Environmental Geotechnics
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Lecture – 44
Electrical characterization – 2

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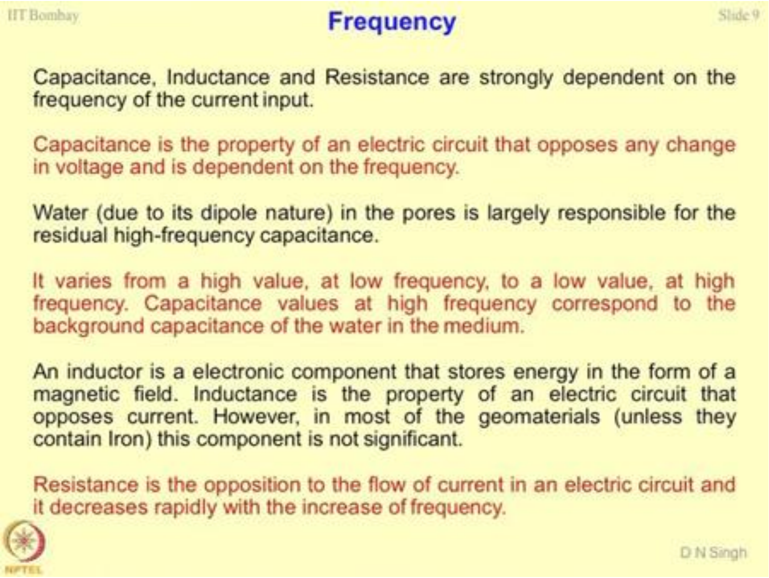

The most important parameter is frequency as we seen in the previous slides what happens because of frequency. We talked about three components of a geomaterial that is capacitance, inductance and resistance and that is why the instrument which is used and which I had shown you sometime back is known as LCR meter. So, L is nothing but inductance; C is nothing but capacitance; R is nothing but resistance. So, a system or a device which measures LCR components that is capacitance, inductance and resistance is known as LCR meter and these parameters will strongly depend upon frequency of the current which has been input. Simple example which we had just discussed, higher the frequency of AC, what happens to resistance component it disappears and then these two components come into picture, clear?

What is capacitance? Capacitance is the property of an electric circuit that opposes any change in voltage and is dependent on the frequency, basically the charge storage capacity of a system or a circuit. Water due to its dipole nature in the pores is largely responsible for the residual high-frequency capacitance. Can you correlate this phenomenon to something which most of the geologists are doing? If water has this fundamental property what is the geologist do? They try to map water table, is it not or water reserves.

So, more charge carrying capacity should also correspond to more water in the aquifers. Why? Because water itself is a dipole material. So, it is charge carrying capacity should be more. So, if you apply this concept in day to day life the aquifers where water is more should be having very high capacitance in terms of electrical resistivity measurement. So, this is how using one component of the material in terms of its electrical property you can identify its characteristics. Is this part clear?

So, basically it varies from a high value at low frequency to a low value at high frequency. If you remember in your physics you must have taught $1/(G\omega C)$. Do you remember or you have forgotten? The resistance offered by a capacitor; do you remember? $R+1/(G\omega C)$ is the total impedance of the resistance of the circuit. I will talk about these things later on. So, $1/(G\omega C)$ terms at very high frequency what is going to happen? This term becomes negligible; at lower frequency this becomes very high. So, capacitance value that high frequency corresponds to the background capacities of water in the medium and using this concept you can use TDR probes or the FDR probes for finding out the amount of water which is present in the pore volume.

And inductor, what is the inductor? Which shows inductance for that matter I am sure you must be knowing how an inductor is depicted, a coil. So, an inductor is an electronic component that stores energy in the form of a magnetic field. Inductance is the property of an electric circuit that opposes current. Lenz's law – if you move current capacity carrying inductors close to each other, what happens? Either current can be produced the electromagnetic effect or vice versa, if the electromagnetic effect then current can be produced. This is how you know the coupling of the transformers.

However, in most of the geomaterials unless they contain iron, this component is not significant. So, this becomes another important tool to differentiate ordinary soils with the electric soils. Electric soils will have more iron component. So, the inductance is going to be much more as compared to ordinary inorganic soils which will not have any iron component.

What is the resistance? The resistance will be opposition to the flow of current in an electric circuit and it decreases rapidly with increase in frequency of current. So, that is how actually frequency plays a very important role and what researchers are trying to do is they are trying to look into the response of the geo-material in a complete frequency range starting from very low frequencies like 100 hertz to gigahertz and this is what is known as again frequency spectroscopy. You are seeing the spectrum of the material how its properties change because of the frequency effect.

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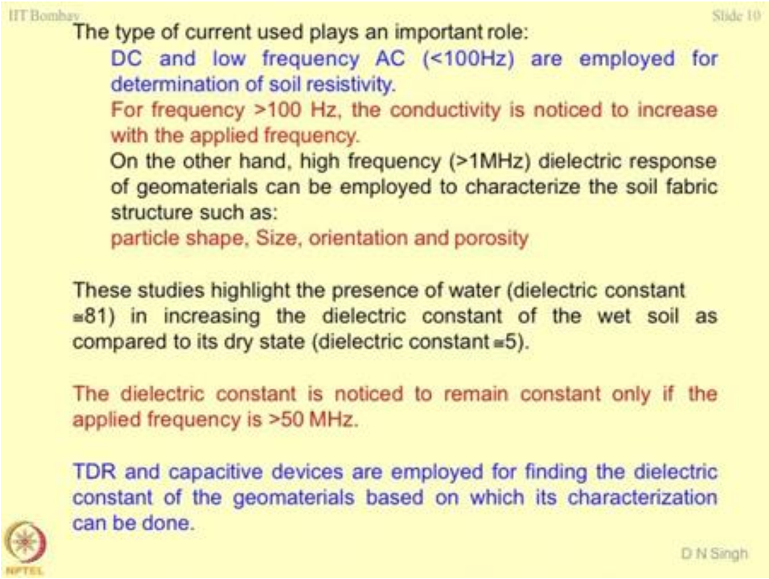

So, the type of current used in the analysis plays an important role. DC and low frequency currents less than 100 Hz are employed for determination of soil resistivity. So, most of the resistivity surveys they are not very expensive alright. They will use low AC current or DC current. For frequencies more than 100 Hz, the conductivity is noticed to increase the applied frequency.

On the other hand, high frequency that is one megahertz the electric response of geomaterials can be employed to characterize this soil fabric structure and you talk about soil fabric structure. These are the three issues particle shape, size and orientation and porosity. This is what Suchit is doing. He is using high frequency AC current more than 1 MHz and then he is trying to study the particle shape effect, size effect, orientation of the grains and their porosity.

These studies highlight the presence of water with dielectric constant 81, in increasing the dielectric constant of the wet soil as compared to the dry state of the soil for dry state of the soil dielectric constant would be 3 to 5. The dielectric constant is noticed to remain constant only if the applied frequency is more than 20 MHz. Now, TDR and FDR devices that is the capacitance flow and a TDR flow they are employed for finding the dielectric constant of geomaterials based on which the characterization can be alright. So, they work all in this based on these concepts.

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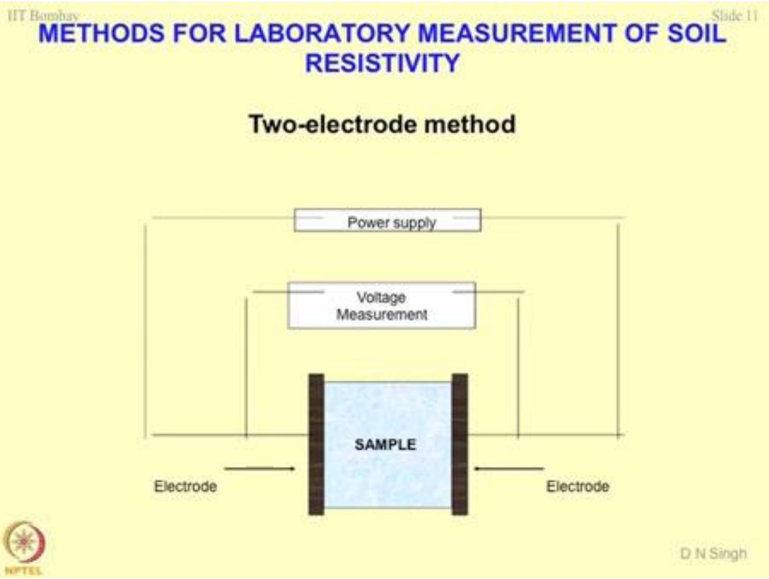

Just quickly to take you through the methods which are normally used the simplest possible method is known as two-electrode method. Take a sample of a geomaterial put it between two metal electrodes, apply power supply and measure the voltage across this, clear? So, depending upon the voltage and the current which is passing through the circuit you can find out its resistance. You know the area of cross-section of the sample, you know the edge to edge difference between the electrodes and you can use the classical equation: $\rho = R. L/A$ to get the resistivity of the material.

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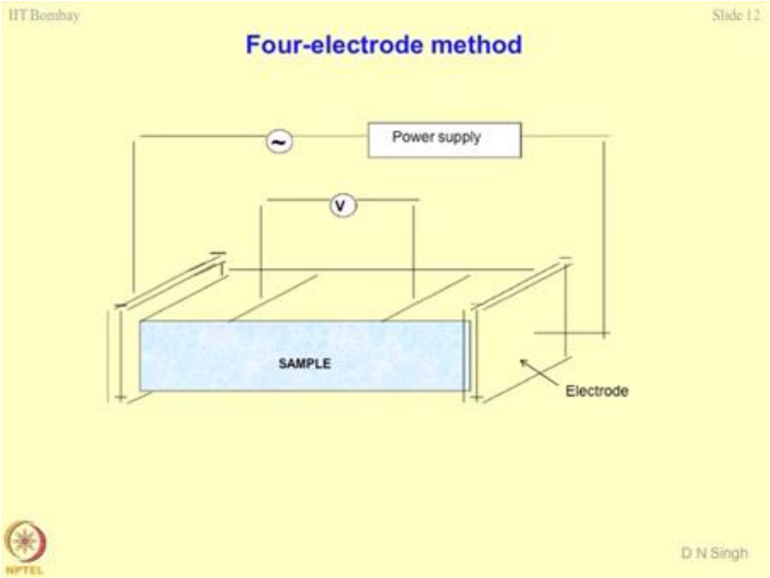

Unfortunately, the two-electrode method has a problem associated with electrode polarization. Whenever you are applying voltage across two electrodes what happens, the electrode themselves become charged and hence the material is going to material is in contact with the electrodes is going to be opposite to the charge. Now this is what is given as electrode polarization and because of this what will happen slowly and slowly the current will not migrate into the material or there could be a reverse current which is flowing through the material into the electrode which is not possible.

So, to overcome that what people have done is they have gone for four-electrode method. So, take the sample apply current across the two external electrodes and measure the voltage in between. Now, can you tell me this concept is used somewhere else in engineering? Where else you use this concept? Resistivity profiling Schlumberger method, correct that is right. It is nothing, but the Schlumberger method.

What do you do; resistivity profiling. So, you apply the current to the outer electrodes and measure the voltage in between. So, if you know the voltage across two points, if you know their distance you have a relationship with which you can find out the resistivity of the system so this is the field method and you can change the spacing of the electrodes.

Here this is a laboratory method what you can do is, you can measure the voltage in the sample across two points when some electric field is applied across and by measuring this voltage you can work out its resistivity. So, this is known as four-electrode method because we have two-electrodes which are outer and another two which are inside the material. Now, this method is better than the two-electrode method why because electrode polarization is not possible in this case. Electrode polarization will always take place at electrodes, but what you are doing is a measuring the voltage in the material and hence there will not be any polarization.

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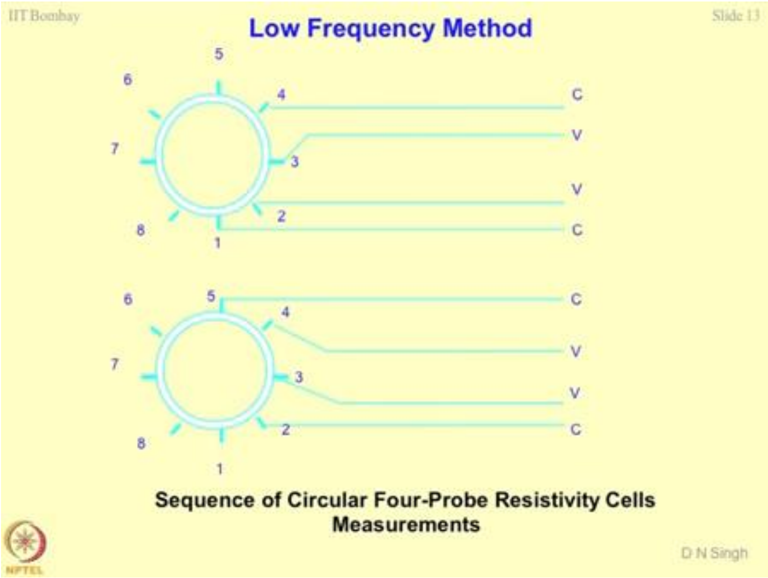

Now, this is a technique by which you can measure the electrical properties by using four-probe resistivity cells. You think of a situation where the cell corresponds to the odometer cell alright and this odometer cell is fitted with eight-electrodes, 1 2 3 4 5 6 7 8 and then you are measuring voltage across two points, where 4 and 1 correspond to the current electrodes. So, because of the application of the current across 1 and 4, I can measure voltage across 2 and 3; it is nothing, but the equivalent of the previous method. So, in this way by changing the location of the current and voltage electrodes you can profile the entire sample.

So, next round 3 and 8 can be taken. You apply current across 3 and 8, and measure the voltage across 1 and 2 ok. So, the material anisotropic can be studied very easily by using this type of concept. What people have done is they have done consolidation studies by implementing this type of a cell. So, what you get it e versus log sigma prime that relationship, at the same time you get sigma prime versus the resistivity and dielectric constant of the material clear. So, it is an interesting way to find out how material anisotropy and its volumetric deformations can be linked with each other.

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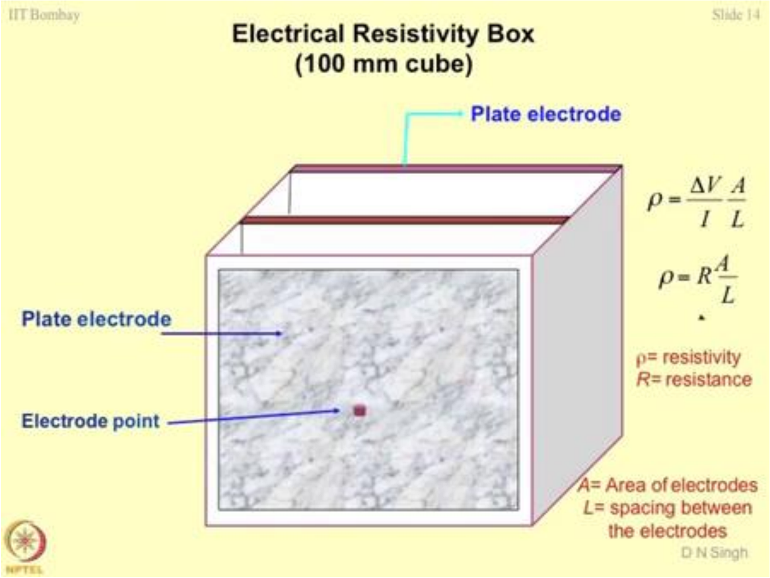

I would like to show you some of the in-house developments which are done by my students. This is a two-electrode method where we took two plate electrodes in a cubical fashion which forms a 100 mm cube. So, there are two-electrodes one is on the front phase another one is on the backside phase and then this is the electrode point. So, which you can apply the voltage across this and this phase and fill up the material in between Clear.

So, you know the volume of the soil mass, you know the area of cross section; you can divide this box in different parts by shifting this plate electrode to another distance. So, what you are doing is we are changing the distance between the electrodes for non-conducting materials and then by using simple equation:

P = (ΔV/ i) (A/L), where A is the area of cross section, L is the length between two-electrodes you can work out the resistivity. (ΔV/i) is nothing, but the resistance, A/L is the geometrical properties of the electrode and rho is the resistivity. So, this is the where we started our studies on characterization of geomaterials.

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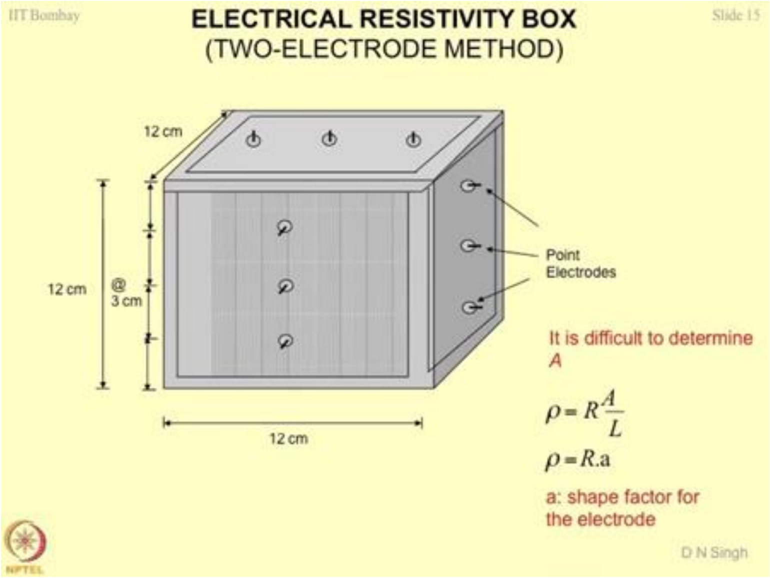

Later on this plate electrodes were changed to point electrodes because plate electrodes has their own problems associated with them. So, this was again a cube of 12 centimeter embedded with point electrodes on all the phases, we wanted to study the material anisotropy due to compaction. So, we are measuring electrical resistivity in the x-plane, y-plane, z-plane and then we wanted to see what type of structure of the soil can be created just by compaction it.

However, you have noticed that here it is very difficult to find the area of cross section of the point electrodes. Because these are the points. So, what is the property of a point area of cross section tends to 0, is it not? So, there is another way of doing this analysis. If you use this equation: $\rho = R. A/L$, if I replace this term A/L with small a, where A happens to be some coefficient shape factor. So, what I need to do is I can fill up some liquid in this box and this liquid will be having known resistivity value. I can measure the resistance across two electrodes across each other and I can get the parameter here. So, this is how you can calibrate this box. I will show you how calibration was done.

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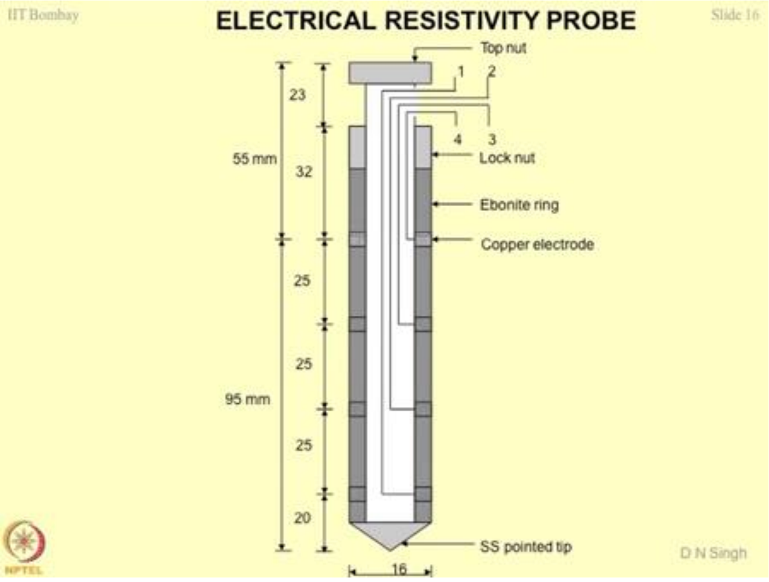

This work was done by Reshma one of my Masters students. She developed this probe also in the box. This probe works on the principle of four four-electrode method. You imagine shaft made up of the gahnite where the copper electrodes are fitted 1 2 3 and 4. So, the motivation behind developing this probe was again the four-electrode method where we use copper electrodes in such a way that the ebonite rings are placed in between two sets of electrodes. These are the rings and these rings are connected to external circuit. You can apply current across the external electrodes and these are the voltage in between, alright.

So, this was a probe which can be inserted in the soil mass and then you can do resistivity profiling.

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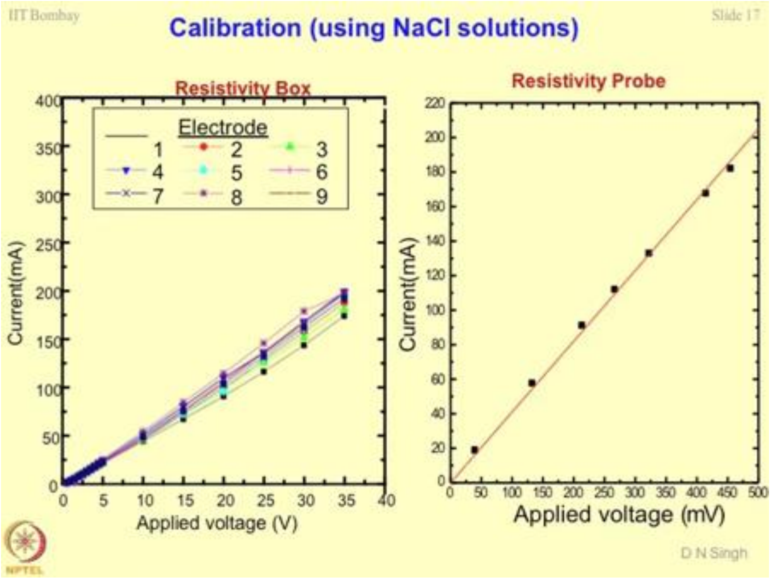

The calibration can be done in this way; as I said you fill the box with a solution of sodium chloride of known resistivity. What we will see is that the current and applied voltage they will be varying in a linear fashion. Similarly, the probe can be dipped in a column of sodium chloride solution. You can draw a relationship between applied voltage in the current.

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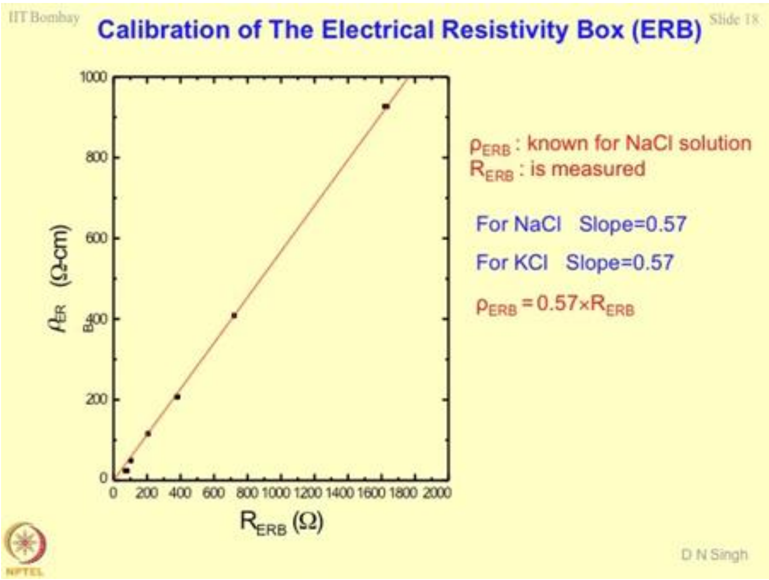

And, then if you know the resistivity of the solution and if you know the resistance which has been measured by using the box resistivity box you can draw a relationship like this. ρ_{ERB} is known that is the solution a specific solution which you are using it is conductivity is known or resistivity is known. Resistance using the box can be measured. You can obtain the slope of this line and this slope of the line will give you relationship between resistivity and resistance.

So, once you have done this calibration you can go ahead with geomaterial characterization, fill up the box with the geomaterial of your interest. You have this calibration with you, what you are measuring is resistance between the two electrodes, multiplied by this factor and you get the resistivity of the material.

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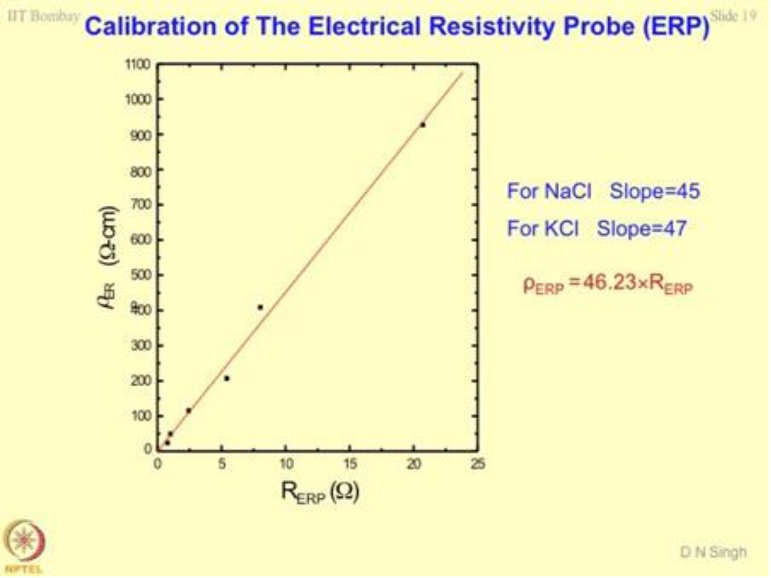

Similarly, for the case of the probe you can do this calibration and again you will get this relationship. There if you measure the resistance across the two copper rings multiplied by this factor it will give the resistivity. So, first you insert this probe in a sodium chloride solution, calibrate it and the same probe can be inserted in a geomaterial. The parameter, multiplication factor remains the same. So, if you measure the resistance multiplied by this parameter it will give you the resistivity.

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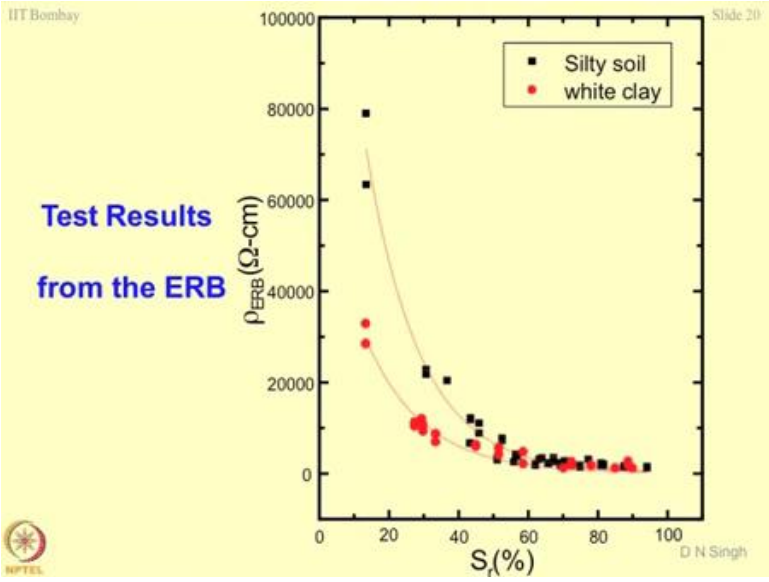

Now, based on this we got the results for resistivity box. At two extreme soils which were tested silty soil and the white clay, what they you show is that resistivity drops down as saturation increases. Remember these are all DC measurements at low AC current alright; say 10 to 20 Hz we have used.

The same trend you are observing for thermal resistivity also; thermal resistivity with respect to dry density and moisture content. But here when we talk about saturation it takes into account volumetric moisture content also; that means, the resistivity which you are obtaining from the box test can directly related to saturation or in terms of porosity or volumetric moisture, clear? And, what it indicates is more the saturation less the resistivity; that is true.

Then why did you say that thermal resistivity is inversely proportional to electrical resistivity? That question still remains. You should understand that this question is incorrect. If you remember we were talking about the biggest loophole in thermal conductivity measurements is that effect of mineralogy cannot be incorporated. However, when you talk about electrical resistivity, that limitation is also overcome here, clear? So, though it appears that the relationships between the two parameters is inverse is not correct because the thermal resistivity does not include as such the mineralogical aspects which are included in electrical measurements. So, electrical measurements are much more versatile than thermal measurements and that is why people are working in this area much more.

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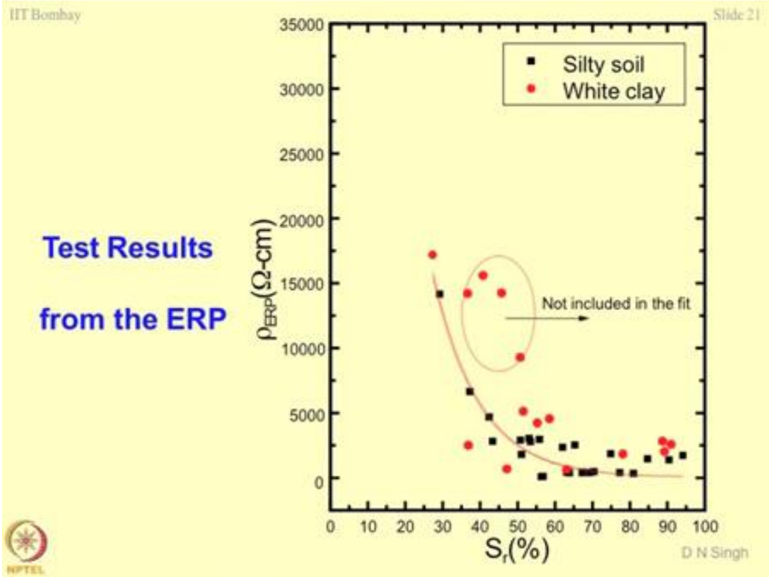

Now, this shows that how probes can be utilized or finding out the in-situ saturation conditions. We are again as the saturation increases what we notice is the resistivity drops and it so happens that because of probe is being inserted in to the soil mass the influence of soil mass does not get highlighted so much except for the scatter. While when you are placing the material in the box you know the compaction and the matrix structure cannot be replicated and hence the conclusion is that the probes are much better than the electrical resistivity boxes and that is the reason why probes are being used and not you take the sample from the field and the undisturbed form place it in the box and test it. That will give you misleading results.

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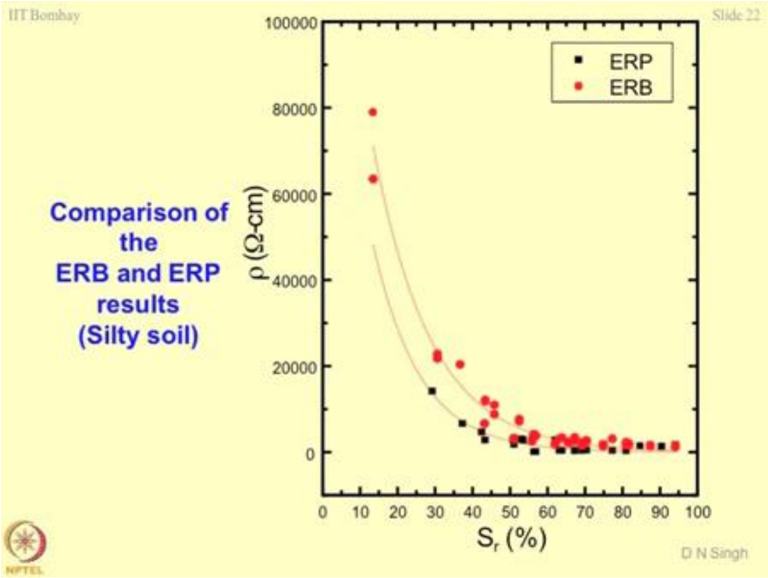

Now, if you compute both the results that is the box and the probe what we will notice is that the box gives higher resistivity as compared to the probe or the same saturation. Why it is so? Any reason? Now, this is where the contact problem comes into picture. When you are burying being when you are filling the soil in the box compacting it there is always a thin layer of air between the electrodes and the material. However, when you are inserting the probe into the soil mass the chances are that this layer would be minimal.

So, basically because of the air pocket formation between the soil sample and the electrodes in case of the box, its resistivities are not so reliable as compared to the probes. That is one of the reasons again that why people would like to use probes rather than the boxes.

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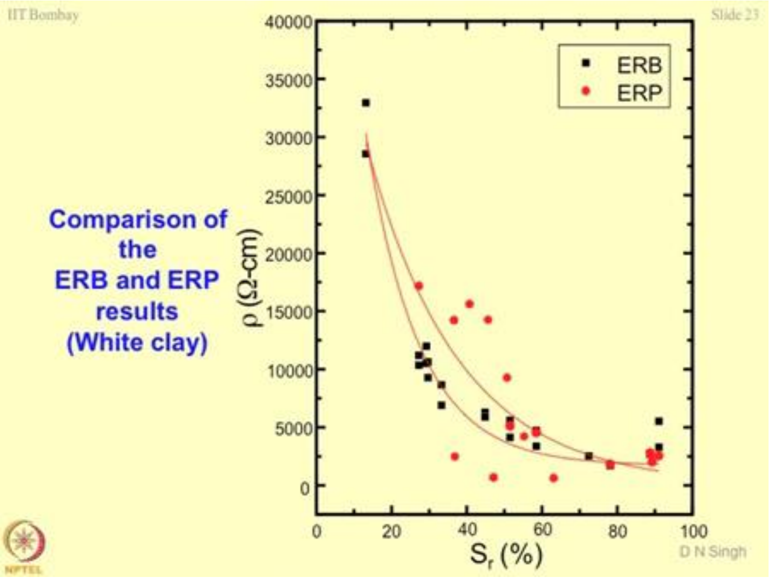

Now, we wanted to see for white clay what happens. In case of clay the results are very misleading because as I said when you are using the probe, the entire volume of the soil is not conducting the current. It is again a contact area problem. These are the small grains of the probes all right which are contributing to the area of cross-section of the flux which is much less and hence you will notic that if you compare the results they do not compare well.

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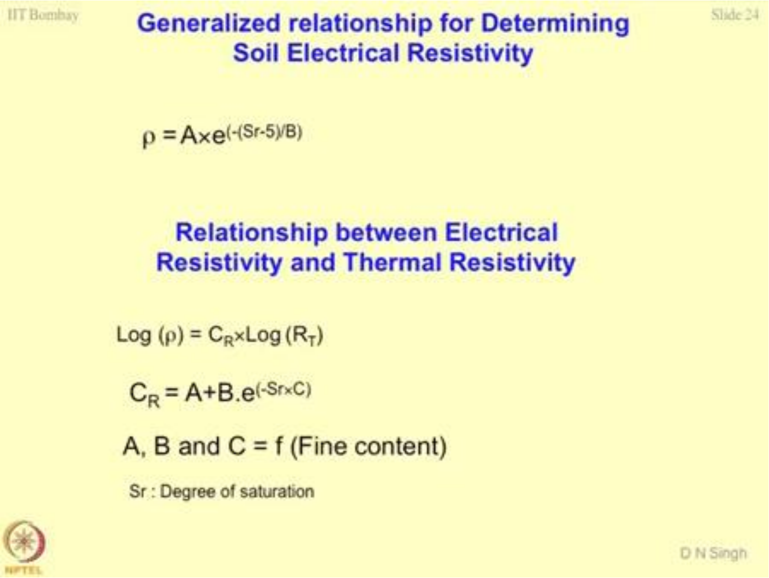

Now, based on these studies some relationships were developed for determining electrical resistivity. So, this is the generalized form of the relationship where electrical resistivity is a function of saturation.

Then, the relationship between electrical resistivity and thermal resistivity; this is how this relationship was developed. What it indicates is that both the resistivities are equivalent to each other except for some multiplication factor alright. So, here this term is known as C_R, where C_R is a coefficient, correlation coefficient which depends again upon saturation and, A and B and C are the parameters which will depend upon the soil type. How to define soil type? So, A, B and C will be functions of fine contents.

So, this is where you and say that these are the relationships which can be utilized for a given soil if you know their fine content. Fine contents are nothing, but the clay contents or silt contents sometimes; the combination of two is also fine content. You can obtain A, B and C if the nomograms are given. Using these nomograms, you can get the value of C_R for a given saturation and using this C_R if R_T is known you can compute electrical resistivity or if electrical conductivity is known resistivity is known, then you can come to thermal resistivity.

Now, my question before I wind up is which one you will like to compute if this equation is to be utilized. You would like to determine electrical resistivity or thermal resistivity? Which one is more easily predictable and precisely predictable? Electrical. So, this equation is normally used to determine the thermal resistivity. And, what is the beauty of this determination of R_T value from electrical measurements? It will also include the influence of mineralogy which could not be included otherwise into the study. So, that is one of the reasons that why electrical measurements and electrical properties are considered to be having a very wide scope as compared to thermal properties.

Another issue is maintaining thermal flux is very difficult as compared to electrical flux. So, under in-situ conditions you can easily obtain rho value electrical resistivity and if you know the C_T values for different type of soil conditions and their degree of wetness and you can compare then you can compute the thermal resistivity’s. So, this is a good application which was published by Reshma and my other students Sreedeep and all. And, this equation is widely being used by the people who are mostly in pipeline industries, either the oil or air conditioning or even the thermal resistivity’s due to the buried cables.