Pavement Materials
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Lecture: 10
Expansive Soils and Stabilization Techniques

Hello everyone, today is the last class on module 1, where we will be talking about the expensive soils and stabilization techniques. In the last lecture we have completed our discussion on the strength properties of soil.

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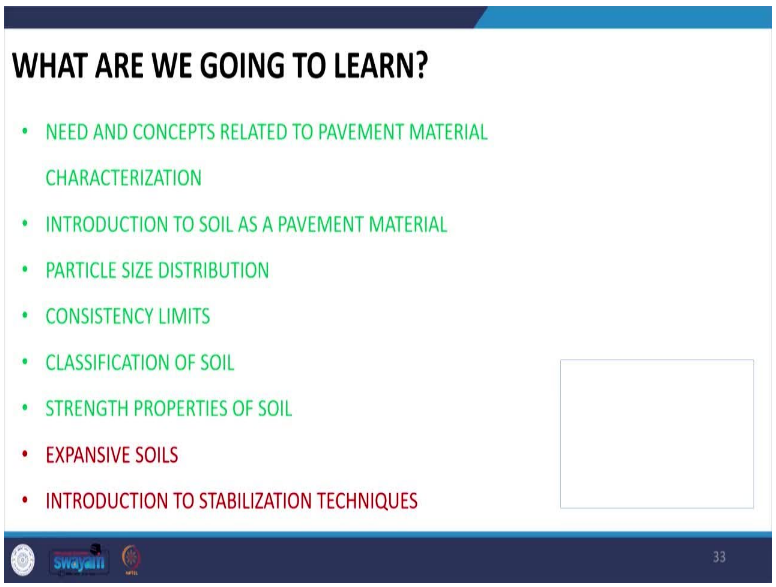

And this lecture is basically focused on understanding a brief overview about the meaning of expensive soils, about the problems caused by expensive soils and then we will look into some of the popular techniques that are being used and have been used to deal with expensive soils. So, I have thought of making this particular presentation this particular class as a question and answer form of lecture.

So, here I will be first asking a question a general question in the area of expensive soils and then we will try to look into the answer for that question and if we take up the most common questions which usually comes in our mind when we think about expensive soils, when we discuss expensive soils, the answers to these questions will help us in understanding the basic concept.

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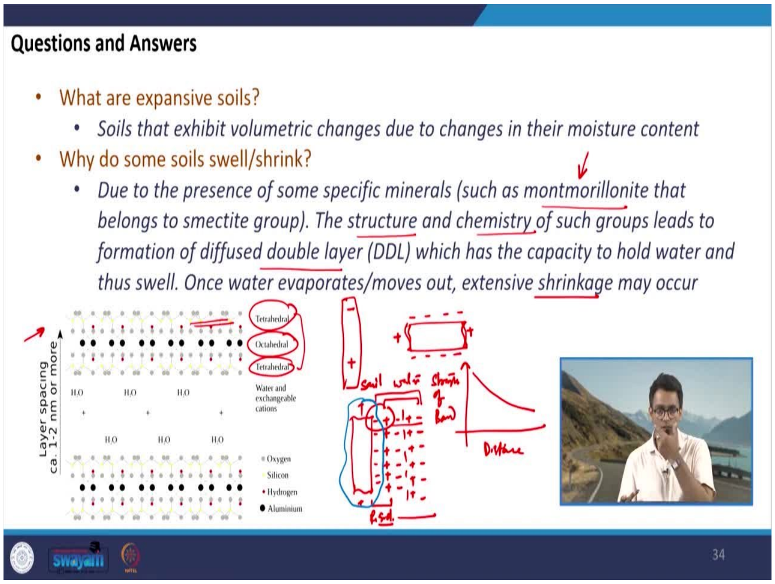

So, the first question which can come to our mind is what are expensive soils? We have been discussing about soils we have been discussing about various properties of soils. So, what are these expensive soils and why are we so, interested specifically in learning about them. So, in very simple terms expensive soils can be defined as those soils that exhibit volumetric changes in fact large volumetric changes due to changes in the moisture content, we have already discussed the relationship between the density and compaction characteristic of soil with change in moisture content.

So, we understand by now that moisture has a predominant effect on various properties of soil, but these soils that are the expensive soils, they are problematic in the sense that when moisture changes in the soil, the change in volume is very high and this change in volume can be very detrimental to the structure which is constructed over it. So, the next question is why do some soils swell or shrink? When I say that there are expensive soils then we should also know that what leads to the changes in the swelling and shrinkage which are basically the volumetric changes in the soil.

Though the actual theory behind understanding this entire process of swelling and shrinkage and learning about the framework of swelling and shrinkage is not very straightforward, but we will try to understand a basic outline of why the swelling and shrinkage in some soil takes place. When this is predominantly due to the presence of some specific minerals. Now, usually this is such type of activity or such type of volumetric change are typical for fine grain soil. And in fact, in the final soil we are specifically talking about clays here that are less than 0.002 mm in size which we have already discussed previously.

Now, if you see the clay minerals, there are various type of minerals which are present for example, we have the Smectite group under which the predominant mineral is montmorillonite. Similarly, we have other minerals for example, we have kaolinite we have allied groups, which are commonly found in clay soils, but some of the specific minerals for example montmorillonite. So, if this mineral is present in excess in the soil which we are dealing with, then the changes in volume or the swelling and shrinkage potential of the soil will be very high.

And why does this happen? This happens because of the typical structure and chemistry of these are mineral groups and because of these structure and chemistry of these mineral groups, there will be a formation of diffused double layer. We will talk about the diffused double layer concept we will discuss that this diffuse double layer has a capacity to hold large amounts of water and since it can hold large amount of water, the volume expansion or the swelling in the soil becomes very large. Now, once this water comes out from the diffused double layer, now the water can go out from the soil in various forms for example through evaporation let us say.

So, through evaporation when the water comes out, now this excess volume gets reduced and the soil particles will come close to each other again, which will reduce considerably the volume of the soil and because of this reduction in the volume, the shrinkage becomes predominant. So, this picture which you see here, this shows the typical structure for the montmorillonite mineral where you have tetrahedral silicate groups.

So, you can see that these are the silicate groups here which. So, we have 2 silicate groups and which are tetrahedral and we have an octahedral Illuminate group which is sandwiched between these 2 tetrahedral silicate groups, this is a sheet like structures what is so typical about this type of structure?

So, what is this diffusible layer and why we say that this mineral this type of clay has the capacity to hold water? So, let us try to understand it using in simpler terms. So, say we have water so, we know that water has a dipole here. So, this will act like a magnet and then we have let us say a clay particle. So, the on the surface the clay particles usually have negative charge and, on the edges, so, these are exposed faces, it will have positive charges, we are talking about this clay mineral here. So, these are the negative charges, now, these charges gets attracted to the positive part of the water.

So, this is the soil here. So, this will get attracted to water. So, water will make a bond with the surface of this particular clay material alright. So, this is water here. So, this bond it forms the rigid bond here. And, we have further water molecules, so, they will form bonds among each other also. So, there will be weak bond between the individual water molecules, so, it will be like plus, plus, plus here then again minus, minus, minus, minus, minus here. So, you can see that the strength in the bond or this with distance it is basically reducing.

So, this part is water here it is forming the rigid bond, but beyond this particular point the bond gets weak so, with distance the bond will reduce and this part since, it is composed of 2 layers, 1 layer is the rigid part where it is making bond with the surface of the clay mineral and then the other part where the individual water molecules are attached to each other.

So, these 2 layers they are combined we call as the diffused double layer depending on the mineralogical composition, the chemistry of the soil, the soil can attract large amount of water and because of the storage capacity of water by that particular soil, the soil swells or it increases in volume.

In other words, if in this soil, I want to reduce the swelling capacity, then I should be able to reduce the thickness of this diffused double layer or maybe I should be able to reduce the activity of the clay surface with the water molecules. So, I may be interested in, coating this particular claim mineral with some other material such that it becomes hydrophobic in nature such that it does not attract water molecules to swell because this is a phenomena how the swelling will take place. So, I will look at measures which can reduce this particular process, maybe I will reorient the soil particles so, that the parallel structures can be avoided and thereby I can reduce the formation of this diffused double layer.

So, there are various means by which we can alter the properties of the soil and once we alter the properties of soil or reduce the thickness of the diffused double layer or we change the activity of the soil particles, we will be able to deal with the problems associated with expensive soil. So, we will look into those techniques today.

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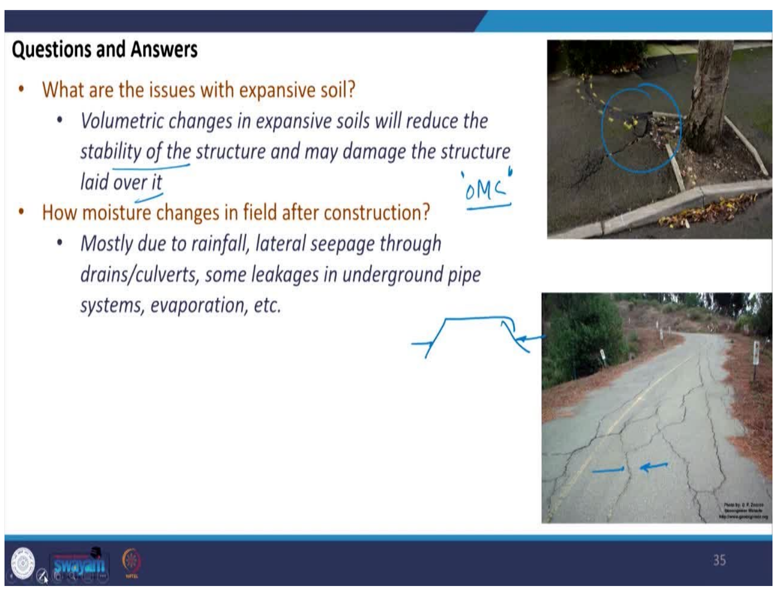

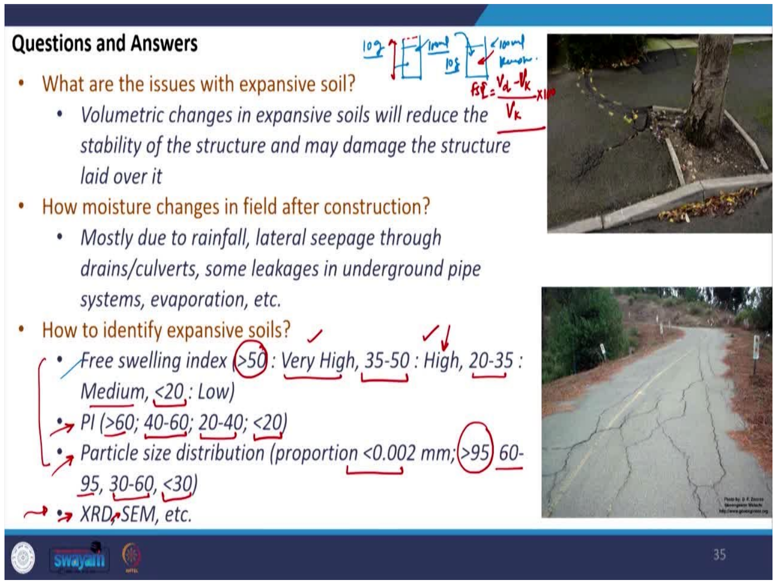

Going further asking more questions and trying to answer them. Let us see the next questions. The next question is what are the issues with expensive soil? I mean, we have discussed the swell and shrink then what is the final result of the swelling and shrinkage in the particular structure I am looking at?

Volumetric changes in the expensive soil it will in general reduce the stability of the structure and it may damage the structure laid over it, I think this we can imagine this we can understand that if the changes in volume of the foundation will ultimately lead to instability in the structure which is constructed over it because of which many problems for example, you will see heaving of the surfaces you will see cracking appearing on the surfaces if the soil has cracked below because of shrinkage and so, on.

So, there are various issues or damages to the structure which we can see if we construct the structure let us say pavement over such weak soils without treating it appropriately. Well, the next question is how moisture changes in the field after construction? We have learned that about the optimum moisture content for a given soil once we evaluate the optimum moisture content, we will do the construction at the optimum moisture content. Then here we are talking that such type of soils are prone to change in volume only when changes in moisture content will take place the question is in the field how is moisture changing, because I have already constructed it at the OMC.

So, how the moisture changes or deviates from this OMC. Well, this also you can imagine very easily that the moisture in the soil can change because of rainfall let us say because of increasing the level of the groundwater table there can be lateral seepage, this lateral seepage can be through drains it can be through culverts, it may happen that some underground system has broken there is some leakages in the underground pipe system which can again lead to changes in moisture content. And then we will also have a reduction in the amount of moisture content because of evaporation, because of excessive heat this water will evaporate and hence again there will be a change in moisture content.

So, these are various reasons because of which we can expect that after construction there can be changes in the moisture content of the soil. Now, an important question is that how do I identify expensive soil suppose I go for a site inspection, I am interested to do some construction on that particular land, on that particular natural ground and I have some soil in front of me.

What tests do I do to understand that this soil which I am dealing with is actually an expensive soil? So, of course in this direction, there are various tests that are available, you can take the soil, you can go to the lab and do some set of testing and the properties or the values of the testing will tell us whether the soil is expensive or not, various laboratory tests have been proposed, these are some of the common or popular tests that are usually used for identification of the expensive soil, the most common test being the free swelling index.

In this free swelling index, let us say we are taking 10 gram of soil. And we will actually put it in say 100 ml of water and then again what we will do? We will take similarly 100 ml of kerosene here and here also we will put similar amount of soil. And then we allow the soil to, change its volume and we will condition the specimen and after the conditioning period, we will see that how much change in the volume has taken place, we understand that presence of moisture will lead to the formation of the diffused double layer because of which if it is an expensive soil, there will be increment in the volume.

But if it is a kerosene, so, kerosene is not going to react or it is not going to participate in the activity with the clay minerals to increase its volumes in the kerosene we will not see such type of expansion. Here, the swelling or the free swelling index is defined as the amount of expansion date has taken place relative to the kerosene solution.

So, we will say that $\frac{\mathrm{Vd}-\mathrm{Vk}}{\mathrm{Vk}} \times 100$. So, this is called as the free swelling index and researchers have proposed over a period of time that how by looking at the free swelling index value, we can know whether the soil is expensive or not.

For example, if it is very high expensive soil, the free swelling index will be greater than 50. If it is a highly expensive soil then the free swelling index usually ranges from 35 to 50. If the swelling potential is medium or average, then the free swelling index ranges from 20 to 25. And for soils which are not expensive in nature, the free swelling index is usually less than 20. So, just do the free spelling test, see the value of the free swelling index and we will be able to know whether the soil is expensive or what is the extent of expansiveness in that particular soil.

Then the other experiment which we have already learned that is the plasticity index value, which we get by doing the liquid limit and plastic limit test on the soil if the plasticity index is greater than 60 such type of soils are very highly expensive in nature, if the plasticity index value is between 40 to 60 we can say this is a highly expensive soil, if it is between 20 to 40 which means the soil is of medium expensive nature or it is it has an average value and if it is less than 20 then we will say that the soil is not expensive, not expensive in nature or has a low expansion characteristics.

The other easy method in the laboratory is to see the particle size distribution, we have learned about the hydrometer analysis, we know how to do particle size distribution of fine grained soil. And based on the sieve size distribution curve, we can look at what is the proportion of material which are less than 0.002 mm.

So, if the amount of material less than 0.002 mm is very high, let us say more than 95percent which means that particular soil is highly expensive in nature, very highly expensive in nature. If the value is between 60 to 95 we say that it is highly expensive, 30 to 60 it is average and less than 30 it is low.

So, again these are some physical tests which can be done on the sample to assess whether the soil is expensive or not. There are other tests on the microscopic level which can be done in the laboratory. And by it is more of a chemical form of analysis looking at the spectrum of the data and that will tell us which type of minerals are present in the soil and looking at the presence of minerals we can know that whether it is in expensive soil or not.

In that direction, we have various tests for example, commonly our XRD, we can do an X ray diffraction test, we can do a scanning electron microscopy test and so on, which will tell us more about the morphologic characteristic of the soil particles. These are some of the test methods to identify the expensive soils. Now, let us go to the next question. And the next question, which we want to ask is, which are the typical locations in India, where you encounter such expensive soil?

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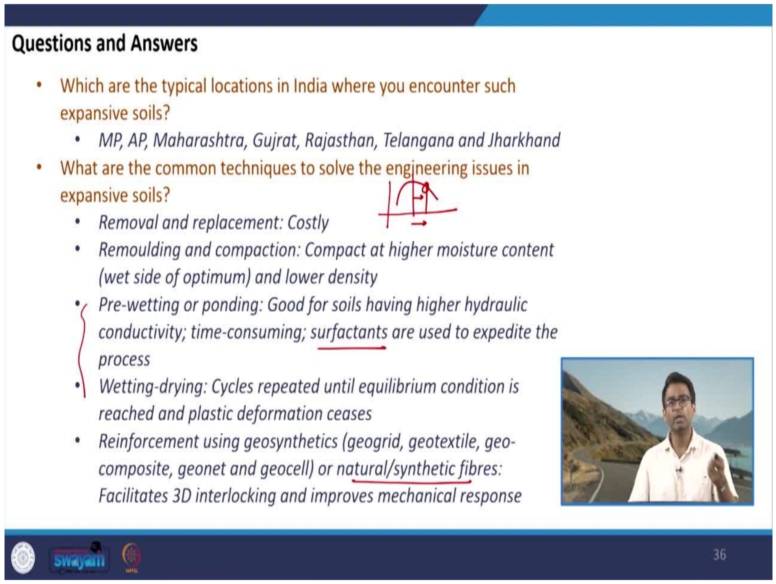

So, this will also give us an idea about the identification of the location where we can expect the presence of expensive soils. So, some of the locations are Madhya Pradesh very commonly you will find the presence of black cotton soil there, in Andhra Pradesh also you will find the same some locations in Maharashtra, Gujarat expensive soils can be found in Rajasthan in Telangana and also in Jharkhand. So, this is specific to India.

The next question is, which is a very important question and which we will discuss in detail is, what are the common techniques to solve the engineering issues in expensive soil? So, this is what we are interested in, if we encounter an expensive soil and we still want to do the construction over it or we want to know that what should be done at this date when such type of soil is present, and I want to, construct a structure over it. In the literature, various techniques are present, there are various review papers that are available, which demonstrates or which highlights various techniques that have been used globally to deal with expensive soils.

So, we will be talking briefly about the prominent methods or the common methods or the popular methods that have been used. The first method is removal and replacement. So, this is a very straightforward method that we do not want to take any risk. We do not want to stabilize the soil, we just want to remove it and we will replace it with some Bureau material soil, which has desirable engineering characteristics, but this type of technique is though it is very straightforward, but it can be costly, let us say if you are doing a construction at a particular site and good soil has to be transported from a very, very long distance.

And if you talk about pavement construction, let us say you have to construct very long road with, several 100 kilometers of road, then you can imagine that this process can be very costly and usually engineers will not prefer this process considering that the cost of the construction will be very high.

The second method is Remolding and compaction again this is like a mechanical stabilization you can say where what we do we will remold the sample of the soil and we will compact it using rollers this method though it may be effective, but it will not always solve the entire problems related to the expensive soil.

Talking about compaction or construction specifically on expensive soil it is recommended and it has been found through many experimental investigations also that the swelling potential or you can say the changes in volume in the soil will be minimum if you compact the soil to a higher moisture content and lower density which means you are on the right side of the curve.

So, you compact it at a lower density and at a moisture content which is higher than the optimum. So, in this state or in this position as we have already discussed the soil particles are more of dispersed in nature and the changes in the volume can be minimized, the next method is pre-wetting or ponding, pre-wetting or ponding the idea behind this method is that, I will add so much water in the soil that whatever diffusible layer has to form whatever expansion has to take place should take place completely. And there will be no further changes in the volume after I do the construction.

So, here what is done that particular soil is flooded with water and it is kept in that position for a very long period of time. Now, this technique again is dependent on the hydraulic conductivity of the soil, if the soil has high hydraulic conductivity, which means it can be easily wetted, then it is good we can use this method though this method is very time consuming, especially in those soils where the hydraulic conductivity is less, in those soils it is very impractical you can say to completely wet the soil because it takes very considerable period of time to completely wet the soil through this particular process.

To expedite the process of wetting, sometimes surfactants are used and this usually helps making the process of pre-wetting fast another method is the process of wetting and drying what we do here, first we will saturate the sample with excess amount of water we will let the expansion to take place. Once the complete expansion has taken place, what we will do we will wait until it complete water is removed.

So, we will remove the water from the soil mass so, that the soil will reduce its volume and it will shrink and this process of swelling and shrinkage will artificially induce in the soil before we can start the construction work and this process what it will do it will make the soil reach an equilibrium condition such that for the plastic deformation will not take place or it will cease to occur when we start doing the construction.

Many times, in this process we also use moisture barriers to remove or to prevent the movement of water out of the soil mass because if the water again goes out, again the soil will have a propensity to swell and shrink. Further we have methods like reinforcing the soil using various geosynthetics, under geosynthetics we have various products that are available.

For example, we have geo grids, we have geotextiles, we have geo composites, we have geo cells, we have geo nets and these geosynthetic materials, they help to reinforce the soil they help to increase the strength within the soil mass. So, it acts like a binding agent or it holds the soil particles together. So, that the movement of soil can be minimized.

We can also use natural or synthetic fibers other than geosynthetics these fibers which are of smaller sizes, what they do? Again, it is a form of physical interaction where it facilitates 3d interlocking between the soil particles and it improves the mechanical response of the material to any given loading condition.

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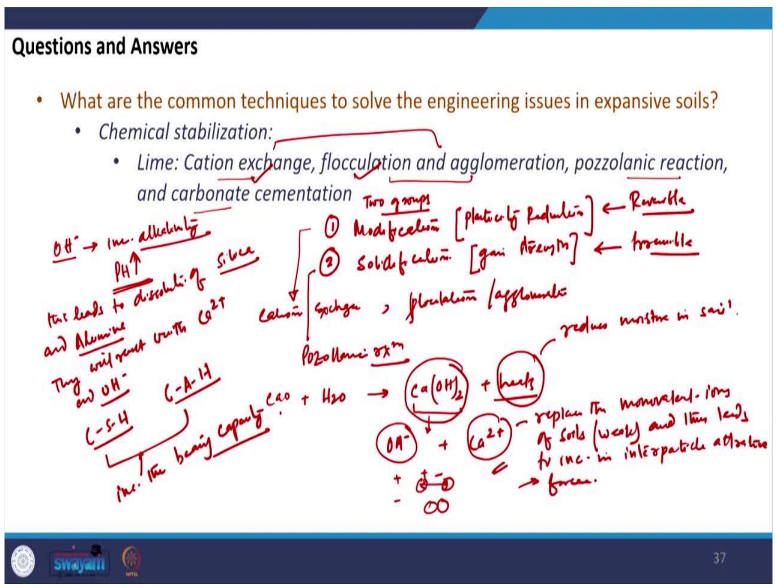

There are more techniques which falls under chemical stabilization. In fact, if we compare all the techniques, chemical stabilization is the most popular technique which is commonly used to deal with expensive soil. Under the chemical stabilization, we have various methods that are available, which means we have various chemicals that are available to stabilize the soil, the most popular being the use of lime.

The lime when it comes in contact with the soil, there is a particular mechanism which itself is complicated chemically to explain, because it is process is very much involved, but it can be viewed as in parts for example, when lime comes in contact with expensive soil the steps of stabilization includes Cation exchange, flocculation and agglomeration, pozzolanic reaction and then carbonate cementation.

I will try to give a brief idea about these mechanisms. So, these reaction mechanisms which we are talking about can be classified into 2 groups. So, first we have modification process, this modification process which is the first step it helps in plasticity reduction. So, this modification process is more of reversible in nature then we have the second part which is solidification which is an irreversible phenomenon and this helps in to gain strength and this is irreversible.

The modification process it includes cation exchange and flocculation and agglomeration. So, the first 2-part falls under the modification process, the solidification it includes pozzolanic reaction which helps in the strength gain of this particular material, let us see what is the process involved.

So, what happens that when we have lime and we just add water to it this leads to the formation of calcium hydroxide and it also emits some heat. So, this is an exothermic reaction this particular heat which gets emitted during this process this reduces the moisture content in soil.

Now, further when the lime is dissolving in water which means more $CaOH_2$ is formed $CaOH_2$ is to further breaks into OH^- ion and Ca_2^+ion. So, what does the Ca_2^+ ion do it replaces the monovalent ions of soil which are more of weak in nature you can say and thus it leads to increase in interparticle attractive forces. So, this is what we call is cation exchange. So, this is the first phase where the intramolecular forces increase.

Now, this increase in intramolecular forces what it will do it will reduce the thickness of the diffused double layer and it will also facilitate flocculation. So, how it facilitate flocculation what will happen in the clay particle that you have positive part and you have negative part let us say you have two soil particles. So, instead of getting attracted to water molecule, the new positive part will get attracted to the surface of the soil particles and they will try to come close to each other and this will facilitate flocculation in the soil and reduction in the double diffuse layer.

And this process entire process where there is cation exchange and flocculation and agglomeration this reduces the plasticity and this also reduces the swelling characteristic. Now, in the second phase that is solidification, how it happens or how it starts that you see we had this OH^- ions.

So, this OH^-, it will increase the alkalinity of the system and therefore, the PH of the system will increase. So, once the PH or the alkalinity increases, this leads to this environment basically this alkaline environment it leads to dissolution of the silica and alumina. And now, silica and alumina are present in the clay minerals.

So, the silica and alumina they will get disassociated in this particular environment and this will further react with the since they are now independent they will react with the Ca_2^+ and OH^- ions that are being formed by the breaking of $CaOH_2$ to form CSH if it is silica calcium silicate hydrate or it can also form calcium aluminate hydrate, if alumina reacts with the Ca_2^+ and OH^- ions and this phenomena or formation of such cementitious products, it increases the bearing capacity.

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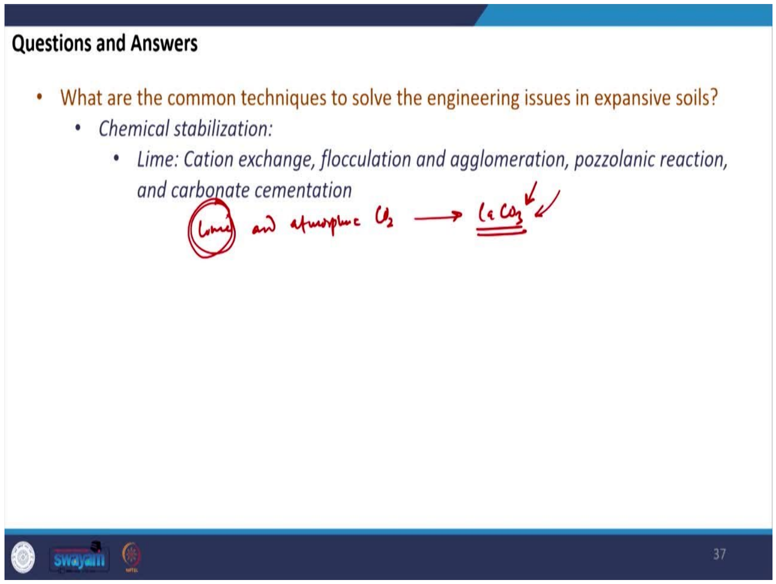

Now, further another reaction I am removing this assuming that this is clear. Now, further so, these are the 2 steps which has taken place further another reaction take place between lime and atmospheric CO_2. So, lime and atmospheric CO_2 they react with each other to form calcium carbonate, which is again a cementing product, but it is weak in nature in comparison to the calcium silicate hydrate and calcium aluminate hydrate that have been formed. And one more demerit of this carbonation process is that this consumes lime. So, since lime is being consumed the formation of more desirable cementitious product like CSH and CAH it reduces therefore, this is not very, very favorable in terms of strength gain.

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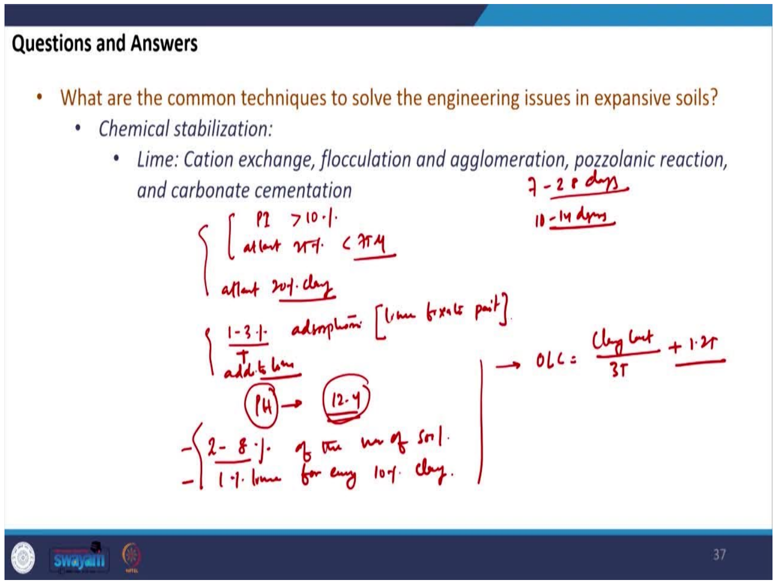

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Well, we have discussed about the mechanism and lime is usually considered as one of the efficient technique to deal with expensive soil, but, there are some points which we have to remember while we are talking about lime for example, lime is more suitable for soils whose plasticity index value is greater than 10 percent or which has at least 25 percent material smaller than 75 micron in size.

In other words, if you have soil that has at least 20 percent clay, they can be well treated with lime if you talk about the dosage off lime then the 1 to 3 percent is typically required for adsorption that is the first part. Adsorption during the cation exchange process and this amount is required for complete adsorption of Ca2 plus to take place this is called as lime fixation point.

Then, we also need additional lime for further pozzolanic activity. So, we need additional lime, sometimes the optimum lime content is considered as that lime content using which the PH of the soil can be increased to 12.4 at least. So, you will find the lime content at which we get the PH of 12.4 for the soil and that will be termed as the optimum lime content we can also use mechanical strength parameters to assess the optimum lime content and usually it ranges depending on the type of soil from 2 to 8 percent of the mass of soil. Some recommendations to or thumb rules in this direction are that use 1 percent lime for every 10 percent clay which is present in the soil.

And a formula also is exist to determine the optimum lime content again an empirical formula that if the $\frac{\text{clay content}}{35}$ + 1.25 to get the optimum lime content. Other points related to the construction of soils using lime is that lime takes longer period to cure longer period to complete all the activities the curing period depending on this type of soil can range somewhere between 7 to 28 days and even longer. On an average it is recommended that 10 to 14 days of curing period should be used while we are using lime as the stabilizing agent. Another problem with lime is when we are dealing with soils which has high amount of sulphate.

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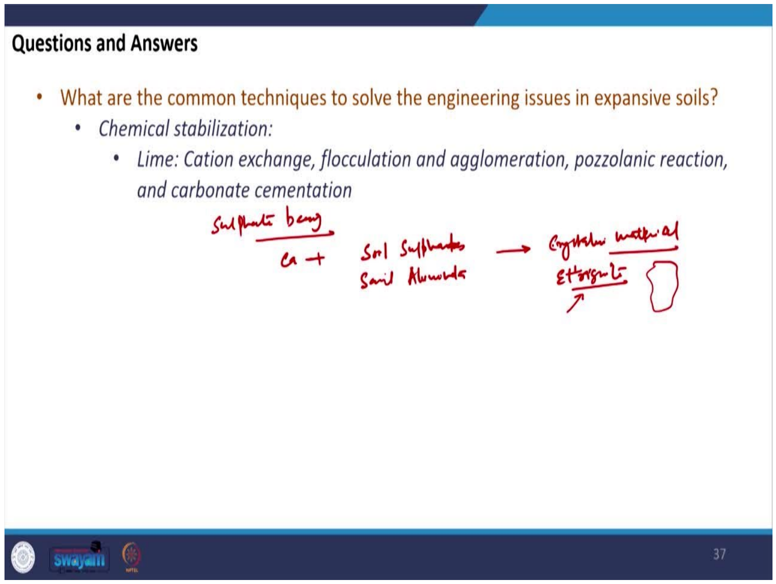

So, if we have sulphate bearing soils then what happens in such type of soil that the calcium from the stabilizer which is coming in that is from lime which is coming in, it reacts with soil sulphate. So, the calcium reacts with soil sulphates and soil Aluminates to form some crystalline material which is called as Ettringite.

So, the formation of this crystalline product it will increase the volume of the soil and what is Ettringite? This is nothing but hydrous calcium aluminum sulphate material and this is not very desirable. So, therefore, probably other techniques have to be used or some procedure has to be developed to deal with soils having high sulphate content.

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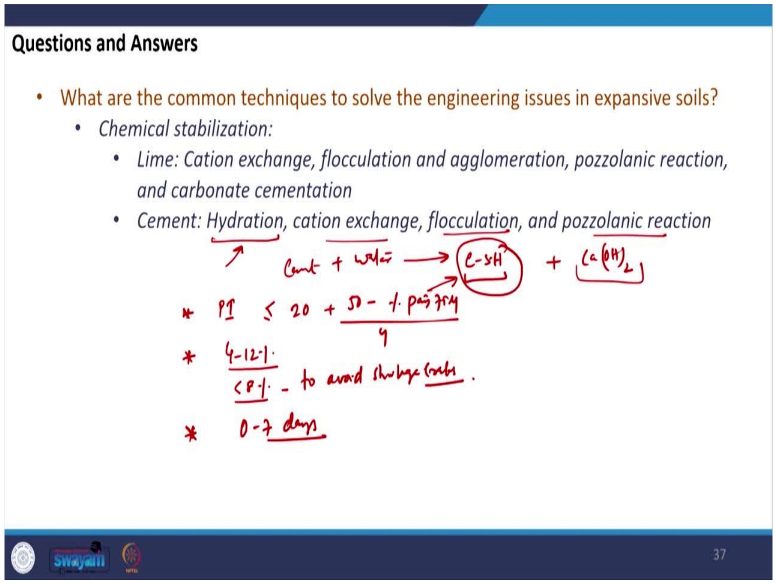

The other technique in this direction for stabilization is the use of cement the process of stabilization, the mechanism of stabilization is very similar to what we have discussed about lime. So, I am not going to write those equations, just a one point that in the beginning when the cement is actually added with water, first the hydration will happen.

So, I hope that we understand that when cement is added with water, we have various hydration products like tricalcium silicate, dye calcium silicate, tricalcium illuminate and so on. And in addition to that we have so, we have CSH products you can see and then we also have formation of calcium hydroxide.

This initial CSH products which are developed and remember this is not in relation to the soil particle this is cement reacting with water. So, the CSH gel will impart strength to the mass and further more reaction will take place depending on the further dissolution of calcium hydroxide which will lead to cation exchange, flocculation and then further pozzolanic reaction which is very similar to what we have talked about lime. Talking about some of the key features when we are looking at cement stabilization then it is recommended that cement stabilization should be used in soils whose plasticity index is less than this $20 + \frac{50 - \% \text{ passing 75 micron}}{4}$.

Again, the coming to the content of lime it depends on the method we are targeting what is the final objective it can typically range between 4 to 12 percent if you look at the strength, but it is also said that the cement content should be kept less than 8 percent to avoid shrinkage cracks, talking about the curing period in cement stabilization the strength gain is much fast in comparison to the lime. So, the curing process the number of days for which curing is required is usually less than what we require in case of lime stabilization. Typically, 0 to 7 days has been recommended again depending on the type of soil and the laboratory investigation which we do.

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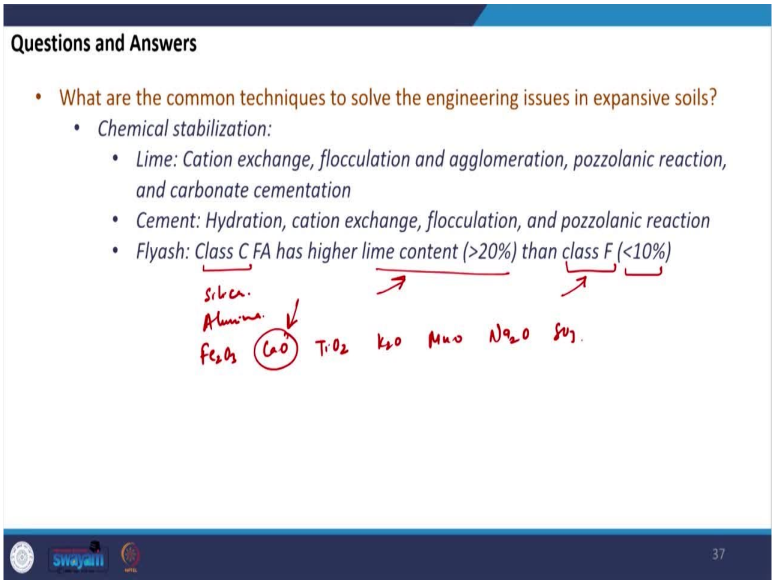

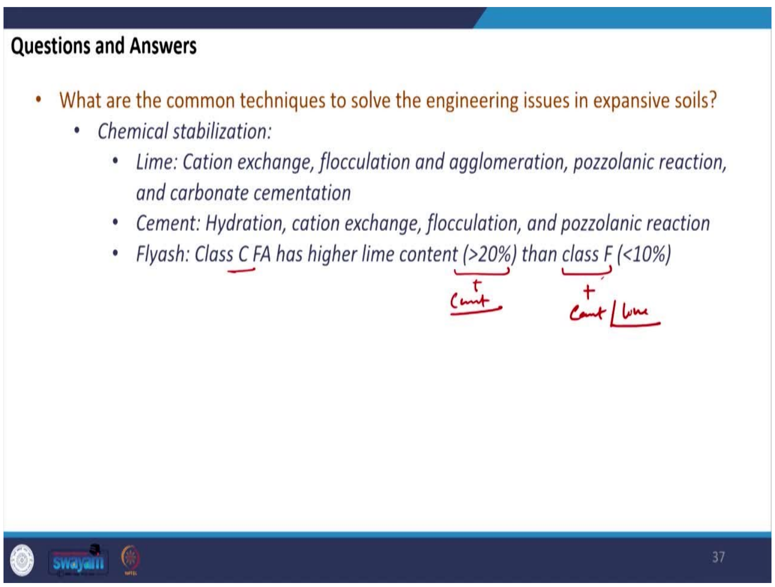

Then we also have flyash, what is flyash? They are coal compounds you can say which are primarily composed of silica we have silica, we have alumina, we also have other oxides like iron oxide, we have calcium oxide, titanium dioxide, we have K_2O, MNO, Na_2O, SO_3 and so, on. Depending on the characteristic of the flyash, usually Flyash is considered as a Class C flyash or Class F flyash.

In class C flyash the amount of lime content is high usually more than 20 percent whereas, in Class F flyash the amount of lime content is less than 10 percent which means that class C flyash itself can produce pozzolanic product when it comes in contact with expensive soils already using the same mechanisms which we have discussed because there is a presence of calcium oxide.

So, we know what happens with calcium oxide further when it comes in contact with water, but Class F flyash it cannot develop pozzolanic products on its own, it is usually added in combination with cement and lime. So, in fact, if you see Class C flyash also though the amount of lime content is greater than 20 percent, but in case of excessive highly expensive clay which are very sensitive to the presence of lime content. We also may need to add cementitious product to accelerate the reactions or accelerate the process of formation of pozzolanic products, to deal with the expensive soil.

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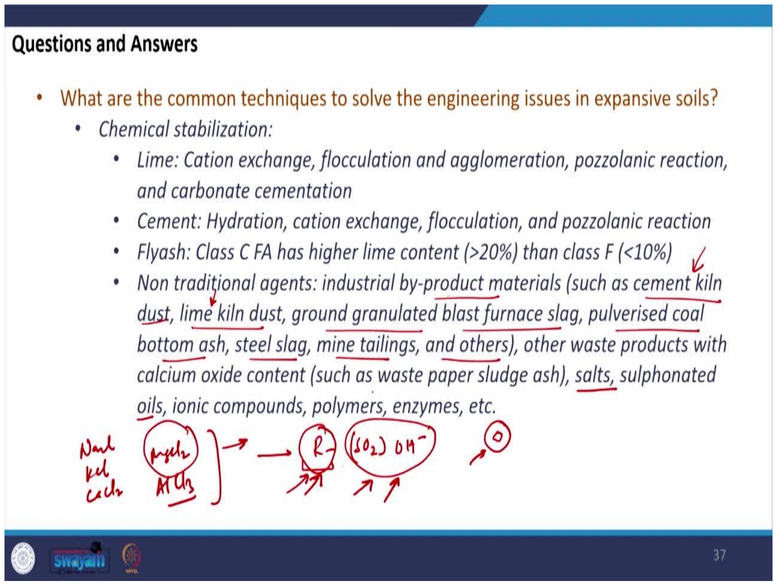

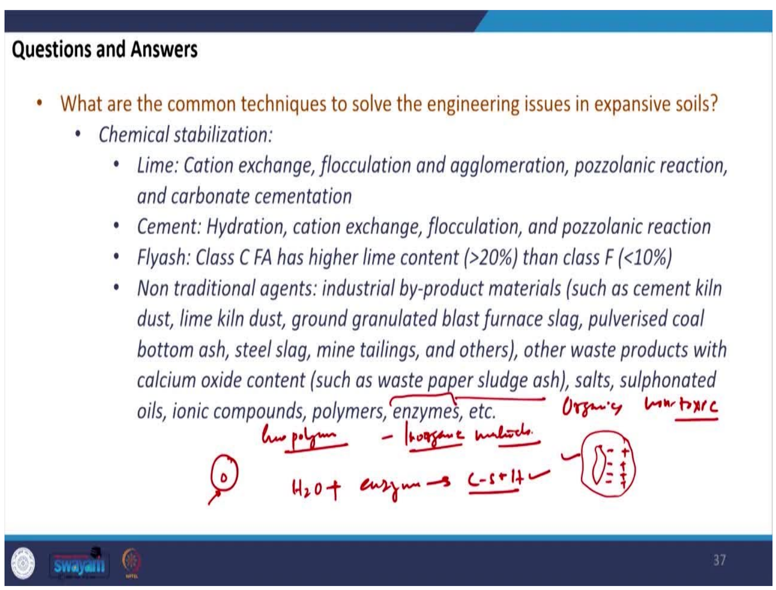

Then in addition to these conventional products, we also have other nontraditional agents. It includes industrial byproducts. For example, cement kiln dust now the process remains same, because you will have ingredients of cement, lime kiln dust again the process remains same. Then we have ground granulated blast furnace slag GGBFS which is again a form of pozzolanic material, we have pulverized coal bottom ash, we can use steel slag, we can use mine tailing and there are various industrial byproducts that can be used either individually or in combination with other cementitious products to deal with expensive soil.

There are various other products in this direction, which are not very conventional for example, use of salt we can use various types of salt like sodium chloride, we can use potassium chloride, we can use calcium chloride, magnesium chloride $AlCl_3$ and so on.

Now, these types of salt they basically help in the stabilization by the process of cation exchange where they will replace the week cation ions that are present in the clay minerals with much stronger cation which comes out through this particular salt, then we can also use sulfonated Oil, sulfonated oils has a generic formula which is $R\text{-}(SO_2)\ OH^-$ this is a 2 part molecule where we you have this nonpolar part and you have this polar part. The sulphonic oil it is basically formed by treating the fatty acid with sulfuric acid and this polar head what it does, it gets adsorbed on the surface through cation exchange, so in the soil surface it will get absorbed.

So, once it gets absorbed it reduces the water absorbing capacity of this particular particle and thus it makes the soil hydrophobic and facilitates stabilization and R it is a form of oil it functions as a lubricating agent and it helps in the compaction process. These are the function of the tail and the head in the sulphonic oil.

Then we have some polymers, polymers again can be of various types for example, these day's people are focusing on use of geo polymers. So, geo polymers are basically inorganic materials and they consist of a network of aluminon silicates and what they do? They create artificial bonds within the soil water metrics and it improves the load bearing capacity.

We also have enzymes here. So, these are basically organic nontoxic materials and they are also biodegradable. So, by adding the enzymes the negative charge on the surface of the clay it gets neutralized. So, we know that the clay particle has negative charges on the surface this get neutralized by the enzyme cations and therefore, since it gets neutralized it will not attract water and it becomes hydrophobic in nature. So, it reduces the affinity of the clay to attract water. Further the presence of enzyme when it comes in contact with water, it also forms CSH gel.

So, it reduces the affinity it form CSH gel it also further coat the soil particles and it prevents further adsorption of the water on the surface of the soil. And in this way, it facilitates the stabilization of the expensive soil and there are various products that are available in the market which can be used or which has been already researched to deal with expensive soils. So, with this we end here today in this particular lecture, we have very briefly discussed about the basic characteristics of the expensive soil, we have tried to answer some of the common questions which comes in the mind when we think or when we are dealing with expensive soils.

We have also briefly talked about the various available techniques of stabilization, though we have not done an extensive discussion here, because this again is a vast subject to be discussed. And I will recommend that you can look into the several review papers that are available which again talks about the details of these stabilization technique and several other additional stabilization techniques that are available in the literature. Thank you and in the next module, we will start discussing about the properties of mineral aggregates.