Ground Improvement
Prof. G. L. Sivakumar Babu
Department of Civil Engineering
Indian Institute of Science, Bangalore

Module No. # 05
Lecture No. # 14

Electro-Kinetic Stabilization

I would be trying to describe some more aspects of this electro kinetic stabilization. We know that from the clay mineralogy, that the clays are made up of small particles and have large specific surface compared to their mass.

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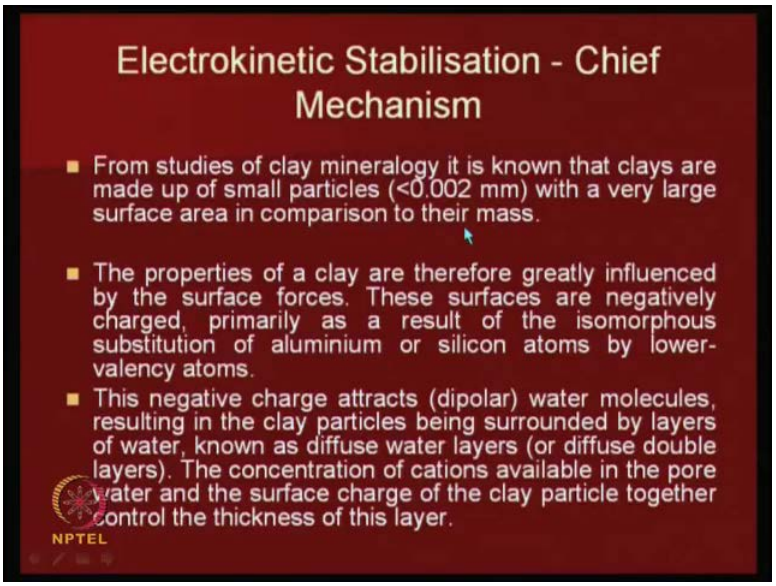

The properties of the clay are greatly influenced by the specific area, we call it. So, surface forces are higher, and these surfaces are negatively charged, primarily as result of the isomorphous substitution. In fact, some of these mechanisms of the soils, mean clay soils, the isomorphous substation is one important mechanism by which there is a change of, say for example, you have a sodium ions but in the there is a calcium ion and sodium ion gets replaced and the calcium ion goes and sits there. So, this is an important concept. And then there is a polarity of this material, where we have this what you call because of this properties we call what is called diffuse double layer formation is there.

The concentration of the cations available in the pore water and the surface charge of the clay particle together control the thickness of the clay layer.

Actually, in Professor Mitchell's book there is an excellent description of the clay soil behavior and how the diffuse double layer theory can explain the various features of the soil behavior, in terms of its the p H. Say for example, the p H of the system can influence the negative charge of the clay particles. How is it? So, you have for example, there are three types of minerals. One is the kaolinite, illite and montmorillonite. In the three cases the surface area are different. How is that, one can calculate the thickness of the diffuse double layer? And also actually assuming that it is all clay platelets are parallel, one can also understand lot of other things there.

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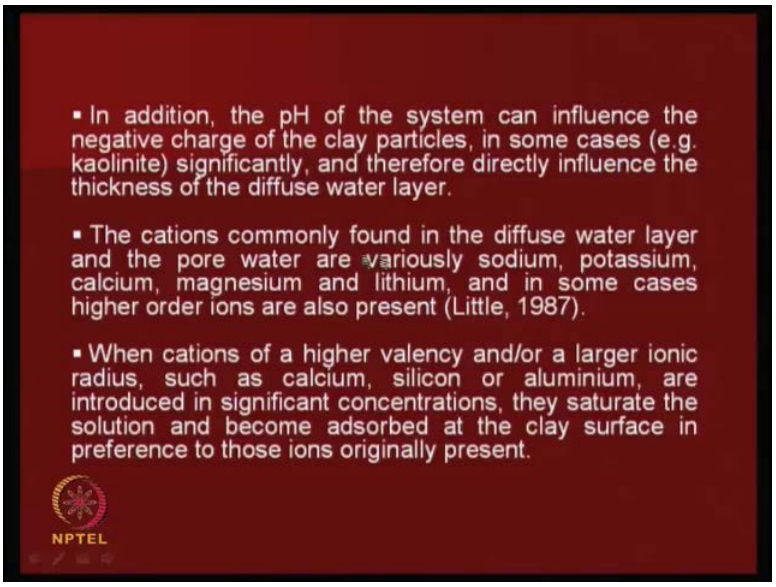

So, the cations commonly found in the diffuse double layer and the pore water are variously sodium, potassium, calcium, magnesium and lithium and in some cases even higher order ions are also present. So, when cation of higher valency are introduced, see that is what, when cations of a high valency or large ionic radius, see there are two things both higher valency as well as larger ionic radius such as calcium, silicon or aluminum are present introduced in significant concentrations, they saturate the solution and become adsorbed at the clay surface in preference to those ions originally present.

So, in fact, they replace the ions and they really dominate the behavior. Say for example, if there is some sodium ions present, then if you saturate the calcium, now the behaviour of the total soil will be towards a calcium based soil. So, for example, in the case of sodium based soil the liquid will be very high, say may be 300 percent or something. But, when it is saturated with calcium it could reduced to about 80 percent. So, this is important.

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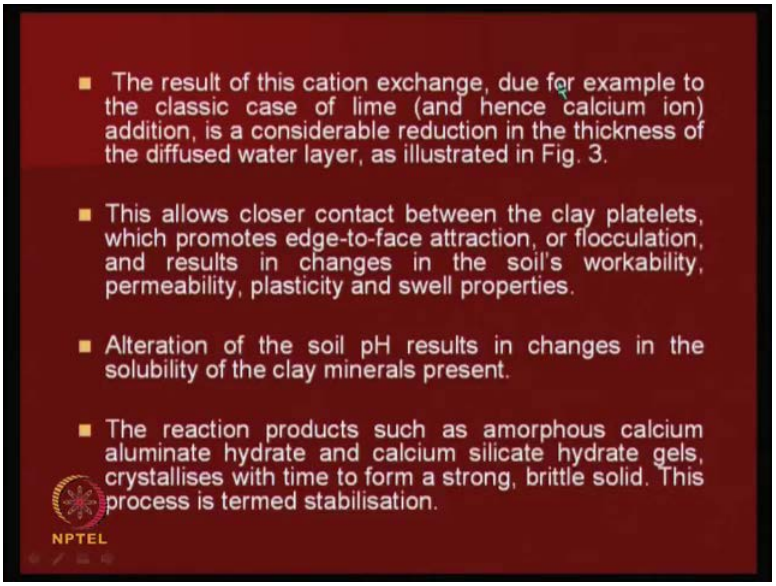

The result of the cation exchange or for the formation of the classic case of lime we know that, say for example, why do you add lime here? But, that is essentially because it reduces the diffused double layer thickness and that is what we know. Not only that, this allows a close contact between the clay platelets, which promote edge to face attraction or flocculation and results in changes in a properties soils workability, permeability, plasticity and swell properties. Alteration of the soil p H results in changes in the solubility of the clay minerals present. The reaction products such as amorphous calcium aluminate hydrate and calcium silicate hydrate gels crystallizes with time to form strong brittle solid. This is process stabilization.

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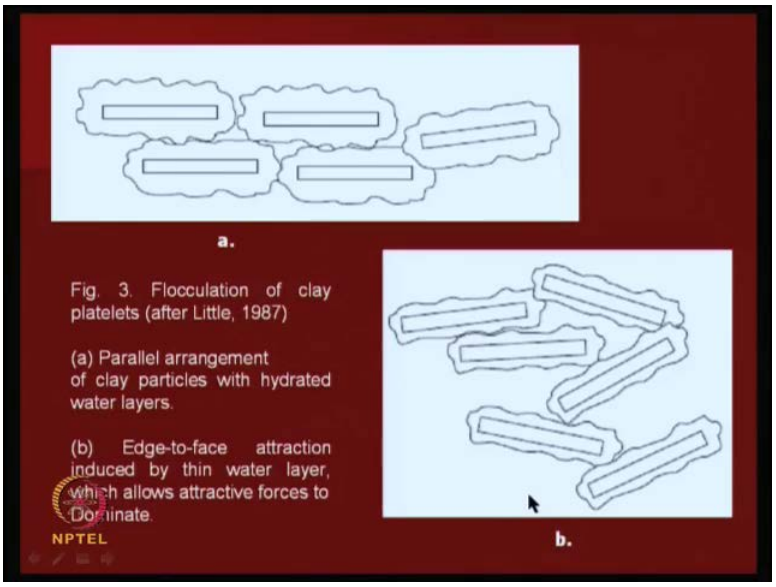

So, this is what is called a clay platelet and this is the diffused double layer theory, I mean according to the theory, you have the formation of a diffused double layer, you can calculate the thickness actually and this we say it is a parallel arrangement with hydrated water layers. Say for example, what happens if the water level enters between the two, there is a tendency to swell like this. That is because, since they are all parallel oriented, there is no resistance to the force of, this force in this.

So, that is what happens in the case of bentonite. That is why, when the water is allowed into the bentonite, there is lot of swelling. But, then when you add for the same sodium bentonite, you add a bit of what you call calcium or saturate with calcium what happens it have that has a formation of the edges like this. Wherein you will see that, edge to flay, edge to face flocculation occurs the problem the possibility is that, now the water gets stored like this and it allows attractive forces to dominate. Say for example, there is an edge to face attraction and then these has a higher void ratio compared to this one. In the sense that, at the same water content you will expect because of the edge to face attraction, you will have a higher void ratio in this and also there is a force here. So, it can take some resistance to apply load.

So, some of these points are very important and say for example, we wanted what is called removal of water, removal of water from the clay. Definitely you have a orientation like this, which is called edge to face attraction or the flocculation type of

structure, it becomes more permeable, it is more stronger and the compressibility is also less as oppose to the case where we have lot of swelling here, lot of settlements here, shear strength is low. So, normally because of this treatment, this is going be more beneficial. So, what we do is that I will try to cover some case studies, which are quite documented in literature.

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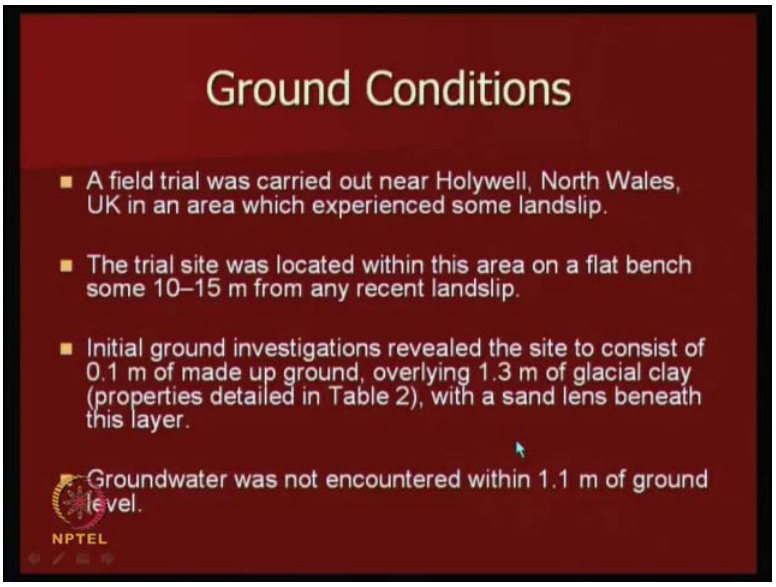

There are very interesting examples. You have a field trail that was conducted in UK and there was some land slip that occurred and close to land slip they constructed this particular field trial. And initial ground investigations revealed that the site have a 0.1 meters of made up ground, overlying 1.3 meters of the glacial clay, with a sand lens beneath the clay layer. There is no ground water within 1.1.

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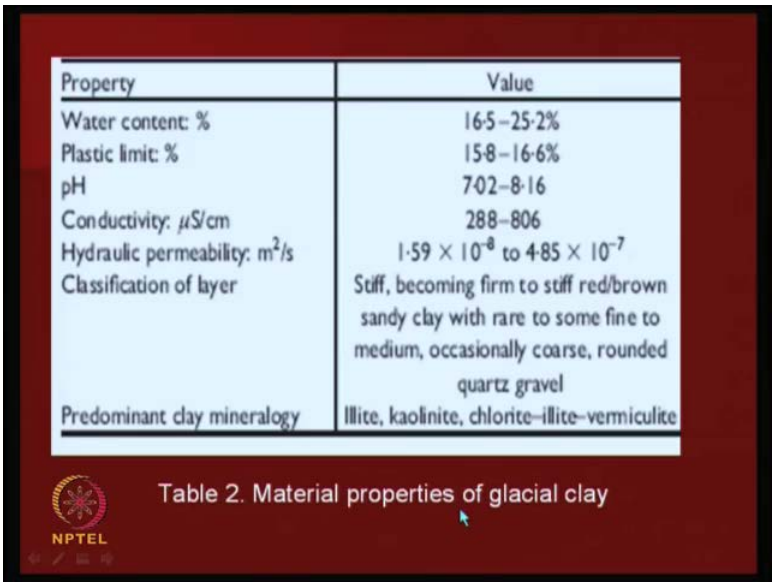

It is a field experiments they have done and the water content is about 16 to 25 percent, plastic limit is this, p H is 7 and then, conductivity of the soil it is in this 288-806,

hydraulic permeability or the permeability of the soil is minus 80. You can see, it is very low, which in terms of the area they have given. Classification of the predominantly it is illite and all that.

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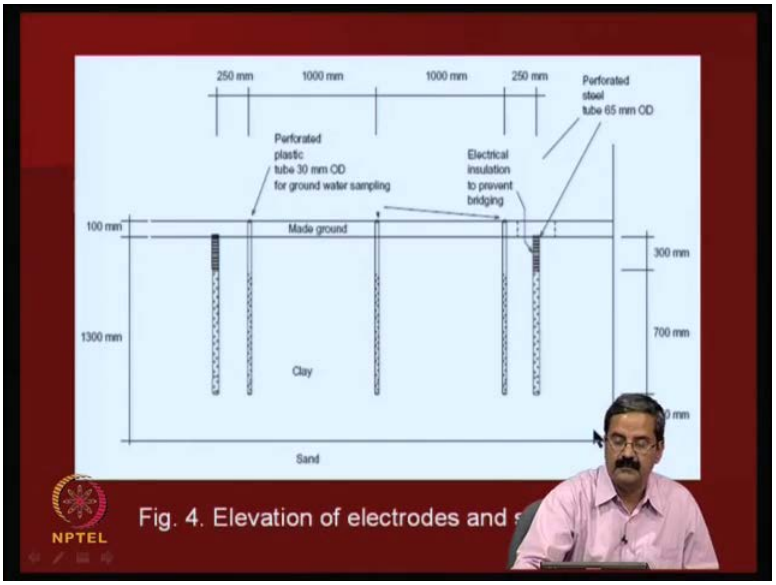

This is arrangement that they have, like as I said it is a small one in experimental stretch and you have a made up ground. This is what is called the electrodes here, on either side. And this is perforated plastic tube 30 mm O D for ground water sampling. If you want to sampling also, because you should measure the various changes in chemistry that are going to take place. Electrical insulation to prevent bridging. As I just mentioned, I do not want short circuiting between the two electrodes. So, this sort of experiments can be even done in the laboratory. One can do this, like take may be if not 1 meter, take half a meter and try to do some experiments. It is possible.

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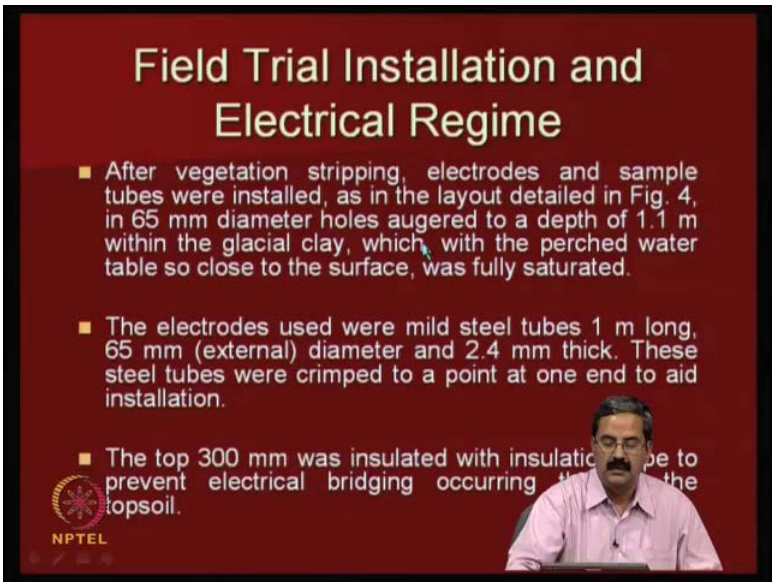

So, what they did in the field was that, they remove the vegetation like vegetation stripping, electrodes and sample tubes were installed as shown in the figure with 65 millimeter diameter holes augered to a depth of 1.1 meters within the glacial clay. Which with the perched water table so close to the ground surface was fully saturated. So, water table is that close to the ground surface. The electrodes used were mild steel tubes of 1 meter long, 65 millimeter external diameter, 2.5 millimeter thick. This show about crimpled to the point to the end to aid installation, like you can make that particular end little make it better pointed. So, that it is easy for installation. The top 300 mm was insulated to prevent electrical bridging. That is important.

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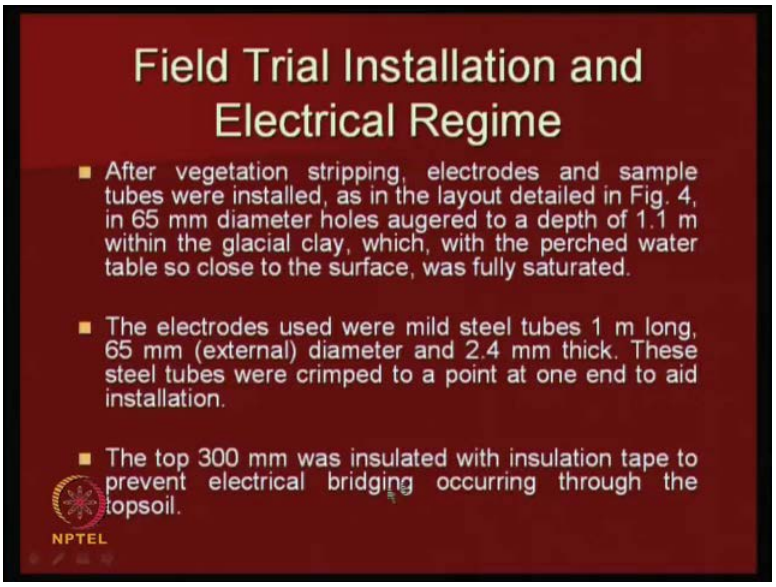

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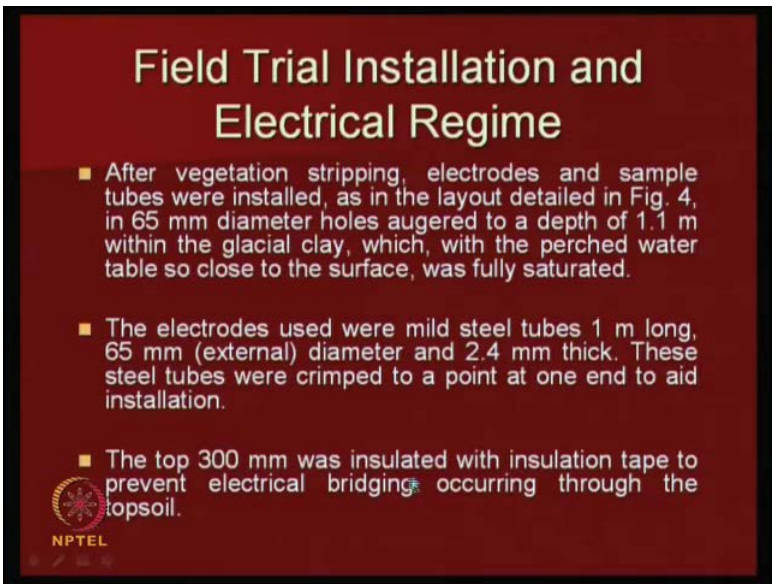

To allow the solution to flow into the soil actually, as I said we need to have some sort of stabilizers to allow the solution were drilled at 50 mm center to center region, three hundred mm from top to, they are able to saturate the hole area. The electrodes were pushed into the holes which had the same nominal diameter and a snug fit was ensured. In addition, electrical continuity was provide by the fluids fed to the electrodes. So, they are trying to ensure that electrical continuity was maintained and you also have sampling tubes with plastic tubes.

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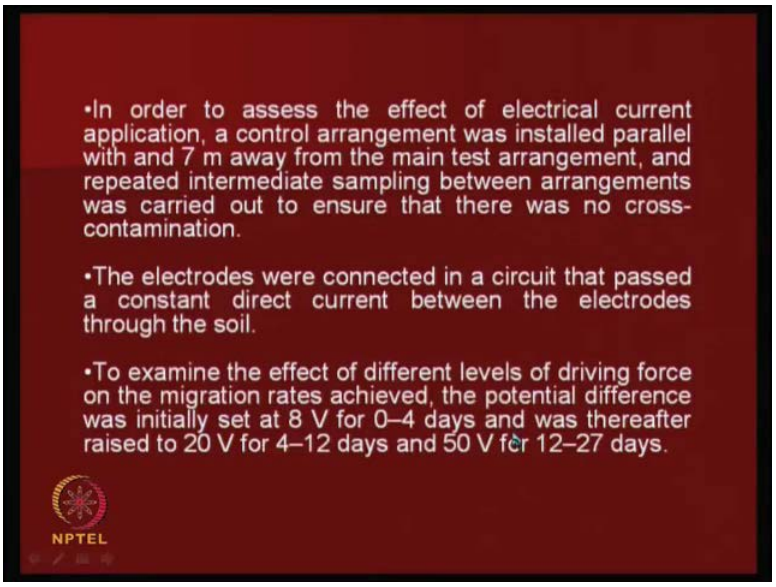

So, what they did was that, in order to assess the effect of the electrical current application, a control arrangement was installed parallel with and 7 meters away from the main test arrangement and repeated intermediate sampling between the arrangements was carried out to ensure that there was no cross contamination. Electrodes were connected in a circuit that passed through, passed at constant direct current between the electrodes through the soil. Actually, you should have a DC here, direct current. As opposed to alternate current, which we are familiar with. So, what they are trying to do is that the dc was arranged and they have some sort of control arrangements, to see what is happening. So, the effect of different levels of driving force on the migration rates, how much is the migration? The potential difference was initially say 8 volts for 4 days. Then it is raised to 20 volts for 4 to 12 days and 50 volts for 27 days actually the whole experiment finished in one month. So, about 27 days they finished.

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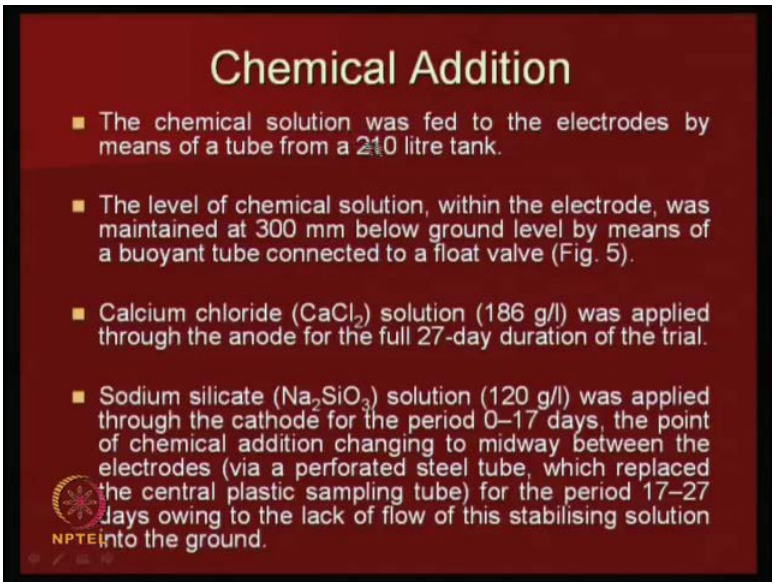

So, they have a sort of a chemical solution fed to the electrodes by means of a tube from a 210 litre tank. The level of the chemical solution within the electrode was maintained at 300 meters below the ground water table by means of buoyant force tube. I will just show you the figure. Calcium chloride solution was applied to the anode for the full 27 day duration of the trial. Sodium silicate again a solution was also applied to the cathode. We can see that, Calcium chloride was at the anode. Then, sodium silicate solution was applied at the cathode for a period of 17 days. The point of chemical addition changing to mid-way between electrodes. This is one thing.

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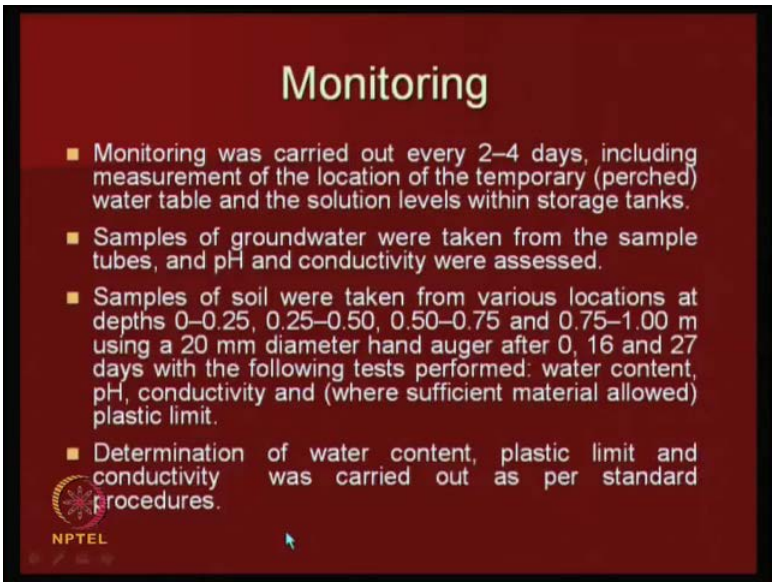

Anyhow, we will see some results. Monitoring was carried out every 2 to 3 days including measurement of the location of the temporary water table. So, they are looking at the reduction of water table, essentially. Why is that we are doing the whole thing? You are looking at how is the migration of ions, how is a water table reduced? So, water table was at the top because they just said that they have simulated this whole experiment. And then they were looking at solution levels within the storage tanks how about they. So, samples of ground water taken from the sample tubes and p H and everything was measured.

And samples of the soil were taken from various locations at 0.25, 0.25 to 0.5, 0.5 to 0.75 using a 20 mm diameter hand auger after 0, 16, 27 days following the test performed. They have performed water content p H conductivity all that. Determination of water content plastic limit and conductivity was carried out as per standard procedures. So, they are trying to look at the results now. So, the effect of applied electrical current on the rate of chemical addition through the steel tubes is in the figure.

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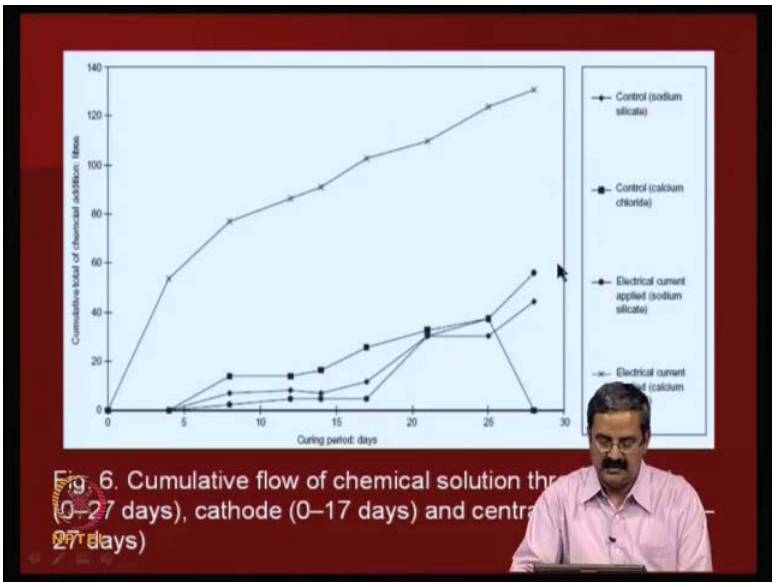

Figure six, this is the cumulative total of the chemical addition in liters, as I said this is control sodium this is control calcium, electrical current applied then electrical current applied at the sodium and all that say for example, sodium silicate calcium silicate. So, they are able to see that, you can see the first one. The chemical additions in various, these are all the chemical additions. Cumulative flow of chemical solution through the anode, means they as I just mentioned, calcium chloride was at the anode and the normally the water will be at the cathode. Sodium silicate for. So, this is what they did and what they observed.

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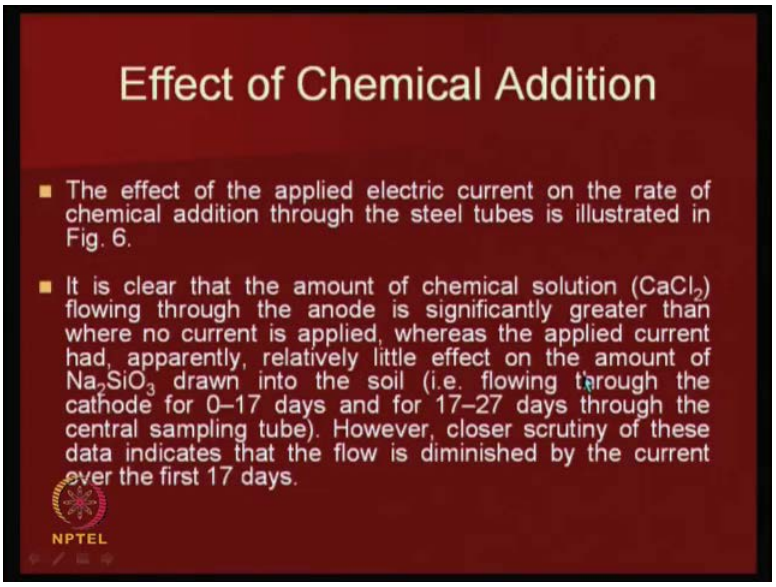

The amount of chemical solution flowing through the anode is significantly greater than when no current is applied. What they observed was that, when there is no current it was there but when the current was applied, apparently little effect on the amount of N a 2 S i O 3 drawn to the soil. However, closer scrutiny of these data indicates that the flow is diminished by the current over, what it means is that, there is an effect of the flow of the C a C l 2 because of the current at the anode whereas the applied current had relatively a less effect on the sodium which is at the anode; which is at the cathode, sorry. This is at the anode and whereas, this is at the cathode.

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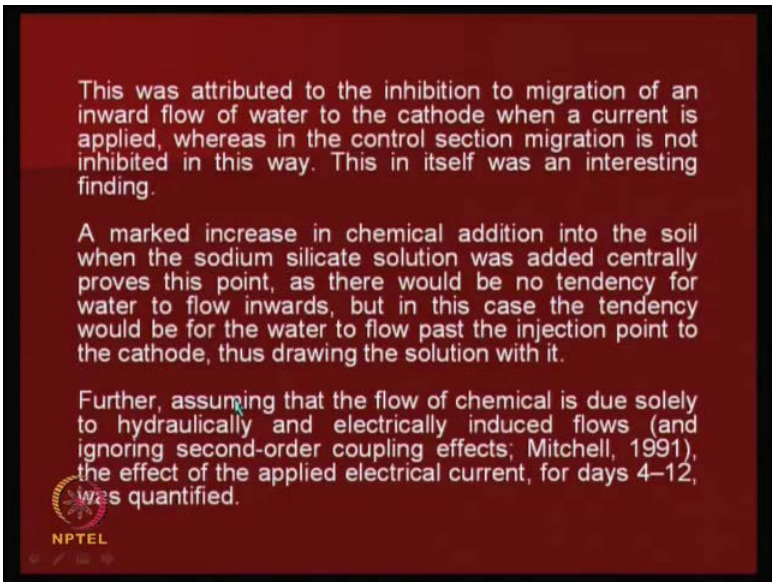

Anyhow, I think you once see the water current differences you will understand. This was attributed to the inhibition of migration of the inward flow of water to the cathode when a current is applied. Whereas, in the control section migration is not inhibited in this way. This itself is an interesting finding. A marked increase in chemical addition into the soil when sodium silicate was added, centrally proves this point that as there would be no tendency for water to flow inwards. But, in this case the tendency would be for the water to flow past the injection point to cathode. Thus, drawing the solution with it. Actually, what is happening here is that, the water the flow of chemical, we are trying to monitor the chemical flow here is due to the hydraulic as well as electrical gradient induced flows. So, what happens is that here, say this particular thing …

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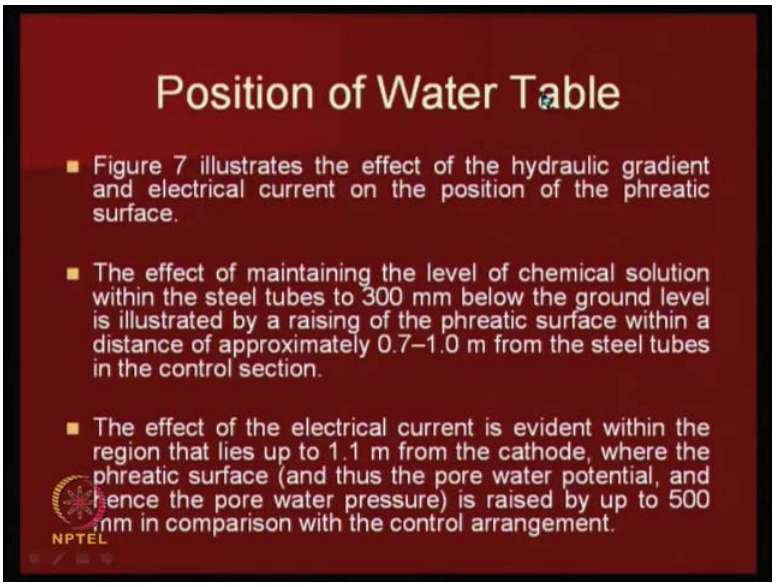

I think we will just see some more results here. Position of the water table will be able to give you better picture on, it is what we clearly understand because figure 7 illustrate the effect of hydraulic gradient and electrical current on the position of the phreatic surface. The effect of maintaining the level of chemical solution between the steel tubes to 300 mm below the ground level is illustrated by raising of the phreatic surface within a distance approximately 0.7 to 1 meter from the steel tubes. The effect of the electrical current is evident within the region that lies up to 1.2 meter from the cathode whereas, the phreatic surface is raised by about 500 mm in comparison to control arrangement.

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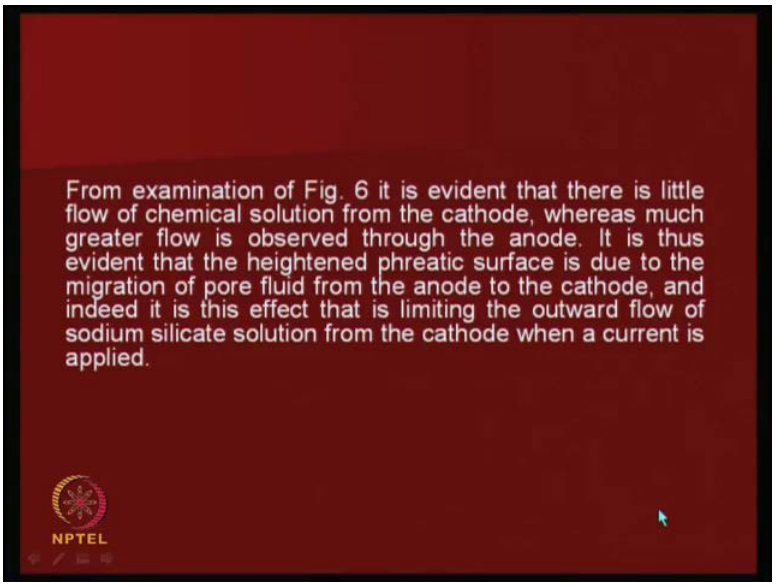

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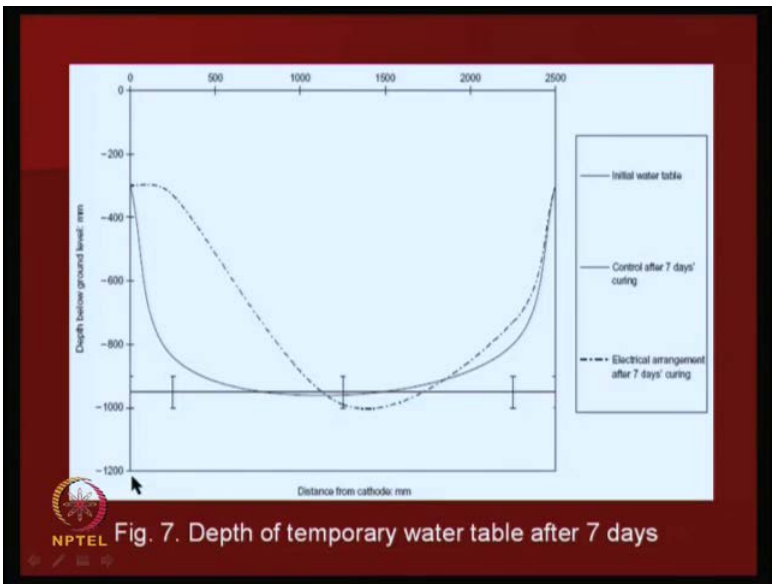

Distance from the cathode. Say for example, there is a 0 volt distance and then as you move away from the distance what is happening? This is a depth of water table and you can see that this is an initial water table. This is initial water table. Then, control after 7 days, this is another one. Electrical arrangement after 7 days, you can see that there is more water being present after what it shows is that this is the water content there is a change like this is one thing but then, if you just see this particular point, you can say

that the water content is higher. Close to the cathode surface because there is a distance from the cathode.

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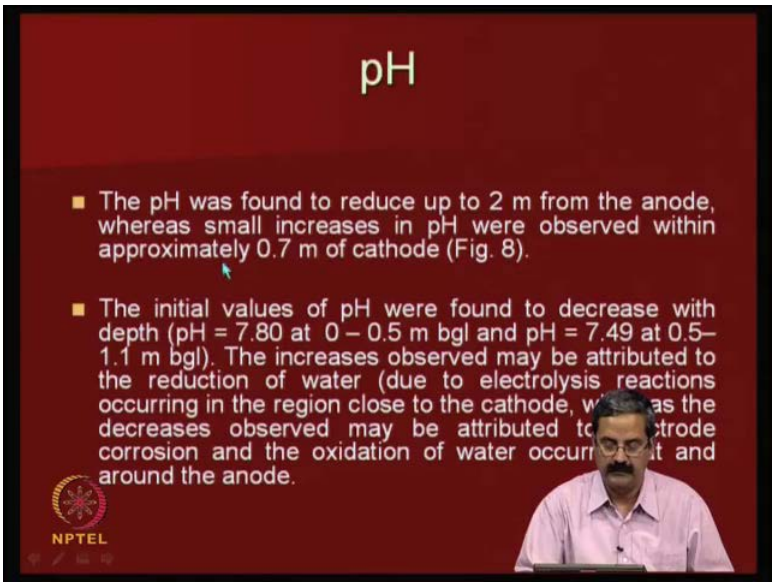

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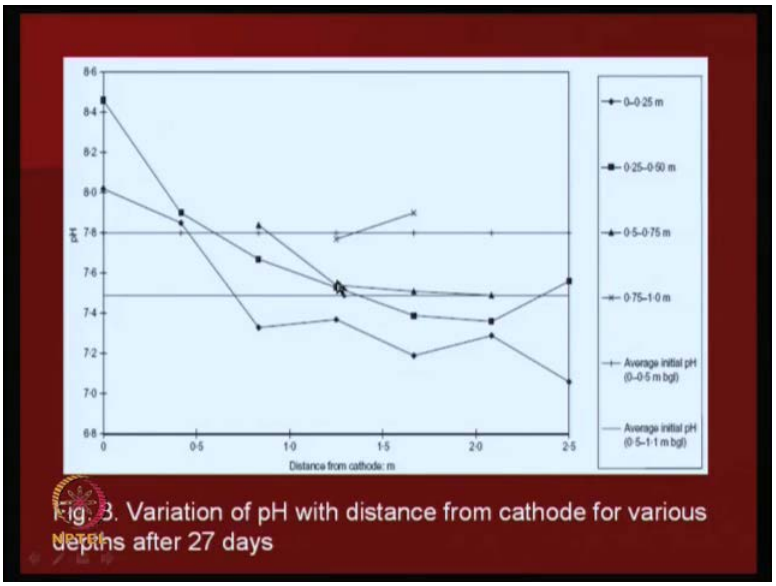

So, p H is something that is they again studied. p H was found to reduce up to 2 meters from the anode whereas, small increases in p H were observed within 0.7 or 70 centimeters of the cathode. So, there is some again see the thing is people have been able to observe lot of some of the studies. But what the distinct effect was again the p H for example, distance from the cathode. what is the distance and what is its variation one can

observe. The variation of p H with distance from the cathode for various depths. So, you can see that at different depths point. So, that is all fine.

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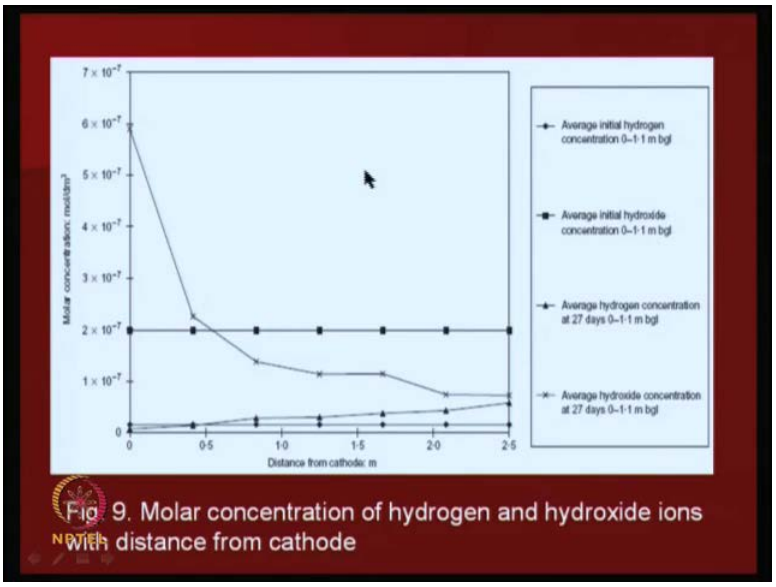

Then molar concentration is something that molar concentration of hydrogen hydroxide ions with distance from the cathode, again you can see that say this is one average hydroxide concentration. So, after 27 days at 1.1 meter this is. So, they are able to see that there is a good concentration of the hydroxide ions it close to the cathode.

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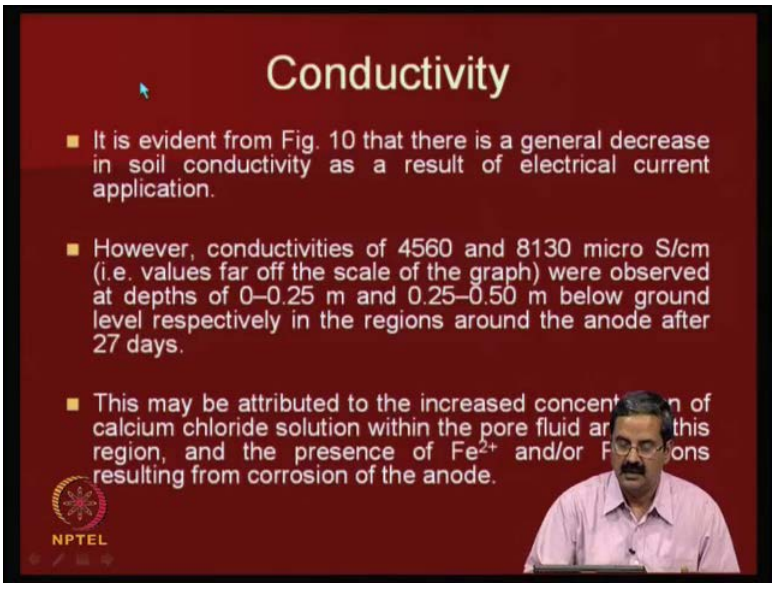

What they are able to observe that there is a general decrease in the soil conductivity as result of the electrical current application. And then they were able to see this in terms of the added conductivities, they have measured and then they were able to see that the, even increased concentration of the calcium chloride within the pore fluid around this region and the presence of iron and or even ferric ions, result from the corrosion of anode. Say for example, within that when the oxidation takes place the possibilities is that you have corrosion also occurring here. And then the water movement there. So, that is what they observed.

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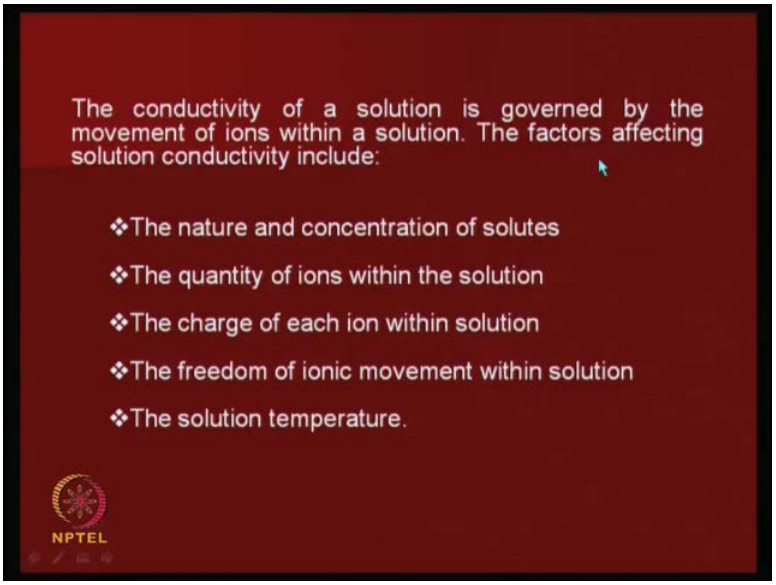

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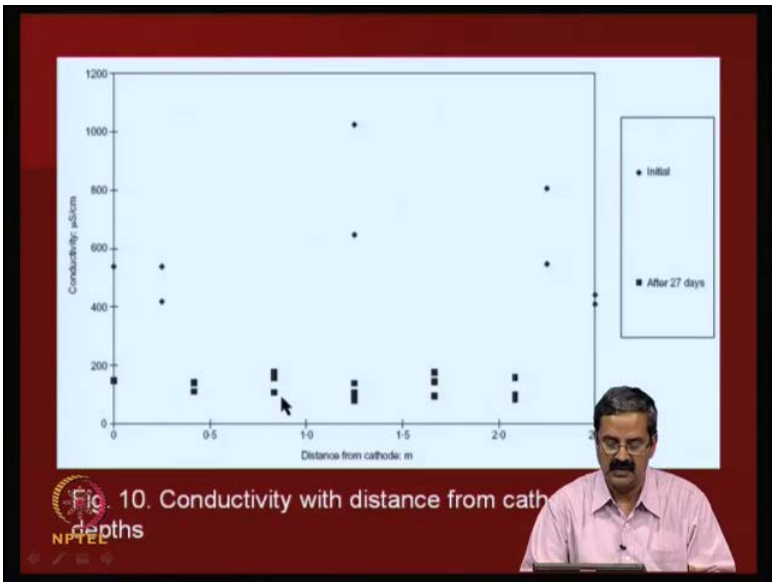

So, the conductivity of a solution is governed by the movement of ions within the solution the factors effecting the solution conductivity or the concentration of the ions, quantity of the ions, the charge of each ion, freedom of the ionic movement, solution temperature and all that.

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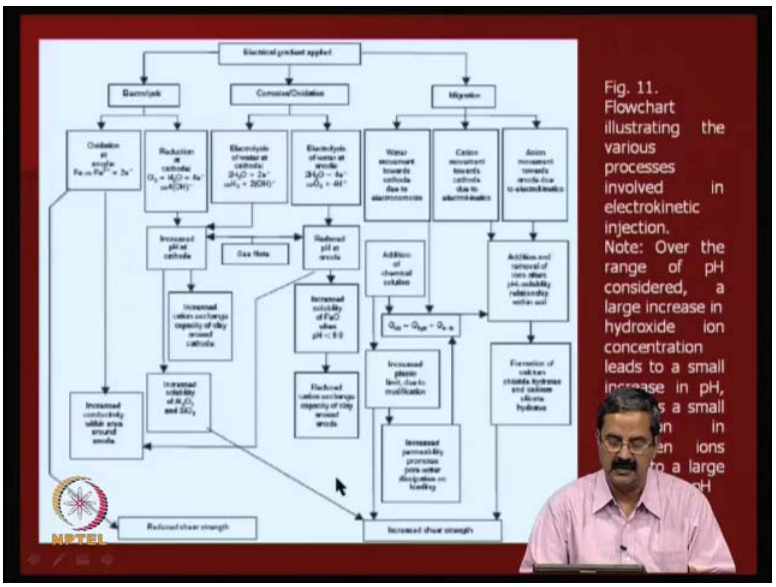

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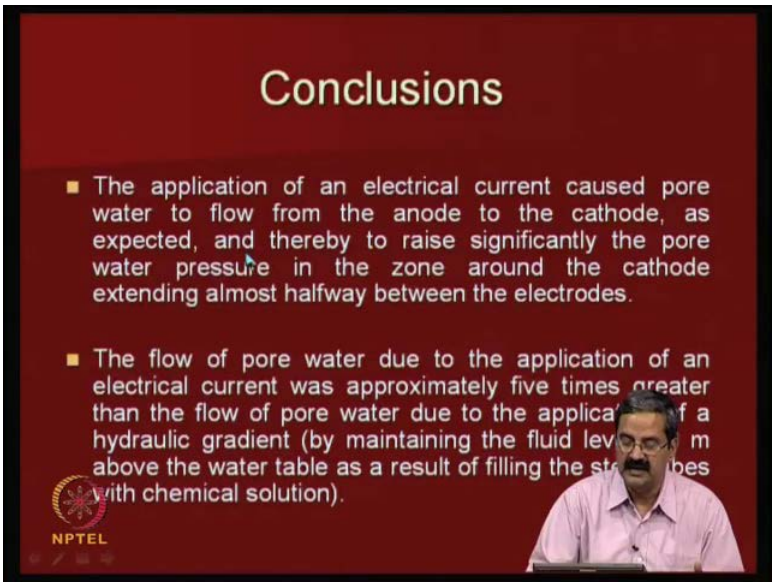

Of course, there is some more study on the distance from the cathode and it is a more of a parametric study and they have done lot of detailed work on how this whole thing happened. You can see the paper that I will refer to for a detailed analysis.

But this was very clear that electrically current causes pore water to flow from anode to the cathode as expected and that to, so that pore water pressure in the zone around the cathode significantly increases and you remove that, once the pore pressure increases you remove it. The flow of water due to the application of an electrical current was approximately 5 times greater than the flow of water due to the application of hydraulic gradient, by maintaining the flow 0.9 times above the water table as a result of filling the steel tubes.

So, this is a very important observation as I just mentioned, that you may have electrical gradients you may have hydraulic gradients like by gravity alone or by drainage, like or even you can apply vacuum, the other day we studied about vacuum consolidation also. You can apply some gradients but then definitely use of this current will significantly change the rate of removal of water. So, this is a very important point. In fact, people have doing lot of field studies on that and I will show some.

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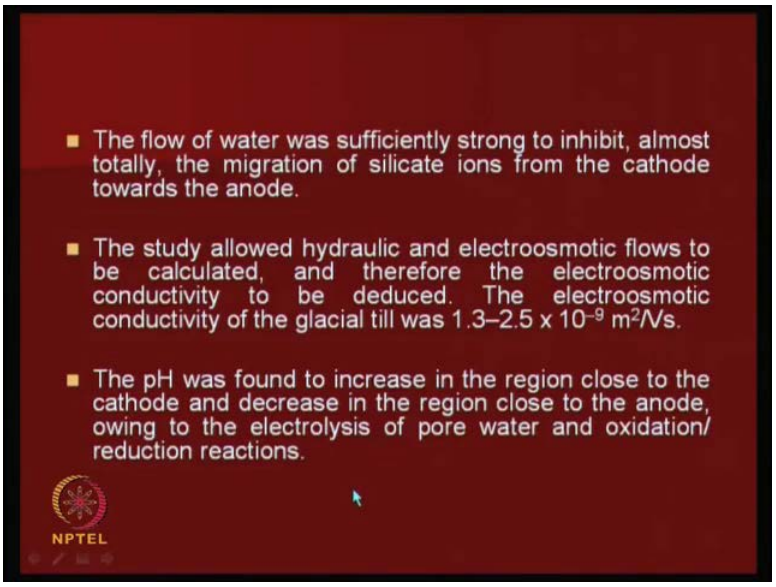

The flow of water was strong, sufficiently strong to inhibit almost totally the migration of silicate ions from the cathode towards anode. This fine the study allowed hydraulic and electric osmotic flows to be calculated. In fact, so they are able to make what is hydraulic flow? What is the electro osmotic flow? How much is the water? So, as I just mention they are able to even measure, see the thing is we try to calculate the Electroosmotic conductivity of the material it is 1.3 to 2.5 into 10 power minus 9 meter square per volt second.

So, even per voltage difference what is the, like in terms of centimeter and all that, one can even say, what is area that you can hydraulic conductivity or you have to compare the hydraulic conductivity and also the Electroosmotic conductivity, I mean water removal essentially you are looking at it. So, this is an important variable and p H was found to increase in the region close to the cathode and decrease in the region close to the anode owing to the electrolysis of the pore water and oxidation reactions.

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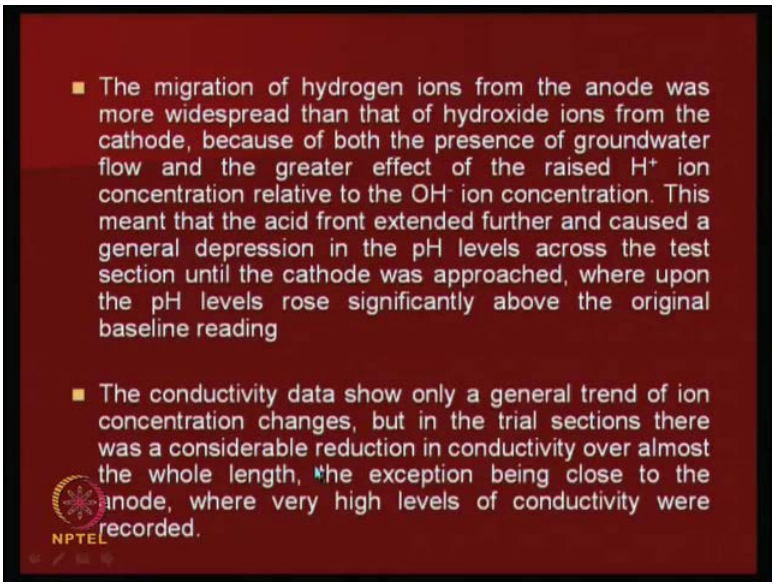

The migration of hydrogen ions from the anode was more widespread than that of hydroxide ions because there are two types of ions. Hydrogen ions as well as hydroxyl ions. Because of, they are all present in ground water and. So, what this means is that the acid they are front that they have, like essentially with extended further and caused a general depression in the p H values across the test section. So p H measurements, based on the p H measurements they are able to say what is the area that is more acidic than more alkaline or whatever. So, these are all very important observation because particularly when you are trying to talk about use of buried pipes or objects and then you are trying to do dewatering close to buried objects which are made of steel, one should really look at corrosion point also and its p H and all that.

Conductivity data show only a general trend of ion concentration changes but in the trial sections there was considerable reduction in the conductivity over all most the whole region length, except being close to the anode where high levels of conductivity were recorded. So, it is the another important point.

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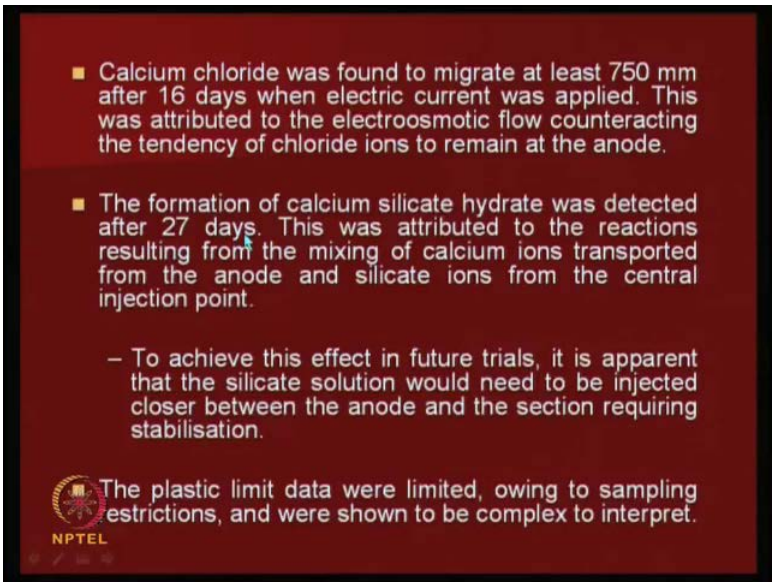

So, in a nut shell what it means is that, it has been quite effective and the formation of calcium silicate hydrated was detected after 27 days. This was attributed to the reactions resulting from the mixing of calcium ions transported from the anode to the cathode. So, this is what they have done.

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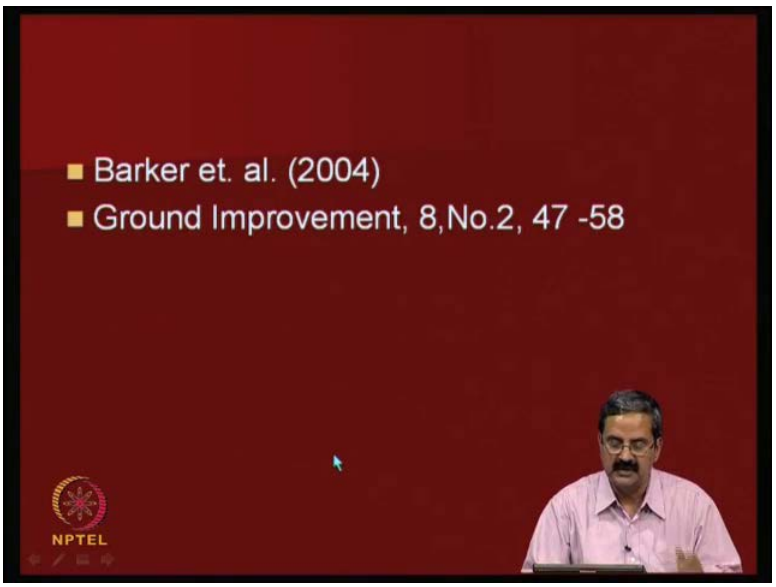

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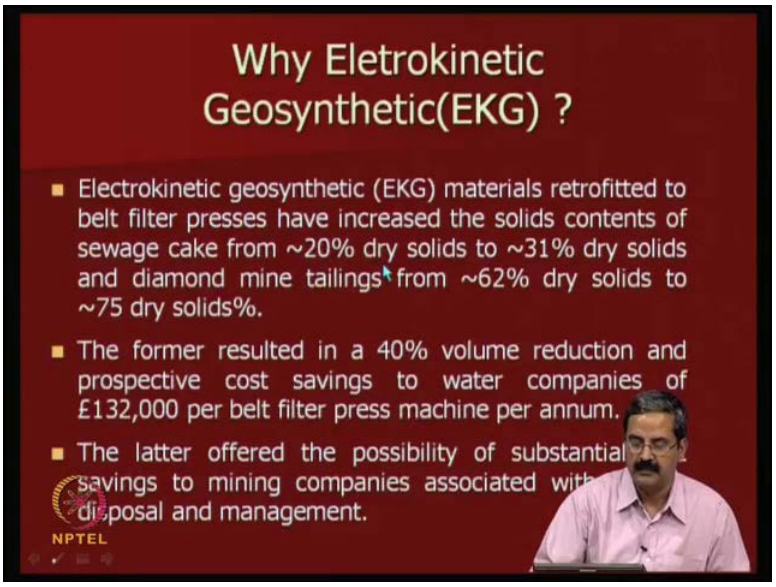

And this is another. So, this is actually a paper in ground improvement which is published in this journal, which is quite useful. So, I would like to just tell you a few more case studies which is, what is called Electro-Kinetic geosynthetics. This is in fact, again an extension of this same concept where see, as I just mentioned, we have prefabricated vertical drains. You have even this materials where you are trying to use as the drainage. You fit these materials to, you are trying pass electricity. Essentially, what you are trying to do is that you are trying to passing electricity and see that the water is removed from the area. That is what exactly. So even now a days, people have used this concept. Now we know only conventional Geosynthetics, of course I would be covering that in a greater detail.

You know that the Geosynthetics, Geogrids and there are many types of materials you have and when you have this electrical systems fitted on to the materials, they are of great help. Why they are of great help is that, they can make a small strip of material and then you can do that. So, I will show you that. See these materials. In fact, particularly in contamination removal and then in sludge handling, they are of very great help. Say for example, what it means is that, the materials that you have, like you have some mining and many other projects, what happens is that many of them there is lot of to remove some things they add lot of liquid handling problem should be there.

So, to handle that see even in fly ash, say for example, you have dry disposal and wet disposal methods of fly ash disposal. And dry disposal is not permitted because fly ash is in the air, it could contaminate. But in the wet state, it has too much of water to handling becomes very difficult. So, what we try to do that is that, in at least in some other if not fly ash in some other materials, people make what you call increases a solid contents. Say for example, you are trying to handle the sewage. Sewage is a more of high, it has more of water parts, water content is going to be very high in a sewage. So what we do is that, we try to increases the solids content there.

So, we try to have what is called there are some materials, like there are different techniques called centrifuges and belt filter methods, where you try to remove some sort of arrangements we make. Say for example, centrifuge you try to take all that say for example, sludge or even sewage you take sewage and put it in a high centrifuge what happens is that it is all that hard material comes down and then liquid can be removed.

So, this is what we have in our lab also where people only remove the water and then the cake whatever is the rest of the material like hard material remove it and then throw it. So, that way you are able to remove, to handle this it is much easier. I will show you some examples. So, Electro-kinetic materials have been quite useful to increase solid contents of the materials from 20 to 30 percent and even in the case of mine tailings, like even to handle the diamond mines, in the case of diamond mines they are able to increase from 62 to 75 percent.

And in some places what happens, liquids and water they have a big volume. So, when you have only solids in a particular system what happens, volume reduction also takes place and the cost savings are huge. Like, if you have a liquid only to be stored. Say for example, there is so, much liquid waste. Liquid plus solid waste like sludge or something. No, not sludge. Say for example, lot of liquid waste, liquid waste with few solids like 30 or 40 percent. They need lot of volume and the objective is to remove all that liquids and then treat them take the solid separately. Say for example, one can make the solids in a separately remove them. Use it for many of the other applications and liquids also you can treat it for dewatering purposes.

And I mean, for once you get the liquids separately, you can do lot of treatments and make them useable. And even solids also you separate out in some form and then use in

some form like say for example, waste use of waste materials in construction one can do that. So, the Geosynthetic Kinetics have been very useful in this and they have been very useful in ground water dewatering.

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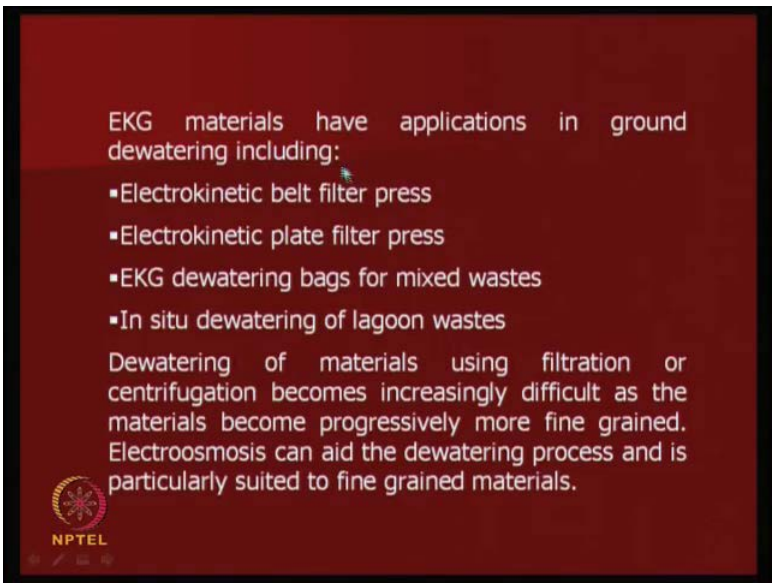

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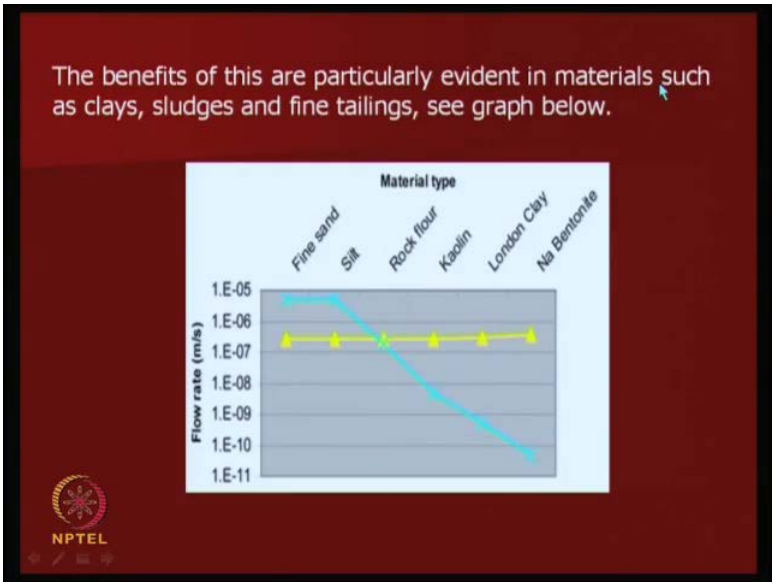

Actually, I am only talking about ground water dewatering here. And they are useful, they are fitted to some of the belts, plates and all that. And we will see that they are quite effective. I will show you that example. Benefits of this are particularly evident in material such as clays, sludges and fine tailings. Particularly in some materials like

where you have lot of clays and all that. It is not, it is very difficult to handle these materials. So, this is an example here. Flow rate, we can see that, depending on the sodium bentonite London every one if the permeability kaolin and all that fine sand. The flow rates are low. So, you are trying to use this method in which one can really come to this level where they are quite efficient.

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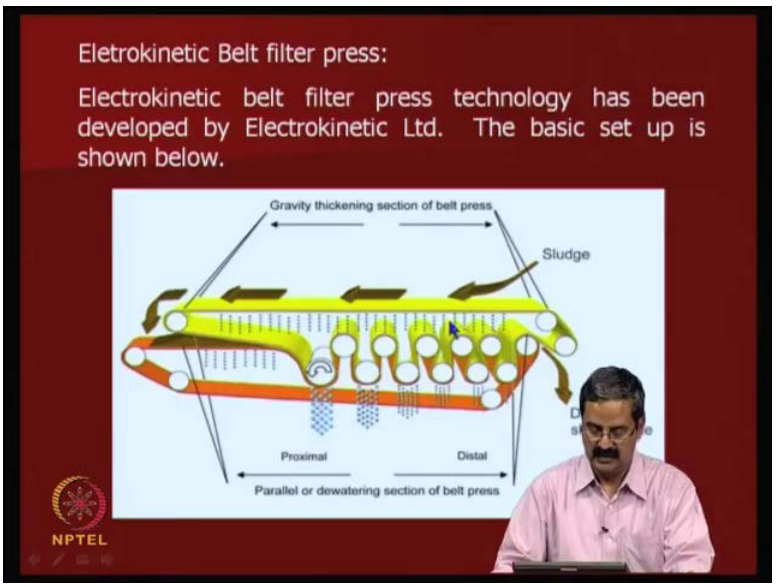

I will show you the process. Normally sludge is something waste material. It is just kept like this. It just goes like this. And it just comes like this. There is a sort of rotation and all that and then there is a cake formation. That cakes do come out dewatered sludge cake and water is like this. Parallel or dewatering section of the process waste. If you go to some of the waste industries, this is all a big process that is done.

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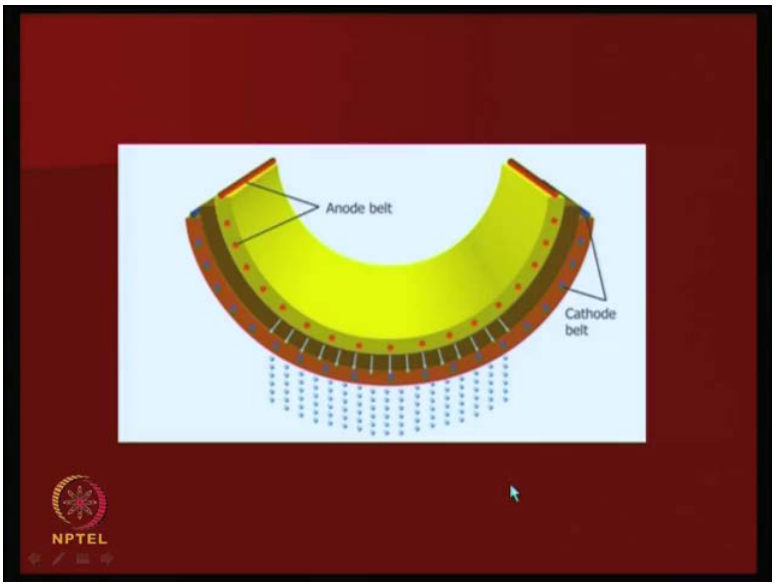

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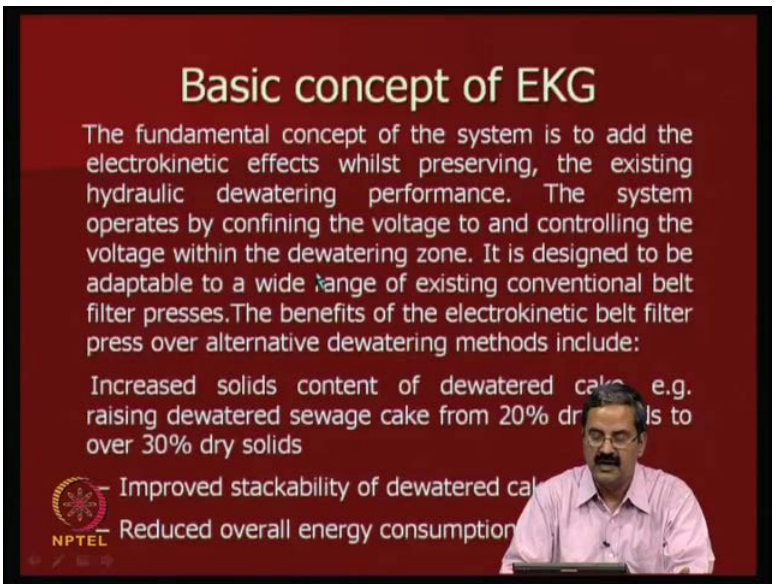

So, what they do here you have anode belt, you have cathode belt. So, in the same thing, so, in this particular belt, so, they are trying to do this particular process here, which is quite efficient. In the regular sense, they have normal belts. But, think of this where you have the sort of arrangement where the advantage would be that it is quite effective. So, the fundamental concept of the system is to add the Electro-kinetic effects without, while preserving the existing hydraulic dewatering systems. So, we are not trying to remove this conventional way but then we are adding it. The system operates by confining the

voltage to and controlling the voltage within the dewatering zone. It is designed to be adoptable to a wide range of existing conventional belt filters process or presses.

The benefits of the Electro-kinetic belt filter press over alternative dewatering methods include increased solids content of the dewatering cake, like raising dewatered sewage cake from 20 percent dry solids to 30 percent dry solids. Improved stackability of the dewatered cake, once you have that materials you can handle it properly. Reduced over all energy consumption. In fact, you have to continuously run this belts and all that. Just to see that, as I said centrifuge is one arrangement essentially we are trying to handle this liquids waste disposal systems.

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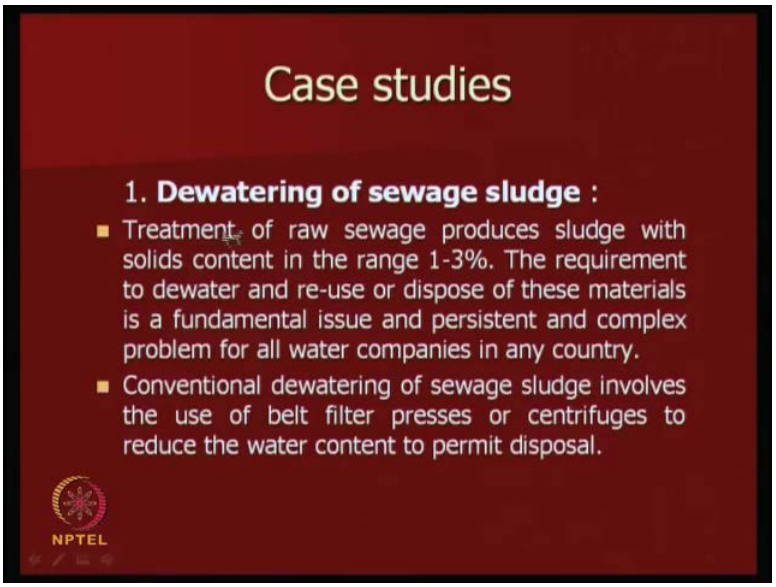

Some case studies that I will show and dewatering of sewage sludge, treatment of raw sewages produces normally a solids contents in the range of 1 to 3 percent. The requirement to dewater and reuse of or disposal of this materials is a fundamental issue and persistent and complex problem for all water companies in any country. It is not, even in Bangalore we have sludge, I mean sewage disposal problems. You go to some companies, see once you where there is lot of treatment water is required and once there is lot of water goes into the treatment, say for the example, in Bangalore or in Karnataka they are planning to have semiconductor industry.

They need to have lot of water first of all in that whole system but at the same time the water is mixed with certain materials and all that. It is now, it is only a some sort of a sewage or a waste water actually. Waste water need to be handled. How do you handled after the use of the water, it becomes waste water. And waste water contains both solids and liquids, you need to separate them. So that it can be used properly that is a whole objective here. And in the conventional dewatering, it only has a filter, the belt filter process or centrifuges to reduce water content to permit disposal.

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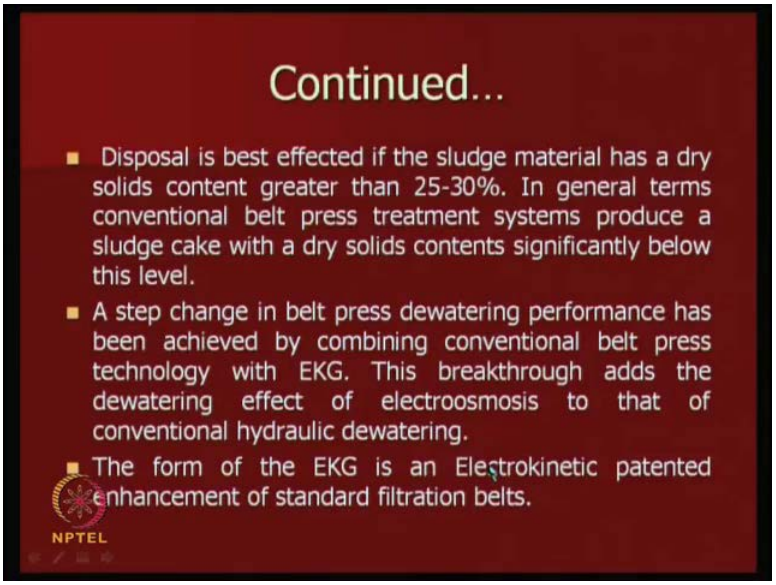

But here the disposal is very efficient and it is best effected if the sludge material has a dry solids content greater than 25 to 30 percent, like if the solid content is going to be higher, it is much better. In general terms, the conventional belt press treatment systems produces a sludge cake with a dry solids contents significantly below this level. So, normally the conventional methods have a less than this number. A step change in the belt press dewatering performance has been achieved by combining a conventional belt press technology with E K G. This breakthrough adds the conventional dewatering effect of electroosmosis to that of conventional hydraulic dewatering. So, the form of the E K G is an Electro-kinetic patented enhancement of standard filtration test. I will show you an example here.

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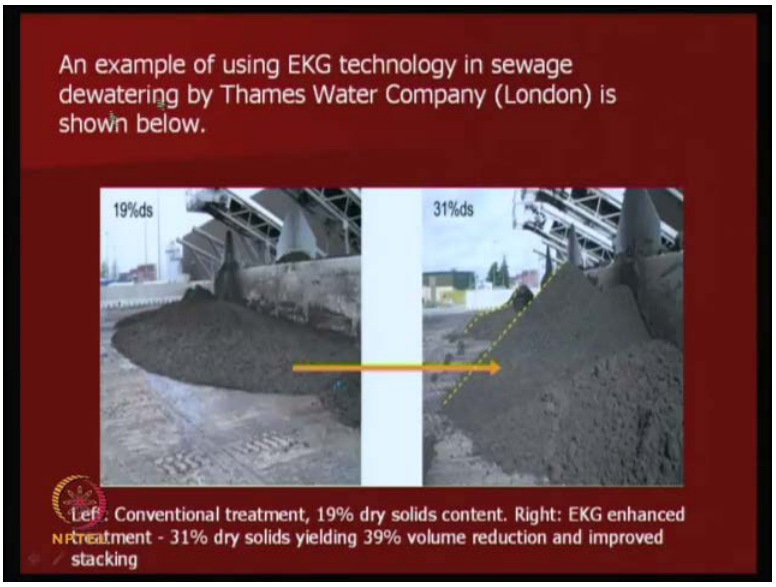

Example of using E K G technology in sewage like one company. Say for example, this all the 90 percent this thing, dry solids you can see that the water content is going to be high, the dry. So, it is may be the rest is like 81 percent. It is in some of low flowable type. 19 percent dry solids content. Whereas you can see it has 31 percent. So, it is like a more easy to handle. So, it has some 31 percent dry solids yielding 39 percent volume reduction and improved stacking. So, at least it is easy to store. In some companies it is very important like if you are trying to work in some industries this point becomes very important.

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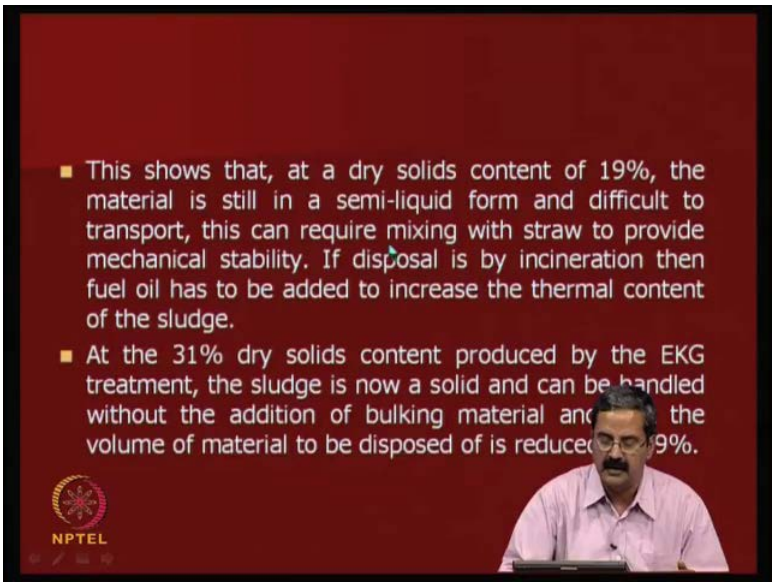

This shows that at a dry solids content of 19 percent, the material is still in a semi liquid form and difficult to transport. It is not easy to transport. This can require mixing with straw to produce mechanical stability. Of course, it is not easy also. If disposal is by incineration then, fuel oil has to be added to increase the thermal content of the sludge, actually to handle the sludge with the high water content is not easy. So, people add fibers to increase its handling like you cannot burn it or you cannot start heating it, because again it is if disposal is by incineration like heating, then the fuel oil has to be added to increase the thermal content of the sludge.

So, you have to add some material to see that, there is a material to be burnt. It is rate of reaction increases. Whereas, you are trying to do electrical method, you have 31 percent dry solids content produced by the E K G. The sludge is now a solid and can be handled without at the addition of bulking material and that the volume of the material reduces by 39 percent, which is quite good.

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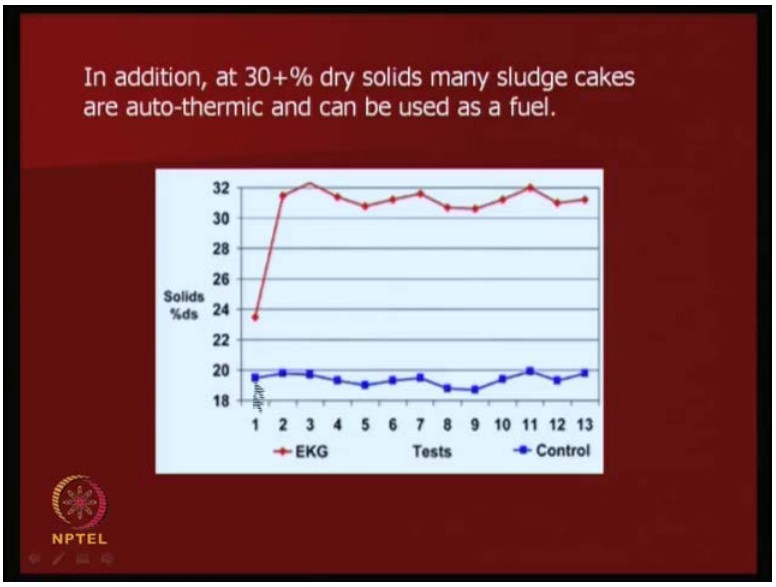

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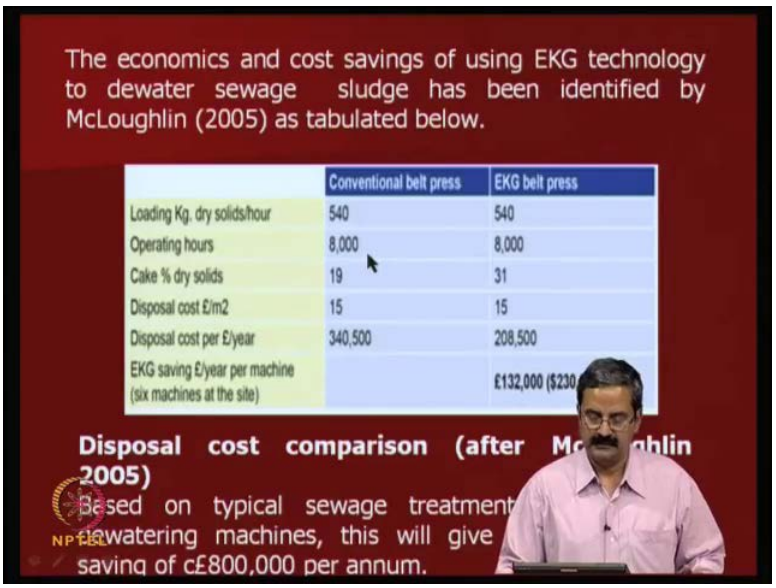

So, this is what people have observed, in couple of number of tests where it is about 19 percent whereas, it is about 32 percent close to that. The economics are also quite good and quite effective, because this slot of savings.

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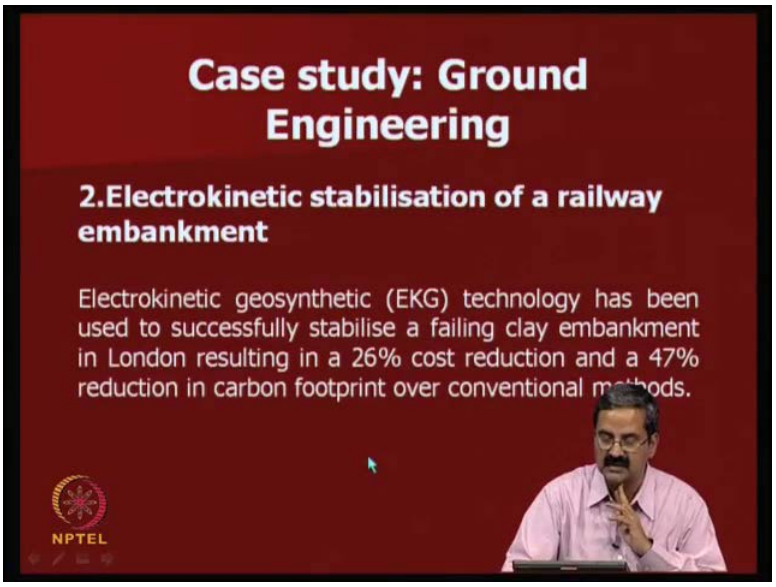

Then, there is some more like an Electro kinetic stabilization of railway embankment. I think for the past few years, this technology has been used in many country, just countries like UK and other places where the soil is soft. We will see that, how they can do that. Actually, here is an example to stabilize a failing clay embankment. It is already failing. Actually, they try to stabilize using this. How they did was that in a conventional technique compared to conventional techniques, there is a reduction of 26 percent.

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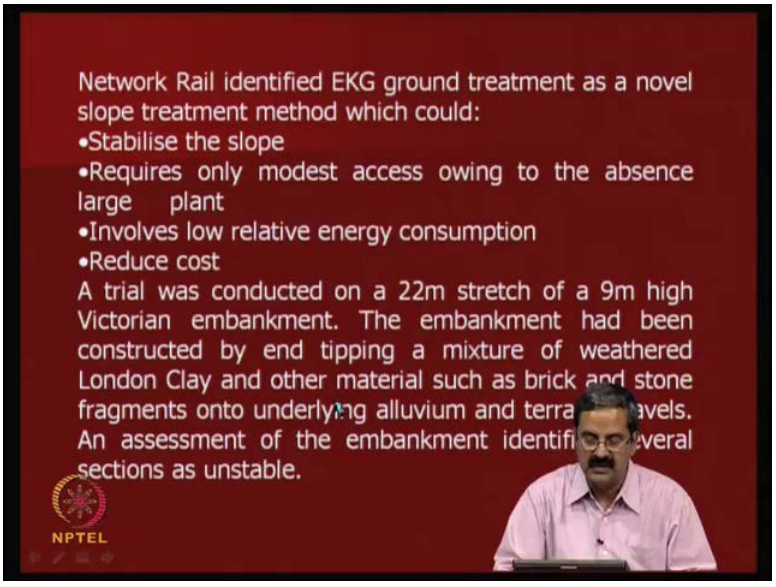

And in fact if you try to use, I will see that this network rail identified the E K G ground treatment as a novel slope treatment method which could stabilize the slope; requires only modest access owing to the absence of the large plant. Actually the thing is electrical things. Once you put all these materials and all that the space requirement is not difficult. Suppose, there is a soft soil area and all that. You do not need to bring, you have to bring the bricks and all that. It is a big equipment, the other thing is that it involves low relative energy consumption reduces cost. So, what they did was, a trial was conducted on a 20 meter stretch of a 9 meter high embankment. The embankment had been constructed by end tipping of a mixture of weathered London clay and other material such as brick and stone fragments, onto alluvium and terrace this thing. The assessment of the embankment identified several section as unstable.

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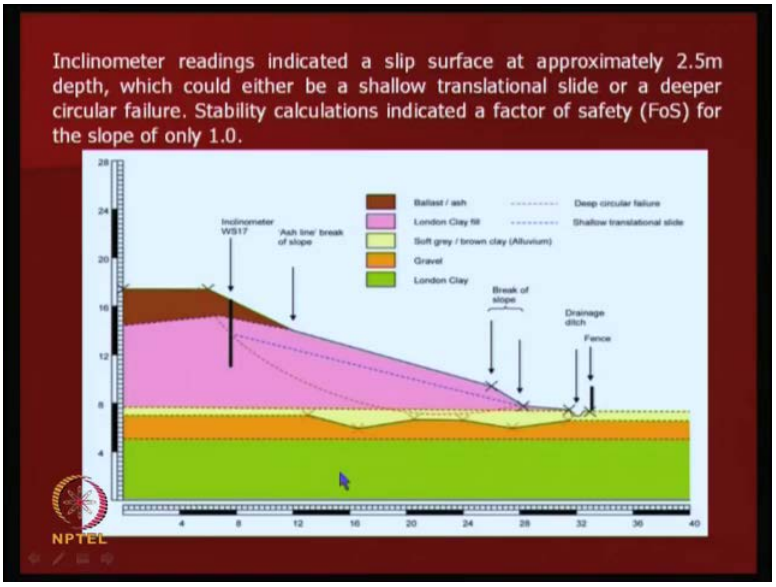

There is a section here. You can see that these are railway embankment and this cell typical material London clay, gravel, soft soil and this another material. So, there is a deep circular slide. That is one thing people have observed. How did they observe? They observed, they have put an inclinometer there. Inclinometer is an equipment to measure or locate slip surfaces. Inclinometer readings indicated a slip surfaces at an approximately 2.5 meters below the, they have identified one slip surface. So, what they were trying to do was that, say once you identify, actually I have used once inclinometer. It is very useful in identifying the rate of shear movement in the slopes. Once they observe some sort of movement here, then it could be the possibility is that one failure

surface is like this, because this is where the toe of the dam, toe of the embankment is there. The other one was like this.

So, we have essentially identified two failure surfaces which can be possible failure surfaces. This is what normally we should do. Like, the moment you try to locate a movement here, you try to see where it will fail. So, you draw a circle lines. Slip circles like this and then another one like this. So, to try to do a factor of safety calculation it shows that the factor of safety is close to one. Which means that there is a possibility that the slope is going to fail.

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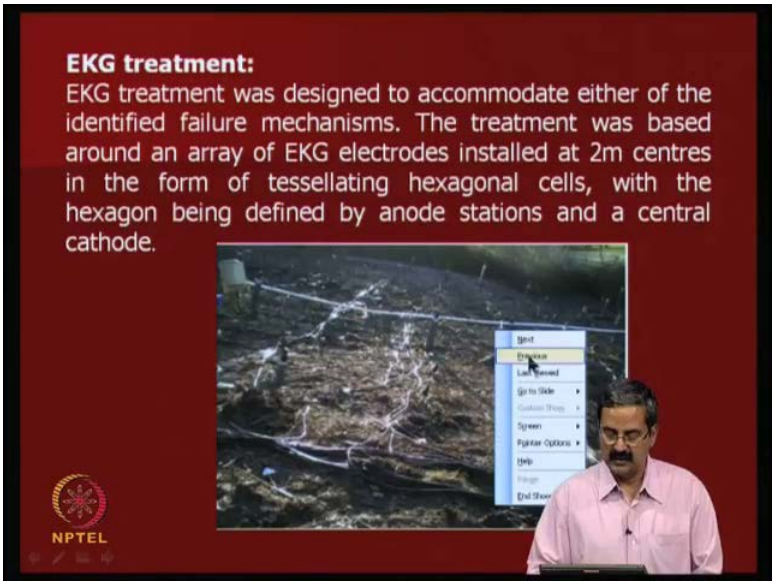

So, and then the material is what you can see that these are all London clay fill they are all very sensitive brown soil, this particularly they are all poor materials actually. So, the Electro kinetic that geosynthetic treatment was designed to accommodate either of the identified failure mechanisms the treatment was based around array of E C G electrodes installed at 2 meter, center to center in the form of hexagonal cells with the hexagon being identified, defined by anodes station and the central cathode. You can see that they have a nice different arrangement that you have a central cathode in which water could be removed and you have an anode, hexagonal cell.

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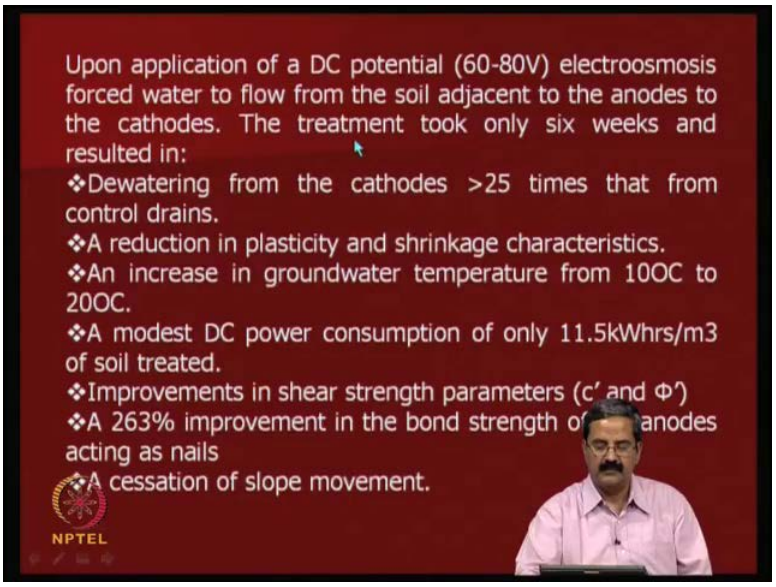

Upon application of the DC potential electroosmosis forced water to flow from the soil adjacent to the anodes to the cathodes. The treatment took only six weeks and resulted in dewatering from the cathodes 25 times more than that control drains where you have a control drain where this is not applied. A reduction in plasticity and shrinkage characteristics because in these soils, in particularly some of these soils they are very highly plastic. So, they have come down. An increase in ground water temperature from 10 degrees to 20 degree centigrade. A modest DC power consumption of only 11.5 is a less improvements in shears strength of the soil will also there. A 260 percent improvement in the bond strength of the anodes acting as nails. It is very other interesting observation.

And then the cessation of the complete movement of the slope actually they were observing with what is called inclinometer, all the movement then once they observed how many days it took? It is about six weeks it took and after the six week, if you try to measure all these properties and for all that. You find that even the anodes are acting as nails like cathodes and anodes and we said. The cathodes we have been used as more as a ground improvement and then there is also dewatering done.

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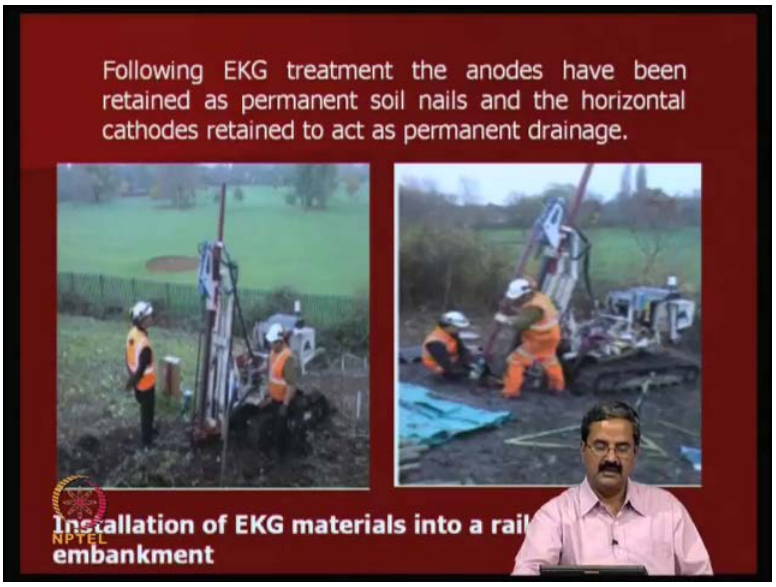

This is what they have been doing. Following E K G treatment the anodes have been retained as permanent soil nails and the horizontal cathodes retained to act as permanent drainage. It is very interesting. You can see that water is getting collected from the cathode. So, let it be act as a drainage in the slope. And there is a nails here put as anodes or the steel. Let it act as nails. It is nice. So, this is very interesting arrangement.

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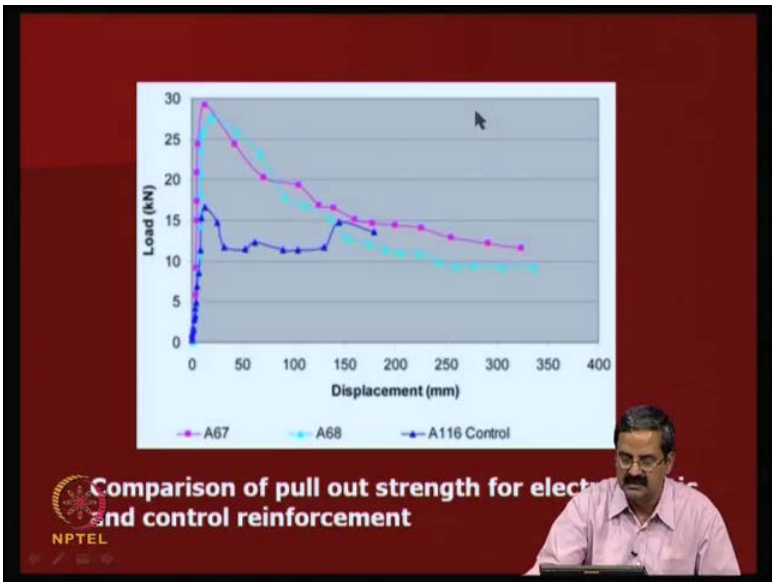

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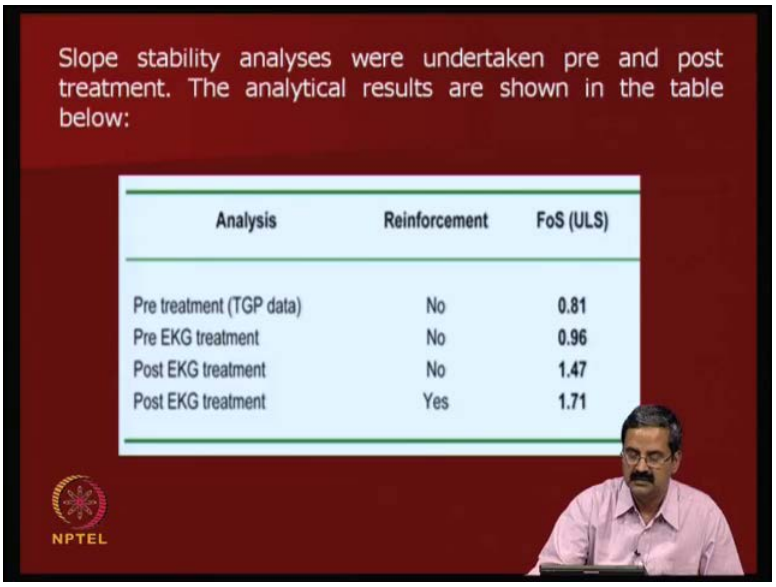

And in fact, they have done the pull out strength of the Electro-kinetic this thing. There are two sections, you can see that the load is quite high compared to a control section where nothing is there. So, it is about 15 to 16 kilo Newtons where this is about 30. Pull out strength of the reinforcement. After that they did the slope stability analysis and then they find that, before the treatment it is about 0.81, pre-treatment again 0.96. So, less than one reinforcement. So, without reinforcement the factor of safety was 1.47. It is 1.7, its increase in this thing. So, one can see that it is a very good treatment in this particular case and it is a trial example.

The use of the E K G to stabilize the slopes is a long term solution because soil softs weak embankment materials consolidate and improve the shear strength with E K G treatment, this consolidation is permanent. Actually, the moment you remove water in a speed, fast manner, that is going to be permanent. Additionally, E K G treatment works best on the soft soils which are critical to stability and in this way the treatment considered to be self selecting. It is a very useful treatment. And modifications in soil, soft soil chemistry such as cementation and plasticity occur under conditions induced by Electroosmotic flow.

Whatever are the changes in physical and chemical things, like as a p H will change and some of these things. They are not reversible like the probability of these changes is negligible, reversal of these changes is negligible and hence the effects are permanent.

Like you make the one is cathode, one is anode and try to do all the whole process the probability is that the changes are going to be not reversible.

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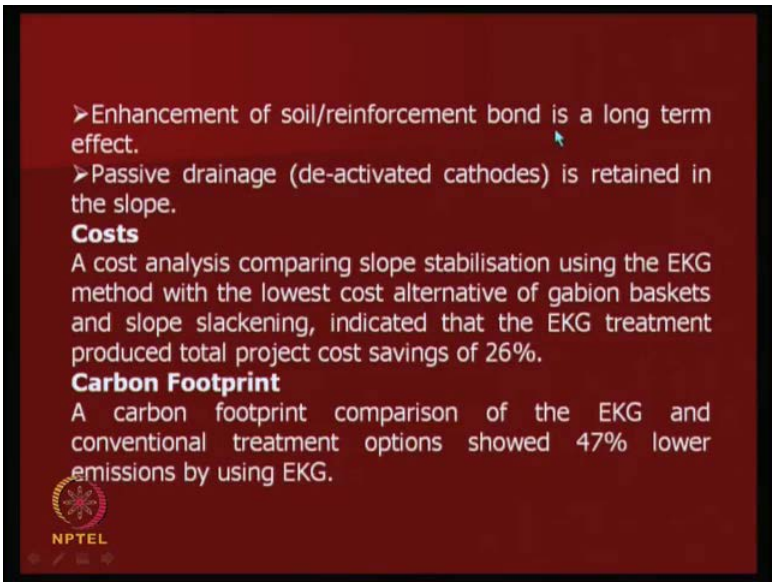

So, and then enhancement of the soil reinforcement bond is long term effect. Then, there is also a possibility of passive drainage in some of the slopes. And cost comparison cost analysis comparing the slope stabilization using the E K G method and the lowest cost alternative of gabion baskets and slope slackening. So, there are different methods of improving the slope stability like say for example, if you put for the same slope or if I want to put soil nailing or reinforcement and all that. It is very difficult. Some are simple ways, cheaper ways would be that you try provide gabion baskets. For example, as you saw in the slope stability the fact of safety is low because there is, at the toe the factor of safety, if you put some load on the toe, then toe will not, slip surface will not come. So, you put increase. So, you can put gabion baskets and slope flattening also can be done.

So, some of these things people did, but then slope slackening and all these they are all very somewhat expensive. Normally, they are cheaper but in this case they ended up somewhat costlier compared to this technique. And another important thing, now a days people have been talking about, is the use of sustainable technologies in construction. The carbon foot print they call it. What is carbon foot print means? If you use, say for example, piles and piles involve the use of concrete and steel. And in the manufacture of concrete and steel there is so much of energy consumed. And the energy consumed

cannot be, you should not. So, they are all energy intensive materials and you have used. In the manufacture of cement, there is so much of pollution is caused environmental pollution is caused.

So, they say that if you are using some material that is appropriate, you do not carbon print. Foot print means the release of the carbon into the atmosphere is going to be less. Contamination or what is called emissions. We call it greenhouse gas emissions. Greenhouse gas emissions are going to be less, if you use E K G technology that is what they have said. So, these are all another important thing. It is very effective. Cost effective up to 26 percent and also that it was about 47 percent better compared to the other one's because of that conventional treatment options are more.

Say for example, gabion baskets. It involves the use of aggregates and not even a steel and all that. In fact, now a days the tendency or the thinking has been, you should reuse all the material available. You should not really try to, say for example, there is a concrete road in a village that, it is not good or you just recycle the concrete and use it. Do not ask fresh bags of concrete to come or try to use all the material, say for example, use fly ash. Do not ask soil to be removed. For example, what is happening, sand is removed from many places and reverse courses are even being affected because of the reverse sand removal. So, people are very serious now a days about all these things. And people are looking fly ash as a better replacement for sand and all that. So, there is some issues about induced current and all that.

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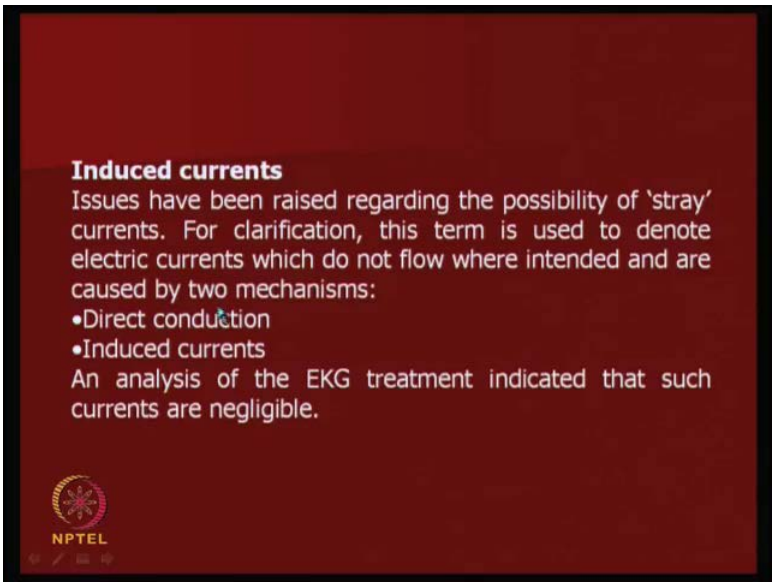

The essentially direct DC is quite useful and they will not be, people have seen that it is much useful. And definitely all the literature says that it results in reduced cost. It works under reduced accesses requirements, where the accesses requirements are less definitely. You do not need lot of bigger equipment. It is quite useful in many cases. And as I said sustainability benefits including reduced carbon foot print and elimination of the use of primary aggregates. As I said aggregates need not to be used. It is a very important thing. Now a days, say for example, if you are trying to construct roads in India, very good roads, how much of aggregate should be consumed? And if you want aggregates requirements and all the hills will not be there. I mean some hills, say nearby hills which are there for the town. If they are not there, definitely there could be lot of changes in the climate and other things. So, people are now very unhappy with, use of the high energy intensive materials. The other one was that it was helpful.

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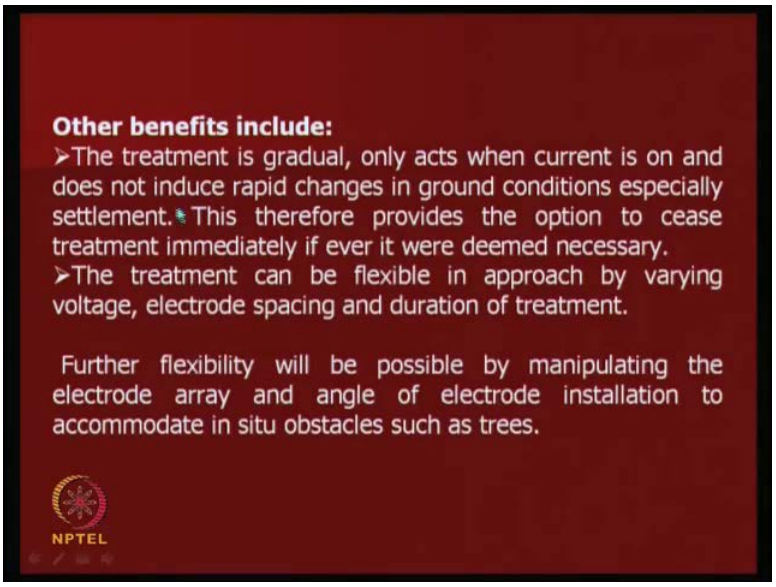

Actually, other important technical benefit is that settlements will be like, see this is not removal of water. Removal of water is there, but it is not accompanied by changes in effective stress. So, the changes in the effective stress are not leading to any settlements. So, whatever the settlements that we are thinking in the earliest stages because changes in settlement because of changes in effective stress are not there here. It is because of the changes in pore water chemistry, changes in the soil structure and all that. This is much more efficient. And the treatment can be very flexible in the approach by varying voltage electrode spacing and duration of the treatment. Further flexibility will be possible by manipulating the electrode array and angle of electrode installation to accommodate in situ obstacles such as trees. One can even do that. This is an another example. They have two more examples.

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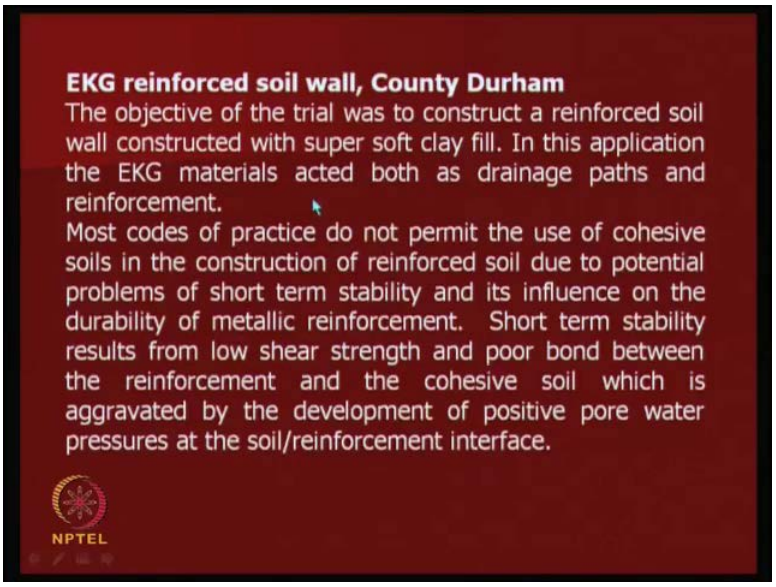

Reinforced earth wall was constructed. Actually in some places you do not even get sandy materials, back fill in a reinforced earth wall you should use sand as a back fill and you do not have a back fill at all place like UK and all that, everything is clay. So, how are you going to get sand? You cannot get sand just like that. So, you have to treat that soil, it is called super soft soil which means that it is like a liquid. So, when it is like a liquid, the shear strength is very poor and drainage is so low.

Now, with this E K G materials it will act as a drainage and reinforcement material and why because, this particularly some people have been doing lot of research. Actually particularly in UK. Because, India is a big country, You have sands and all sorts of aggregates and there is no problem at all. But, have something available to do something. Even it is expensive alternative but in some countries, you do not have aggregates. You do not have sand. How do you do this? So, what they did was that, so, as I said most countries do not permit the uses of cohesive soil in construction of reinforced soil due to potential problems of short term stability and influence on the durability of metallic reinforcement.

In fact, you have codes on reinforce soil wherein you cannot use some of these materials and only sand should be used. But if you use the clays, the problem is that it is cannot be stable because there is a low shear strength, poor bond between the reinforcement and

soil and there are. So, many issues there because of the development of poor pressures at the soil water interface and all that.

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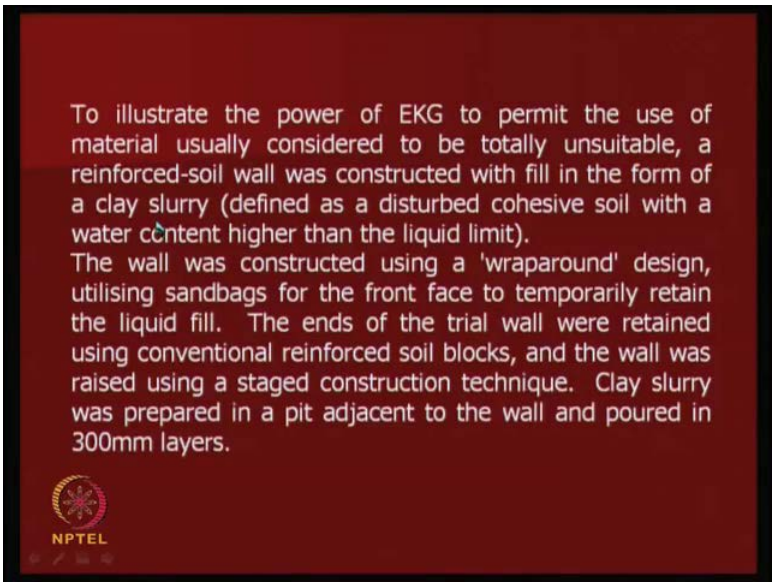

So, what they did was that they constructed an R U wall or reinforce soil wall in the form of the clay slurry. You can see that, it is a slurry dumped with a water content is higher than the liquid limit. It is very high. The wall was constructed using the wraparound design, utilizing sand bags for the front face to temporarily retain the liquid fill. The ends of the trial wall were retained using conventional reinforced soil blocks and the wall was raised using a stage construction technique. Clay slurry was prepared in a pit adjusted to the wall and poured in 300 mm layers. It is like this, how they are doing that.

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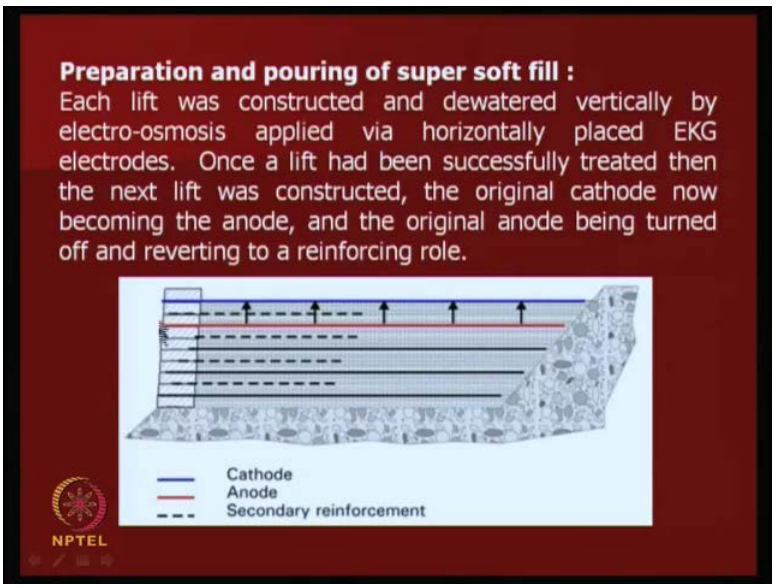

This is an R U wall that they constructed. Any how we will discuss it in detail. You can see that this is facing panel. You have a cathode there. You have an anode there. And you have some secondary reinforcement. So, main thing is that these materials are providing as drainage channels as I said and also somewhat reinforcement, little bit. So, preparation and poring of the super soft fill, each lift was constructed and dewatered vertically by electroosmosis applied via horizontally placed E K G electrodes. Once a lift had been successfully treated then, the next lift was constructed. The original cathode

now becoming anode. The original anode become, turned off reverting reinforcing role. So, they were able to even do couple of things here and quite effective.

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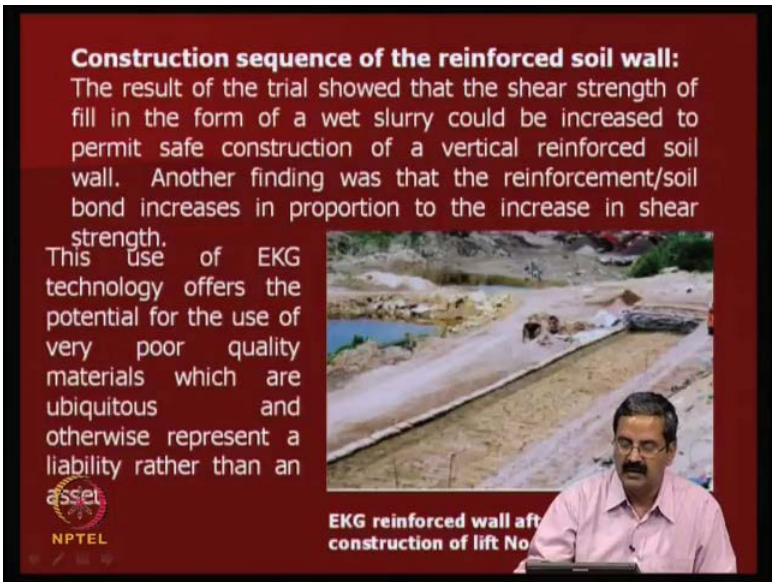

So, the technique was that, it was able to permit a safe construction. Another finding was that the reinforced soil bond increases in proportion to the increase in shear strength. The use of the E K G technology offers the potential for the use of the very poor quality materials which are ubiquitous and otherwise represent liability. See you are trying to make a liability into an asset using some of this technique. You can see the cracks here. You are constructing the R U wall here. So, it is all like this. Otherwise, if without this the liquid would have flowed and blocked all this area. It is a very interesting example here.

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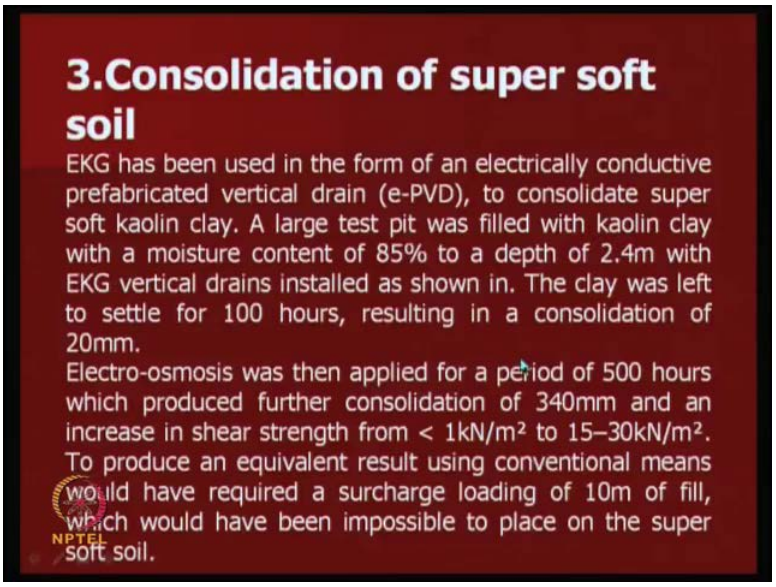

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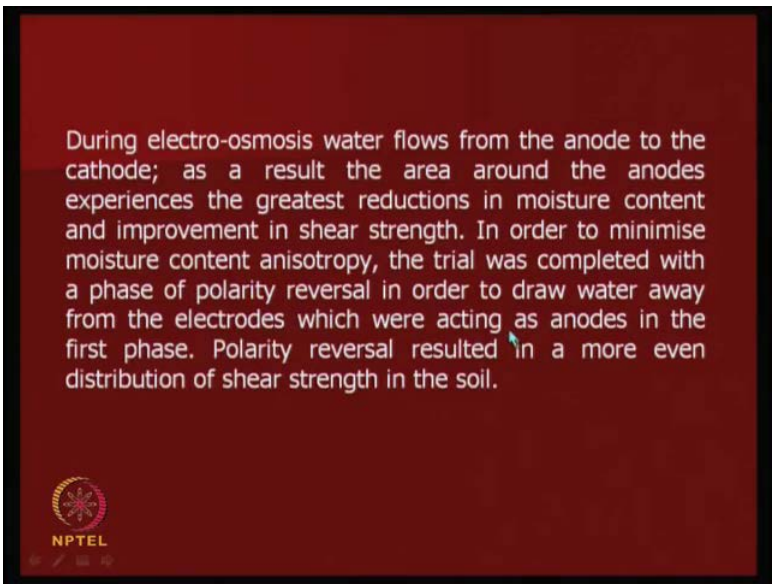

We also talked about P V Ds just now. Here also even you can accelerate the consolidation of P V Ds also using this. And there was an experiment done. And Electroosmosis was then applied for a 500 hours which produce further consolidation of 340 mm and an increase in shear strength from less than to 15 to 30. It is quite excellent. So, they are able to observe some of this, whatever you observed the greatest water reductions in moisture content and the improvement in shear strength.

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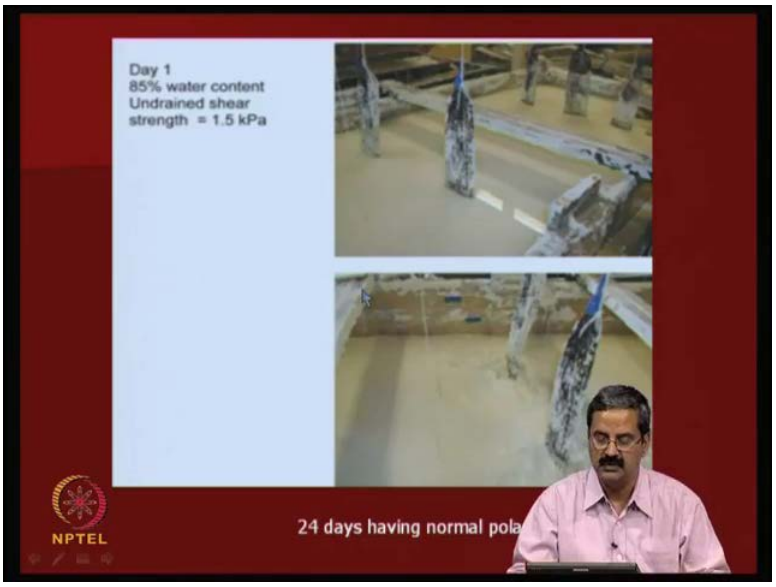

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And they are able to do some reversals also which were able to quite you can see that super soft soil. Take the slurry in this thing. And then put this prefabricated vertical drains and undrained shear strength and all that, is there. For day 40, shear strength is about 35 K p a. You can see that little harder. It has come down, water content has gone down. And there is an increase in shear strength. So, even they have been quite effective and the beauty is that, it has a number of potential advantages over conventional wick drain technologies. It is very fast, compared to fast definitely, because electrical

gradients, no surcharges is required. The effectiveness of the e-P V D is unaffected by kinking or smearing as consolidation proceeds. So with this, I conclude.