Expansive Soil
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Lecture 07
Definition, Type and Behavior

Hello everyone, welcome to the course Expansive Soil. Today we will learn about the Introduction to Expansive Soil. This will be the sixth lecture and the third module of this course. In this class we will learn about the expansive soil, its behavior, its occurrence and how its damage the structures. And also we will learn about how we go for the site investigation and what procedures we need to adopt in there.

Before, we learned about the formation of the soil, how the soils are formed from parent rock, what are the different types of minerals, what are their properties, what are the index properties of the soil, what are the engineering properties of the soil, how the clay mineralogy controls the behavior of the soil. In today's lecture we will go more about the expansive soil.

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So, by definition of the expansive soil, it is defined as the type of soil which increases its volume due to absorption of water. Any soil which expands also shrink. So, when a soil loses its water the volume of the soil will decrease or the shrinkage of the soil occurs. Generally, the expansiveness or the volume increase of the soil is very difficult to predict.

Expansiveness of the soil is generally higher than the elastic deformation of the soil and cannot be predicted by the elastic or plastic theory, we need to determine the expansiveness of the soil from the laboratory investigation only. And also there are several other factors we will learn about those things later on.

The factors such as the soil profile, the soil type, the environmental properties, the loading properties also controls the amount of expansiveness of the soil. Since it depends on many factors, it is very hard to predict how much soil will swell in the field. When a soil swells or when it shrinks, then there will be a heaving or a subsidence of the structure occurs. Thus, if this process is repeated many times, then there will be a damage to the structure.

The structure will get distorted or it will have some cracks or the walls will get tilted or there will be jammed in the building's window and doors. These are the various kind of damages which may occur in a structure when the soils gets expanded or shrink. In an estimate the total damage caused due to expansiveness of the soil or due to the expansive soil is far higher than the total cost of the damage caused due to flood, earthquake, hurricane combined together. So, by this you can imagine how big the problem of expansive soil in the world.

And another problem associated with expansive soil is its strength. When the expansive soil is dry, it will have a very high strength, on the other hand when it will be wet or when it is saturated the strength will be very less. So because of this, it is very difficult to predict the strength of the expansive soil in real field situation.

Then we go to the different causes behind the expansiveness behavior of the soil.

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Mostly the mineral montmorillonite, which we have learned earlier, controls the swelling behavior of the soil. Due to the presence of mineral montmorillonite, the soil swells. Any soil which swells also shrink. And generally the soils in mostly in arid and semi-arid region are expansive types of soil.

Why? This is because in arid and semi-arid region the rainfall amount is very less in comparison to the evaporation of occurring through the soil. And because of that the soil will be in a dry state or in a desiccated state and because of this moisture deficiency when there is a rainfall occurs, then the soil will have a tendency to absorb more moisture. When it absorbs more moisture, the soil volume will increase.

So, when there is a rainfall occurs, the volume of the soil will increase. Similarly, during the dry season the water will get evaporated and the soil will shrink. So, therefore, this swelling and shrinkage phenomena takes place in a cyclic manner. During the dry season the soil will shrink and during this monsoon or wet season or rainy season, the soil will increase in volume or expand.

And this swelling and shrinkage phenomena is not fully reversible or recoverable. That means, any soil which will be swelled to a certain extent will not shrink to same extent during the dry

season. And due to this cyclic swelling and shrinkage behavior, the structure which is present above the soil will get damaged.

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Here we can see some of the diagram in which it shows that how the structures are getting damaged because of the expansiveness or shrinking of the soil. Here we can see, in this structure a large crack has appeared on the side wall, so here you can see, a large amount of crack, this is because of the swelling and shrinking behavior of the soil.

Similarly, here also we can see a large amount of crack has appeared and here we can see the cracks has been propagated from ground to the window level. So, this reflects some of the damaged caused to the structure above the expansive soil. Not only houses we can see here also some highways, you can see some undulation is happening, some wavy structures are there because this is happening because of the soil in this part is getting swollen and as a result of which there is a wavy structure.

And also you can see there are cracks appearing on this road because of this presence of expensive soil beneath this pavement. So, this damage is not only limited to the houses or pavements, certain earth structures such as dams or earth retaining structures also get damaged due to this expansive soil.

Mostly due to the expansive soil the structure gets distorted and the cracking of the pavements occur and the beam, walls will crack and also the windows and the doors will get jammed and similarly the lateral forces because of the expansiveness of the soil also have some buckling effect on the basement and the retaining wall. And sometimes the maintenance cost of this due to this damage will be more than the total cost of the structure.

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This expansive soil is a worldwide phenomenon. It is not limited to any particular country, you can see the list of countries which are experiencing the expansive soil problem starting with India, US. In India it is a huge problem, similarly, in US it is a quite big problem as well, mostly in African countries, in Australia and Argentina, so it is a worldwide phenomenon.

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And if we look into the map of the world here we can see the distribution of expansive soil in different parts of the world. Here we can see India, Africa so it is mostly present in almost every continent or every part of the world. If we look into the US map of expansive soil distribution we can see the western part of the America, the northern part, the southern part there is a huge amount of expansive soil is present there.

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In India also it is a huge problem mostly in the entire Deccan plateau, the Western Madhya Pradesh, then parts of Gujarat, Andhra Pradesh, and then the western Madhya Pradesh and parts of Uttar Pradesh, Karnataka, in those parts the expansive soil in the form of black cotton soil is present. In India it is roughly around 20 % of the land mass is covered by the expansive soil.

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In India this expansive soil is known as the black cotton soil. In India, this is generally covered an area of 0.8 million square kilometer which is roughly about 20 % of the total land mass in India. Mostly it is present in the central and southern part of the India. This black cotton soil is named has been derived because of its color. The color of this soil is mostly black or dark gray and generally it is good for cotton plantation.

So, therefore, the name derived from its color and from the type of plantation that is cotton, so it's the name called black cotton soil. The mineral which controls its behavior is montmorillonite, so large amount of montmorillonite generally present in this black cotton soil and some amount of illite is also present there. So, the presence of montmorillonite and illite imparts its expansiveness behavior.

And generally, these BC soils are found in the area where the slope of the terrain is less than 3 degree and the rainfall in the range of 300 to 900 millimeter. And generally, the black cotton soil has a clay content in the range of 50 to 70 percent and also silt content of 15 to 30 % with a liquid limit of 40 to 100 % and plasticity index of 20 to 60 %.

So, due to this high liquid limit and plasticity index it is also a very compressible soil. Now, this black color of the soil is due to the presence of the humus and organic iron and aluminum. And sometimes it is also deficient in nitrogen organic matter and phosphoric acid. However, this is very rich in lime.

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The important characteristics of this volume change behavior of BC soil is due to the change in the moisture content, we will learn about that one in the later slides. Generally, this black cotton soil can absorb 20 to 30 % of the moisture by its volume. And due to high swelling pressure when its expands it can lift up the structure. And on the other side, when the soil is dry, it becomes very hard and strength will become high. Similarly, when it is dry, it will also get settled down or the structure above it will get subsided.

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Here we can see the distribution of the moisture content beneath a soil and how this controls the expansiveness of the soil. In this diagram we could see the variation of the water content at different season and at different depth. This diagram has two parts, I will cover one by one. In first part, on this part which is present on the right side, a slab is present. So slab represents the position of any foundation or any structure above it.

So due to the presence of this slab, the water below this slab will not be able to get evaporated. And this is the distribution of the water content with depth, these three lines represent the distribution of the water content with depth. Since the water content or the water cannot be evaporated because of presence of this slab, the water content generally higher, below the slab in comparison to outside the slab.

So here we can see, there are three curves for different seasons, first one is this one represents the water content during the cool season. When the cool season, when the moisture is more the evaporation will be less, so the water content will be higher. Water content will be higher at the surface and it will keep on decreasing and ultimately it will reach to a certain value.

Similarly, during the dry season, the evaporation will increase, then what happens, the water will gets evaporated from the soil and there will be a reduction in the water content. So, the second curve represents the distribution of the water content along the depth below the slab. So, in comparison to the first curve the water content in the second curve will be less or during the dry season the water content will be less.

The third line represents the distribution of the water content outside the slab, you can see here, there is a large decrease in the water content outside the slab during the dry season. Now, if we look into all these three curves what we will observe is the water content keep on decreasing with the depth but after reaching a certain depth the water content will almost remain constant.

So, the depth up to which the water content will change is known as active zone. Now, there will be a variation in the water content only in the active zone. So, in other word, during the dry season the water will get evaporated in the active zone only, similarly, in the, during the rainy season the water content will increase in the active zone only.

So, due to this change in the water content of the soil in the active zone there will be expansiveness or shrinking behavior of the soil. When there is a rainy season the water content will increase and because of that the soil will increase its volume or soil will expands. As a result of which we can find some heaving here. At the same time when we look into the soil during the dry season, again, the water content will decrease during the dry season and because of that there will be a subsidence of the soil and the structure will get subsided.

So, this process happens in a cyclic manner, that means, in rainy season it will expand, in dry season it will contract. So, this is what is observed below a slab. And most of the time the variation in the water content in this zone and this zone will be much more in comparison to the zone below, centrally below this slab. Therefore, the structure around this edge of the slab will experience more damage in comparison to the central portion.

Now, consider the other part of the diagram. In this, we can see there are some plants there, shrubs, plants there and this shrubs and plant also releases water because of the evapotranspiration. These shrubs and plants absorbs moisture from the soil and then they release in the form of evapotranspiration. And also the soil will also release some water because of the process of evaporation.

Now, when there is a precipitation occurs some water will get infiltrated to the soil and some will get evaporated, some will be lost because of the evapotranspiration. Now, similarly, here also we will get two curves or two distribution of the water content along the depth of the soil. Here we can see this is the water content during the cool or rainy season which will be generally higher in comparison to water content in dry season.

But again, after reaching a certain depth the water content will almost, will remain almost constant. So, that means this will be active zone. So, any change in the water content in this zone will change the behavior of the soil. When there is an infiltration of the water occurs the water content will increase and there will be a heaving, during the dry season when there will be lots of water because of this evaporation or evapotranspiration, then there will be a subsidence to the structure and the structure will gets subsided.

So, this is how we can see the variation of the water content along with the depth and the rise or the heave or subsidence of the structure related to this one. Here we need to understand that this only occurs in the part of active zone. That means, the active zone only contributes to the swelling and shrinkage behavior of the soil. This is all because of the change in the moisture content due to evapotranspiration.

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So, this diagram, this graph shows the distribution of the water content along with the depth. Here we can see, a large amount of water content, a difference in the large amount of water content is occurring at a shallow depth in comparison to a larger depth. Here in this larger depth the variation in the water content for different seasons are very less, whereas, in this portion this will be very high. So because of this the, swelling and shrinkage phenomena occurs only on this part of the soil. So, this will be the active zone of the soil.

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Next we will learn about the different causes for this heaving and subsidence of the structure. There are different causes which has been categorized into three different conditions like, first one, the change in the field condition. Field conditions means when there is a long drought followed by heavy rainfall then the soil will have a more tendency to absorb moisture and

because of that the soil will absorb more moisture and soil will expand to a large extent and that will result in an edge movement of the structure, that means the edge of the structure will get lifted up.

Change in the depth of water table. If there is a water table occur at a shallow depth, then it will contribute more moisture to the soil and therefore the soil will expand to a higher value. If the water table is located at a large depth, then it will not be able to contribute to the, it will not be able to contribute water to the soil and therefore, the soil will not be able to expand.

If any amount of chemicals present in the water, then that will control the swelling behavior. So, this thing we will learn in the later classes that how the different kind of salts affect the swelling behavior. The soil might have some chemicals present in the form of due to the oxidation of iron pyrite. So, these chemicals when present in the water or the soil that decreases the expansiveness of the soil.

Similarly, due to some construction activities the soil will undergo swelling and shrinkage. For example, if a soil is covered by a slab, then in that case the evaporation will be reduced and because of the reduction in the evaporation the moisture loss will be less and the swelling and shrinkage will also be reduced significantly.

Similarly, if the trees are removed from the soil then, what will happen, the soil will lose less amount of moisture because of the evapotranspiration. So, that means more moisture will be present, so the soil will be expand more and shrink less because of the less evapotranspiration. Similarly, if there is a ponding of water due to inadequate drainage facility, then this water will percolate into the soil and the soil will absorb more moisture and soil will expand.

Similarly, if the water seeps through the interface between soil and foundation then the soil will find more moisture to absorb and it will undergo a significant increase in the volume. If the foundation is exposed to drying, then the soil will lose more moisture and there will be more shrinkage.

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The third phenomena which controls the swelling shrinkage will be due to the usage. While watering the plant and lawn we use large amount of water, that water seep into the soil and

increase the soil water content. As the soil water content increases, the soil expands and the volume will increase.

The presence of large amount of trees close to the foundation increases the evapotranspiration. The roots of the plant will absorb more moistures from the soil and it will lose those water in the process of evapotranspiration. So, the soil will lose moisture and the soil will undergo a shrinkage process.

Similarly, if there is a furnace or boiler present in the basement of a structure, then due to the heat emitting from those structures the soil will dry and it will shrink. Similarly, if a underground water and sewer lines is there and if it is leaking the water content of the soil will increase and that contributes to the expansiveness of the soil. These are the different factors which can contribute to the swelling and shrinkage behavior of the soil.

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Now, due to this change in the moisture content the structure will have a differential swelling and settlement phenomena. Differential settlement and swelling of the soil beneath the foundation result in the damage to the structure. When a soil undergo a differential settlements, then what happened, the load which was designed for a structure will get redistribute and because of that the foundation for which the structure has been designed may not be able to sustain that load further and that create a problem to the structure above it.

The occurrence of the damage to the soil will may not happen immediately. The damage can occur within a few months after the construction and it may also occur after few years also. So, it is not always that the damage will be caused immediately due to the swelling and shrinkage. And it also depends on the permeability of the soil. If the soil has very low permeable one, then what happens, the water will seep through the soil very slowly and as a result of which the swelling of the soil will occur very late.

The structures which are susceptible to damage are the foundation and walls of lightweight structure, roads, canal and reservoir. Here we need to understand the only the lightweight structure undergoes a large settlement or damaged because of the swelling behavior or shrinkage behavior of the soil.

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In this diagram we could see the swelling and shrinkage phenomena occurring below a house. This house is located above an expansive soil, this part of the soil has more moisture in comparison to this one. This is because of the water cannot escape out through here, so large amount of water content is here as a result of which this part will go more swelling.

Similarly, on this part, the root of the plant will absorb moisture and the water will be lost through evapotranspiration so this part of the soil will undergo shrinkage. Therefore, we can see the structure is having differential settlement or differential heaving. This part of the structure is undergoing settlement, this part of the structure is getting heaving and again this part of the structure is getting settled. So, because of this one, cracks starts to develop on the structure and because of this the structure will get damaged.

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If you look into this diagram, this is a uniformly loaded slab. Now, assume that soil beneath this slab is an expansive soil. When this soil expands, it will exert an upward pressure on the slab and this upward pressure will be not uniform because of the non-uniformness of the moisture content below the slab.

And here we can see the structure, on this part of the slab more amount of swell pressure will be there in comparison to this part. As a result of which this part will get lifted off in comparison to the central portion. If we draw the movement of the structure with the vertical load we can see the corner portion is having more movement in comparison to the central portion.

And similarly, the edge portion will be in between the corner portion and the center portion. Therefore, more amount of damaged is caused on the corner portion of the soil due to the expansiveness of the soil.

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Here we can see how the structure gets damaged due to shrinking and expansion. Consider a building which is located in expansive soil, which is the structure is located over an expansive soil and there are cracks over here through which the water can seep through. Due to rainfall the

water will seep through this soil and as a result of which this volume of the soil will get expanded and these cracks will get filled up.

As the soil absorbs more moisture it will exert an upward pressure to the soil on this part. As the soil expands, it will lift up this foundation and as a result of which the building will get distort and finally it will crack from the corners.

Similarly, during the dry season the soil will shrink because it will lose moisture because of the evaporation or evapotranspiration as the soil loses its moisture the volume decrease takes place and the soil will move in a downward direction and because of this the structure will get settled or get distort over here. And as a result of which it will starts developing cracks.

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So, this is how the seasonal wetting and seasonal drying damage the structure. Due to the seasonal wetting, the moisture due to the rainfall will penetrate into the soil. There will be a swelling of the soil and as the swelling is happening this part of the soil or the structure will get lifted off and it will, the structure will damage like this one.

Similarly, during the drying season, the moisture of the soil will get removed or will get lost because of the evapotranspiration and this part of the structure will get subsided and the structure will move in a downward direction. So, this is how the seasonal wetting and seasonal drying changes or damage the structure.

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In addition to that, one the presence of any plant near to a building or a structure can also damage the structure. Here we can see due to the evapotranspiration, the moisture move to the plant through its root and then it will get lost because of the evapotranspiration. As the water from the soil is removed because of the evapotranspiration, the soil on this part will get shrink and because of that the structure on this part will get settled or distort and cracks will starts to appearing on the structure.

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When we talk about heaving or expansiveness of the soil, there are three different kind of movement associated with the soil. First one is a dooming heave, in dooming heave the maximum amount of heave occurs at the center and less amount occurs at the edges. So, when this dooming heave occurs the external walls or the structure above it will move in outward direction, in this way, which will be resulting in a horizontal, vertical and diagonal cracks which are larger at the top in comparison to bottom. So this kind of cracks will appear. So, this crack will be larger at the top in comparison to bottom.

There is another kind of heave which is known as edge heave. In this large amount of heave occurs at the edge in comparison to the center. So, this kind of heave when occurs then the structure will move in this direction and then the cracks which will be formed will be wider at bottom in comparison to at top. And this is generally occurs when there is a loss of the water because of the evapotranspiration due to the presence of plant and trees.

There is another kind of movement which is known as lateral movement which occurs on a retaining wall or any structure because of the expansiveness behavior of the soil. Here we can see a lateral thrust on this structure due to the soil around here try to expand. So, because of this it can cause the bulging and fracture of the basement walls.

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In this diagram it shows that how the upward lift pressure and the dooming heave and edge heave damage to the structure. Here this is a dooming heave, you can see the maximum swelling is occurring here or maximum pressure has been generated at the center. Because of this the structure on this part will get lifted up. And the walls will move in this direction the outward direction and here we can see the cracks which are wider at the top are generated in the structure. So, this is for dooming heave.

Now, in the edge heave the reversing happens. The maximum swelling pressure will be generated at the outward and this may be because of the more moisture present in over here in comparison to the central portion. This may also occur in the form of shrinkage. So, when this edge heave or edge shrinkage happens the structure will move in the inward direction like this one.

And the cracks which will be generated here will be wider at the bottom in comparison to the top. So, these are the two different kind of heaving or shrink in the form of dooming heave or edge heave which occurs to any structured based on expansive soil. Next we will learn about what are the different factors which controls the expansiveness and shrinkage behavior of the soil.

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The most important factor which controls the effect, controls the swelling and shrinkage behavior is its clay mineralogy. The presence of mineral like montmorillonite and illite particularly montmorillonite imparts a higher swelling tendency to the soil.

Then comes the soil water chemistry, presence of any chemicals in the water reduces the swelling behavior, or any swollen soil which is coming under any soil, any water which is contaminated with any salt then the shrinkage will occur to that kind of soil or presence of any salt in water leads to decrease in the swelling and increase in the shrinkage behavior.

Another factors which controls the swelling and shrinkage behavior of the soil is its plasticity, higher is the plasticity of the soil, higher will be its swelling and shrinkage phenomena. Then comes the soil structure, like whether it is a flocculated structure or dispersed structure, we will discuss all this one by one in the later lectures.

Next is a dry density, a soil compacted on the dry side of the OMC generally have a more swelling tendency in comparison to compacted on the wet side of the OMC.

Moisture content, moisture content of the soil also controls the swelling and shrinkage. Soil compacted on the wet side of the OMC, generally have less amount, less tendency to swell and compacted on dry side of the OMC have a higher tendency to swell.

Moisture variation in the active zones also controls the swelling and shrinkage behavior. A large variation in the water content produces large amount of swelling and shrinkage. Climate plays an important role as we know that in dry season the soil will be in desiccated state and it will have a more tendency or more suction to moisture and will be a more swelling soil in comparison to in a wet climate.

Position of the water table like when if the water table is present and at a shallow depth, then it will control or it will contribute more moisture to the soil and the soil will swell more in comparison to water table present at a larger depth. Drainage conditions also controls the behavior of the soil. If the drainage is good, then more water will percolate into the soil and more amount of swelling will happen.

Soil permeability, if the soil is less permeable, then the water will pass through the soil very slowly and the swelling will be bit less. If the soil have a large amount of load in it, then the soil, the tendency to swelling will also get reduce. If the loading is more than or the stress coming to the soil because of the presence of any load more than its swelling pressure, then the swelling of the soil will get reduced significantly.

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Next will be the site characterization. Suppose, if we have a site to visit and we need to know what kind of soil it is, then we have to go for a site characterization or site investigation. Generally, the site investigation has three parts, one is a reconnaissance survey, then the preliminary investigation, then field investigation. So these are the three investigation mostly on which we need to decide whether the soil will be having expansive soil or not. If it is an expansive soil then what steps we need to do?

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Here we can see the different steps for a site investigation. The first one will be reconnaissance survey. Then that will be followed by preliminary investigation in which we have to do some testing to the soil, field testing, laboratory testing. Then based on that we have to do some detailed investigation.

In the reconnaissance survey, first we will go to the site to locate the potential problem areas and then we need to determine what are the different factors which are contributing to the swelling and shrinkage behavior of the soil. In preliminary investigation, generally the swell shrinkage behavior of the soil will be determined.

In this method the soil will be identified and classified by some testing. In the preliminary investigation some soils will be taken from the site by drilling and sampling as well as some field test will be performed on the site. Then the soil will be drilled and sampled and few samples will be taken as disturbed soil, few will be on undisturbed soil.

On the disturbed soil, few laboratory tests will be performed like swelling pressure test, swelling potential test, liquid limit, plastic limit. Then here we need to determine whether the soil will be having some swelling potential or not. If we find that soil is having swell potential or it is an potential to swell, then in that case a detail investigation will be performed in which the different soil properties will be determine, then quantification of the soil shrinkage potential will be determined more accurately.

And then the site will be further investigated. And if it has been observed that the soil can possess a serious problem to the structure, then we had to design the alternatives for the structure.

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So, here we can see, in the reconnaissance survey we have three different steps which will be studied using map, aerial investigations, that is a preliminary investigation and detailed investigation. In preliminary investigation the soil swelling and shrinkage tendency will be determined and which will be included in preliminary subsurface and subsurface sampling and laboratory testing.

And based on the final findings of the preliminary investigation, a more detailed investigation will be conducted in the detailed investigation parts, where in which a detailed soil profile of the site and the accurate determination of the swell shrink potential will be determined. Then from some undisturbed soil sample the soil properties will also be determined.

And if we find this structure is not suitable or the soil is not suitable, then we may have to change the design of the structure or we may have to do some treatment to the soil to decrease its swelling shrinkage phenomena.

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Once we have some expansive soil, then we need to determine its expansiveness. By different techniques we can identify the presence of an expansive soil at a site. The first one is a mineralogical identification. In mineralogical identification microscopic studies will be performed, XRD test will be carried out, then differential thermal analysis test will also perform.

Scanning electron microscope will be performed, infrared spectroscopy will be done, methylene blue test can be performed. All these test can be performed to determine what kind of mineral is present in the soil. If the soil is consisting of expansive mineral like montmorillonite or illite, then that will indicate a potential of swelling and shrinkage behavior of the soil.

In addition to mineralogical identification some of the index or engineering properties of the soil can also be determined like Atterberg limits, liquid limit, plastic limit, shrinkage limit. Then the free swelling test can also be performed, particle size analysis to determine the presence of clay mineral.

Swelling pressure test can be performed to determine how much swelling or how much pressure it can generate while swelling. Similarly, swelling potential test can be performed to know what is the total extent of the increase in the volume of the soil. Then finally, the volumetric or linear shrinkage test can also be performed to determine the potential shrinkage of the soil. So, based on these tests we can determine the behavior of the expansive soil.

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These are the few of the summaries of today's lecture.

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And these are the few references. Thank you very much.