Environmental Geotechnics
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Lecture – 45
Electrical characterization – 3

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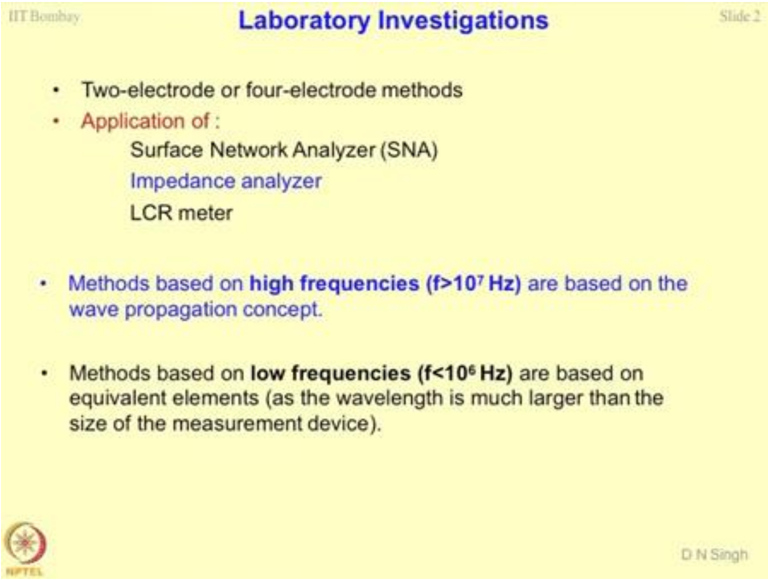

So, let us start with the laboratory investigations. As I discussed in the previous lecture normally two-electrode upward electrode methods are used for determining the electrical properties of the soil that is the conductivity or resistivity and dielectric constant. Now, what are the applications of these type of investigations? Surface network analyzer is a equipment which is normally used for determining electrical properties under laboratory conditions can have impedance analyzer or an LCR metre depending upon the frequency range in which you are interested in conducting the studies or mapping the impedance spectroscopy or impedance response of the geomaterial.

Now, the basic difference is that the methods which are based on high frequencies they basically adopt wave propagation concept pass through the system and then try to map the velocity of electromagnetic waves or the time taken by them to get refracted from certain end or certain point in the medium. I am not going in to the details of these methodologies, I am just giving you some general idea about the basic difference between how the frequency guides the basic methodology.

The second class of methods is based on low frequencies where the frequency is less than 1 MHz and these are based on equivalent elements or equivalent circuits because the wavelength does not come in to the picture and the wavelength happens to be much larger than the size of the sample which is being studied. So, this is the basic difference between why do you adopt a low frequency and high frequency device for measuring electrical properties in laboratory.

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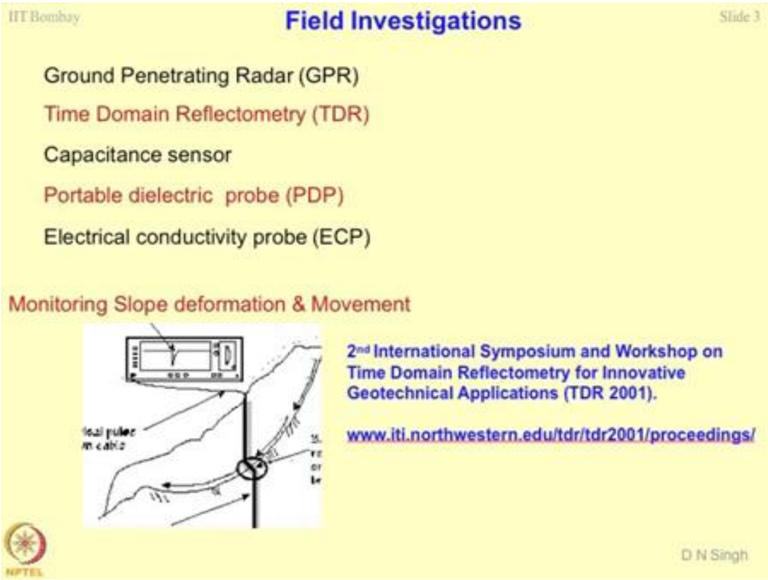

Then comes the concept of field investigations. Good example of a field investigations using electrical properties is Ground Penetrating Radar. I had given you some idea in the previous lecture particularly people from earth sciences and remote sensing people are using GPR importing concrete also for finding out the texture and the you know anomalies in concrete you can use GPR technique. Time Domain Reflectometry this we have been talking a lot time and again TDR is a good example of how field investigations can be conducted to obtain the thermal electrical properties of geomaterials.

Capacitance sensors this also we have discussed in details FDR sensors. Portable dielectric probes are being used for determining electric properties of the soil and hence the moisture content or the degree of salinity of the soil mass. Electrical conductivity probes, ECP they are also used for the same purpose for determining the level of salinity of the soil mass moisture content. Sometimes temperature also can be recorded with the help of these probes.

There is a very good reference I thought I will just give you the reference here. This is the second International Symposium and Workshop on Time Domain Reflectometry for innovative geotechnical application whenever you get time you can go through this is the link which contains the proceedings of TDR 2001, shows the different type of applications of TDR in present day geotechnical engineering and subsurface you know profiling and soil survey.

One example which I would like to sight over here is monitoring slope deformation and the movement. This is one of the best techniques which can be utilized or employed for establishing the slope deformation and movement and landslides in real life. This was slope and, in this slope, one fibre optics cable is embedded. Now, under any eventuality when the failure takes place what is going to happen to this fibre optics cable or the TDR cable this is going to deform.

Now, because of deformation of this cable the impedance of the cable is going to change. So, if you can measure over a period of time how impedance of the cable is changing, you can estimate whether slopes are stable or not. So, using this concept some people have installed TDR cables in the Konkan belt particularly for Konkan railways. So, this also comes under the tag of early warning systems which railways has devised in the recent time with the help of IIT, Bombay and some other organizations.

So, you think of the situations where these types of cables are embedded in the slope at every 100 metres along the tracks. Even a smallest possible disturbance in the slope will lead to certain deformation of the cable which can easily be measured by using some electronic device or some readout unit. So, these are the early warning systems which are becoming very handy for defining or for determining the instabilities in the slopes, mines, landslides, avalanche and so on.

It is a good example of how field investigations can be done with the help of TDR. Among all these techniques, GPR is getting lot of importance these days and TDR has already shown its potential in geotechnical applications.

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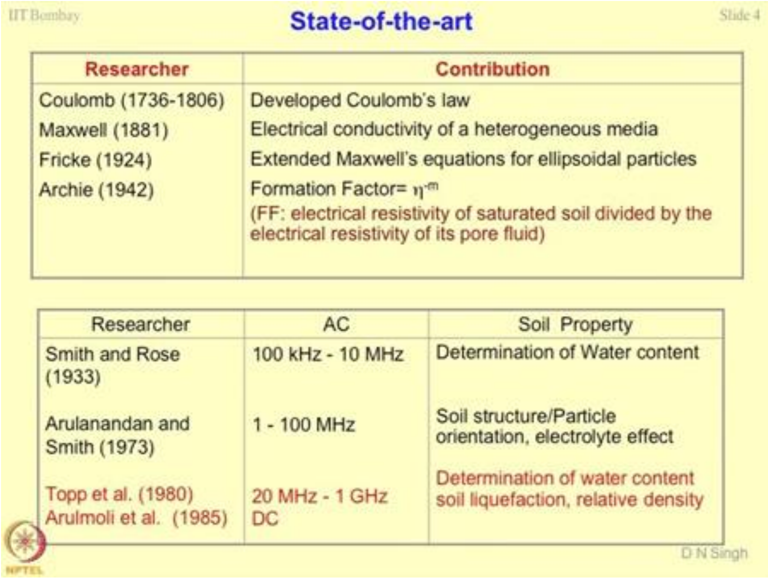

A bit on state-of-the-art on the subject this is how this subject started you can see that Coulomb's law came in 1736 and this was the developed development of Coulomb's law of electricity or the charges. Then came Maxwell's law which is electrical conductivity of homogeneous media, followed by Fricke law which is nothing, but the extended Maxwell's equation for ellipsoidal particle shape.

So, you can say that geotechnical engineering people must have adopted this technique in 1924 onwards. It is not a very recent trend, but somehow the exploitations of the technique has been done very recently. So, this was the first referred by Fricke when he employed Maxwell's equation for ellipsoidal particles and you will agree that most of the geomaterials fall in this category either they are flaky or they are platelets or they are irregular, but ultimately, they can be clubbed under the category of ellipsoidal particles.

Then came famous Archie's law. Archie's law you will find everywhere in whether it is electronics, electrical engineering is a famous Archie's law, it is a very general formula. If you remember in diffusion analysis also, we talked about Fricke's law and the Archie's law for diffusion. So, here the formation factor is defined as the porosity to power some coefficient. This formation factor is nothing, but the ratio of the electrical resistivity of the bulk soil divided by the electrical resistivity of the pore solution.

Now, this law is a very handy tool for defining the stratification in the soil mass or anisotropy of the soil mass or inhomogeneity of the soil mass. So, Suchit is trying to employee this law for his research work in defining the anisotropy in terms of fabric structure in the soil; that means they should be cross anisotropy of the material in 3-dimension if this law is valid for electrical properties. So, this is what the basic idea of his PhD thesis is. It is really a hard subject and we have contributed quite a lot in this theme.

Now, from here onwards people started picking up studying electrical properties. So, Smith and Rose they started working in KHz to MHz range for determining water content of soil mass basically. The whole idea of giving you this state-of-the-art table is that you should realize that what type of parameters and what type of studies have been done in the past and this seems to be a very promising subject in the days to come.

Arulanandan he is a very pioneer researcher in this area. He also studied, but he has studied soil properties like soil structure, particle orientation and electrolytic effect in the soil mass. So, these are very fundamental studies which were done by Arulanandan and Smith. Then came the contribution by Topp. If you remember this is the equation given by Topp that is theta or the volumetric moisture content is directly proportional to dielectric constant or dielectric constant is directly proportional to volumetric moisture content of the material. This equation is known as Topp’s equation. I will show you the basic form of the equation slightly later and he studied the properties from 20 MHz to 1 GHz range for a variety of soil properties, the determination of water content, soil liquefaction and determination of relative density. Arulmoli he used DC current for studying these properties.

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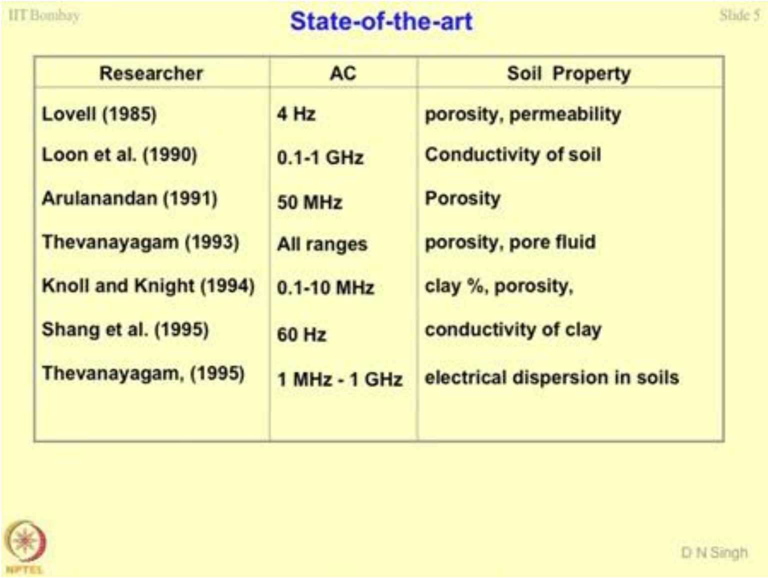

Researcher	AC	Soil Property
Lovell (1985)	4 Hz	porosity, permeability
Loon et al. (1990)	0.1-1 GHz	Conductivity of soil
Arulanandan (1991)	50 MHz	Porosity
Thevanayagam (1993)	All ranges	porosity, pore fluid
Knoll and Knight (1994)	0.1-10 MHz	clay %, porosity,
Shang et al. (1995)	60 Hz	conductivity of clay
Thevanayagam, (1995)	1 MHz - 1 GHz	electrical dispersion in soils

Now, this table gives a very clear picture of what is happening since last. So, many years and what is the contribution of the people. You will notice here porosity, permeability, conductivity, clay content, conductivity of the soil, electrical dispersion everything has been studied by people in different frequency ranges. So, for that matter if you start with Lovell in 1985, he started with 4 Hz; 4 Hz is nothing, but a DC frequency. So, though I am writing here AC, but truly speaking because frequency can be associated with this, it will be characterized as a DC current. So, GHz range, MHz range and so on and the entire gamut of properties has been started by the people.

Now, if you remember the central theme of doing these studies is how to determine with precision the porosity of the porous system and that is what is basically meant by porous media characterization. How best precisely you can determine the porosity of the material. So, most of the studies are related to porosity. Even this permeability term is linked with the porosity of the porous media. Conductivity is also linked with the porosity of the material because if you remember the previous law which talked about Archie’s law is nothing, but the formation factor is a function of porosity to the power minus some parameter.

So, that means, conductivity is inversely proportional to porosity and the beauty is that you can instead talk about the clay content of the material; that means, as I have been telling you sometime back the most futuristic studies would be that without conducting any classification test just by looking at the values of electrical properties you can ascertain what is the composition of the soil that would be the ultimate in our subject and this is where actually most of the people are trying to work and contribute.

Electrical dispersion in soils is an interesting phenomenon. Later part of the lecture would be dealing with electrical dispersion in soil mass, what is meant by dispersion and how to utilize the dispersion analysis results for characterization of the soil mass.

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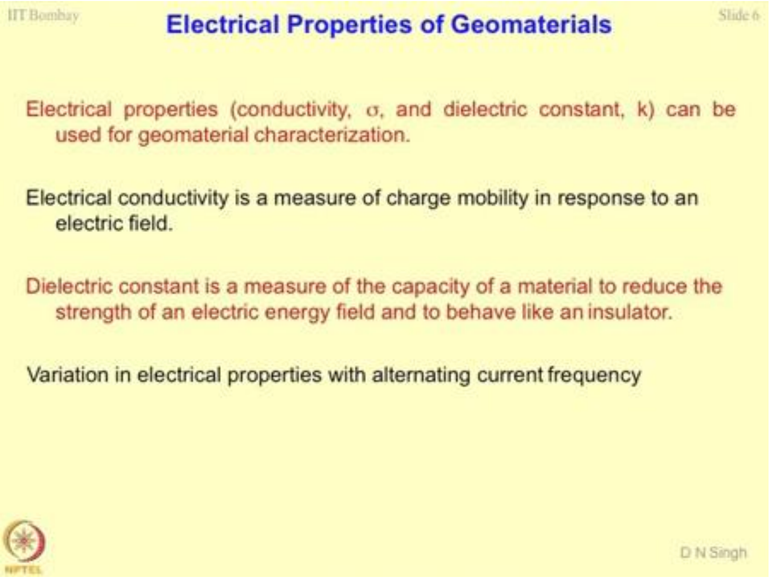

So, let me remind you the electrical properties of the materials are basically conductivity and dielectric constant. And what people have realized is that if you know conductivity and dielectric constant the materials can be characterized very easily. What is electrical conductivity? As the name suggests is a conduction of current through the porous media and the ease of conduction of the current. So, the definition is electrical conductivity is a measure of charge mobility in response to a certain electric field.

In previous lecture, we talked about how to determine electrical conductivity by using two apparatus or two equipments, electrical resistivity box and electrical resistivity probe. So, with the help of these simple devices you can easily determine electrical conductivity. Now, what is dielectric constant? So, dielectric constant is the measure of the capacity of the material to reduce the strength of an electric energy field and to behave like an insulator.

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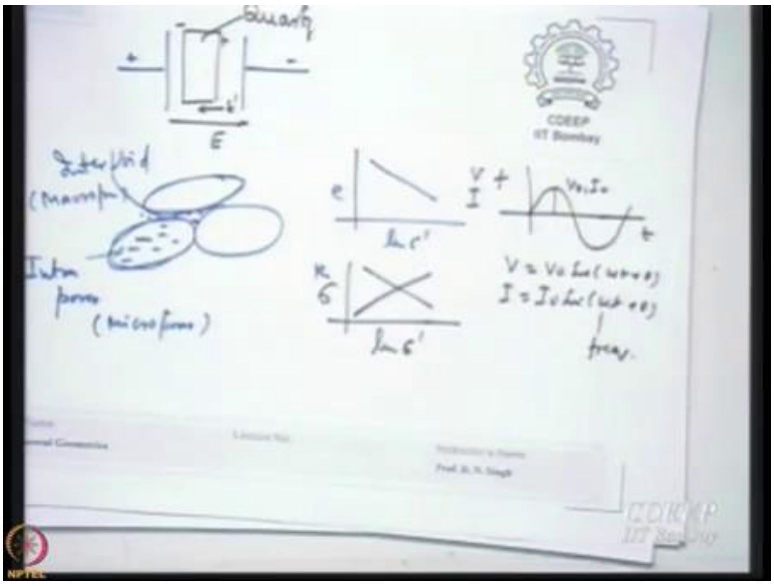

So, if you remember we were talking about in the previous lecture if you take an example of simple plate capacitor. So, if you consider a simple parallel plate capacitor. Now, without any dielectric material this is the structure. Now, if you put a dielectric material in this say sheet of a quartz or an oil or water or even air. So, they all behave like a dielectric material. What is happening with this material now? This will be getting polarized.

So, if the direction of main electric field is like this because of the dielectric material there is a effective electric field in the opposite direction which is opposing the electric field or it is nullifying the electric field which is applied on to the system. Now, these types of studies are very important for those who are studying mineralogy of clays and characterization of the clay is based on electrical resistivity and the electric models because plate platelets are also nothing, but negatively charged particles. So, when they come in contact with water this is a polar material this type of a phenomenon takes place.

So, dielectric constant is a measure of the capacity of a material to reduce the strength of an electric energy field and to behave like an insulator. So, this is the property of the material which shows that how good a bad conductor a material would be. Is it not? And this is linked with the charge storage capacity. So, variation in electrical properties with alternating current frequency is that what you want to capture alright. So, when you do these types of investigations the basic idea is how properties are going to change when frequency of AC gets changed. Now, this is sort of a finger print of the material which gets reflected in the form of a frequency domain and that is why this is known as spectroscopy in terms of frequency or impedance in spectroscopy; that means, you are trying to find out the impedance of the material for a entire range of AC current frequency.

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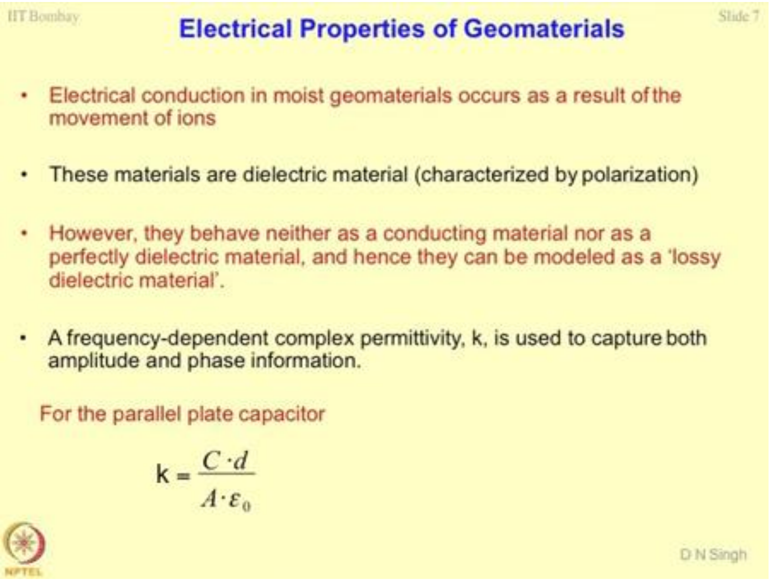

So, electric conduction in most moist geomaterials occurs as a result of the movement of ions there is nothing, but the ionic conductivity which normally we consider in our studies and basically these materials are dielectric materials which are corrected characterized by polarization. I showed you how polarization gets induced if we place a material in an electric field will be a reverse polarization which is acting on the material itself.

So, all these materials geomaterials, they are dielectric in nature because they are not good conductor of current. They get polarized easily and hence if you can study their polarization properties or susceptibility to get polarized alright, then you can characterize them very easily. A good example of this would be soils which are dry, soils which are wet, soils which are partially saturated soils which have humus or organic materials in them or soils which are having more iron in them. So, their responses will be totally different. Soils which are fine grained, soils which are coarse grained, soils which are combination of the two and so on.

So, what it leads to is that overall characterization can be achieved just by studying the dielectric response of the material and it is conductivity, but there is a problem. The problem is these materials they behave neither as a conducting material nor as a perfectly dielectric material and hence they can be modelled as a lossy dielectric material. What is the meaning of the word lossy dielectric material? Suchit you cannot can take microphone.

Student: (Refer Time: 18:30).

And that too with respect to time. So, that is what I am not sure whether studied or not relaxation factors; relaxation factor would be how much charge is stored after certain time. So, the charge is also a function of time. So, C becomes a function of T or C T. So, with this concept a frequency dependent complex permittivity k is used to capture both amplitude and phase information of this phenomenon.

So, if you remember this parallel plate capacitor model what we charge carrying capacity of a parallel plate capacitor this is k.A.ε_0/d. So, from here you can get easily the value of k. So, k which is complex permittivity would be a function of geometrical properties of the capacitor, d is the distance between the plates, A is the area cross-section of the plates, C is the total charge which is accumulated in the system and ε_0 is the permittivity of free space. So, this is how you can compute k value directly.

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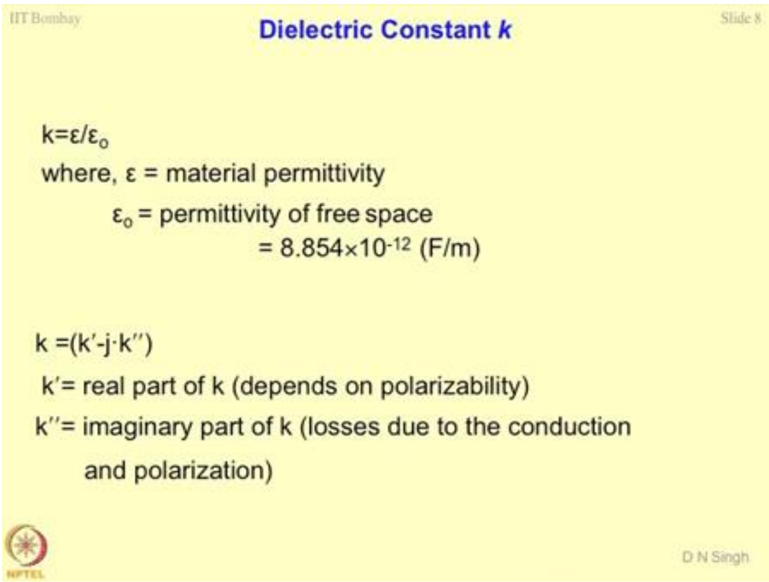

Now, what is the meaning of dielectric constant k? So, k is defined as epsilon upon epsilon naught. This we studied in the previous lecture where epsilon is the material permittivity and epsilon naught is the permittivity of free space which is given as 8.8×10^{-12} F/m. So, if you know the k value multiplied by the ε_0 it I will give you material permittivity or vice versa if you know material permittivity, you know epsilon naught value you can get the value of k.

So, k happens to be a very peculiar parameter for a given soil water contaminant system, is this part clear? And it is very susceptible to any change which may take place in this system. So, that is the reason why people are studying dielectric constant or conductivity for characterization of geomaterials. I use the word complex permittivity in the previous slide. So, complex permittivity k = (k'- j. k'').

Now, j k'' is nothing, but the imaginary part of k. You must have done in your complex algebra all these things, is it not? And k prime is the real part of the k which depends upon the how easily a system can get polarized. So, this is what is known as polarizability of the material. k'' is the losses in charge due to the conduction and polarization effect. So, it is also important to measure k' and k'' parts of the material for its complete characterization.

Without getting bothered too much I think you must have realized one thing that these parameters or these factors are going to be having a specific value for a phase of a material, clear. So, why detection of these parameters is important so that when we talk about multiphase system and if you know these material properties you can easily find out what is the contribution of each phase into a system. It is not so difficult the way it looks here. There are devices from which you can directly measure the k' and k'' values or you can compute them by using simple equations which are normally used in electrical engineering. Is this ok?

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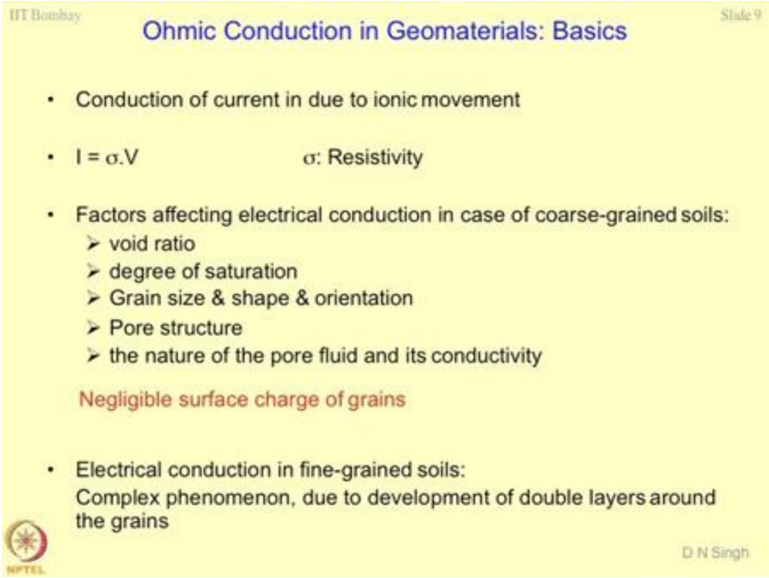

What are the basics of ohmic conduction in geomaterials? Conduction of current is due to ionic I am sorry this is not in, this is conduction of current is due to ionic movement and the equation which is normally used is i= σ. V, where σ is the resistivity.

The simple term would be V= i. R. So, 1/R=σ or 1/σ= R. So, factors affecting electrical conduction in coarse grained soils would be void ratio, degree of saturation, grain size and shape and orientation alright, the pore structure, the nature of the pore fluid and its conductivity.

So, what is the significance of this? When you are studying ohmic condition in coarse grained materials, the ohmic conduction is going to be a function of all these parameters. So, when you are doing those sieve size analysis to determine what is the fraction of sands or silts or the gravels which is present in the material and the grain size is contributing to the void ratio. So, if you know the void ratio you can indirectly find out what type of grains are present in the system.

If you remember your cubic or rhombic arrangements has a peculiar e_{max}, e_{min}. Clear, do you would agree? So, on a scale of maximum and minimum e_{max} and e_{min} or in other terms porosity maximum and porosity minimum you can scale the properties of the coarse-grained soils by measuring its electrical properties, it is ok?

Similarly, when you are talking about degree of saturation so, saturations less than 80 percent are considered to be dry soils partially separate soils. So, their properties are going to be totally different than the soils which are going to exhibit saturation more than 80 percent or 100 percent. Grain size, shape and orientation is a very challenging work. Since Smith is trying to do it in his thesis and he is trying to link this with the pore structure analysis.

I have shown you some I see a micro graphs long time back if you remember where we had talked about flocculated structure; dispersed structure, combination of these structures of the grains. So, this is one way of capturing the response of the or the structure of the grains. Another way of capturing the response would be if you allow a current of certain frequency and magnitude to pass through and collect its fingerprint and see what has happened to the current which was being input when it comes out of the material.

So, any sort of attenuation; attenuation means reduction in the properties of the input waves can be mapped with the response of the porous media. That means, if you input some current and whatever output is coming out if you compare the two, you can always make sure what is the contribution of the porous media in changing the properties of the input current. So, this type of concepts can be utilized when we talk about grain size, shape orientation and the porous structure of the soil mass and of course, the nature of the pore fluids and its conductivity.

So, pore fluid could be water, it could be air, it could be partially saturated soil. So, there you have water air present both; some vapours may be present, hydrocarbons can be present, combination of all these and so on. However, there is no conduction through the grains in case of coarse-grained materials, why it is so? Because these grains are not charged. So, this concept can be utilized while looking at the impedance response of a material. At the end of the lecture I will be showing you the basic models which are used for developing AC flow in the soil mass and that is where all these concepts will be very handy and you can literally see whatever conduction is taking place in a certain material.

However, when you talk about the electrical conduction in fine-grained soils it is a very complex phenomenon. Why it is so complex? It is because of the charge it is because of the double layer, it is because of the diffuse layer, it is because of the you know clods formation and clods are nothing, but what type of pores they will be giving you ,what type of voids they will be giving you, micro or macro? They will be giving you macro pores; that means, if they are not the micro pores which you are going to talk about it is a combination of micro pores and macro pores.

Do you remember or you have forgotten micro and macro? You have forgotten? See, these are the two clods and these are the platelets. So, when you come to when you consider the force which are present between the two platelets. These are going to be intra; intra voids, intra pores agreed or intra voids. Now, this is one unit which is in association with another unit. So, whatever word space you have in between this is going to be inter void or inter pores or micro macro pores. So, these are macro pores and these are micro pores alright. We have not talked about mesopores here. I hope you will remember all these things after 2 years also ok.

So, you can understand that using this type of models you can study whether the pores are dominated by micro pores or macro pores, they are inter pores or intra pores, inter voids or intra voids and so on. So, when you study where each one of this units is known as a clod. A simple example is you take some water; you sprinkle it on a dried clay. What did you notice? Lumps, exactly. So, these lumps are nothing, but clods. So, the biggest problem of working with clays is you cannot even compact it properly, why? Because of clod formation alright.

So, look at it like this that each individual particle is having charge, number of particles get associated to form a clod, each clod will be having some electro dynamic effect on another clod and hence compaction cannot be achieved alright. So, this is when you go too much into the microstructure of the clays, then as a third eye. I repeat the word third eye you require electrical properties which can guide you in the best possible manner to understand what type of mechanism is taking place in clays. So, this is a big advent you know in the history of civilization where electrical engineering concepts are being put into some new concepts to understand what is going on in the clays at the micro level.

Now, most of you have been doing the swelling index test, but to understand the swelling phenomena and swelling mechanism and shrinkage mechanism is there any tool to measure the properties of the micro level? You always talk about the macro level deformations, but what is causing these macro level deformations is the micro mechanism and that is where these types of studies are becoming very important alright.

So, classical geomechanics simply says that the clays cannot be compacted and hence you should use a sheep foot roller. But that is not the correct way of defining the things. Why clays cannot be compacted? What type of viscous forces are going to act? What type of double layers are going to act? What type of diffuse layers are going to act? What type of mechanisms are going to take place? If you want to study all those things and why these studies are becoming very important? Because, we are migrating now slowly and slowly from saturated or classical geomechanics to unsaturated classical geomechanics, alright.

So, this is where the transformation has to be in the subject thinking, understanding and the realization of the mechanisms which are taking place in a soil system. So, with all this in view I wrote this line here that electrical conduction in fine grained soils is a very complex phenomena and mainly it is due to the double layer formation around the grains.

What is the double layer? In the childhood you must be doing an experiment. You take one grape, dried grape. Put it in a water, glass of water. What happens next day morning?

Student: It swells.

It swells. The same thing is happening to clay, particles or grains, platelets, clear? So, the moment you put them in water what happens there is a double layer formation all along the clay particle. Now, the entire dynamics is different. Clay particle itself is not contributing to anything. It is shielded or it is bounded by a water which is all around its surface and that is the reason you cannot compress it too much you think of 2 capsules you know because after hydration what is happened to the clay? It has become a sort of a swollen capsule. You cannot compress the capsules too much. The only possibility they should burst, but then the viscosity of water is so much, electromagnetic charges are so much that bursting is not so easy.

So, this all concepts will lead to understanding and revisiting consolidation theory of clays and that is the reason I showed you in the first lecture people are trying to put electrodes along with oedometer tests to derive void ratio versus σ' response as well as conductivity versus σ’ response, dielectric constant versus σ’ response. So, it is very interesting.

See, this is the typical response of e vs log (σ) alright. So, as σ’ increases void ratio decreases. Now, suppose if I ask you to plot conductivity versus log (σ’), what is your gut feeling? Now, during consolidation what is happening?

Student: (Refer Time: 35:27).

There is a decrease the sample is getting more dense, clear. So, what about conductivity?

Student: (Refer Time: 35:35).

So, this is one school of thought. The second school of thought says, exactly. The pore solution is coming out of the grains and if the pore solution is coming out of the grains what should happen to the conductivity? So, some of you may believe in this school of thought and some of you may be believe in this school of thought. So, this is where the greatest confusion is. You agree? It is not so easy.

This school of thought says contact between the grains without talking about electrolytic properties of the soil mass which is not correct. So, if you are dealing with coarse grained materials even then this may not be possible, but if you are dealing with fine grained materials even then this may not be possible. So, this is where what you have to do is, I will give you this answer later on the which one is correct.

So, the second graph should be dielectric constant vs σ’. What I am trying to show you here is if you do not understand at micro level what is happening it becomes very difficult to capture the response of the material. Is this part clear? Because when we say consolidation the pore fluid is coming out and when the pore fluid is coming out the conduction is going to get effected alright.

So, let us keep this question open for the time being and by the time we end up this chapter again we will revisit this issue. So, these are the issues associated with electrical conduction in fine grained materials.

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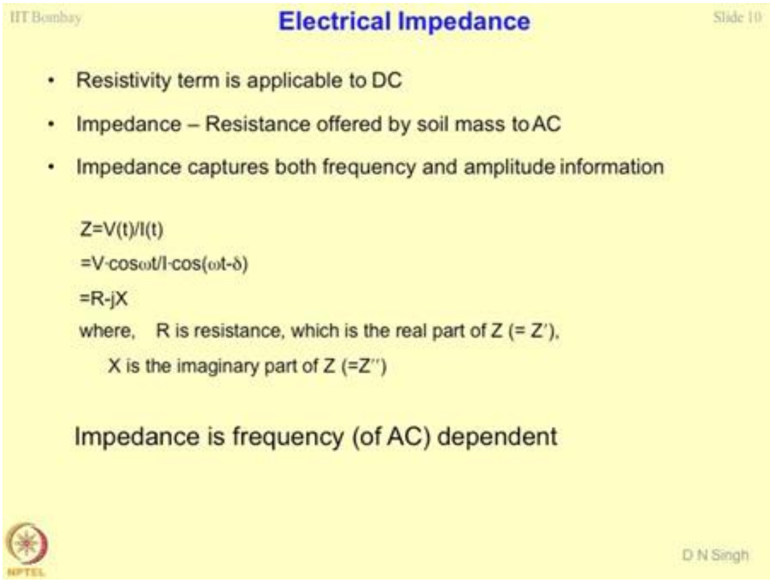

What is electrical impedance? When you talk about simple resistivity it always connotes to DC measurements. So, V= i. R; where V is the voltage, I is the current, R is the resistance or I= σ. V, where σ is the conductivity resistivity sorry σ is the resistivity sorry, σ is the conductivity. So, when you use the term resistivity it always corresponds to DC measurements. When you talk about impedance it is nothing, but the resistance due to AC. So, that means, a frequency can gets associated with the resistance, is this part clear?

So, impedance captures both frequency and amplitude information. Just to clear your basics this is a sine wave, this is t axis, this could be some function. Now, this function could be voltage, this function could be current. So, if this is the amplitude if I say V naught or I naught. So, your V is nothing, but V naught sin of omega t plus theta. Similarly, current will be I naught sine of omega t plus theta. Now, depending upon whether current is lagging or voltage is leading this theta may becomes 0 or it may become 90 degree alright. So, basically this type of functions when you are using here omega is nothing, but the frequency of AC.

So, in DC measurements this omega term is 0. So, what happens you only talk about V and I and we say V upon I equal to R when we talk about AC then frequency term comes into the picture and in that case your impedance terms become important. So, that means, what will happen this R which was a DC term if you write it as a function of time it will be Z, where Z is impedance. So, Z will be V t upon I t. This is V cos of omega t divided by I cos of omega t plus minus delta depending upon whether it is lagging or lagging behind leading behind. So, this term can be written as R minus j X where R is the resistance which is the real part of impedance it is defined as Z prime and X is the imaginary part of Z which is defined as Z double prime.

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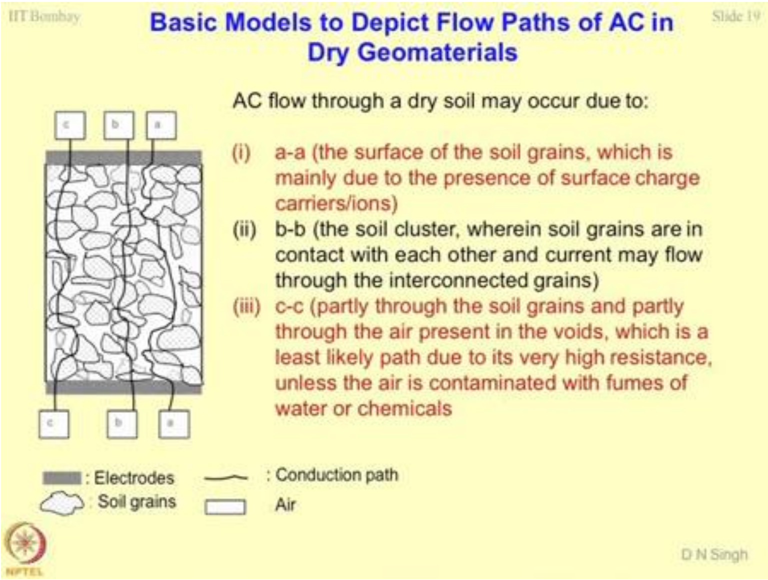

So, the first when we are dealing with the dry geomaterials these models seem be or you have some suggestions. So, when you talk about c-c type, so, it is partly through the soil grains and partly thorough the air which is present in the soils or the voids which is the least likely part due to it is very high resistance unless the air is contaminated with fumes or water or chemicals.

So, when you talk about characterization of geomaterials and if you want to study the interaction problems alright, Srinivas then this becomes a very interesting tool; that means, you can talk about the edge to edge contact when you talk about even the contact of the fluid phase with the grains and what is contributing most to the conductance of the current.

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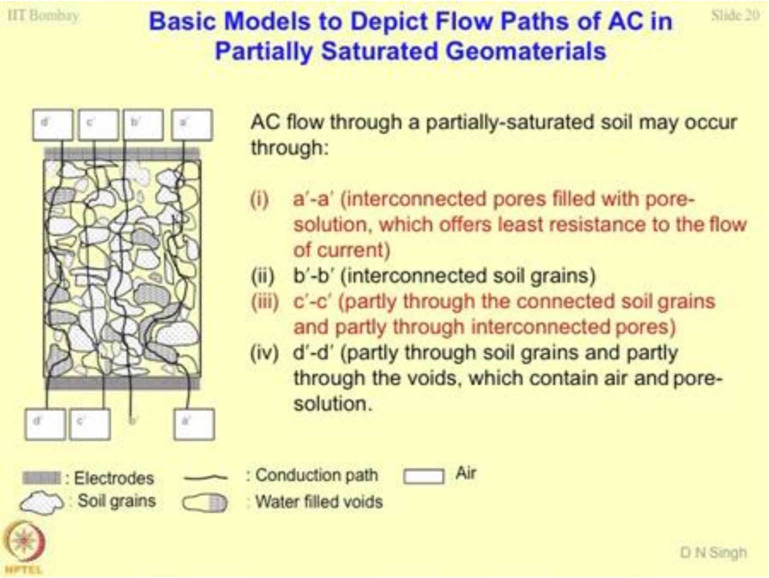

So, we will look into the second phase when we talk about the partially saturated system. So, this is a slightly complicated system where you have again the electrodes which are connected on both the sides, the soil mass is sandwiched in between. The soil grains have been depicted with the dotted lines and then these sorted lines are water filled with voids. And then you have certain amount of air which is present in the soil mass. Now, can you tell me what type of conduction mechanisms are possible here?

Student: (Refer Time: 41:57).

That is right so or water or basically pore solution pore solution. So, one more mechanism gets added here. Now, you think of a situation where pore solution is highly conducting, what is going to happen? There will be a short circuiting of the grains and the boundaries and the edges and the voids and what will happen? All the current will pass through the pore solution which is highly conducting alright. So, this gives you another extreme where the resistivity of the pore solution become so important that the grain structure you know subsides. And the pore solution properties become very important. You must have studied superimposition principle structures and may be in simple mechanics.

Now, this leads to a very interesting thought that if I saturate the porous media with a solution of known solution conductivity clear and if I measure the conductivity of the material and dielectric constant and if I remove this pore solution by some method and again if I measure the properties the difference in the two sets of the properties is nothing, but with a good indication of what type of interaction has taken place between the porous media and the contaminants alright.

So, if you look at the mechanisms here there are four possible mechanisms. The first mechanism is a you have contact between voids filled with water and the grains. So, a is the interconnected pore filled with pore solution which offers least resistance to the flow of current. What about the b? It is again grain to grain contact. What about c? Now, c is partial between through the connected soil grains and through the interconnected pores and what about the fourth one d-d prime? Where the d-d prime shows the conduction is through the grain conduction is through the water conduction is through the grain boundaries and so on.

So, it is partly through the soil grains, partly through the voids which contain air and pore solution alright. So, these type of mechanisms are possible when you talk about flow of AC in geo materials.

Student: (Refer Time: 44:40).

Yes, homogeneity has not been studied here yet, but in what way inhomogeneity is going to bother you? That is right. So, basically this is a lumped model which talks about the minerals or the grains and the voids. So, you are right your input is very correct that if you talk about the inhomogeneity here you know then you are creating a multi phase mineralogical system of the soil. So, this I intent to cover in tomorrow’s lecture when we will be talking about multiphase minerals and how do they contribute to the dielectric constant of the soil mass.

Now, if we consider your suggestion would be it is very difficult to differentiate between the conductivities of different minerals, but it will be very easy to differentiate between dielectric constants of the conductors. So, nobody talks about a mixed phase conductivity model, people talk about mixed phase dielectric constant model. So, this I intent to cover in tomorrow’s lecture alright and this is what people are using in CSRE in remote sensing to identify what type of contamination of the soil has occurred otherwise because of oil or because of gas or because of water or because of erosion and so on because the mineralogy is becoming a very important parameter whenever the interaction takes place.

Student: (Refer Time: 46:15).

No, no, no these are philosophies. These are philosophies. It could be either 1, it could be number 2, it could be number 3, it could be number 4 or it could be a combination of all. These are philosophies in dry phase also. You know this is how you would speculate that conduction may take place, either it could be through air or it could be through b or it could be through c and the other three logics which come to the mind and then immediately you can capture that the conduction of current is taking place through grain boundaries also.