Expansive Soil
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Lecture 23
Chemical methods - 1

Hello everyone. Welcome back to the course Expansive Soil. Further continuation of the chapter The Treatment of Expansive Soil, today we will be learning about the different chemical methods which we can undertake in the field for improving the soil behavior. This will be the 21st lecture in the module 7.

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As I told you previously also the main objective of any treatment of an expansive soil - To increase the shearing strength of the soil, to reduce the compressibility, to control the swelling and shrinkage behavior and to control the permeability and reduce the pore water pressure. So, these are the four main objective of any treatment method related to an expansive soil. So, all the methods which we have to implement in the field should fulfill all these criteria.

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There are various method of modification of expansive soil - The mechanical methods, hydraulic methods, chemical methods and by inclusion or confinement. In the previous classes we learned about mechanical methods, hydraulic methods and in the today's class we will be learning about the various chemical methods which will be required in the field for the modification of an expansive soil.

Under the chemical methods different methods are there like lime stabilization technique, grouting, cement stabilization, flyash stabilization and bitumen stabilization. We will be learning about all these methods one by one.

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As the name suggests in a chemical method the soil density is increased by adding different amount of chemicals or admixture to the soils. In this method the soil is allowed to mix with different type of chemicals and thereby, those chemicals forms the cementation bond with the soil particles and as a result the particles will be bonded together and thereby, the density, the

shear strength of the soil will gets increased and also their compressibility behavior also gets decreased.

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The different benefits of using the chemicals for the soil improvement are its dry up this wet soil quickly, its improved the strength of the soil like a solidification for the waste disposal methods. It provides a volume stability that means to reduce the swelling and controlling the shrinkage behavior. It reduces the soil deformation that means reducing its compressibility behavior. It reduces the soil erosion by increasing the surface strength of the soil.

It improves the durability to dynamic repeated loads, it controls the permeability, it reduces the traffic generated dust which are generally produced when we use the other methods.

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As a consequence of all these chemical techniques the soil improvements have been responsible for improved working platform and workability of the soils. It reduced the thickness of roadways layers. It provides the slope stabilization. It provides a foundation or structural support. It provides excavation support. It gives the liquefaction mitigation.

It reduces the leakage or seepage from hydraulic retention or conveyance structure. It stabilizes the marine sediments and also it can be used for the environmental remediation technique, mostly contamination remediation technique. So, the soil improvement using the chemical methods can have all this implementation.

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Now there are several type of chemical methods are available, So, we need to decide which method we need to select, So, those selection depends on the soil type, then the purpose of the use, then the engineering properties which we need, the minimum requirement or specification for engineering properties, the availability of the material, the cost and the environmental concern. So, these are the different points which we need to take care of or which we need to consider while selecting a method of improvement of soil stabilization.

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In a chemical stabilization technique these are the different steps which we generally undertake. In the first step the soil will be excavated and break off into small particles. Then

different type of admixtures such as lime, cement, bitumen or fly ash will be added and it will be added with the soil along with water if required. Then once the admixture is added to the soil the soil will be compacted to a desired density.

Once the compaction is achieved then soil will be allowed to cure. In some process the curing may not be required but in some process like cement stabilization or lime stabilization the curing is very much essential. So, generally, these are all the different steps which are required to undergo in a chemical stimulation technique.

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First of all I will start with the lime stabilization technique. In lime stabilization technique lime is used to increase the strength of the soil. Generally, when we use lime either it will be in the form of quick lime or calcium oxide or it is a hydrated lime in the form of calcium hydroxide. When the quick lime or calcium oxide react with water it will form calcium hydroxide or hydrated lime along with the heat.

This heat will remove the water from the soil, thereby binding the particles together and we gain some strength because of this. And quick lime is more effective in comparison to the slaked lime or hydrated lime and quick lime is used for soil stabilization in the field.

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The addition of the lime affects the shear strength, the compressibility and the permeability of the soft clay. When we add lime to the soil the different reactions takes place in a soil. After adding the lime to the soil the following reaction takes place, one is a cation exchange, the flocculation and cementation. Few of the reaction like cation exchange and flocculation will takes place immediately.

Whereas, cementation is a time dependent process and also it is a temperature dependent process and it goes on for a long duration and it imparts a large amount of strength to the soil. So, in comparison to all these three different procedures, cementation impacts a large amount of strength to the soil.

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Under the cation exchange we know that the soil has different type of cations that is we know the exchangeable cations. When we take a soil there are the negative charges on the surface

and there will be the exchangeable cations. During the cation exchange process the calcium ion removes the exchangeable cations and thereby, it goes into the soil surface or it will stick to the soil surface, thereby the diffuse double layer of the soil will get reduced and particles will get flocculated together.

As the diffuse stable layer will get reduced the repulsion between the particles will decrease, the particles will come closer and there will be a flocculation of the particles. And this cation replacement takes place in their order of the replacing power that is lithium is less than sodium will be less than hydrogen will be less than potassium and so, on.

So, we can see the calcium can remove a large types of cations and thereby it can reduce the diffuse double layer thickness and thereby it will flocculate the soil particles. Since the cation exchange is highly dependent on pH, this process also gets affected due to the pH and as we know that Montmorillonite has a large amount of cations or negative charge on their surface, so, therefore soil containing Montmorillonite will be mostly used for the lime stabilization or most effectively can be used for lime stabilization in comparison to the other type of soil.

And also the lime stabilization technique is most suitable for clayey soil and it is not suitable for sandy soil or gravel kind of soil. So, due to the cation exchange the cations or the calcium ion removes the different type of exchangeable cations present in the soil and thereby, it starts to flocculate the soil particles.

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When we add lime to the soil the different properties of the soil gets changed because of the formation of two compound that is CSH which is known as calcium silicate hydrate and calcium aluminate hydrate. These two are produced when calcium react with silica and when calcium react with alumina. So, when the calcium react with silica the calcium silicate hydrate will be produced and when this calcium react with alumina it produce calcium aluminate hydrate or CAH.

And due to the production of this calcium silicate hydrate and calcium aluminate hydrate it produce some Pozzolanic reaction, thereby it gives the cementation properties to the soil. And this reaction is much slower reaction than the hydration process of cement and hence sometimes the cement is added to increase the rate of reaction.

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When we add lime to the soil that there are two type of reaction takes place, one is a short term reaction and another one is a long term reaction. The initial strength gain of the soil takes place in the short term reaction, whereas the long term reaction gives the strength gain in a long term. Say, for example, in the short term reaction there is a hydration process and the flocculation process.

So, this two process gives rise to the short term reaction and short term strength gain of the soil. During the long term reaction there will be the cementation reaction and the carbonation reactions and these two reactions give the long term strength gain to the soil lime.

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In the hydration process when we add lime to the soil the lime will react with the water present in the soil. We know that water has, we know that the soil has water in it in the form of either diffuse double layer water or free water. So, when we add the quick lime to the soil the, quick lime will react with the water present in the soil and that will produce calcium hydroxide and it will emit some heat.

Due to this heat the water in the soil will get evaporated or the soil will get dried up, because of this process of drying off the soil will gain some of the strength and due to this removal of the water from the soil, the soil will starts to consolidate or some amount of consolidation takes place because of the removal of this water.

Therefore, in the hydration process the water present in the soil will react with the quick lime and that will forms calcium hydroxide along with the heat and this heat will remove some of the water. As the water gets removed from the soil the soil will flocculate and starts to gain some strength. And also as the water gets removed from the soil there will be some consolidation process takes place.

Next to the hydration process there will be the flocculation process. Hydration process takes place quickly or immediately after adding the lime to the soil. In the flocculation process the calcium ion will react with the clay surface and as a result of which the clay will get flocculated. We know that clay has some negative charge on its surface and some exchangeable cations.

So, those exchangeable cations can be replaced by the calcium ion which are present in the lime and this calcium ion will then react with the exchangeable cations and remove them and

as a result of that the diffuse double layer thickness will decrease. Similarly, due to this positive charge of this calcium ion those calcium ions will stick to the clay surface and the diffuse double layer thickness will reduce and as a result the repulsion between the particle will reduce and that will reduce the plasticity behavior of the soil.

As the plasticity behavior of the soil will get reduced the soil will become more workable and there will be some increase in the strength of the soil. So, this happens because of the flocculation which takes place inside the soil lime matrix. So, these are the two short term reactions which takes place immediately after adding lime to the soil.

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Then the long term reactions also takes place in the soil matrix. In long-term reaction cementation is the most important reaction which gives more amount of strength to the soil. We know that the soil has silica in it, silica and alumina in it. So, in this process the calcium ion will react with silica or alumina and it will produce the insoluble calcium silica hydrates and calcium alumina hydrates.

So, this calcium silica hydrates and calcium and aluminum hydrates impart the cementation properties to the soil and because of this cementation properties the strength of the soil will increase. And here we need to remember one thing, this cementation or this CSH and CAH will be produced as long as the silica is present in a clay.

Once the silica is used off, then a further addition of this lime will not produce any increase in the strength. Therefore, the cementation reaction will take place until and unless all the silica are used up by the calcium. During the cementation process the soil gain a large amount of strength and this is the primary reason of the strength gain of a soil treated with lime.

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Some amount of strength gain also occurred due to the process of carbonation. In the process of carbonation the lime will react with the carbon dioxide which is present in the atmosphere or present in the void of the soils. As the carbonation reaction takes place, it will develop some of the cementing agent and it will impart some of the strength to the soil.

However, the strength which gained from this process will be quite less in comparison to the cementation reaction. So, out of all these four processes cementation generally generate more amount of strength in comparison to the carbonation and or hydration and flocculation. As the strength increase, it takes place because of the cation exchange or amount of silica present in the soil, so, this lime stabilization technique is only limited to clay type of soil.

Because of the presence of negatively charged particles as well as different type of exchangeable cadence, generally soil of clayey type is more active in comparison to the other kind of soil and soil of clayey type will be or can be treated more effectively in comparison to the sandy soil.

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There are different factors which can controls the characteristics of lime treated clay. Say, for example, type of lime, whether it is a quick lime or hydrated line. Generally quick lime is more preferred in comparison to the hydrated lime because it gives more amount of strength to the soil. However, the usability of quick lime is bit difficult and we have to be careful while using the quick lime in comparison to the hydrated line.

Next is the lime content, the amount of lime content which increases the strength of the soil is also limited. When we add lime to the soil initially the strength of the soil will keep on increasing, but after reaching a certain point a further addition of the lime will not increase the strength of the soil. So, therefore, the lime content should be kept in the mind while adding the lime to the soil.

Next is the curing time. Curing time, it is the time which we should give to the soil after adding the lime for the curing. With increase in the curing time the strength of the soil will increase. Next comes the type of soil, as I told you earlier the lime stabilization is generally preferred for clayey type of soil in comparison to the sandy or gravel kind of soil.

Soil containing some clay amount like silty clay or clay or gravelly clay are used for the lime stabilization technique in comparison to the sandy soil.

The next comes the clay minerals. As the cation exchange process or specific surface area of the soil controls the soil-lime reaction, generally clay with higher amount of cation exchange capacity or higher amount of specific surface area is more effectively can be treated using lime in comparison to the other minerals.

Next is the soil pH. The cation exchange process which is generally takes place in lime soil reaction is a pH dependent. As we studied earlier the pH can affect the cation exchange of the soil, therefore, when we change the pH of the soil that also controls the soil-lime reaction. Next is the curing temperature. The curing temperature also controls the behavior of the soil. If we cure a soil, say for example, at freezing temperature below 4 ^{0}C, then the strength gain of the soil will not be that much, because the Pozzolanic reaction may not take place at that temperature, therefore by increasing the temperature of curing we can gain more amount of strength in comparison to curing the soil at a low temperature.

We need to add certain amount of additives to the soil to imparts the initial strength. As we have seen that there are two different type of reaction, one is a quick reaction and another is a long term reaction. During the quick reaction we generally get a less amount of strength gain by adding lime. So, by adding different type of additives such as cement, fly ash, we can impart the initial strength to the soil. These are the different factors which can controls the characteristics of lime treated clay.

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The evolution of the soil reactivity depends on type of soil. Generally, the lime is not suitable for all type of soil. Lime is primarily used for treatment of clayey soil. A soil where the lime treatment leads to the cementation is termed as the reactive soil or the soil for which we can gain some shear strength or we can gain some increase in the strength due to the cementation process will be called as the reactive soil.

This reactive soil will react with the lime and gives the increase in the strength of the soil. The most reactive mineral which can be used for the lime treatment is montmorillonite. And the minerals such as kaolinite and illite are less reactive in comparison to the montmorillonite mineral.

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When we start to adding lime to the soil the strength gain of the soil will starts to take place or the soil will starts to increase its strength. Initially when we keep on increasing the lime to the soil the liquid limit of the soil will keep on decreasing and the plastic limit of the soil will keep on increasing.

So, as the liquid limit of the soil keeps on decreasing and the plastic limit is keep on increasing, the plasticity index of the soil will keep on decreasing. So, when we add lime to the soil with the increase in the lime content the plastic limit of the soil will keep on increasing, but beyond a certain amount of lime content the plastic limit of the soil will not increase further.

So, that amount of lime content is known as lime fixation point. So, lime fixation point is defined as the maximum amount of lime, which is required to increase the plastic limit of the soil. Beyond this lime fixation point a further addition of the lime will not increase the plastic limit of the soil or it will not decrease the plasticity index of the soil.

And generally, this is varies between 2 to 8 %. However, when we keep on adding the lime to the soil the strength of the soil will keep on increasing, because there will also be some other kind of reactions which will be taking place which will give the Pozzolanic reaction to the soil. And thereby, the strength of the soil will keep on increasing.

And after reaching a certain level beyond this lime fixation point, the strength of the soil will not increase. So, that point is known as the optimum lime content. So, therefore the optimum lime content is defined as the amount of lime required for satisfying the immediate soil lime reaction and still provides the sufficient amount of free calcium and residual pH necessary to initiate the long term Pozzolanic reaction.

So, basically, if I define, the line fixation point is defined as the point or the maximum amount of lime content up to which the increase in the plasticity, plastic limit of the soil take place or the decrease in the plasticity index takes place and beyond that point a further addition of the lime will not change the plastic limit or plasticity index.

So, that is known as lime fixation point, whereas, the optimum lime content can be defined as the maximum amount of lime, which we can add to the soil to increase the strength of the soil and beyond that there will be no further increase in the strength of the soil will take place. So, this is known as optimum lime content.

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Next is how to mix lime with the soil. These are the different steps to apply lime to the soil. In the first stage or first, in the execution stage we need to prepare the soil. In this step the

soil will be excavated and it will be pulverized. The soil will be excavated and the larger particles will be crushed to make smaller particles.

And this can be carried out using a ripper or a harrow or a plough. This will also help in modify the humidity of the soil. Once the preparation of the soil has been performed, then the next step will be the spreading of the lime. In the spreading of the lime process, the lime will be spread uniformly over the soil surface which has been prepared in the previous step.

So, this can be achieved using a spreader which will be directly connected with a silo vehicle or a using a buffer silo. So, in this process we could see that lime has been sprayed on the soil surface. So, in this process the powder form of lime or lime in the form of slurry can be used. When we use the powder form of lime then in that case we need to add some water. Once the lime has been spread to the soil then it will be mixed in the next step.

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During the mixing stage the lime will be mixed with the soil and in this step the soil will be spread out and at the same time the lime will be mixed with the soil and we have to ensure that the lime has been mixed thoroughly with the soils for a proper utilization of the soil-lime mixture. So, this work will be done with a pulvimixer or a rotary pedal mixture.

Once the lime has been mixed with the soil the next step will be the compaction. In the compaction when the grading, the layer thickness that can be compacted by rolling should be taken into account and after the grading the treated soil has to be compacted using a compacting machine and in generally warm weather we have to have some gap between, we have to have some curing time before the compaction should be carried out.

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So, if we summarize, in the first step the excavation and breaking of the soil will be carried out. Once the soil has been broken into small particles, then the lime will be added either in a powder form or in a slurry form. If we are using the lime in a powder form then we have to use some amount of water.

Once we add the lime to the soil, then the soil will be mixed and we will allow the lime-soil reaction to take place. And once the lime-soil reaction is completed, then the remaining amount of lime will be added and it will be mixed with the soil. Then the spreading of the soil to require grade and compacting the soil will be carried out.

Once the lime is added with the soil, then using a roller the soil will be compacted. Once the soil is compacted then it will be allowed to cure for generally 1 to 7 days. So, these are the different steps which we generally performed in the field for a lime stabilization process.

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There are different engineering benefits of lime, first is workability. The workability of the soil will increase with the increase in the lime content. Particularly if the soil has more water content then it will be very difficult to work. So, by adding lime it will increase the workability of the soil. The compaction characteristics of the soil will also changes. The maximum dry density of the soil will decrease and the optimum moisture content of the soil will increase due to addition of the lime.

By adding the lime the volume stability of the soil can also be achieved. That means, the swelling-shrinkage characteristics of the soil will decrease due to the addition of the lime. The shear strength of the soil will increase due to the addition of the lime. So, these are the different engineering benefits of the lime which we can get.

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In this picture we can see, as we increase the lime content the Atterberg limits of the soil will change. Say, for example, the liquid limit. The liquid limit of the soil will decrease with the addition of the lime content. Similarly, the plasticity index will keep on decreasing with the addition of the lime and the plastic limit will keep on increasing.

So, the liquid limit and plasticity index will decrease, whereas, the plastic limit of the soil will increase. And beyond this lime fixation point there will be no change in the plasticity index or plastic limit or liquid limit of the soil. Similarly, if we see the effect of lime content on shrinkage limit the shrinkage limit of the soil will increase due to addition of the lime.

As we add lime to the soil the soil will flocculate and thereby, a flocculated particles will be formed and which will be containing a large number of voids, therefore water can be held on those voids and therefore, the shrinkage limit of the soil will be increased. As you have seen earlier that with increase in the amount of flocculation the shrinkage limit of the soil increases.

So, therefore in this case also as we add lime to the soil the flocculation behavior of the soil will increase, thereby the shrinkage limit will increase. And if we look into the relationship

between the maximum dry density and lime content, we can see with the addition of the lime the maximum dry density will decrease initially and then it will reach to a certain value.

And there will be a little bit increase in the maximum dry density will take place and that it will remain constant. So, similarly, when we check about optimum moisture content and lime content relationship, initially, there will be an increase in the optimum moisture content and then it will decrease and then it will remain constant. So, therefore, by adding lime to the soil the maximum dry density will decrease and optimum moisture content will increase.

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Generally, the lime stabilization techniques can be carried out for a shallow surface, that means the soil up to say few feets can be treated with the lime. However, if we want to do this lime treatment for a deep soil then we need to go for a lime column. In a lime column technique a column will be created using the limes.

Here we can see these are the different process. The consolation and strength gain of the treated soil take place in this method with any loading. In this process a casing pipe will be inserted over here which will be carrying a side hopper here and here the lime will be injected with a pressure with the compressed air which will forced the lime and as the lime will be injected here a column of lime will be created.

Now this column of lime will be created at different locations and this lime will react with the surrounding soil, thereby, increasing the strength of the surrounding soil.

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So, when we add lime to the adjacent soil the following reactions takes place, which increases the strength of the soil. First one is the dewatering and the consolidation. As we know that when the quick lime reacts with the water present in the soil it will produce the slacked lime and also heat. This heat which is generated is helpful in dewatering of the soil as well as the consolidation of the soil.

So, therefore the dewatering and consolidation of the surrounding soil take place because of the quick lime reacting with the water present in the soil. The next step is the ion exchange. As we know that the negative charge of the clay surface will be carrying different amount of exchangeable cations at the same time the lime will be containing the calcium.

So, this calcium ion present in the lime can be adsorbed on the clay surface as well as the acceptable cations can be removed by this calcium ion. So, this results in a decrease in the diffuse double layer thickness. As the diffuse double layer thickness get reduced the repulsion between the particles get reduced and the particles will be flocculated together.

As the particles get flocculated or there will be a decrease in the diffuse double thickness, there will be increase in the strength of the surrounding soil will take place.

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Then long-term Pozzolanic reaction will take place because the calcium ion will react with the silicon oxide or aluminum present in the soil and that will form the silicate hydrate and calcium aluminate hydrate and this CSH and CAH will cause an increase in the shear strength of the soil. Another process, the carbonation will also take place. In the carbonation process the lime react with carbon dioxide present in the atmosphere as well as in the soil void.

And that will impact a long term strength gain to the soil. Although the change in the gain strength in the, this process will be less in comparison to the Pozzolanic reaction and this will increase the rigidity of the lime layer or column to provide a kind of structural reinforcement. So, these are the different type of reactions which can take place in a lime column on the surrounding soil and thereby it will increase the strength of the surrounding soil.