Environmental Geomechanics
Prof. D.N. Singh
Environmental Geotechnology Laboratory
Department of Civil Engineering
Indian Institute of Technology-Bombay

Lecture No. 51
Electrical characterization-I

We have been talking about geomaterial characterization, and today I will be discussing about the electrical characterization.

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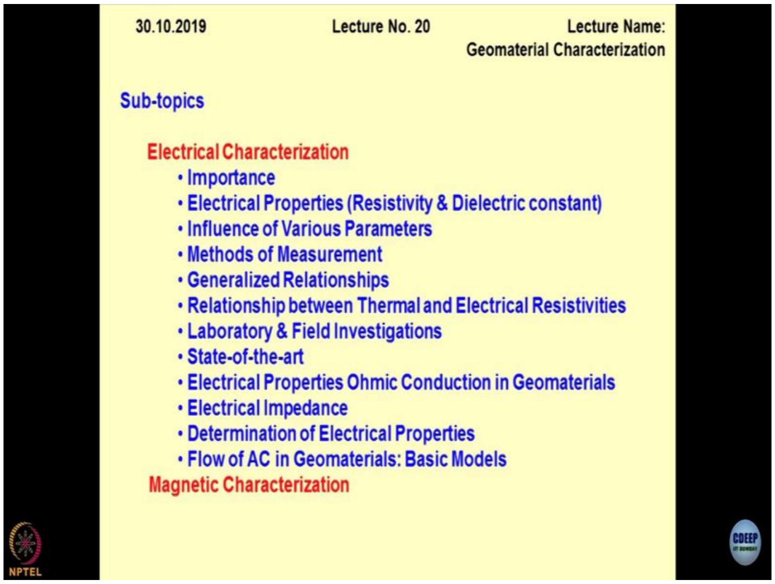

You will find it very interesting to note that during our 10+2 physics when we were studying the electrical properties of materials, we never realized that where these concepts can be utilized particularly in the realm of civil engineering, geotechnical engineering. And now in the realm of environmental geomechanics, the basics are same, and these basics have been extended to solve very complicated looking problems which an environmental geotechnologist faces in today's world.

And this is what you are going to find out from today is discussion. So, under the realm of electrical characterization, I will be talking about the importance, then what are the electrical properties, electrical resistivity and dielectric constant of the material followed by the influence of various parameters on the electrical properties of geomaterials. This will be followed by the method of measurement of electrical properties.

The generalized relationships which we have developed and we have proposed and which are published in the literature, which are helping people to obtain the electrical properties which can be utilized for understanding various micromechanisms in particular which are happening in the geomaterials. Now, this will be followed by the relationship between the thermal and electrical resistivities.

This is an interesting concept where we can show how thermal regime migration in the geomaterials can be related to the electrical regime or the potential regime which develops in the system. Now, this will be followed by the laboratory and field investigations which have been conducted state of the art on different types of measurement techniques, then a little bit on what is the ohmic conduction in geomaterials.

and then I will be introducing the concept of electrical impedance and this will be followed by again the determination of the properties of geomaterials by using the impedance, which is a very state of the art and contemporary subject, which some of my students have used as I discussed earlier also to exhibit how the unsaturated soils can be characterized, contaminant transport in unsaturated soils can be established.

And nowadays we are utilizing the concept of electrical properties in defining the multi-phase of the geomaterials, particularly gas hydrates. So, guys, I refer to the subject where we realize that the electrical properties can be utilized as a signature of the material to demonstrate how the mechanism occurs, and I will also cover a bit on how the AC migrates in the geomaterials that is alternating current and the basic models which are developed by my students to understand the flow of current which is identical to the flow of water, the flow of thermal flux and the flow of electromagnetic flux also. So, these concepts become very interesting. And the last topic which I will be discussing during the next lecture would be the magnetic characterization of geomaterials.

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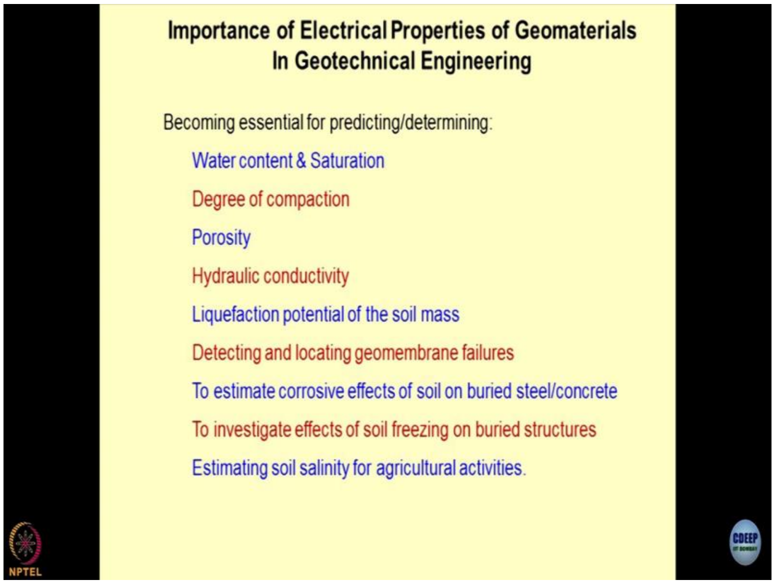

So, to begin with, what are the importance of electrical properties of materials in contemporary geotechnical engineering, this becoming essential for predicting and determining the most fundamental parameter related to the geomaterial which is the water content and saturation. See gone are the days when people used to take out samples from the field, and they used to test them and then they used to analyze the results.

Because first of all of us are aware of the limitations associated with the sampling from the field and bringing the samples to the laboratory, where we disturb the samples, particularly its moisture state, so, in most of the problems, nowadays, people are interested in measuring the in-situ water content and in-situ saturation. Because as I have discussed in the previous lectures, most of the mechanisms depend upon the in-situ water content.

Which is the volumetric water content and the saturation of the geomaterial. A good example of this would be whenever we talk about the coupled phenomena where we talk about, let us say moisture migration out of the sample because of thermal gradients, so, this becomes a coupled phenomena. I would be very eager to understand how the saturation is changing within the sample of the geomaterial over a period of time.

And this is how we determine the unsaturated hydraulic conductivity of the soils. Another good example is how the contaminant front is migrating in the geomaterials, which is a function of saturation and in-situ volumetric moisture content of the geomaterials. Degree of compaction. So, nowadays, this is the age of electronics and people would like to measure or establish what is the degree of compaction of the soil mass. Core cutter technique and sand replacement method and balloon method and all those methods have really been shelved off now.

And looking at the speed and the pace of infrastructure development, it becomes very difficult to adopt the old techniques or the conventional techniques of finding out the degree of compassion. So, people are interested in finding out the in-situ densities. So that the degree of compaction can be established by using sensors, so, one more thing I think you will realize from this discussion is that in today's electronics era, when the electronics is at its peak.

Everybody would like to sense the parameters associated with the geomaterials by using sensors, and this is again the electrical property the geomaterials become very very important. So, most of the sensing techniques which I will be talking about would require electrical properties of geomaterials. The third one is porosity, from the discussion, which we had until now, I hope you have realized that the porosity is the parameter which requires a very very dedicated efforts very intricate parameter to obtain. And I will be discussing this separately also how to determine the porosity of the geomaterials by giving you complete details of how the porous structure modelling is done in the subsequent lectures. So, one of the techniques of finding or the porosity was to resort to molecular diffusion. So, when you were talking about the contaminant transport to diffusion, if you remember there, I had introduced the concept of the equation where the diffusion coefficient is a function of porosity and free diffusion coefficient can be known and hence the porosity can be obtained this concept is being utilized in most of the projects, particularly which are of strategic importance or were the porosities are absolutely attending to 0, but you still want to establish them. A good example would be the design of nuclear dorms. What type of materials should be utilized at what compaction states of the concrete they should be placed or compacted so that nothing diffuses out to the dorms of the atomic reactors?. Similarly, in the case of soils also you must have noticed that I can cut short the advection phenomena, but diffusion predominates. Now, unless you understand the porous structure and how the pores are interconnected, it becomes very difficult to do the modelling of the geomaterials.

So, porosity is a parameter which requires a very special treatment, and I will try to do that the next one is hydraulic conductivity, conventional test for determining hydraulic conductivity have several limitations all of you are aware of it. So, the question is, if I really want to find out the inch to the hydraulic conductivity of geomaterials, what type of systems I should be utilizing, what type of mechanisms which I would like to study and how whether electrical properties can be utilized or not.

This is what is becoming quite useful in contemporary discussion. There are some efforts which have been made to obtain the liquefaction potential of the soil mass also. That means people have tried to determine the in-situ density and the porewater pressures which build up in the soil mass by using electrical sensors. Detecting and locating geomembrane failures, the basal liners for the landfills when they get punctured, because of the placement and the compaction. The biggest issue is that there is no way to obtain whether or to establish whether the geomembranes have failed or they have got punctured by placing them in the form of the GCLs or CCLs. This is where the electrical properties could be utilized, where the electrical sensors can be placed beneath the landfills and the compact clay liners or geotextile clay liners. So, when the contaminants migrate to the geomaterial, the resistivity drops and this can be measured by using the electrical signals and analyzing them to estimate corrosive effects of the soil and the buried steel structure. This is also a very contemporary subject most of the industry is wants experts who can establish the state of the structure which is buried inside the soil mass. And lot of money is being spent by the industries to establish this type of state of the buried structures including the piles.

So, those of you who might become an expert tomorrow in the retrofitting of structures, buried structures you will be using a lot of electrical properties of the geomaterials. To investigate the effects of soil freezing on buried structures, freezing and thawing phenomena can also be captured by using the electrical properties. And of course, if you want to find out the salinity of the agricultural soils, for agricultural activities, the electrical properties would be very useful.

There are sensors which can be we call them as resistivity sensors or soil salinity sensors. They can be embedded into the ground. And you can data log the entire network of the sensors to see whether that the soils are more saline less saline, whether they are losing the nutrition and how to replenish the nutrition by doing fertilizing.

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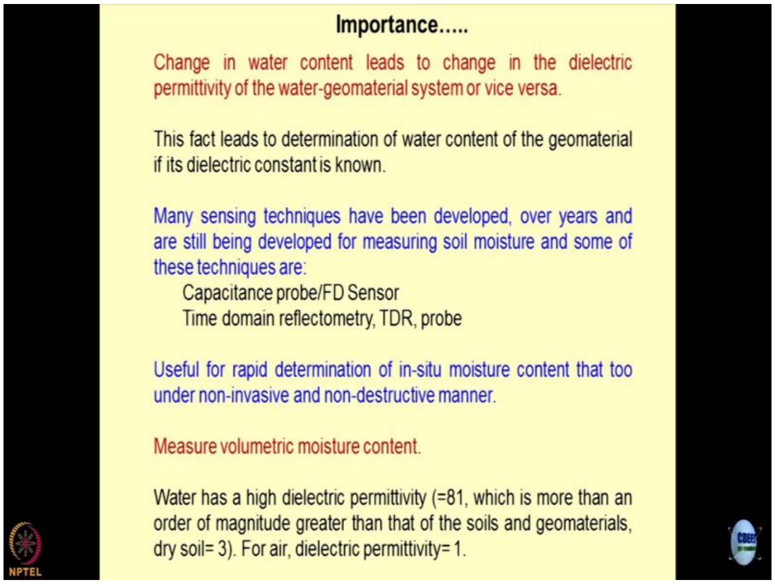

Another set of importance is that these are the concepts which have been used in understanding the electrical properties of the geomaterials. The basic hypothesis is that for any material, the dielectric constant of the dielectric permittivity defines its properties. In other words, for every material, there will be a unique dielectric constant. And the reason is that most of the geomaterials are made up of oxides of silica element ion, sodium, potassium, calcium and so on.

So, if you have done the chemical analysis of the material, you can always link it with the dielectric constant of the geomaterial. And the beauty is that this dielectric constant could be either for the dry soil, partially dry soil or fully saturated soil. So, if I know the water and dielectric constant of the water, when the water goes and sits into the voids of the geomaterials, this becomes a water geomaterial system, and I can measure the dielectric constant of water geomaterial system.

And I can show how the dielectric properties are changing over a period of time. Many sensing techniques are developed nowadays, which use this concept of measurement of dielectric property of dielectric permittivity. And depending upon the dielectric permittivity, you can express the dielectric permittivity as a function of volumetric measurement. So, once these two are known, I can manipulate the other properties of the geomaterials. Good examples of these type of techniques are capacitance props and frequency domain probes, FD probes we call them or FD sensors we call them.

There is another set of sensors which is known as TDR probes time domain reflectometry probe. So both these probes are being utilized. Both in the laboratory as well as in the field to measure the electrical properties like dielectric permittivity of the material which is linked with the volumetric moisture content. And volumetric moisture content is linked with the saturation and the density of the material.

These are the techniques which are non-invasive and non-destructive. So, that is the most advantage of resorting to electrical measurements, that you are not changing the structure of the soil at all. You are not destroying the sample; you are not invasive it. And that is the biggest advantage of resorting to electrical properties of geomaterials for characterization. Any questions? How accurate are the results with respect to that over-drying, from this?

If I am applying a voltage across two electrodes, what is the inaccuracy which I am going to impose to the system so you must be realizing no see the whole society is graduating from conventional to electronic devices? The real answer to your question is these measurements are quite precise. So, this one of the concepts is that water happens to be a very dielectric material. So, it is dielectric permittivity the 81, and for air, it is one.

So, what it indicates is when you are dealing with the dry soils, the permittivity is going to be extremely less, but when you are dealing with the wet or saturated soils, the permittivity are going to be extremely high because of the presence of water. Okay?. Now you can do the entire manipulation within a scale of 1 to 81. And then you can see how the whole system is behaving.

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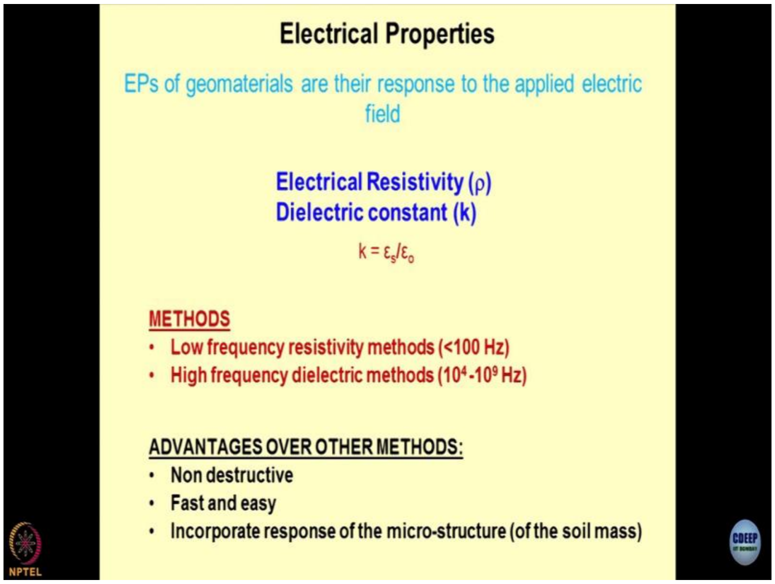

So the electrical properties are electrical resistivity in 10 + 2 physics I am sure all of you have started and the dielectric constant K. So, there are two broad methods of determination of electrical properties. One is we call as low-frequency resistivity methods where the frequency of the current is less than a hundred hertz. However, there is a second category which is known as high frequency, electric methods, where the frequencies are up to the order of mega to gigahertz.

So, suppose if I ask you a question what the advantage of pushing in let us say AC at a very high frequency into a material, what will happen is? Why do you require very high frequencies of the current to be pumped into the sample, what heavy high frequencies would do?. The quick answer would be when the AC frequency is more the passage of current becomes easy as compared to the current, which is of low frequency.

So, this concept has been utilized to analyze the results of the electrical signatures of the materials. Now, the advantages of these techniques over other methods are that these are non-destructive, and these are fast and easy most of the time, these techniques can be utilized under in-situ conditions. So, I will just insert a probe or a sensor, and then I can get the properties. Now, as far as the accuracy of the results is concerned, you have to rely on the measurements are the best way would be you repeat the experiments and see how reliable the results are.

Another interesting thing is when we talk about the electrical properties of the geomaterials, the microstructure of the soil or the geomaterial gets. So, one of my PhD scholars did his PhD thesis Dr. Suchit Gumasthe, who has tried to quantify the degree of anisotropy in the system in the soil mass by quantifying what the degree of flocculation is and what is the degree of dispersion of the clays. So, I hope you can realize that when you can go up to this minutest details of the fabric of the geomaterials, your measurements are going to be quite precise.

Now, there are two more things which we should remember that the electrical properties of the geomaterials are their response to the applied electric field. And I am sure you must have come across this function in your 10+2 physics that dielectric constant is the ratio of E_s and E_0. E_s is the permittivity of soil; E_0 is the permittivity of the free space. So, we utilize these concepts to decode the geomaterial. I will show you how.

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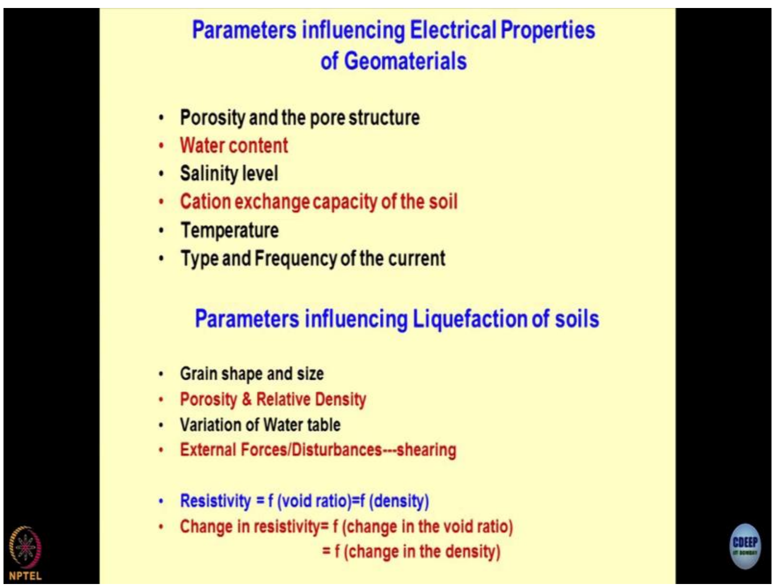

Now, comes the parameters which are influencing the electrical properties of geomaterials, porosity and the pore structure is number one. And because the passage of current through the geomaterial is because of its inherent porosity and its pore structure, so I am sure you have come across these concepts of why permeability is more in the flocculated state of the geomaterial or the soils as compared their dispersed state.

That means the pore structure has to play with Important to the orientation the grains have to play a very important role. Water content, the salinity level, the cation exchange capacity of the soil. Why?, the more the cation exchange capacity of the geomaterial, the cations are going to adhered re on the surface, and they act as the conductor of correct All right. So, as compared to sense, the fine-grained materials which have negatively charged grains would be better conducting of correct.

Of course, the temperature plays an important role in the previous lecture I was talking about when you pass current through the cables, heat gets generated and if soils are not able to dissipate the temperature quickly, the heat within the soil mass increases, which indirectly increases the temperature of the conductor or the cables. Now, once the temperature of the cables increases their resistance is going to increase and once the resistance of the cable increases the ampacity drops or the amount of heat which is getting emitted into the soil mass also increases.
So, the temperature is a phenomenon which can be considered as a coupled phenomenon; it could be because of heating of the geomaterial, how the temperature of the conductor is changing or if I pass current through the conductor, because of this conduction, how the temperature gets generated in the system and as discussed sometime back the electrical properties would get influenced by the type of current which is used, I am sure from your 10 + 2 physics you must have learned that which current is non-heating type, which one is a heating current you are right. So, DC is a heating current, and AC is a non-heating current why so you know the answer.

So, suppose if you are using a DC current, the chances are that the soil properties in terms of its moisture content would get altered because of the heating of the sample and that is the reason most of the time high-frequency AC is used for these measurements and the resistance offered by the material when you use AC of high frequencies is known as impedance. Impedance is the resistance which is dependent upon the frequency of the current. In this context, because we are geotechnical engineers, I thought it would be a good idea to draw a parallax between the parameters which influence the liquefaction potential of the soils and how the electrical properties can be utilized to map them. So, grain shape and size can easily be mapped by using the electrical properties of geomaterial. And we know that liquefaction is associated with coarsegrained materials which are very regular in shapes or a spherical in shape. So, we tried studying the grain shape and size effect by using the impedance, and we were successful.

These studies are still ongoing porosities, and relative densities which again are related to the liquefaction potential can be easily captured by electrical properties and variation in the water table. So, what a table is a variation in nothing but saturation as a function of depth, including their capillary zone. So, if you derive a relationship where the saturation is a function of the dielectric constant of the material, which is a function of depth, you can map the water table also. External forces like shearing effects, so, some of my PhD scholars are now working in this area of what happens when shearing takes place and whether we can capture the shearing response by using the electrical signatures of the material a lot. So, the philosophy is like this resistivity the function of void ratio, and the void ratio is a function of density, so if I can map these three parameters by conducting good electrical properties experiments.

I can even find out the liquefaction potential of soils. So, on the net, if you search you will find that there are some efforts which have been made by the researcher in this context. And please remember all this is being done in-situ, so, those of you who are aware of disadvantages of finding or liquefaction potential of size by conditional SPT would appreciate that this technique would give you the liquefaction potential under in-situ state and you can monitor when the systems are going to liquefy this can also be extended to the fact that delta of resistivity that is a change in the resistivity is going to be a function of change in the void ratio and change in the density of the geomaterials efforts can be made to find out the e_{cri}, if you remember the critical void ratio when you shear the sample, and then you plot the dilatancy and compressibility of the soils.

And then you define a band of 10 to 15% of the void ratio which falls under the category of e_{cri} where the system becomes constant. That can be used as the reference electrical signal for establishing the liquefaction potential of the soils.