Environmental Geomechanics
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Lecture No. 52
Electrical characterization-II

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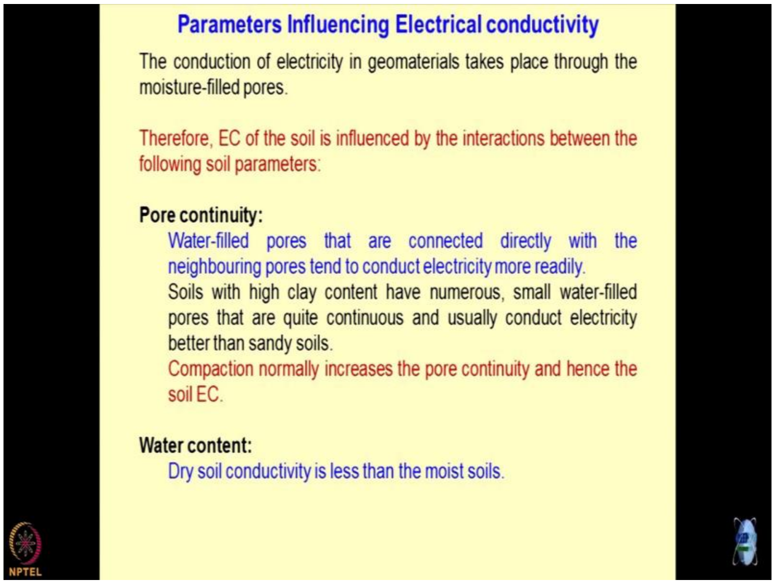

A bit of theory of why these parameters influence the electrical conductivity of geomaterials because we are all aware that the conduction of the current is going to be through the fluids which are present in the pores provided the soil grains are bad conductors of current. So, most of the time the silica being a good dielectric material, it will not allow passage of current easily unless the particles of the sands are coated by cations or by some conducting layer of letting us say bacterial skim.

So, the moment this happens, the conductivity could be more on the surface rather than through the pores. So, these concepts are being utilized nowadays in designing different types of filters. So, these are the parameters which interplay or influence the electrical conductivity. The one is the pore continuity whether the pores are continuous or they are not. So, I will discuss this in the next lecture, where we will define the pore continuity.

If pores are conducting are continuous, the flow of ions will be continuous, and the conductivity is going to be much more next is the water content, the more the water content which is present in the soils. The soils will be more conducting and if I put more contaminants in the soils, particularly the contaminants which have ionic species then also conductivity will be more so, dry soil conductivities less than the moist soil.

I think I discussed the mechanisms and the details. Another interesting thing is that when the soils have high clay content on it, and small waterfilled pores that are quite continuous and these type of systems would conduct electricity better than the sandy soils. We compare the hydraulic conductivity of two soils; this means if the soil has contaminants. Yes, the answer is Yes because imagine within the sample if I am missing the electrical properties at two different points.

When I can see how the contaminant front is migrating, I can always establish that uncontaminated soil conductivities are going to be less as compared to the contaminated conductivity. But, the contaminants will be ionic then it will show. Ya, see the simple presence of water itself increases the conductivity. When you have more it conducting content in the water, the conductivity will increase further so; this concept can be utilized to detect the state of materials.

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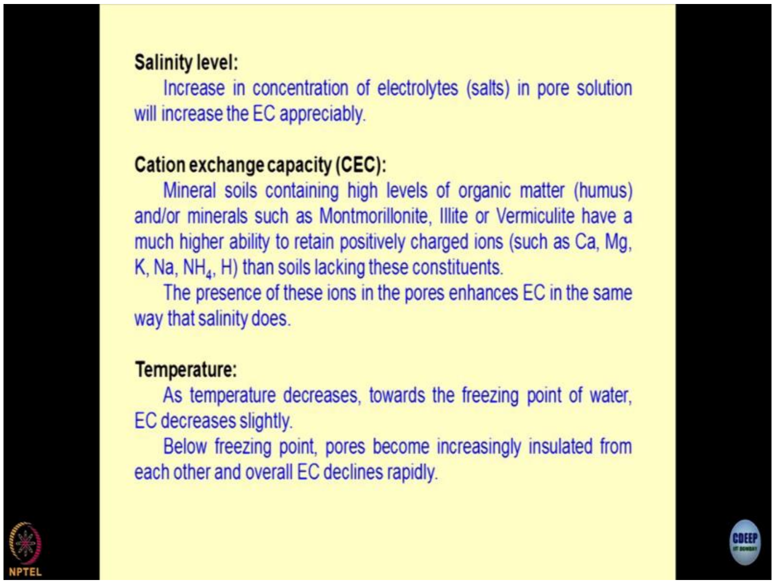

It is all about the conduction of the electrons or the current. Salinity level. So, when the more salts are present in the pores or when more electrolytes are present in the pores, the electrical conductivity is going to be higher. Similarly, cation exchange capacity for the soils which have very high cation exchange capacity their conductivity is going to be more nut the soils which have more organic content in them conductivity is not going to be higher then comes the effect of temperature.

As temperature decreases towards the freezing point of water, the electrical conductivity decreases this concept we are utilizing to capture the phase transition, which occurs in the geomaterials. Now, a phase transition could be freezing, or this could be boiling, or this could be precipitation of chemicals which are contaminating the soils and because of the pH change and environmental conditions change they might precipitate in the pores.

So I am sure this must be given an idea that electrical properties appear to be a sort of a hidden I, for the technologist would like to see what is happening inside the system. Now, as the water freezes, its conductivity is going to decrease because the ionic movement decreases. So if you want to differentiate between the 3 to 4 to 5 phases of the soil mass, I think this is what you were asking some time back you start with a 3 phase system, where you have soil particles or the grains, minerals, then water and the air.

If I freeze the sample, what is going to happen some part of the water which is present in the post might get frozen until some part remains as the fluid water. So I have created four states. So this is a phase transition, which is actually now if I want to see how the freezing front is migrating in the geomaterial. Again, I can use the concept of electrical conductivity. So the dielectric contrast or the in impedance contrast or the resistivity contrast within the sample is going to tell me what is happening.

Where in the soil sample and this concept is used for locating the reservoirs of hydrates in nature? So, what we call them as resistivity plots or resistivity logs so if you do the resistivity log from top to bottom, you can identify the places where the hydrates are formed.

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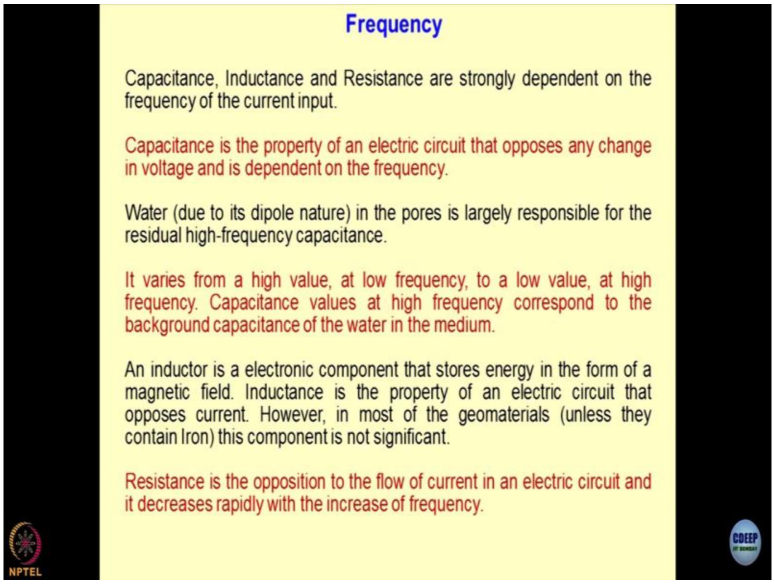

A little bit on the frequency of the current because this governs the whole process and the mechanism. Though I have talked about the low-frequency domain and the high-frequency domain, I am sure in your 10+2 physics you must have studied that how the capacitance, inductance and the resistance depending upon the frequency of the current is it not. So, this concept can be utilized to see whether material is conducting or an insulator.

So for insulators, the dielectric constant is going to be higher as compared to the conductors. Is this okay?. Because their charge storage capacity is high. Similarly, the soils which have very high water content would exhibit very high dielectric constant. So suppose if I am doing resistivity mapping and if I get a place or a geomaterial strata where the dielectric constants are extremely high, one of the interpretation is that these are the natural aquifers.

So, when I do satellite imagery, I get the same signals. For the places where the more moisture content is present, I will be getting higher dielectric constant as compared to the places where the less moisture is present, and hence the less water is present in the soils. Water is a polar dipole material. So, they get resonated, when you use high frequencies and hence the conductivity increases and hence the dielectric constant decreases.

So, this concept is used most of the time for analyzing the results of the geomaterial. Most of the time what we do is we try to develop the models all the materials which are electrical models by using the concepts of capacitance, inductance and resistance and we transform the soil mass and the geomaterials to an electrical circuit, and this is how the further analysis is done, and this would answer your question that how will you differentiate between the size which is contaminated or not.

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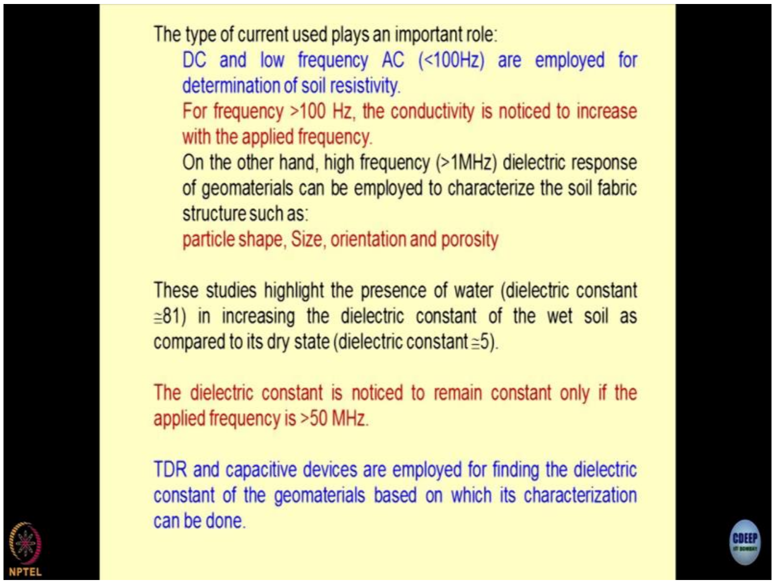

So, as we discussed earlier now, DCs and ACs have their own strengths and limitations. AC is supposed to be a good current or quite a useful current as far as the microstructure mapping of the size of the geomaterial will be concerned, but I am sure you will realize that when you go beyond hundred hertz, it requires special equipment is, and it requires special paraphernalia also. So, the entire process of measurement of electrical properties changes when you switch over from low to high frequencies.

So, all these get added up, and then it creates background noise. So, unless your experiments are being done in a shielded environment when you speak, that frequency gets added up, or there could be an interference with the frequency which is in the background, and that might influence the results. So, most of the time you use the frequencies in the megahertz or the gigahertz range, curtsy modern-day electronics, the cost of these gadgets are not very high.

But and very high is also a very relative term. So, a modern-day impedance analyzer will not cost you less than 50 lakhs. So, the whole research is based on gadgets which are quite expensive, but they are useful in creating the micro-mechanisms. There are efforts which have been done to capture the orientation porosity, shape and size of the particle which I discussed in the past also.

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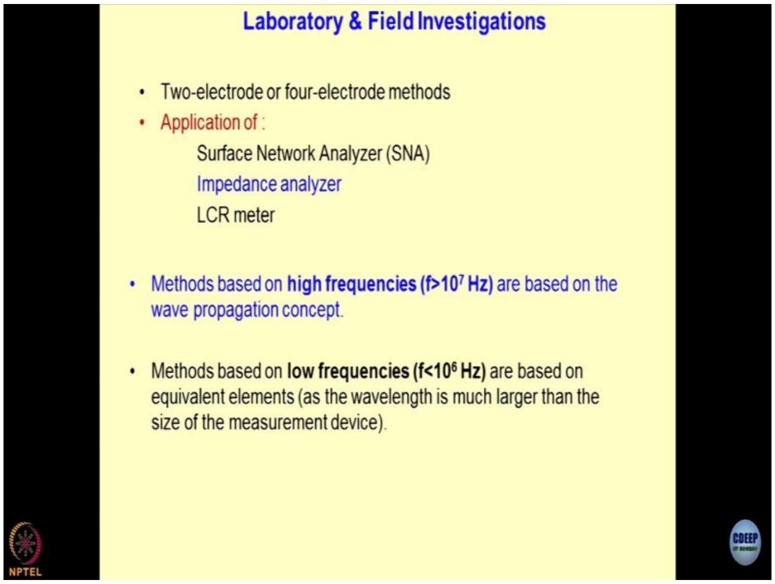

I will come to the laboratory and field investigations. Simple experiments can be done in the laboratory by adopting two electrodes configuration of 4 electrodes. And the applications are sometimes we use surface network analyzer Also, if you have done a course in electronics in your undergraduate, you must have used this SNAs, surface network analyzers, if you want to find the fault in a cable system or where there is a short circuit which has occurred.

You can use the network analyzers, and you can find out the fault in the system, and this is where we use the impedance analyzer also, which I was talking about or an LCR meter. So, LCR meter and impedance analyzer these are the devices which are used to find out the impedance of the sample at very high frequency. LCR meters basically give you the L components C component and R component. These are inductance, capacitance and resistance of the soils up to 40 megahertz range.

We use the concept of wave propagation when we deal with the megahertz regions of the frequencies that you use, and we talk about the interference of the waves, however, when we deal with the low frequencies which is less than a gigahertz range, we use the equivalent element method. I will come to this.

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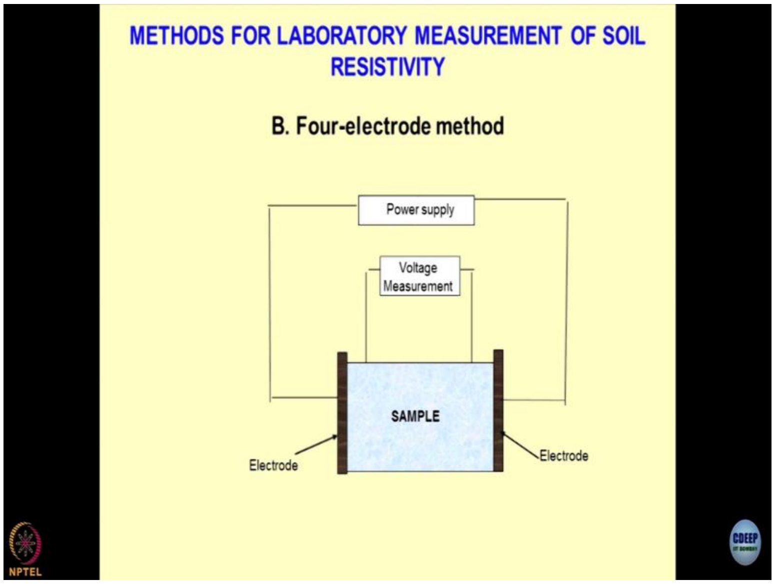

So, this is a simple to electrode method, take the sample of the geomaterial, sandwich it within the electrodes, and the electrodes are connected to the power supply. So, this power supply passes current to the sample, and you can measure the voltage across the sample, and this becomes the two-electrode method. The biggest problem with this technique is if you are using DC current heating up of the sample might occur.

And you must be realizing that when I keep the sample between 2 electrodes and apply DC, what will happen whatever the polarity of the electrodes is the sample gets oppositely polarized. So, there is a reverse electric fuel that gets generated in the sample. I hope you must have done it in your 10 + 2 simple electronic circuits. This concept can be utilized to analyze the samples and to find out their properties; I did a lot of consulting work by using samples from different, industries, this could be the sample of ore, this could be the sample of a tile, this could be the sample of the granite rock, this could be samples of the concrete, soil mass and whatever. So, the biggest problem as I said is when you apply a voltage across the electrodes, the sample gets oppositely charged. So, if you want to come out of this situation, what you should be doing, you can go for a four-electrode method. How do you do profiling of the soils for obtaining ya wester Gard's method? Exactly. So, this is the geophysical method, so, what we do is we apply the power supply, we apply the current to the sample, and we measure voltage within the sample. So, this becomes four electrodes one electrode two-electrode three and the fourth electrode, these type of measurements are more precise as compared to the two electrode method. Because even if the polarization occurs at the interface of the sample, I can utilize the properties of the sample which is not connected with electrodes directly. Simple devices, but they reveal a lot.

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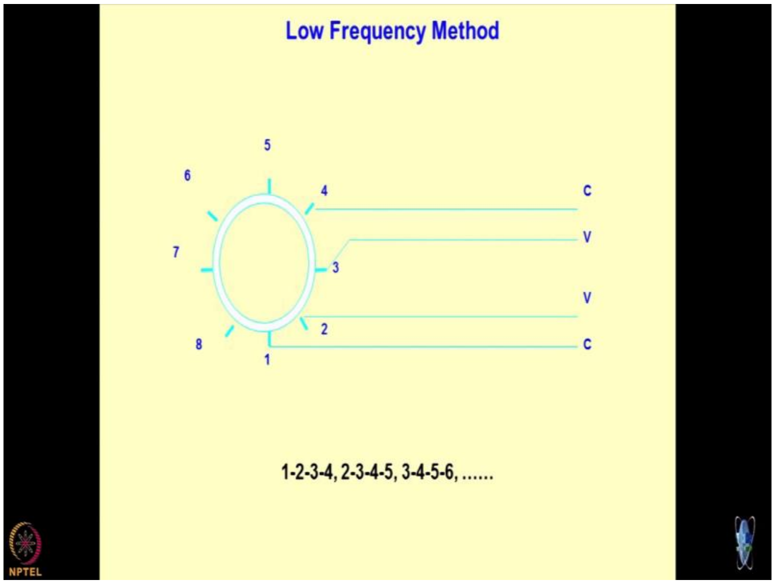

Based on this, some people have done a consolidation test by inserting electrodes into the odometer cell. And what they have done is they have placed let us say eight electrodes. These are point electrodes, small pins which have been inserted into the sample holders or the odometer cells of certain diameter made up of stainless steel. So, this becomes an electrode and what they have done is they have measured the properties of the soil across four-electrode.

So, 1 and 4 electrode is the current-carrying electrode, and the voltage is measured in between. So, this procedure is repeated by changing the electrode combination so, 1234, first time, w345 Next time 3456 next time and so on, and whatever properties are obtained we can be, we can take the average where this has been used. So, conditional oedometer results have been compared with how the void ratio changes and how these changes influence the dielectric constant of the material.

So, dielectric constant as a function of log(σ’) is going to be very useful if I am let us say monitoring, how a building is settling down in real life. So, suppose if I place the sensors below the foundations and as the consolidation occurs, I can dry relationship between e vs log(σ’), which is equivalent to dielectric constant versus log(σ) and dielectric constant can be monitored easily.

And this is what is going to tell me how much settlements are going to take place in the foundations because that is related to the density of the geomaterial and void ratio. So, these type of tests has been done at low frequencies by several people.

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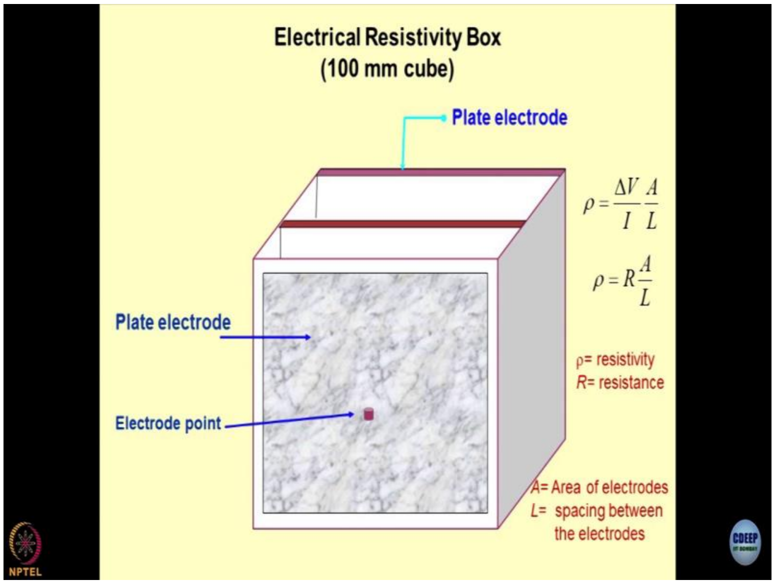

My M.Tech. Students’ long back, particularly the group of students, Rohini and Sneha Kurian and Reshma, they worked on these type of setups which were created by them. We took a small box; we placed electrodes from inside across the 2 sides of this box. And then we made a small container which is a sort of a capacitor. And then we use this system for characterizing the geomaterials for measuring the electrical properties.

The beauty of this system is that you can also decrease the spacing between the two electrodes read letters, and you can generalize the laws which are being proposed. So, you can show how much is the dependency of the electrical properties on the distance between the 2 electrodes, because if you remember the equation of a parallel plate capacitor, so capacitance is proportional to the area and inversely proportional to the distance between the two plates.

Maybe this is one of the answers to your question I can calibrate the setup by using some known materials first and then you can use those results for geomaterial characterization. And this is how the calibration is done; we can find out the resistivity of the geomaterials by filling up this box with some known fluid, mostly sodium chloride potassium chloride is used, and A/L becomes the cell coefficient.

So, whatever voltage you are applying whatever current you are measuring, if the area of cross-section and the distance between the electrodes is known, you can find out the resistivity. So, I can place the soil mass in between, and I can measure the electrical properties of the soil mass. This is how we started our studies.

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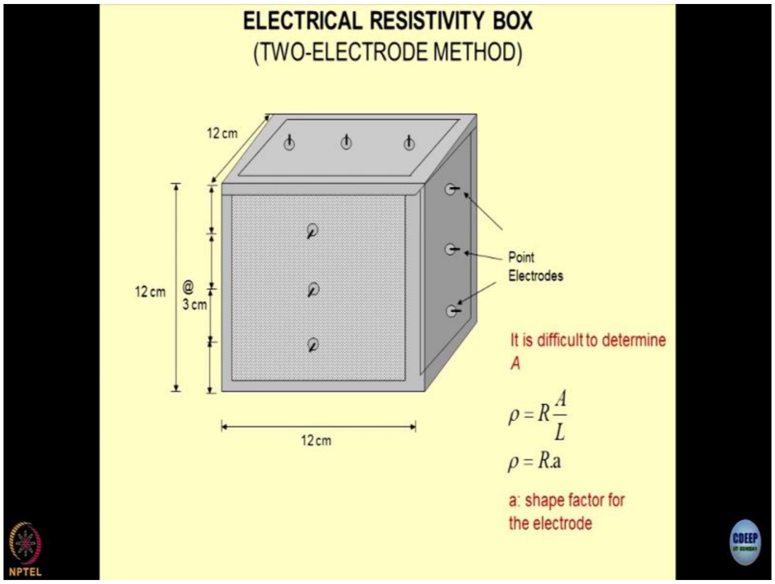

We went ahead with another type of box where we embedded three electrodes on each face of the box. And then we measured the electrical properties across the pair of electrodes. I hope you can realize that the efforts were on to find out the equivalent circuits for the geomaterials because this point electrode and the one who is hiding behind would form a pair of electrodes. So, across the vertical plane, I can get three values of the resistance and the capacitance and inductance.

So 33639 I will be getting nine values of the parameters, and then I can average them. These setups look very simple, but there was a time, and we took enough time and efforts to synthesize them, and the credit goes to my master's students, and they created all these facilities. In this case, because this is the point electrode, you cannot obtain the area of cross-section of the electrode. So, we can still go ahead by drawing some relationship as coefficient 'a' which is the shape factor for the electrodes. So, this type of mathematical manipulations can be done too often the results.

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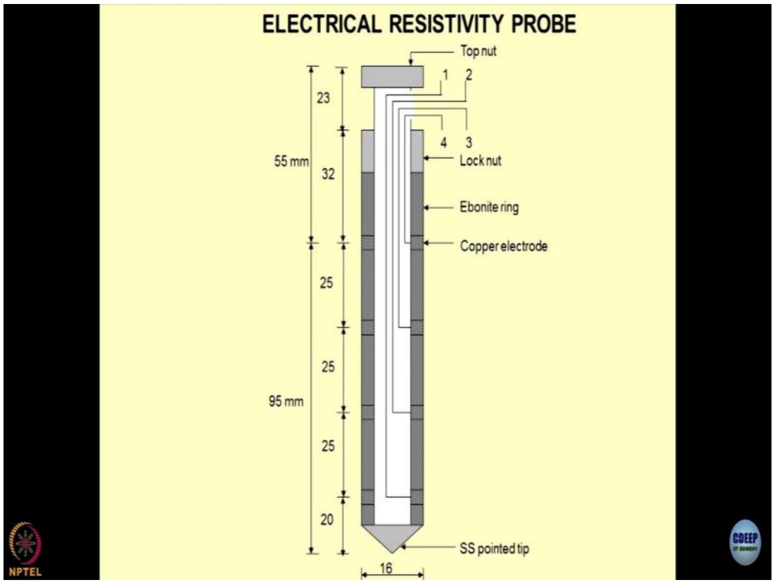

My student Reshma created this probe which is now Dr Reshma. This is an electrical resistivity probe, very interesting way of measuring the electrical properties of the geomaterials in their compacted form, what we have done is we have taken a cylindrical rod, and on this cylindrical rod, we have placed four electrodes. So, this is one ring electrode, another ring electrode and another ring electrode.

So, four ring electrodes have been fitted and so, that they do not get short-circuited, what we have done is we have put ebonite ring in between. So, this is the outer electrode this is an outer electrode, which is connected to the current and this is the inner electrode, and this is the inner electrode, we measure the voltage across this. So, truly speaking this is a four-electrode method which I showed you which resembles like what I discussed sometime back.

This is the one; you are applying current to the outer electrodes and measuring the voltage across the inner electrodes. So, once this type of probe is ready this probe can be inserted into the soil mass, remember we had designed the thermal probes these are similar to the ones the concept remains same, and you can find out what is electrical resistivity of the materials. For easy insertion into the soil which is compacted at the bottom portion of the probe has been tapered.

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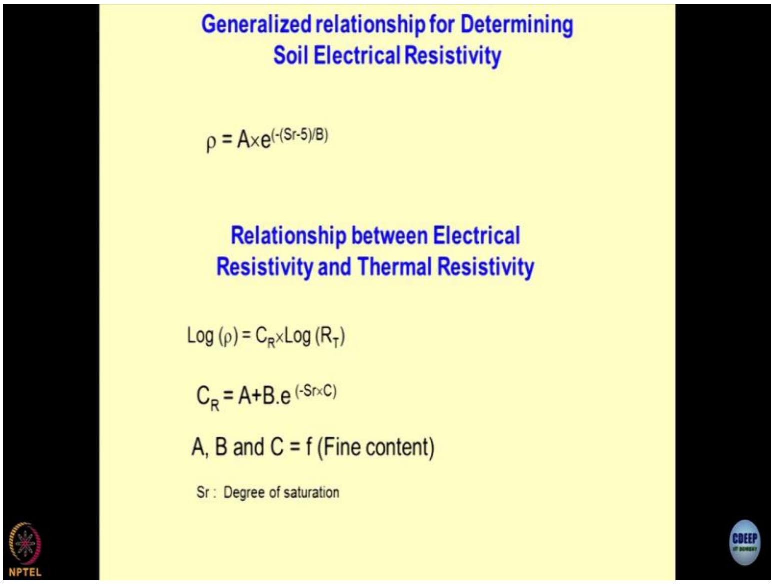

Based on these simple experiments, we obtained the relationship between saturation and resistivity of the soils. I hope this was the first effort which was done by researchers in geotechnical engineering fraternity to relate saturation and density, sorry resistivity, and nowadays we find that these type of studies have become so, useful when we have gone for advanced material characterization. This is a relationship which deals with the electrical resistivity as a function of thermal resistivity, and CR is some coefficient. So, this coefficient can be defined as a function of saturation.

A and B are the material properties. So I am sure you will realize that these simple experiments can also be utilized for characterizing the geomaterials provided their electrical properties are known. So, this also proves the point that electrical resistivity can be utilized to differentiate the states of the material and to characterize them. And subsequently, we related A B and C with the fine contents and fine contents is the one with differentiating between the coarse and the fine-grained materials.

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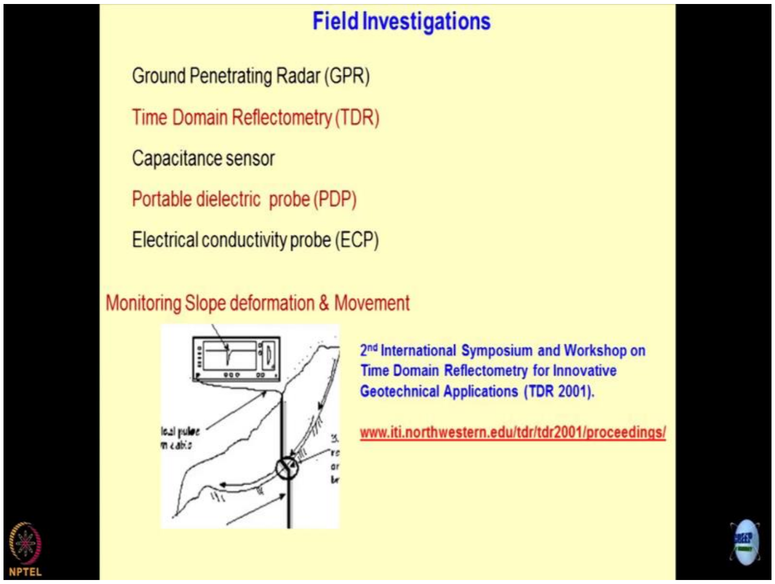

Some field investigations which are becoming very popular in these days, where the GPR is the leading example, from ground-penetrating radars, TDRs are being used for finding out the subsurface profiles of the material and the capacitance sensors which are used for finding out the degree of contamination of the geomaterials. There are portable electric probes also which are available in the market.

And all these techniques are being utilized for monitoring the environmental impact on the geotechnical structures, and particularly landfills would be a good example. So, there are few landfills where we have adopted these techniques for profiling the state of material which is getting decomposed in the landfills one of my PhD scholars, Dr Agnes, she has worked in this area, and you can go through her papers where the profiling of the landfills and when the landfill should be biomined.

This question has been answered by using the TDR probes, and this type of concept was given by Dr. Patil, one of my another PhD scholars, who has used TDR probes and the capacitance probes to relate the degree of decomposition of the municipal solid waste in the landfills. There are some electrical conductivity probes also which can be used in the market. There are a lot of specialized conferences which are being done on the application of TDRs.

This is a beautiful example of why TDR is becoming so popular almost 18 years back there was an International Symposium and workshop on TDR applications in geotechnical engineering and what is shown over here is if you want to monitor the movement of the slope, and if you want to design the early warning systems, the TDR probes can be utilized. So, what they do is they drill the bore logs and or the boreholes, and in these boreholes, they place the TDR cables and once the movement of the slope starts the cable gets stretched, and because of the stretching of the cable the resistance is a change or the electrical signals change. These signals are recorded on the oscilloscopes. And then you can make sure whether the slope is stable or unstable. Now, this concept can be utilized for monitoring the settlements of the building also. So, wherever the monitoring is being done in today's professional activities, these sensors are becoming quite useful, particularly TDR and all.