Expansive Soil
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Lecture 15
Factors Controlling Shrinkage Behaviour of Soil

Hello everyone, welcome to the course Expansive Soil. Continuing with the swelling and shrinkage characteristic of expansive soil, today we will be learning the factors which control the shrinkage behavior of soil. So, this will be the lecture number 14 of module 5.

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In this class we will be learning about what are the different factors which control the shrinkage behavior of the soil. So, when we say a shrinkage of a soil that means the reduction in the volume of the soil due to change in the water content. When we take a soil sample from a high-water content and air dry the soil sample its volume will reduce continuously with reduction in the water content.

When we reduce continuously a stage will come, with a further reduction in the water content the volume will not change, that point will be known as the shrinkage limit of the soil and the curve which we will obtain between the void ratio or the change in the volume or the volume of the soil and the water content will be known as the shrinkage curve. So, here we will be learning what are the different factors which control the shrinkage behavior of the soil.

First, Tempany in 1917 stated about the shrinkage behavior of the soil. Then Terzaghi in 1925 stated the shrinkage behavior and compared the shrinkage behavior with the compression of the soil and stated that it is nothing but a artificial compression under a load and the natural shrinkage is due to the drying of the soil, and only the difference between the artificial compression under the load and the natural shrinkage due to drying is that the compression can be carried almost indefinitely, while for a shrinkage it is due to the evaporation of the water and at a point is reached with a further reduction in the water content the volume will not change or the volume will remain constant.

When we talk about the water present in the soil, we can see the water in a soil can be of various types. We can name this water as 1, 2, 3 and 4. The water which is present next to the clay soil is termed as the adsorbed water, so here we are named as 1. So, this adsorbed water are held strongly with the clay surface and cannot be removed by oven drying at 110 ^{0}C. The next to this adsorbed water is the diffuse double layer water, which can be removed by one drying at 110 ^{0}C. This diffuse double layer water is not held that tightly in comparison to the adsorbed water.

Next to this diffuse double layer water the third is known as the capillary water. This capillary water is held very lightly and can be removed by air drying of a soil. Next to the capillary water comes the free water and this free water can drain down from the soil or can be removed by the drainage of the soil.

So, when we dry a soil sample by oven drying or by air drying, the water present in second and third will be removed. When we air dry the soil sample the water present in the zone 3 will be removed, whereas, when we oven dry the soil sample the water present in the second zone will be removed whereas the fourth zone water can be removed by simple by gravity or by drainage.

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In the last class I explained about the mechanism of shrinkage. When we talk about a soil sample, the soil has three components in it particularly if it is unsaturated soil and if it is a saturated soil we have two components. So, here I am explaining about a saturated soil sample. Here we can see the solid particles and water particles and between the different solid particles there are void spaces and these void spaces are filled with water.

So, when we dry the soil sample the capillary forces initiate the shrinkage process. When we take a soil sample, for example here, a curve interface is formed between the void space and the water and a lower pressure will be generated at the lower end of this curvature, whereas, a high pressure will be developed at the upper portion.

Due to this difference in the pressure the water will be drawn out from the soil surface and as long as the shear stresses induced by the capillary forces are more than the shear resistance which will be developed by the frictional resistance as well as the inter particle repulsion at the particle level the shrinkage of the soil mass will continue. As the volume change takes place the capillary forces and hence the shearing stresses as well as the shearing resistance increases.

But after a certain time the rate of increase in the shearing resistance will be more than the rate of increase in the shearing stress. And when this shearing stress and shearing resistance becomes equal there will be no change in the volume takes place of the soil, and we say that is we reach the shrinkage limit. At that point the air will start to enter into the system.

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This is the diagram between the volume of the soil and volume of water. We took a soil sample the soil is fully saturated and at point C, where, the initial water content can be like liquid limit or maybe it insitu water content or maybe compaction water content, but since saturated soil the soil is at a higher water content and may be a liquid limit or slurry state.

So, when we dry the soil sample there will be decrease in the volume of the soil and this decrease in the volume of the soil will be equal to the decrease in the volume of the water of the soil. So, we will get a line which will be sloping at an angle of 45 ^{0}C and here we will get a large portion of shrinkage of the soil and this part is termed as the normal shrinkage.

Once we reach point B, with a further reduction in the water content, the volume decrease of the soil will not take place. At this point the air will start to enter, so the point can be termed as air entry value. Since the air will start to enter into the soil the point B can be termed as the air entry value of the soil. With a further reduction in the water content the water will be replaced by air and the soil becomes start to unsaturated.

So, beyond this part the soil is fully saturated and once we move over that point B the soil becomes unsaturated and at point D, when the soil is fully dry, all the water will be replaced by air and point B onwards the decrease in the volume of the soil will be minimal or becomes constant. So, this is how the soil shrinks for a saturated soil sample, but if we take an unsaturated soil sample the change in the volume of the soil will be different in comparison to that for a saturated soil sample.

Here we can see, this is for a saturated soil sample, this is the curve when S equal to 100 percent that means the soil is fully saturated but for unsaturated soil depending on the degree of saturation say for example 90 percent or 60 percent and 30 percent, the shrinkage curve variation will depend on the basis of the degree of saturation. So, here we can see this is, I am taking this point on onwards, so this is the shrinkage curve which we get when we dry the soil sample. At this point at B′ point the slope of this curve will change and this will be known as the air entry value.

At this point the air will start to enter and the change in the volume from point B onwards will be different. So, in this path the unsaturation can take place in two ways, path A′ and B′ will be obtained if we keep the degree of saturation constant throughout the drying. The path A′ and C′ will be obtained this blue line will be obtained if the degree of saturation is reduced during drying, I will explain this thing again in the next slide.

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So, this is how a shrinkage curves looks like, so shrinkage curve is nothing but the relation between water content and void ratio. When we start drying a soil sample, point A when the degree of saturation is 100 percent it will becomes a linear variation and this is for normal shrinkage. At point B onwards the air will start to enter and the degree of saturation start to reducing from point B onwards and if we extend the line AB and line CD we will get a point here, so that will give the shrinkage limit of the soil.

At this curve, the unsaturation of the soil will take place and water will be replaced by air. And as I told you earlier the soil can be dried from three condition, in-situ field condition or compact condition or from a slurry state condition with a water content which will be near to the liquid limit, and the water content at this intersection between the minimum void ratio and the saturation line is defined as the shrinkage limit. So, this point C is the minimum void ratio, so if we extend a line from point C to intersect the line AB at D we will obtain the shrinkage limit.

This is for an unsaturated soil sample. So here we can see this is a 100 percent saturation line and if we dry the soil sample keeping the degree of saturation constant, we will get a line AB, keeping the degree of saturation constant means whatever water has been removed the same amount of air will be replaced.

This point A is the hypothetical starting point for drying a soil that is initially unsaturated. For path AB the degree of saturation will remain constant that is the constant ratio of air to water in the voids will be maintained. So, here we can see this line AB will be obtained maintaining the constant degree of saturation.

If we dry the soil sample in such a way that the degree of saturation reduces during the drying of the volume or the volume of the air remain constant then we will get the line AC, this AC will be obtained when the degree of saturation will not remain constant during the drying or the volume of the air will remain constant. So, here ΔV_a equal to 0 but in this case ΔV_a is not equal to 0, so either way we can obtain this shrinkage curve for an unsaturated soil sample and the point D will be the point of minimum void ratio and here this is the shrinkage limit.

This is how the drying of a soil sample takes place for an unsaturated soil sample. The path AB will be obtained by keeping the degree of saturation constant that is the ratio between air and water will be maintained throughout this drying and for AC that is the degree of saturation will keep on reducing with the water content of the soil. So, this is how the shrinkage curve for an unsaturated soil sample will look like.

Now going by the factor which controls the shrinkage.

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The main factors which controls the shrinkage behavior are the clay mineralogy, the clay content, plasticity, soil water chemistry, soil suction, soil structure and fabrics, initial density, initial moisture content, loading and soil profile. So we will go one by one on all these factors.

I will start with the clay mineralogy. As we know that a soil which swells to a higher value will also shrink when we remove the water by drying. Therefore, any factors which control the swelling also control the shrinkage behavior of the soil, and in the earlier classes we learned that the swelling behavior of the clay mostly depends on the type of mineral present in it.

Say for example Montmorillonite will give a higher value of swelling in comparison to Illite and Kaolinite. So, therefore, if a clay soil which contains montmorillonite is allowed to swell then it will swell to a higher value, and if we dry that soil sample from swollen state it will also shrink to a higher extent. Other way, if we compare with a non-swelling soil like Kaolinite then the Kaolinite soil will not swell when we wet the soil sample, therefore it will also shrink less. Hence, we can say, that the soil containing a high swelling mineral such as Montmorillonite will undergo a large shrinkage in comparison to a non-swelling mineral.

Also, we need to remember that for Montmorillonite the reversible swelling and shrinkage on re-swelling and re-drying will will be possible. That means if we take a soil sample containing Montmorillonite and if we swell the soil sample and then we if we dry and again if you swell the soil sample it will swell to a same extent and it will also shrink to the same extent, whereas, for Illite and Kaolinite the initial large value of shrinkage on drying will be obtained. If we again re-wet the soil sample the less amount of swelling will take place but in case of montemorillonite we can almost get identical amount of re-swelling and re-drying or identical amount of swelling and shrinkage on re-swelling and re-drying.

Also, we need to remember, not only the clay mineralogy the type of exchangeable cations that is a cation exchange capacity, the ESP, the Exchangeable Sodium Percentage also plays an important role in controlling the swelling behavior and it also controls the shrinkage behavior of the soil.

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Next comes the clay content. Generally higher is the clay content higher will be the shrinkage of the soil. Here you can see a research by a Tempany in 1917 shows that source for different type of soils containing different amount of coloid content that is clay content and we can see that the shrinkage curves are different in fact the shrinkage curves or the shrinkage is increasing with increase in the colloid content.

Similarly, a research by Sridharan and Prakash also shows that with increase in the clay fraction size, the shrinkage limit is decreasing, that means a less shrinkage limit means a higher amount of swelling. Therefore, with increase in the clay fraction size the shrinkage of the soil is increasing. Here we need to remember, lower is the shrinkage limit higher will be the shrinkage; higher will be the total shrinkage.

This increase in the shrinkage behavior due to the presence of higher amount of clay content may be due to the presence of high amount of water held by the clayey particles. Again, in the presence of sand and silt sized particles the total shrinkage of the soil gets reduced. Again, if we have large amount of or large aggregate particles say for example 1 to 5 mm aggregate particles or less than 2.5 mm aggregate particles the shrinkage curve will be different.

The surface soil with a small clay content or well-developed crumb structure will show less amount of normal shrinkage. So, here we can see in this, case the soil has less amount of clay content or the larger aggregate particles. So, here we can see a less amount of normal shrinkage has been occurring while drying and also the total shrinkage of this soil is also been less, but if the aggregate size is very less in comparison to this one we can get a large amount of normal shrinkage and also the soil will shrink to a higher extent.

So, this is the total shrinkage of the soil that means the total shrinkage is more in comparison to this large aggregate particle and also the shrinkage limit which will get for this particle will be less, so this is shrinkage limit 2 this is string case limit 1. So, we can see a lower amount of shrinkage limit is for soil containing small aggregate size particles and also large amount of normal shrinkage and the large amount of total shrinkage for soil containing small aggregate particles. So, therefore we can conclude here the soil containing large amount of clay content will have lower value of shrinkage limit and a higher value of total shrinkage. And also we need to remember that the change in the shrinkage limit of the soil will also not be uniform.

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Next comes the plasticity. Plasticity as we know that it is defined by the plasticity index that is a difference between the liquid limit and the plastic limit. Generally, soil with a higher plasticity will undergo a higher shrinkage, as the soil with a higher plasticity will have higher amount of water in it, so therefore when we dry the soil sample a large amount of water will be evaporated and the soil will undergo a higher shrinkage.

Next comes the soil gradation. Soil gradation is one of the most important factors which control the shrinkage behavior. I have already discussed about the shrinkage and how the shrinkage takes place. Generally, shrinkage is nothing but a packing phenomenon; the shrinkage limit of a natural soil has been primarily result of packing phenomena which is governed by the grain size distribution of the soil. If we take a soil sample like this, these are the large aggregate particles this will be filled by small fine particles, say these aggregate particles are like sand and this will be filled by small particles like silt particles.

So, here we can see, when the void space between the sand particles are filled with the silt particles so this is the sand particles and these small are the silt particles and further this void between the sealed particles are filled by the clay particles. That means the small-small voids will be filled by the clay particles; then we will get a denser state.

So, here by this packing phenomenon we will get a high dense soil and when we dry the soil sample the shrinkage of this soil will be less. Since the shrinkage is nothing but the water coming out from these voids and the particles approach to a closer space, but due to the presence of this fine particles inside this void space the shrinkage of this soil will get reduced.

Therefore, the total shrinkage of this soil will be less, so depending on the packing of the soil samples the shrinkage of the soil can be more or less. So, therefore the shrinkage can be termed as a function of relative grain size distribution. So, this optimal packing of soil particles gives the lowest shrinkage or in other word the shrinkage limit is basically a result of the packing phenomena and the function of the relative grain size distribution. Here we can see the shrinkage limit versus clay fraction, so with increase in the clay fraction this void between the large particles will get filled up and the shrinkage limit will keep on decreasing like this, because the soil will move to a denser packing.

Now, after reaching a certain optimal point once all these voids are filled up then with a further addition of the clay particles, the optimal packing will not be achieved and here we can see there is a rise in the shrinkage limit of the soil with a further addition of this clay. This is known as the critical clay fraction portion. So, therefore this soil gradation depending on how much are the fine particles, how much are the coarse particles, how much are the silt particles, so for a particular gradation the shrinkage of the soil will be minimum or the shrinkage limit of the soil will be less.

So, here a research by Professor Sridharan and Prakash shows that the shrinkage limit as a function of the grain size distribution of the soil. You can see, the two soils 9 and 13 as well as 14 and 16 are having almost identical grain size distribution, so here we can see 9 by 13 and 6 and 14 but their liquid limit is differing much.

However due to this packing phenomena their shrinkage limit is almost identical. Hence, we can conclude that the grain size distribution controls the packing phenomena of the soil, and hence they can also control the shrinkage behavior of the soil. Therefore, a tighter packing will give less amount of shrinkage in comparison to a loose packing containing a large number of voids, which will give a very high value of shrinkage of the soil.

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The next factor which comes is the soil structure and fabrics. So again, this is one of another most important factor which controls the shrinkage behavior of the soil. In the earlier classes I have explained you about different type of structure or fabrics of the soil. We know that clay has a negative charge on the earth surface and positive charge on its edges, so basically depending on the orientation of these particles there are three different kind of arrangement possible. One is edge to edge; that is the plus and this plus charge will be coinciding together and the particles will place like this.

The second one is edge to face, the positive edge of this clay will be lying on the negative surface of this clay surface, so this is called edge to face or face to face, where, the negative face and the negative face of the two clay particles will be lying over one another. However, to obtain this one and this one we need some external forces, because the positive and positive end, whereas, negative and negative end will repel each other.

Therefore, we need some external forces to bring this kind of arrangement, whereas, the edge to face arrangement occurs due to the attraction between the negative and positive end therefore it can occur naturally. But depending on whether it is edge to face or face to face the soil structure can be different, and we can term that as flocculated or dispersed structure. Here is flocculated and a dispersed structure. In flocculated structure you we can see we have edge to face structure, whereas, in dispersed we have face to face, mostly face to face or edge to edge structure.

So, depending on whether structure is a flocculated and dispersed, the void between these two structures will be different or the arrangement of the voids will be different and this soil structure and fabrics is one of the most important parameters which controls the shrinkage behavior of the soil. Here we can see between the flocculated structures, large voids are present and due to this large void a large amount of entrapped water will also be present. When this soil is dry, the water from this pore space gets emptied first and once the soil reaches the shrinkage limit a further reduction in the water will not change the volume.

So, when we dry this soil sample the water gets removed here, as the water gets removed these voids will start to fill with air and the volume change of this soil will not further take place once it reached to this state. So, therefore at higher water content the de-saturation of the soil will start to take place, therefore the shrinkage limit of this soil will be higher. Since the shrinkage limit of the soil will be higher, the shrinkage of this soil will not take place further from the shrinkage limit and the total shrinkage of this soil will be less.

Therefore, for a flocculated structure due to presence of larger size voids the water content corresponding to the shrinkage limit is higher, therefore the shrinkage of the soil stops at higher water content. As a further reduction in the water content will not decrease the volume of the soil and the total shrinkage will be less, but if we take a dispersed structure a small but numerous number of void spaces will be present between the clay particles which will be filled with water. As water gets removed the particles will come closer and as the particle comes closer the volume reduction will take place, and at a very low water content the particles will stop coming closer.

That means after that point the air will start to enter into the system and the shrinkage limit of the soil will be achieved. Therefore, the shrinkage limit for a dispersed structure will be less in comparison to a flocculated structure. So, here we can read that for a dispersed structure due to the presence of smaller size of voids the water content corresponding to the shrinkage limit will be lower, therefore the shrinkage of the soil stops at lower water content. As a further reduction in the water content will not decrease the volume, the total shrinkage will be high.

So, therefore if we compare with the flocculated structure, flocculated structure will be high shrinkage limit and low total shrinkage, whereas, for a dispersed structure we have low shrinkage limit and high total shrinkage. Therefore, if any structure which having a flocculated arrangement will undergo a low total shrinkage comparing to its soil having a dispersed arrangement.

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Here we can see the variation of the shrinkage with the particle orientation. In this graph the particle orientation has been plotted in y-axis and the total shrinkage has been plotted in x-axis. Lower means the particles are mostly random that is mostly flocculated. So, moving from 0 to 100 the orientation of the particle will change and it will more move towards the parallel structure. So, this represents flocculated structure and this represents dispersed structure. As we can see here as the more particles becomes parallel the shrinkage of the soil is increasing.

So, shrinkage of the soil is increasing with increase in the parallel orientation of the particle. Less amount of flocculated structure means less amount of shrinkage; more amount of parallel structure means more amount of shrinkage. Therefore, soil having more amount of parallel structure or dispersed structure will shrink more in comparison to soil having more amount of flocculated structure. Here we can see, a plot between the water content and ratio between the linear dimension and minimum dry dimension.

If we draw a line for any particular water content we can see that the soil with a random structure, and random means more flocculated structure, will have a less amount of shrinkage in comparison to a soil with a semi-oriented structure. So, here the difference between the linear dimension and the minimum that is L/L_d, so this soil is shrinking more in comparison to this soil.

So, this soil shrink more and this is less at the same water content. Similarly, if we draw at any other water content we can see soil with more semi-oriented particles will shrink more in comparison to a random particle. So, these two graphs shows that with increase in the orientation of the particles that is when more particles are dispersed the total shrinkage of the soil will increase.

Therefore, any change in the soil structure or any environment which change the particle orientation also change the shrinkage behavior of the soil. So, this can be like the depositional environment, the salt solution, the mode of the soil in which it is deposited or by remolding the soil; so these are the few factors which can control the shrinkage behavior.

Next comes the shrinkage limit of the soil.

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The shrinkage limit of a soil significantly influence the shrinkage behavior or in other word is also indicates how much a soil will shrink. Lower is the shrinkage limit higher will be the total shrinkage of the soil. As we discussed earlier the shrinkage limit primarily depends on the fabrics, type of clay minerals, the mode of deposition, therefore, this factors also controls the shrinkage behavior of the soil. If we compare a dispersed Kaolinite structure at a pH 10 it will mostly containing the semi-oriented structure and the shrinkage limit will be 19 percent and therefore the oven dry density will be 1.7 gram per cc of this soil.

Whereas flocculated kaolinite particles at a pH 4 will mostly have a random structure, the shrinkage limit will be 26 percent, and the oven dry density will be 1.52 gram per cc. So, if we compare these two, we can see if the particle are having semi-oriented structure then the shrinkage limit will be less; less is the shrinkage limit the density will be very high, and if the density is very high so it will come to a very dense packing and therefore the shrinkage of this soil will be more.

If we take the random structure or flocculated structure the shrinkage limit will be 26 percent, and because of the shrinkage limit is 26 percent more amount of void space will be present between the particles, therefore, the dry density will be less and the shrinkage of this soil will be less, the total shrinkage of this soil will be less.

So, here we can compare by plotting a graph we can see. This we can draw between water content and void ratio, say for example, if we take a soil which goes like this and another soil goes like this, if we start from the same point this is the soil 1 if we say this is soil 2, this is the shrinkage limit of soil 2, this is the shrinkage limit of soil 1.

Now, we have started from the same point, so here we can see in soil 1, the most of the particles will be flocculated one, therefore it will have a higher value of shrinkage limit and higher is the shrinkage limit so this will be the total amount of shrinkage taking place. Now, if we compare with the soil 2, soil 2 have a lower value of shrinkage limit, it will be mostly a dispersed structure and the total amount of shrinkage will be this much.

Now, if we compare between soil 1 and soil 2, soil 1 is having a higher value of shrinkage limit and this amount of total shrinkage, whereas, soil 2 is having a lower amount of shrinkage limit and this is the total amount of shrinkage.

Therefore, the soil 2 will be shrink more in comparison to soil 1. So, we can conclude that soil having a lower value of shrinkage limit will shrink more. So, this has been summarized face to face particle interaction, the unsaturation start at a higher water content and therefore higher shrinkage limit will be obtained, a face to face particle interaction will brings unsaturation at a lower water content, therefore lower shrinkage limit will takes place.

Lower is the shrinkage limit, higher is the total shrinkage, say for example, Montmorillonite soil, the shrinkage limit is between 10 to 15 percent and it will shrink very high. Higher is the shrinkage limit lower is the total shrinkage and example is Kaolinite which is a shrinkage limit ranging between 20 to 25 and it has a low value of the total shrinkage. Therefore, shrinkage limit can also tell us about how much a soil will undergo or will experience the shrinkage.

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Another factor which controls the shrinkage is the soil suction. As a increase in the soil suction, the water present inside the soil crumbs will also be removed. We can see here with increase in the soil suction a large amount of volumetric shrinkage is taking place. This takes place as the increase in the suction removes the water present inside the voids between the soil particles.

So, as a large amount of water gets removed the soil will come to a closer packing, and threfore the shrinkage will increase. Therefore, we can conclude with increase in the soil suction the volumetric shrinkage will also increase for a soil, as with increase in the suction the water present inside the void space will be removed.

Next comes the initial dry density; the shrinkage of a soil decreases with increase in the dry density. However, the decrease in the shrinkage with the dry density is depending on the initial condition, say for example, if we take a soil sample in its natural state and if we dry the soil then the shrinkage will be bit less or depending on the dry density the shrinkage will be different, and if we are taking a soil in its natural state and if we dry with increase in the dry density the shrinkage will reduce further, because with increase in the dry density the packing of the soil will be more dense, therefore, the shrinkage of the soil will reduce.

So if we increase the dry density the shrinkage of the soil will decrease. However, this decrease is not that much significant, but if we take a soil sample and if we allow the soil sample to swell and then dry then the shrinkage behavior of this soil will be different. Because we know that the dry density controls the swelling behavior. With an increase in the dry density the swelling of the soil will increase, as the swelling of the soil will increase the shrinkage of the soil will also increase.

Therefore, depending on its initial condition, the variation of the shrinkage with the dry density will be different. Say, if we dry a soil from initial state from a non-swollen state then with increase in the dry density the shrinkage will reduce marginally, but if we wet the soil sample or if we allow the soil sample to swell and then dry then the shrinkage will also increase.

If a soil is allowed to swell then dry, the shrinkage will increase with increase in the dry density. With the increase in the dry density the swelling is increased when the soil is submerged. A higher swollen bentonite or soil will undergo a higher shrinkage upon drying, therefore depending on the initial condition, the shrinkage of the soil will change with a change in the dry density.

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Now, on this behavior we can draw a shrinkage and swelling curve. So, this is the variation of swelling and shrinkage with dry density. We can see, with increase in the dry density the shrinkage of the soil is reducing. Similarly, when we increase the dry density, the swelling of a soil is increasing.

So, if we draw thess two curve it will meet at a point and if we draw a vertical line on the dry density, we will get a point which will be known as the critical dry density. At critical dry density the swelling of the soil will be equal to the shrinkage and this initial dry density at this point is known as the critical dry density.

The critical dry density varies with the soil property and initial moisture condition. If the initial dry density is greater than critical dry density, the swelling will be larger than the shrinkage. If the initial dry density is less than the critical dry density then the shrinkage will be greater than swelling. So, here we can see, if we take a point from here this will be total shrinkage and this will be our total swelling. So, here if you compare the shrinkage is more than swelling.

If we take a point here we can see this is the total swelling and this is the total shrinkage, so swelling is more compared to shrinkage, but at the critical dry density we have equal amount of the shrinkage as well as swelling. So, therefore, while designing a structure we need to have this critical dry density in our mind to reduce the amount of swelling and shrinkage due to moisture variation of the soil.

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Another most important factor which controls the shrinkage behavior is the initial moisture content. Depending on how much water is present in a soil, the shrinkage behavior of the soil will be different. If we take two soil samples with different amount of initial water content and we dry then we will get two different values of total shrinkage. Say for example, in this case, here, the water content is hundred percent when we dry the soil sample, we are drying the soil sample here, now the water content has reduced to 80 percent and so the volume of the soil will also reduce.

In the next step the water content reduce to 60 percent and so the volume of the soil will also reduced. Next stage will be 30 percent water content and this 30 percent water content corresponds to its shrinkage limit. So, this is the final volume of the soil. Beyond this any change in the water content will not change the volume of the soil. So, therefore this to this will be the total shrinkage of the soil. Now, suppose if we take another soil sample and if we start with initial water content of 80 percent and then we dry then again at the shrinkage limit of 30 percent the volume will remain constant.

So, again this will be the total shrinkage of this soil. If we compare these two soils with the initial water content of 100 percent and 80 percent the soil with a higher water content will shrink more in comparison to soil containing less water. So, this can be shown in this diagram we are drying the soil sample, as we are drying the soil sample the volume of the soil is also decreasing. Here we reach to the shrinkage limit where the ΔV equal to 0. If we compare this to soil this point to this point will be the total shrinkage.

Now, if we take a soil from here with this water content, this will be the total shrinkage. If we take another soil sample here, then the final volume of the soil will remain same this will be the total shrinkage. So, this graph indicates with reduction in the initial water content of the soil the total shrinkage will keep on decreasing.

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The next comes the soil water chemistry. We know that soil water chemistry controls the swelling behavior of the soil. A higher swollen soil will also shrink more, and also presence of the soil water chemistry changes the particle orientation in a soil sample. The presence of salt solution, more flocculated structure will be generated and more the flocculated structure higher will be the shrinkage limit and higher is the shrinkage limit; lower will be the total shrinkage. Therefore, the presence of salt or any factors which changes the particle orientation also changes the the shrinkage behavior of the soil.

The factors which can control or which can change the particle orientations are the salts concentration, the valency of the cations, the pH and the dielectric constant. So these factors can change the particle orientation. For example, with a decrease in the salt concentration the particles become more dispersed, therefore, the total shrinkage will be more.

The decrease in the valency again will make the particles more dispersed, so therefore, the total shrinkage will be more. Increase in the pH will make the particles more disperse the total shrinkage will be more. Increase in the dielectric constant, the more will be the dispersed particle more will be the the total shrinkage, and vice versa, that means with increase in the salt concentration particles will be more frocculated and the lower will be the total shrinkage.

Increase in the valency of the cations more, will be the flocculated structure the lower will be the total shrinkage. Decrease in the pH the particles will be more flocculated lower will be the total shrinkage. Decrease in the dielectric constant more will be the flocculated structure lower will be the shrinkage.

Therefore, if we compare two soil samples with say 1N of sodium chloride and 0.1N of sodium chloride, then this soil will have low value of total shrinkage, high value of total shrinkage, because here more will be the flocculated structure and here less will be the flocculated structure.

If we say take calcium over here and same concentration of calcium and sodium ion then for calcium the low will be the total shrinkage and high will be the total shrinkage. Similarly, we can compare with the pH. So therefore any factor which changes the particle orientation also changes the shrinkage behavior. More is the flocculated structure higher will be the shrinkage limit lower will be the total shrinkage or more is the dispersed structure, lower will be the shrinkage limit, and higher will be the total shrinkage.

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The next comes the mode of geological deposition. The soil which is deposited in salt water will have random or edge to face structure with a large amount of volume of entrapped water. So, this result in a high initial water content and also the overburden pressure consolidate the sediments and decrease the water content and when the repeated swelling and shrinkage occurs, the effect of this geological deposition gets changes. So, therefore, when the soil present or deposited in soil water will have more edge to face structure, it will have a lower value of shrinkage limit and a lower value of total shrinkage.

However, the effect of this mode of geological deposition reduces when the soil will undergo a repeated swelling and shrinkage cycle.

And also the orientation of the particles controls the shrinkage. Say for example, for oriented soil the shrinkage normal to the particle orientation is higher than the shrinkage along the plane of orientation with a decrease in the water content.

Say for example, if we take a flocculated structure like this and if we take a dispersed structure like this one, then for a dispersed structure the shrinkage normal to the particle orientation that means the vertical shrinkage for this soil will be more than the shrinkage along the plane of orientation.

So, that means for dispersed structure the vertical shrinkage that means shrinkage is in this direction will be higher in comparison to shrinkage in the horizontal direction. Here we can see a plot between soils with a partial orientation particle, here we can see, more is the vertical shrinkage in comparison to the horizontal shrinkage at any water content.

This is because the proportion of the water to the solid is higher in a line along the vertical direction, so if we draw a line over here more amount of water is present along this line or the ratio between the water to the solid will be more along this line in comparison to if you draw a horizontal line like this.

Therefore, more is the water associated with it more amount of shrinkage will takes place. So, therefore, the vertical shrinkage in this case will be more in comparison to the horizontal shrinkage. Furthermore, due to the inter particle repulsion is higher between the flat surface resulting in a larger average distance in wet sample between the flat surface than the between the edges. Then the rate of vertical shrinkage gradually decreases with the rate of horizontal shrinkage increases until the shrinkage limit is reached.

And if we compare the slope of this line we can see that the rate of vertical shrinkage will decrease gradually, whereas, the rate of horizontal shrinkage will increase gradually until the shrinkage limit of the soil will be reached. Therefore, we can see depending on the orientation of the particles the vertical shrinkage and the horizontal shrinkage will be different. For a oriented soil or for a dispersed soil the shrinkage normal to the particle orientation will be higher than the shrinkage along the plane of orientation with a decrease in the water content.

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Next is the remolding of a soil. As we remold a soil sample that will change the orientation of the particles. As the orientation of the particles gets changed, the shrinkage behavior of the soil will also change. Here we can see, relationship between the dry density and the water content for a natural soil when we remold the soil we get a different value of relationship between the dry density and water content.

Generally, the surface soil with crumb structures on remolding increases the range of normal shrinkage and decreases the shrinkage limit, whereas, the clayey soils which do not contain large voids has a marginal effect on the remolding of the soil. So, this is all about the different factors which control the shrinkage behavior.

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These are the few points which I have discussed in today's class; these are the few of the references which have been used to prepare this lecture, and thanks for your attention