. Now, if we draw a line connecting points to points 3, 2, 1, we will get a line which will be inclined 45^0 to the X-axis.

If we dry the soil sample further from point 3 to point 4 onwards the volume of the soil will not change; change in the volume of the soil will remain zero. At this point the air will start to enter into the system. Here we can see at this point the soil will be fully saturated beyond this point the air will starts to enter and the volume will remain constant.

So, soil becomes unsaturated at this portion and on further drying, when the water content becomes 0, there will be only two phase that is air and solid and again the volume of the soil will remain constant. So, this curve if we connect point 5, 4, 3, 2, 1, we will get a curve which is known as a shrinkage curve. So, a shrinkage curves gives a relationship between the void ratio and water content or the volume of the soil and water content during the drying of the soil sample.

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So, again if if we look to a shrinkage curve, this is how it has been plotted against the volume of the soil and volume of the water. The soil has started to shrink from point C onwards, and at point C the soil has two phases that is water and the solid particles, so it is a two-phase system.

Then when we dry the soil there will be a change in the volume of the soil and this change in the volume of the soil is entirely due to the change in the water in the soil. The volume of the solid will always remain constant throughout this drying process. This line makes an angle of 45^0 to here, and at point B if we dry the soil further then the air will start to enter over here.

So, point B onwards the soil will be having solid particles, water and air, so it becomes a three-phase system point B onwards. On drying the soil from point B onwards the air will starts to enter into the system and the soil becomes unsaturated. Now, this soil has three constituents one is air water and the solid particles, so the soil will be in three phase systems from point B onwards.

Now, if we further decrease the amount of water or if we dry the soil sample further then the amount of water will keep on decreasing and amount of air will keep on increasing and at point D when the soil is fully dry there will be no water and all this void space will be occupied by air.

So, here the soil will be having a two-phase system that is made of air and the solid particles. During the entire process the amount of solid will remain constant and the amount of water will keep on decreasing. At point C the amount of water will be maximum, and at point D the amount of water will be 0 and amount of air will be the maximum. So, this is how shrinkage of a soil takes place.

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Before going into details, we need to learn the mechanism of shrinkage. Here we will be learning how the shrinkage phenomenon takes place in a soil sample. In this diagram we could see a two-phase soil system that is soil fully saturated and we have the water here and we have the solid particles here. The force causing this shrinkage arises from the pressure difference across the curved air and water interface of the voids at the boundaries of the soil sample. So, when we dry the soil sample, air and water interface will be developed like you can see in this diagram.

When we keep on drying the soil we have a, this is air and this is water, an air water interface will take place. As the water evaporates from the surface a curved interface is formed in the voids at the surface with a lower pressure on the inside or on the convex inner side and a higher pressure on the upper side. So, due to this pressure difference between air and water interface at the void between the solid particles, the water will be drawn out from the soil samples and that will create the shrinkage phenomena of the soil.

A curved interface is formed in the void space due to the evaporation of the water and we need to remember that the higher pressure will be developing on the upper side, whereas, lower pressure will be developing on the convex inner side. So due to this pressure difference the water will be drawn out from the soil from the inside of this void space and due to this movement of the water, the solid particles will also try to come closer.

Now, between the solid particles we have different resisting forces, maybe this is because of the frictional forces or may be due to the inter particle repulsion forces, so this pressure difference will try to bring these particles together. At the same times this frictional resistance as well as the repulsive forces will try to prevent the particles coming closer. But as long as this pressure difference or the suction of the soil is higher than these resisting forces, the particles will come closer and there will be a reduction in the volume of the soil.

So, here we can see, due to the pressure difference so water will be drawn from the inside of the void space, the soil will remain saturated as long as this force exceed the particles resistance to the closer spacing. Until this point the soil will remain saturated and the change in the volume of the soil is equal to volume of water evaporated.

So, as we have seen, this change in the pressure or this pressure difference between the outer and inner portion, the water will try to come out from this void space. As the water try to come out from this inside of this void space it will also try to bring the solid particles together. Now, this resistance force as long as is lower than the pressure difference the solid particles will come closer and there will be shrinkage, but once the particle interaction restrict the shrinkage a further reduction in the water will be replaced by air.

As long as these forces of resistance is less than the pressure difference there will be a decrease in the volume of the soil, but once this resistance force exceed the pressure difference then there will be no further movement of the solid particles and there will be no change in the volume of this soil sample.

But with the further decrease in the water content or amount of water, the air will start to enter. So at that point the unsaturation of the soil take place and also beyond this the volume of the soil will remain constant. A minimal or a small amount of volume reduction can take place due to the fabric rearrangement or bending of the particles at that point.

So, this is how the soil shrinkage takes place. Basically the pressure difference across this curve interface between the water and air is responsible for the movement of the solid particles or the shrinkage behavior of the soil.

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We have seen that when a soil gets dried, cracks start to appear on the soil surface. So, these are the different amount of cracks which are appearing on a dry soil, this cracks appears on a soil surface due to drying. We need to remember that the cracking of the soil will take place at the point where the cohesion between the particles are lowest.

So, if we take this soil as an example then the cohesion between the solid particles is lowest at this a line of cracks, and not only for the dry soil, for some wet soil also there will be some cracking. If the drying is not uniform then even in for the wet soil there will be some cracks. And due to this cracking there there will be a change in the particle orientation occurs due to the formation of the crack and if the soil has not been disturbed or remolded and then if we re-wet the sample and then again if we re-dry the sample then the cracks will appear at the same point again.

If we take a soil sample which has formed the cracks at this point and then if we add water or if we re-wet the soil sample then these cracks will disappear and again if we re-dry the soil samples the cracks will appear at the same point if the soil has not been disturbed or has not been remolded because this will again be the point of the lowest cohesion.

So, therefore the cracks will appear at the same point. And the number of cracks developed per unit area depends on the clay minerals as well as the particle arrangement of a soil.

Generally, for flocculated clay a large number of cracks will be developed, whereas, for semi-oriented clays with higher question a few but large cracks will be formed.

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Here we will learn about the shrinkage process of the soil. So, sinkage as we learn is nothing but a decrease in the volume of the soil due to evaporation of the water. So, shrinkage process indeed is nothing else than compaction taking place under the action of the capillary forces in a soil. When we dry a soil sample and if we plot the graph between the void ratio and water content due to drying generally we get a curve like this. It will give a S kind of curve and if we divide this curve into three distinct part then we will get a residual shrinkage, a normal shrinkage and structural shrinkage.

During shrinkage, the structural shrinkage comes at the beginning. During the structural shrinkage water losses from the few of the macro pores and volume change will not be equal to the volume change of the water. Generally, the structural shrinkage takes place in a soil with some stable aggregates, however, for clayey soil this structural shrinkage is mostly remain absent. In a soil with a well-developed crumb structure there are large voids between the crumbs in which water is held by capillary forces. The first water lost on drying comes from this void space. So this stage is generally observed for a soil with large stable aggregates.

In this stage of shrinkage, the stable pores gets emptied and the decrease in the volume of the soil is less than the volume of the water lost and this stage is absorbed only in the surface soil with a large stable aggregate structure, but for clayey soil this is negligible as the bonding among the slurry clay particles is low and stable pores will not be developed.

The structural shrinkage will be followed by the normal shrinkage; in normal shrinkage a large amount of shrinkage takes place. Normal shrinkage is more responsible for the shrinkage phenomena of the soil.

For initial stage of shrinkage when the water content is very high the volume decrease due to the shrinkage will be equal to loss of the water from the soil. So, in this stage of shrinkage, the volume change of the soil due to the shrinkage phenomena will be equal to the change in the volume of the water, so therefore this line makes an angle 45^0. And in this stage of shrinkage the water within the crumb will be lost entirely. Depending on the soil type, the the range of this normal shrinkage will vary.

For a clayey soil generally, the normal shrinkage is very large, whereas, for a large aggregated soil the amount of normal or the range of normal shrinkage will be less. But talking about a clayey soil, this is more responsible for a shrinkage behavior of the soil and generally 70 to 80 % of the shrinkage phenomena take place in the normal shrinkage portion of the soil.

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The normal shrinkage will then be followed by a residual shrinkage. In residual shrinkage the air will starts to enter into the soil and the volume will be fairly remain constant at this point and the unsaturation of the soil also takes place at this point. And the amount of shrinkage at this portion will be quite less, and a small amount of shrinkage takes place on further drying and this portion is known as the residual shrinkage. So, from this portion of this residual shrinkage and normal shrinkage we can have three points A, B, C which will define the unsaturation stages or the shrinkage limit of the soil.

The point C will define the total shrinkage and the point A will define the shrinkage limit of the soil. So, generally, for any soil the amount of residual shrinkage will be very less and the normal shrinkage will be maximum and the structural shrinkage will be in between. So, these are the three stages of shrinkage for any soil. So as I told you earlier if the soil is a clayey soil then we will have a large amount of normal shrinkage followed by some amount of residual shrinkage. If the soil is an aggregated or large or have large pore spaces then it will have more amount of structural shrinkage and less amount of normal shrinkage.

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Again, we need to see in here that by remolding the shrinkage curve of a soil gets changed. The change in the shape of the shrinkage curve on remolding gives us information about the particle arrangement and the fabrics of the soil structure. So, here we can see it is a natural soil and this is a remolded soil and this is a shrinkage curve for both the soil.

So, due to this remolding of the soil we can have two different type of shrinkage curve. When a surface soil with a crumb structure is remolded the large void disappear, the range of normal shrinkage increases while the water content at the shrinkage limit will decrease.

So, the surface soil with crumb structure on remolding increases the normal shrinkage and decreases the shrinkage limit, whereas, for clayey soil which do not contain any large voids has a marginal effect due to the remolding of the soil.

Now, what is the engineering significance of the shrinkage behavior? The shrinkage cracks occurs when the capillary pressure exceeds the tensile strength of the soil, and these cracks are generally part of the micro structure and are generally termed as the zone of weakness.

And due to the formation of the cracks, the strength of the soil or the stability of the soil will decrease and also the permeability of the soil will increase due to the formation of the crack. Therefore, this will bring instability to any structure.

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The problem associated with shrinkage are the settlement, as I told you earlier if the settlement is uniform then it can go unnoticed but if the settlement is not uniform or when there is a differential settlement then the structures above the soil will be under stressed and it may get some damaged. Similarly, the cracking phenomena which are associated with shrinkage can cause problems to the pavement or the earthen embankment. These are the few points which I discussed in today's class.

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So, these are the few text books which have been used for this class. In the next class we will learn about what are the different factors which control the shrinkage behavior of the soil. So, with this I will conclude today's class. Thank you for your attention.