Expansive Soil
Professor Doctor Anil Kumar Mishra
Department of Civil Engineering
Indian Institute of Technology, Guwahati
Lecture 22
Hydraulic Methods

Hello everyone. Welcome back to the course Expansive Soil. Today's will be the 20th lecture in the module 7 and it will be covering the Hydraulics Method in the Treatment of Expansive Soil. In the last class we learned about the different mechanical method of modification of the soil.

(Refer Slide Time: 0:54)

When we go for any treatment of an expansive soil we have certain objectives, like to increase the shear 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.

(Refer Slide Time: 1:05)

All this can be achieved using these four different methods of modification; that is a mechanical modification, the hydraulic modification, chemical methods and by inclusion and confinement. In the last class in the mechanical methods we learned about the compaction, preloading and the stone column. In today's hydraulic method we will learn about the vertical drains, the vacuum consolidation, the electro kinetic dewatering, all these methods.

Generally, all these methods are applied in the field to have increased the bearing capacity and reduce the settlement of an expansive soil and these are under the hydraulic methods.

(Refer Slide Time: 1:45)

The different advantages of hydraulic modifications are, it provides a dry working area, it stabilize the constructed or the natural slopes, it reduces the lateral earth pressure, reduces the compressibility, increases the bearing capacity, improves the workability, reduce the soil liquefaction in case of there is an earthquake and prevent the soil erosion.

We know that the soil has water in it and due to the presence of the water the soil bearing capacity will get reduced. Similarly, if the soil consisting of a large amount of water its compressibility will also increases; that means it will consolidate to a large volume. Therefore, in order to increase the stability or increase the bearing capacity and reduce the settlement of the soil we need to remove the water from the soil.

The process in which the water is removed from the soil is known as the hydraulic modification. Generally, in the hydraulic modification the ground water table is lowered by removing or by diverting the water from the soil. So, here we will learn about the different methods of hydraulic modification.

(Refer Slide Time: 3:02)

So, going by the definition, hydraulic method is a method of soil modification in which the density of the soil will be increased by accelerating the rate of dissipation of the pore water pressure. And this hydraulic modification of a soil is achieved by lowering the water table or redirecting the seepage or reducing the water content of a soil.

(Refer Slide Time: 3:26)

Depending on the soil particle size, the various method of dewatering or hydraulic modification can be applied. If the soil consisting of very fine particles, in that case we have to go with the electro-osmosis method. If the particle size in between the silt and sand, in that case we need to go with the Wells and Well-Point method using a vacuum or without using a vacuum. Similarly, if the particle size is quite large then we can go with the gravity drainage like subsequence excavation or grout curtain may be required.

So, generally, when the particle size is less we have to go with the electro-osmosis method, if it is little bit larger than that then we have to go with the Well and WellPoint's method, all depends on the hydraulic conductivity of the soil in the field.

(Refer Slide Time: 4:22)

First I will go with the gravity flow and pumping method. In the gravity flow method the groundwater will be lowered using an open sumps or using a pump or gravity flow of water. So, in this method the seepage water is removed by gravity or by pumping. Here we can see, this is the initial water level and a sump has been ditched over here. With this sump the water will collect over here, then this water will be removed using a pump.

So, depending on the hydraulic conductivity and the water level the flow of water to the sump can be the gravity or if the hydraulic conductivity is very less then we have to go with a vacuum pump method. So, this method works well in relatively shallow excavation in dense and well graded coarse soil. Similarly, if we have a clayey soil then the dewatering of an unstable clayey soil can be carried out by the combination of the toe drain which is provided over here and gravel filled with the lateral slot.

So, this is the gravel. So, by this method we can dewatering of an unstable clay or soil by providing drains and also by a lateral slot filled with the gravel. And this open sumps and ditch method is quite economical or quite cheap and very largely used in the field. And also this is why quite simple method in comparison to the other methods.

(Refer Slide Time: 6:01)

This can also be carried out using a Well point method. In this Well point method a large number of wells which are closely spaced single-pipe well of small diameter will be used which is connected with a central pump installation, which is known as the Well point system. So, a Well point system can be defined as a system of closely spaced-single pipe well of small diameter with a common header pipe and a central pump installation.

This Well point will be driven into the ground and then a sand filter is provided all around the well using the coarse sand. Then the water will flow to this well and then it will be removed using the pump. So, water has to flow to this well under the gravity and then drawn to the surface by a vacuum header main. In case of a fine sand or fine soil having a less value of hydraulic conductivity, then the vacuum can be applied to remove the water.

So, here you can see this, is the initial stage of or initial ground water level. When the water was removed using this well, then the water level, the phreatic water surface got reduced over here and then the excavation was carried out. In the second stage again this wells were used to remove the water and again the phreatic surface got reduced because of the removal of the water and the further excavation was carried out. So, in this method the different stage of excavation can be performed by lowering the water table using this Well point method.

So, in the Well point method the water can be removed from the soil using different wells driven into the ground and connecting those with a header pipe and using a pump the water can be removed. So, this is a quite easiest method and mostly used method and also it is quite economical method in comparison to the other methods.

(Refer Slide Time: 8:25)

The next method is the vacuum consolidation method. In this vacuum consolidation method a vacuum is created which increase the rate of flow of water and thereby, the rate of consolidation also increases. So, the vacuum consolation is an effective means of accelerating the improvement of saturated soft soil. It was first proposed by Kjellman in 1952 who developed the vertical wick drains.

And the soil site is covered with an airtight membrane and the vacuum is created underneath it. This is a soft soil, then vertical drains has been driven over here, and all these vertical drains will be connected with a horizontal drain like here and a drainage layer will be provided on it and a fill surface layer will also be provided at the top. Now all this will be covered with an impermeable membrane. So, that airtightness will be maintained over here.

And atmospheric pressure will be acting at the top, then all this will be connected with a trench, which will be filled with bentonite and polyacrylate, then a vacuum will be created here. This is a vacuum phase booster, this is a vacuum pump and once the vacuum is created the water will be forced into the drains. As the water is forced into drains it will be removed using this vertical as well as the horizontal drains and it will be sent for the water treatment station.

As the water moves through this drains the rate of consolidation of the soil will increase, therefore, the soil will get consolidated faster in comparison to the normal method. So, in this vacuum consolidation method a vacuum will be created which will accelerate the movement of the water thereby increasing the effective stress and it will remove the water from the soil and as a result of which, the shear strength of the soil will increase.

(Refer Slide Time: 10:50)

So, these are the different stages which we can see over here. This is a fill layer, this is an impermeable layer and these are the horizontal drains connected to the pump. Here these are the pumps connected to the horizontal drains and those horizontal drains again are connected with the vertical drains.

Here you can see the impermeable layers and the horizontal drain pipe, these are the pumps and once the water has been removed the water will be discharged to this stream over here. And we need to take care of the stream such that the water should not again percolate into the ground. Therefore, again we need to provide an impermeable layer of bentonite polyacrylate, So, that the water will not again percolate into the ground surface.

(Refer Slide Time: 11:45)

By going through this vacuum consolidation generally we increase the effective vertical stress. Here we can see in this diagram, in the in-situ condition when we apply a vertical pressure then there will be the pore water pressure and when we subtract the pore water pressure from the vertical pressure we will get the effective vertical stress over here and with increase in the depth the total vertical pressure will increase.

The pore water pressure will also change and accordingly the effective vertical pressure will also change. Now if we go with a conventional surcharge method without any vacuum consolidation method or vacuum method, then we will increase the vertical pressure by applying the surcharge. So, when we apply the surcharge the vertical pressure will increase, the pore water pressure will remain like this.

So, therefore, as vertical pressure will increase and the pore water will be like the previous in-situ condition the effective stress will increase, as the effective stress will increase that will increase the bearing capacity or strength of the soil. Now if we go with the vacuum induced method, here we do not need to provide a surcharge. So, the vertical pressure will be like what was in the initial stage like this.

But as we apply a vacuum, the pore water pressure will become negative; as the pore water pressure becomes negative the effective stress will increase. As the effective stress is nothing but the total stress minus the pore water pressure. As the pore water pressure is negative here, so, that will increase the effective stress. So, thereby, without inducing any surcharge we can increase the effective vertical pressure by just applying a vacuum.

So, this vacuum induced consolidation or vacuum method generally increases the effective stress because of providing a negative pore water pressure. And this vacuum induced consolidation can provide a surcharge of around in the range of 4.5 meter to 6 meter of equivalent; that means the vacuum will give an equivalent surcharge of 4.5 meter to 6 meter of fill soil.

(Refer Slide Time: 14:22)

This is the time settlement graph shows for different stages of a vacuum induced consolidation; on y-axis we have the settlement, on x-axis we have the time, with the time the soil will undergo consolidation. So, this will happen without a fill. Now we will provide a fill of 0.8 meter over here and here we will provide a PVD; that is prefabricated vertical drain.

As we provide the PVD installed at this point and again if you provide a 0.5 meter of fill, rate of consolidation or rate of settlement will increase or the settlement will increase and this will follow like this. If we provide a vacuum induced consolidation or if I provide a vacuum over here then the settlement will increase significantly here.

So, this graph we will get without providing any vacuum and this will get when we provide a vacuum along with a PVD installed drain and the surcharge. So, therefore, when we provide a vacuum induced consolidation the rate of settlement or the total settlement of the soil will increase and the soil will be stabilized to a large extent in comparison to only the fill or the PVD installations.

(Refer Slide Time: 15:50)

These are the different equipments and the construction process related with the vacuum consolidation process. First of all we need to place a free drainage sand blanket, which will be of thickness 60 to 80 centimeter above the saturated ground to provide a working platform. Then we need to install the vertical drains, which will be around 5 centimeters in equivalent diameter, as well as the relief wells from the sand blanket.

Then we need to provide the horizontal drains, then we need to connect the horizontal drains in longitudinal and transfer direction. Then we need to excavate a trench around the perimeter of the preloaded area, which will be below to the ground water level and it will be filled with impervious bentonite polyacrylate slurry for subsequent sealing, such that the removed water cannot percolate into the ground again.

Then an installation of the impermeable membrane on the ground surface will be carried out and it will be sealed along the peripheral trenches. Then vacuum pumps will be connected with the prefabricated discharge module extending from the trenches. So, these are the different stages by which we can go for a vacuum induced consolidation.

(Refer Slide Time: 17:15)

However, there are some limitation or the problems associated with vacuum induced consolidation. So, the different problems associated with vacuum consolidations are, to maintain an effective drainage system under the membrane that expel water and air throughout the whole duration.

To maintain an effective level of vacuum; to maintain a leak proof system and to anchor and seal the system at periphery. Since, the efficiency of the system mostly depends on the vacuum, therefore, all the system should be a leak proof system. If there is any kind of leakage, then the method will not work properly.

(Refer Slide Time: 18:01)

Next is the electro kinetic dewatering method. Generally, this electro kinetic dewatering method is applicable for a clayey soil. In this method an electrical potential will be applied to a saturated soil mass to cause the pore water flow towards the cathode. If the water is collected at the cathode is removed, that will result in a lowering of the moisture content and corresponding increase in the shear strength.

And this technique is particularly suited to weak clayey soils that requires strengthening and possess a low hydraulic conductivity, thus preventing the economic and introduction of chemical grout using the conventional hydraulics method. So, this method is applicable for clayey soil with a lower value of hydraulic conductivity.

(Refer Slide Time: 19:05)

Here we can see the principle in which this method works. This is a clayey soil with a lower value of hydraulic conductivity. Then we need to insert two electrodes that is anode with a positive terminal and cathode with a negative terminal. Now an electrical potential difference will be applied across the soil mass. We know that the soil has different cations in it, say for example, sodium, calcium, potassium, magnesium.

When we apply an electrical potential, the cations will try to move towards the oppositely charged electrode; that means the cation will move towards the cathode which is a negatively charged and as the cation will move towards the cathode it will also bring some water molecules along with it. So, therefore, the water will get removed as the cations will try to move towards the cathode.

And this water will get accumulated here and then it will be removed from the cathode. As the water gets removed from the cathode soils water content will change, as a result the soil bearing capacity will increase. So, applying an electrical potential to a saturated soil cause hydrated positive ions to move towards the negatively charged electrode that is the cathode and when this ion move it will drag the free water along with them.

This movement will primarily generated in the diffuse double layer where the cations are dominant. Therefore, this method is applicable for a clay soil containing the different amount of cations or exchangeable cations. In the absence of exchangeable cations the method will not work properly. Furthermore, we know that water is a bipolar in nature; that means positive end and the negative end.

And due to this also the positive end of the water molecules will also get attracted towards the cathode and therefore, the water will also move towards the cathode due to its bipolar nature. This technique is particularly suited for a weak clayey soil that requires strengthening and poses a low value of hydraulic conductivity.

As in other methods the hydraulic conductivity is of primary concern because the movement of the water depends on the hydraulic conductivity of the soil. If the hydraulic conductivity of the soil is less, then the removal of the water will be slow and hence, the other methods will not work. But in this method, although the soil has a lower value of hydraulic conductivity the movement of the water molecules towards the cathode can be accelerated by applying a electrical potential. So, therefore, this method is quite economic instead of going for other methods of removal of water for a clayey soil.

(Refer Slide Time: 22:20)

Here we can see the effect of the strength due to the electro kinetic dewatering. On x-axis the ratio between the undrained shear strength to the initial shear strength has been plotted and on y-axis the ratio between the water content and the initial water content has been plotted. In the absence of electro kinetic dewatering method we will get the shear strength like this; that means the amount of increase in the shear strength will be quite less.

However, if we provide an electro kinetic dewatering method we can see a large increase in the shear strength of the soil will occur at the cathode. If we compare with any water content we can see that a large increase in the shear strength is occurring at cathode because of the electro kinetic dewatering. Similarly, at the other point also we can see the undrained shear strength is increasing at the cathode in comparison to a static consolidation method.

Similarly, if we go with the electro kinetic method the compressibility of the soil will be reduced. In this plot the compressibility of a treated soil and untreated soil has been shown. For an untreated soil the compressibility of the soil is quite large. As the water has been removed over here the soil will be compressed to a lower extent in comparison to the untreated soil.

(Refer Slide Time: 23:58)

Similarly, when the electrode are provided along with the pile there will be an increase in the pile capacity. In this plot the penetration resistance has been shown along with the depth. When there is no electro-osmosis this is the penetration resistance along with the depth. Now, when we provided an electric potential to the pile or when the pile act as anode. So, the negative pore water pressure will be developed next to the pile and that will increase the side resistance. As the side resistance increases the load bearing capacity of the pile will increase.

Similarly, when we use a pile as a cathode, then high pore water pressure will be developed adjacent to the pile which will decrease the pile side resistance. At the pile side resistance will decrease it will be easier to drive a pile into the ground. So, therefore, the driving of the pile will be easier. And if we use pile as anode in that case the load bearing capacity will increase as the frictional resistance will increase.

(Refer Slide Time: 25:35)

These are the different advantages and disadvantages of electro kinetic dewatering. The advantages are: It can be applicable to low permeable soil as well as heterogeneous soil. This is a less expensive method of treatment of the soil. And can be applicable for both saturated as well as unsaturated soil. The disadvantages are, if there is any buried metal objects is there then it can cause a short circuit.

The acidic conditions and electrolyte decay can corrode the material using the anode. Similarly, the electrolysis reaction can change the soil pH leading to the complex geochemical process and the process of dewatering becomes more complex or can change. The potential gradient should not exceed 0.5 volts per centimeter in order to prevent the considerable loss of energy due to heating of the ground. So, these are the few of the advantages and disadvantages of this method.

(Refer Slide Time: 26:40)

Then I will explain about the preloading with sand drains. In the previous class I explained you about the application of preloading for the soil modification. In the preloading method a soil surcharge or soil fill was applied. As the load was applied to the soil the pore water pressure got increased and as the pore water pressure got increased, it got dissipated and the shear strength of the soil got increased or that will increase the shear strength.

Now, the process can be further accelerated by using the sand drains. So, in preloading the bearing capacity increases and compressibility of the weak soil decreases by forcing the loose cohesion less soil to densify or clayey soil to consolidate, but when we provide vertical drains then the rate of increase in the shear strength or consolidation can accelerate further.

And we need to understand for a clayey soil if we go for a surcharge load without providing vertical drains then the bearing failure may occur during the placement of the fill, therefore the provision of vertical drains are necessary to prevent the bearing failure of the soil. In this diagram we could see when we do not provide a surcharge load or sand drain, this will be the rate of settlement of the soil.

And this will reach to a final value of settlement at a quite large time that is t3. When we provide with sand drains the rate of settlement will increase here and the time to reach final value of settlement will be less than the previous one, but when we provide sand drains along with surcharge load the rate of settlement will further increase significantly and we will get a time settlement curve in this way and the final settlement can be achieved at a very less time in comparison to the t2 and t3.

Therefore, a preloading with sand drains can increase the rate of consolidation, therefore achieving the final settlement at a less time in comparison to without any surcharge load or sand drains or with only sand drains. Therefore, the preloading and with sand drains can be preferred in comparison to without surcharge load or sand drains or with only sand drains.

(Refer Slide Time: 29:22)

The process takes place like this, when we apply a surcharge load or fill the pore water pressure will be generated and water will try to move towards the drainage layer. So, if we take this as a middle line the water has to move from this point to this point in order to escape or in order to get removed. Now the time to move from this point to this point will be quite large and this time can be reduced by providing this vertical sand drains.

As we provide vertical sand rains the water will move from this point to this point or this point to this point which will be quite less in comparison to this distance or this drainage path. So, by providing a vertical drain or vertical sand drains the drainage path for the water will get reduced and that will increase the rate of consolation. As water will move to the sand drains it will be removed from here. So, vertical drains are installed to accelerate the settlement and gain in shear strength of cohesive soil.

(Refer Slide Time: 30:47)

This is how it takes place. This is a surcharge load, horizontal drains has been provided here. So, when we apply the surcharge load the excess pore water pressure will be generated, this excess pore water pressure will move towards this sand drain and from there it has to be removed. As the water gets removed then the strength of the soil will increase, the compressibility of the soil will decrease.

These are the different stages; the vertical drains will be provided that will shorten the length of the drainage path. As the drainage path length has been shortened that increases the rate of dissipation of pore water pressure, as the rate of dissipation of pore water pressure has increased the rate of consolidation will also increase.

And as the rate of consolidation will increase the consolation will take place faster and the soil will get consolidated quicker in comparison to the other methods. And since, the removal of water constitutes the primary settlement or primary consolidation, the vertical drains accelerate the primary consolidation, however, the secondary consolidation which will be due to the particle to particle interaction will not be changed due to this vertical drains.

(Refer Slide Time: 32:06)

The vertical drains can be installed as a strip drains or prefabricated vertical drains. So, these are the different installation steps. First, the strip drains or PVD will be pushed into the ground along with a mandrel over here, then it will go into the ground here. Then this mandrel will be removed, once this mandrel will be removed strip drains will be cut over here. So, finally we will get a strip drain which will be inserted into the ground.

And here this process has to be repeated at many locations and finally, we can see the different vertical drains or strip drains at different location and all will be connected with a horizontal drain pipe to remove the water.

(Refer Slide Time: 33:03)

The advantages of this sand drains are, this is very easy and rapid installation process and this is made of uniform material that particularly strip drains and PVD and can be easily stored and transported. The equipment needed is lighter in comparison to the rigs required for the equivalent sand drains and low cost. So, therefore, generally PVD in the form of strip drains will be used.

(Refer Slide Time: 33:33)

Now when we provide a strip drain or a vertical drain there will be some smearing effect takes place. This is a sand drain and because of this, water will move from here to the sand drain and then it will be removed. The installation of PVD is achieved by pushing a steel mandrel into the clay layer to the desired depth and this result in a significant disturbance to the clay layer surrounding the drain resulting in a smear zone.

So, in the absence of this vertical installation of the PVD or strip drain, then this should be the movement of the water, but when we provide a strip drain or PVD, then the mandrel has to go into the soil. When the mandrel goes into the soil, the surrounding soil get disturbed. As the soil gets disturbed over here, then a low permeable soil will be generated around this vertical drains, as a result of which the flow of water through this smear zone will get reduced.

Since, the horizontal permeability of this zone will be reduced; the total values of permeability and the rate of consolidation of the soil strata also get reduced. So, this smear zone effect will increase with increase in the drain diameter. As we increase the diameter of this drain the more area or the zone of the smear effect will also increase and that will also reduce the efficiency of this sand drain.

Similarly, the dynamic driving creates more disturbance in comparison to simple static pushing, therefore, more is the dynamic driving more will be the reduction in the rate of consolidation. So, this smear zone not only impact the efficiency of prefabricated vertical drains, it also reduces the rate at which the strength gain can be achieved.

(Refer Slide Time: 35:36)

Now another thing we need to consider is the spacing between the vertical drains. Generally, the vertical drains can be provided in terms of a square pattern or a triangular fashion. If it is provided in a square pattern you can see these are the different sand drains provided in a square pattern and this is the zone of influence. This is their zone of influence. So, this is a sand drains of diameter 2rd, this is the zone of influence which has a diameter of 2R.

So, depending on whether it is a square pattern and triangular pattern, the diameter of the influence will be different. If R is the radius of the influence, then the spacing between the sentence can be related with the RS like;

For a square pattern installation, R = 0.564 S

For a triangular pattern installation, R = 0.525 S

Where, S is the spacing between the two sand drains.

If it says square fashion then S will be equals to R divided by 0.564, if it is a triangular pattern then S will be equals to R divided by 0.525.

(Refer Slide Time: 37:03)

So, these are the different advantages of the vertical drains. First, it increase the rate of gain of shear strength of the clay and it enables the load to be applied more rapidly, thus better use of the construction plan. In case of embankment the steeper slopes and provisional berms can be avoided. Lower amount of soil fill is required, increased rate of consolidation can be achieved; consequent saving in the constructional cost can be achieved.

It can increase the rate of consolidation by which we can reduce the time required for the primary settlement. The structure or embankment can put into commission quite earlier in comparison to without this vertical drains and the reduction in the cost of maintenance can also be achieved.

(Refer Slide Time: 37:54)

These are the different references and bibliography for preparing this lecture. And thank you very much.