Environmental Geomechanics
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Lecture No. 54
Magnetic Characterization

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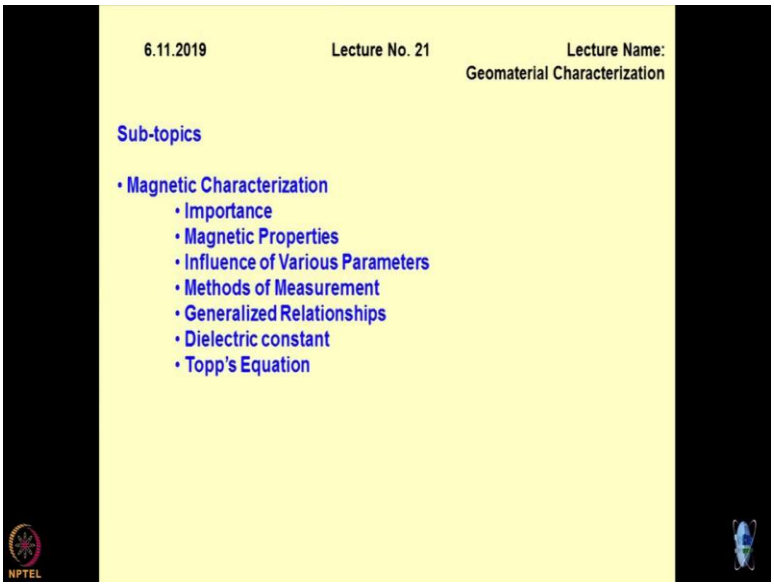

Today I will be discussing the magnetic characterization of geomaterials, and that is the last part of the characterization schemes for the soil or the geomaterials which we have been doing as a part of our research activities, and some of my students are working very actively in this field of environmental geomechanics. Under the head of magnetic characterization, I will be discussing the importance followed by what are the magnetic properties of geomaterials.

What are the factors which influence them and what are the methods of measurement of these properties, and then some generalized relationships which are being used for determining the magnetic properties and particularly the dielectric constant and how the dielectric constant has been used for determining the volumetric moisture content of the geomaterials, which is a very contemporary thought?

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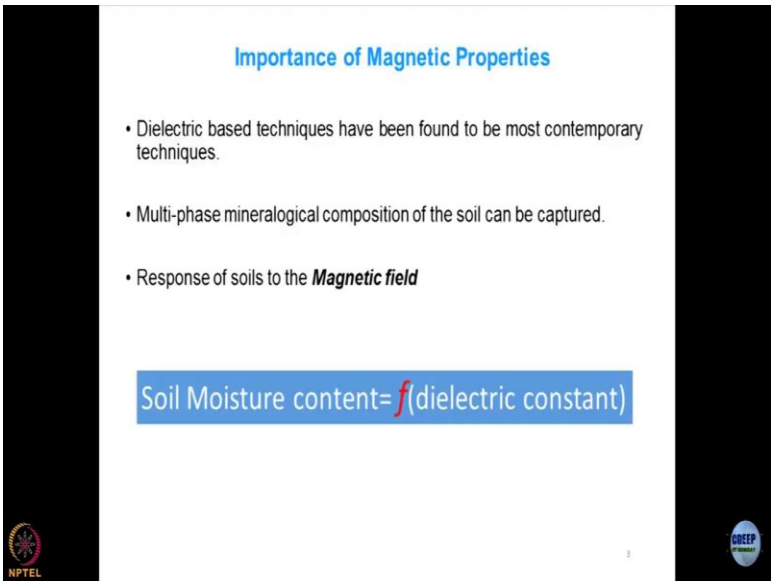

So, not much research has been done in this area until now, and this seems to be a very promising area for the researchers who are having the tendency of understanding nature better. So, I am sure that even when you visit a departmental store, I mean, the bar reader reads the value of the utility item. And this is the whole concept of magnetic properties, dielectric reflectance and electric impedance of the material comes in the picture.

So, the magnetic properties will depend upon the electric property of the material which we discussed in the previous lecture when you we were talking about the electrical properties of materials, non-conducting materials have a tendency to store charge, and the charge of storage capacity is in other words defined as the dielectric behaviour of the material. So, contemporary geomechanics like any other subject in modern-day science and technology is based on this parameter that how to decipher the dielectric constant of the material and relate it with different properties.

So, when we talk about the magnetic properties truly speaking the dielectric property is become very very important and their applications you will be noticed in a short while, the beauty of these type of techniques, when they are used for material characterization, is that I can get up to the minutest details of the geomaterials in terms of its mineralogy and mainly because soils are a multi-phase system. In terms of the minerals which are present in it, except for the magnetic

property of the geomaterials, nothing appears to be a very comprehensive scheme of characterization.

Where the weightage can be given to different types of minerals and their phases are concerned. So, those of you will get a chance to work in this area; you will realize that the best way to obtain the mineralogical composition of the soil would be to do XRD analysis, x-ray diffraction and from there you can obtain the types of minerals and the phases which are present in the system.

Now, each mineral and each phase of the mineral would have a specific dielectric constant. So, ultimately what we can do is we can talk about something like effective dielectric constant of the system and I can differentiate between the types of geomaterials based on their mineralogical characteristics. So, when we talk about the magnetic properties, the basic premise is that the dielectric constant of each mineral and its phase is a fingerprint. And this property can be utilized to correlate the material response with the moisture content.

And moisture content controls most of the mechanisms which occur in the geomaterials, including the shear strength if you talk about the shear strength is a function of the moisture content. Compressibility is also a function of moisture content; contaminant transport depends upon the moisture content; hydraulic conductivity depends upon the moisture content compaction characteristic depend upon the moisture content.

So, in short, the basic research is going on in the direction to obtain the soil moisture content and particularly in the volumetric form, and relate it with the dielectric constant, because dielectric constant can be obtained very easily by using different techniques. One of the beauty of this type of discussion is that remember, we were talking about the particle energy field concept. So, it is a good example of how geomaterials would behave when they are kept in a magnetic field. So, this is the philosophy which is being used to understand and decipher the response of the geomaterials.

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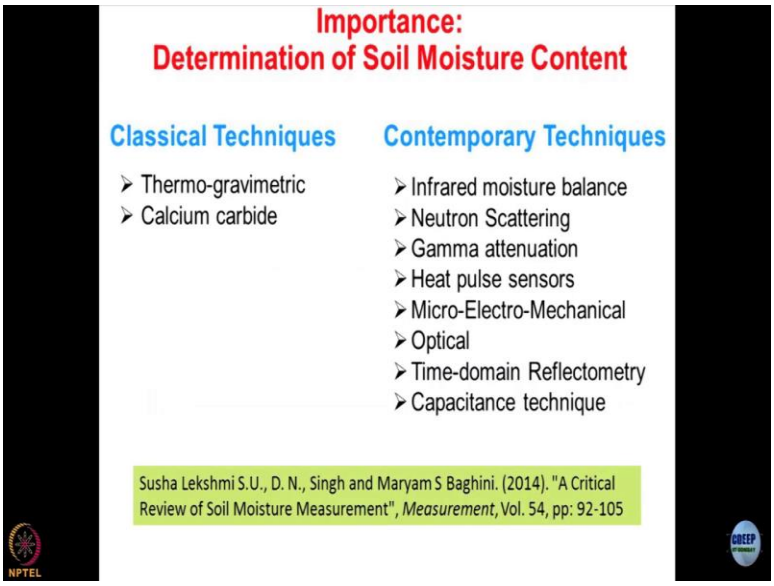

Importance of studying the magnetic characterization of geomaterials gets reflected from the fact that there are several techniques of determination of moisture content, which have been now sort of blacklisted, blacklisted in the sense that people have understood their limitations. So normally, we do not talk about the classical concepts when we determine the moisture content, and in place of that, the contemporary techniques are being used.

So here what I have done is I have listed the classical technique like thermogravimetric analysis, you take some amount of soil and heat up it heated up in the oven up to a certain temperature and found out the weight difference, and from there you can compute the moisture content. Some of you must be dealing with the calcium carbide method also of finding out the moisture content, but these techniques have their limitations. These are not very precise techniques.

And the second thing is that these are ex-situ techniques that mean you have to take out the sample, bring it to the lab and then do the test or sometimes on the field also you can do this test, but then again you have to take out the sample from the in-situ condition and then do the analysis. So, there is a school of thought which says that you have already disturbed the sample and it is very difficult to maintain the what you call it as intactness or integrity of the sample.

So, to overcome, this is the future of our subject, where a lot of contemporary techniques have been evolved for finding out the soil moisture content. The infrared balance, which you must

have noticed when you went to our lab, it is an advanced technique of finding out the moisture content, neutron scattering is another technique, gamma wave attenuation is another technique, heat pulse sensors.

So, when you are talking about the thermal characterization of geomaterial that I have talked about, how a heat pulse can be utilized to pass the heat through the geomaterials and that can be related to the moisture content. So, thermal conductivity, thermal resistivity, thermal diffusivity and specific heat of the geomaterials also indicates the moisture content of the geomaterial, that is a complicated process. Microelectromechanical devices we call them as mems.

So, people are trying to develop these type of circuits where different types of sensors which are MEMS-based, are being used to obtain the moisture content. And I have guided two PhD thesis one is by Dr Vinay and one is Dr Susha Lakshmi. Where we have used these techniques,, and we have compared them also sometimes optical techniques are utilized to find out the moisture content.

And as I said when we are talking about the electrical properties of the geomaterials, TDR and time domain reflectometry probes and sometimes the capacitance probes are utilized for finding out the moisture content. So, you must be wondering that normally, we do not take soil moisture content determination so, seriously. But, if you realize in today's world the most of the emphasis is on the determination of soil moisture content precisely and then link it with different properties of the geomaterials and they the interesting paper which we have published, she was my student, Dr Susha Lakshmi.

And Professor Maryam is the one from MEMS, nanoelectronics department of IIT Bombay. We were collaborating, and we have published this paper a critical review of soil moisture measurement. Very recently, you can get hold of this paper and then you can realize what is transpiring in the subject in the current scenario, just let me remind you that why all this research is being done because people are utilizing sensors and different types of probes to link and monitor all the mechanisms which happened in geomaterials.

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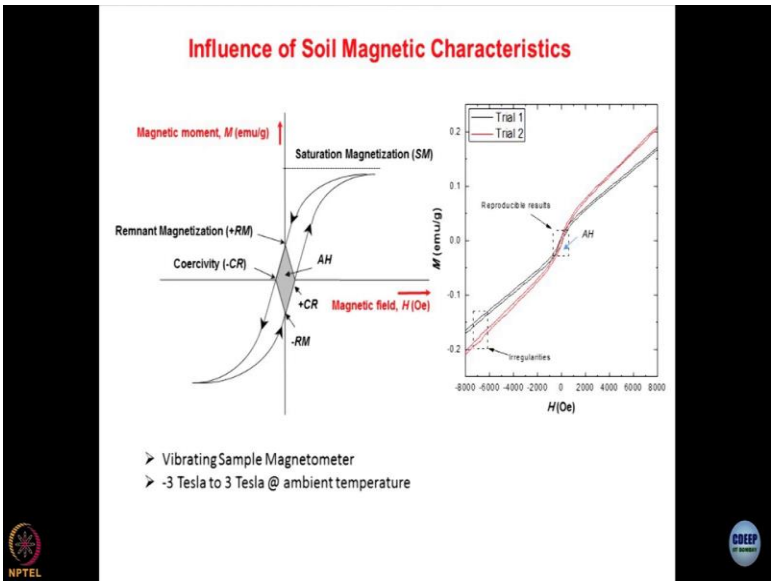

This is the basic concept I am sure you must have studied in your 10+2 physics and that time you did not realize that we are this can be utilized in advance R and D in the field of civil engineering particularly. So, this was our concept on with Dr Susha Lakshmi worked influence of soil magnetic characteristics on different parameters. The philosophy is that if I keep a small sample of soil, in a magnetometer, these are known as vibrating sample magnetometer.

And if I expose it to different magnetic fields, how much the soil gets magnetized and this magnetization is measured in the form of the magnetic moment, so, starting from point zero. The more and more magnetic field which you apply, do you remember, OE corresponds to the oysters. And emu per gram is the magnetic moment unit. So, as you increase the magnetic field, the material gets magnetized. And this magnetization is computed normally in the form of the magnetic moment.

There is an increase in the magnetic moment, and it becomes constant, and this point is known as saturation magnetization, Sm. In other words, this is the maximum capacity of the soil mass up to which you can magnetize it. And this concept, in our opinion, is very useful for differentiating soils of different types. So, all these philosophies have been given by my student, Dr Susha Lakshmi, and earlier they did not exist in the literature. Having achieved the maximum magnetization suppose if I demagnetize the soil mass either by reducing the magnetic field or by applying a reverse magnetic field.

So, this is how the hysteresis gets completed; this is what is known as a hysteretic curve, and this hysteretic curve can be utilized for linking various soil parameters with the magnetic properties of the soils. So, there are two properties which we look for of the soils or geomaterial. One is known as eminent magnetization the remnant magnetization corresponds to at 0 magnetic fields what is the amount of magnetization which still remains in the system, and this could be both positive as well as negative depending upon the magnetic field direction.

So, the moment you reverse it, the RM will become negative. Then the second parameter which normally we used is coercivity. So, coercivity is CR, and again you will be having two values of CR and two values of RM. And to our surprise, when we started working on soils, we realized that soils follow this philosophy. So, here what you are seeing is for a given soil, when we magnetize it and when we demagnetize it

That means when we plot the results on the magnetic scale, moment scale versus the magnetic field is game, what you will observe is there is a bit of hysteresis which appears at this point. So, this is where we spend most of the time to ultimately filter out the CR and RM parameters or different types of soils. We studied about 42 types of soils with different methodology, and we came out with these results. And for me, this area of the hysteresis curve which is getting bound by RM and AH becomes a very important parameter.

So, we call this as AH, the area within the hysteretic curve. So, I am sure you must be realizing that these are the philosophies which have been utilized to derive something which was in our mind. Normally depending upon the type of vibrating sample magnetometer which you are using, we normally go from - 3 tesla to 3 tesla, which is a decent amount of magnetic field at the ambient temperature. So, once this type of relationship is known, you can do a lot of things with it. I am not going to cover the entire discussion, which is available in Susha Lakshmi's thesis.

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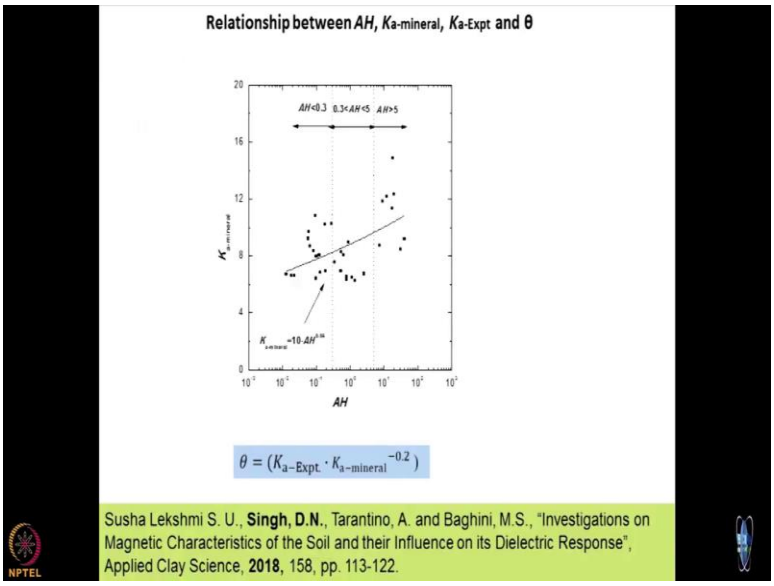

Just a quick way to analyze the results. The area of the hysteresis curve has been linked with the dielectric coefficient of the minerals. So, once you have magnetized and demagnetized the soil, it can be linked with K value and once the K value, I can link it with the theta which is the volumetric moisture content of the soil. I will tell you how it is done. So this is the basic premise of our research.

That area itself can be demarcated in three segments. Less than 0.3, 0.3 to 5, and then >5. You need not write down all these things; it is just the conceptual work which we did. And then we came out with the relationship that dielectric constant is a function of the area of the hysteresis. Area of the hysteresis becomes a number parameter, which contains all the information about the geomaterials.

And what we have done is we have gone one stage ahead, and we have related this K value with the volumetric moisture content. Where ka from the experiment that is the bulk dielectric constant of the soil sample. And then the type of minerals which are predominant in the soil mass have been linked together. It is a very interesting philosophy which you will find in this paper which has been published by us. Investigations on magnetic characteristics of soil and their influence on the dielectric response. A very fundamental work which was done by my student Applied Clay science in 2018.

The philosophy is like this that the volumetric moisture content has two components, one is the porosity, and another one is saturation or the moisture content, which is present in the dry density form. So, that means, the volumetric moisture content could be of the bulk and the minerals, and when we talk about the bulk, this is where pore structure gets inbuilt into it fine.

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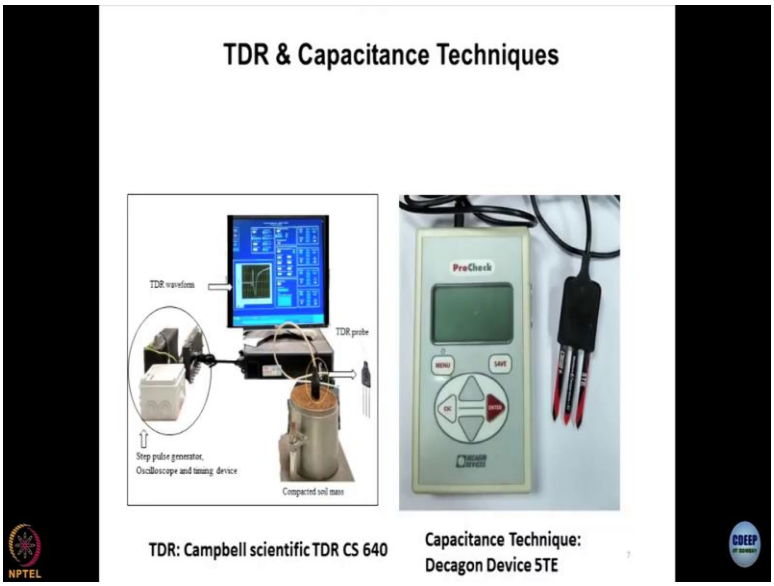

So, this was the thought process which we had and to show you what ultimately we did is we utilize these type of equipment which are available in our laboratory. This is what is known as a TDR probe, which you have already have discussed in the class that how to TDR probes are used for obtaining the TDR waveforms, and these TDR waveforms can be analyzed to obtain the dielectric constant of the geomaterials.

Now if I measure the moisture content and if I know the TDR value, dielectric constant I can correlate the two and I can see for a given dielectric constant, how much the moisture content of the soil would be. Now, this is a typical capacitance probe, which is known as a Decagon device. These are three probes, three-element probes, this is also three-element probe, and this is inserted into soil mass, and then you can obtain the capacitive values associated with the soil mass and capacity values mostly the dielectric constant.

So, these are the two techniques which we wanted to compare, and we wanted to see which one is having the upper edge as compared to the other one. Incidentally, these techniques have also

been utilized by us in monitoring the health of the landfills. So, one of my students Dr Agnes she has worked and particularly Dr Patil these two have done TDR and capacitance analysis of the live landfills and to scan from top to bottom of the landfills what is the state of the MSW inside. And now, we are trying to work on the models to define the state of decomposition and degradation of the municipal solid waste over a period of time. So, these are interesting techniques which people are trying to use in today's context.

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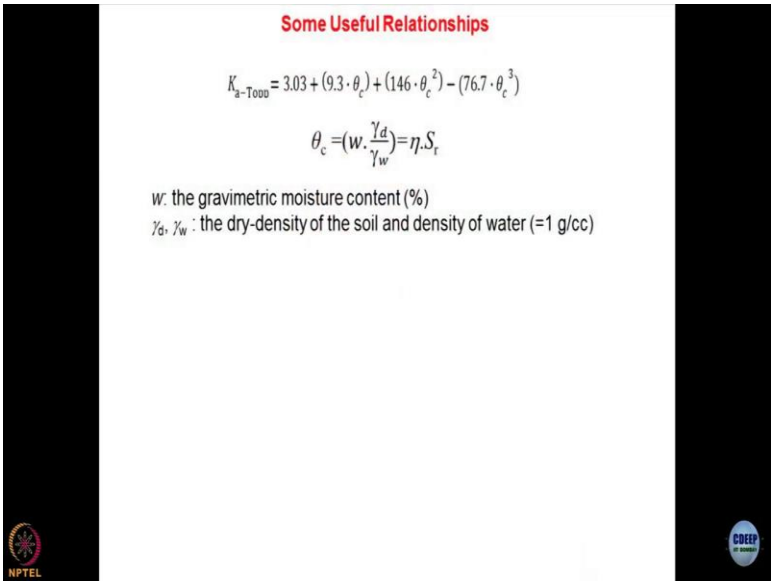

These are some interesting relationships, which are used for this is what is known as the Topp's equation, these relationships can be utilized for various purposes, this equation is known as Topp's equation to PP top and what it shows is that the dielectric constant of a soil mass is a function of volumetric moisture. It is a cubic law. So, where θ_c is the computed volumetric moisture content, and this is even as the $W \times (\gamma_d/\gamma_w)$.

There is another form of writing θ_c value which is equal to the porosity of the soil mass multiplied by saturation. I think you can realize that obtaining θ_c is quite complicated because there is no way you can estimate the saturation under in-situ conditions. Porosity, itself is a big question. So, I will be talking about how the porosity of the soils is determined. And so, truly speaking in laboratory samples, of course, you can try getting the porosity and saturation that that self is quite a tedious task, if not inaccurate.

Getting the gravimetric moisture content is easy. You can take the sample out from the field, bring it to the lab, obtain the moisture content multiplied by its γ_d, and that gives you the volumetric moisture content. **"Professor - student conversation starts"** Sir, as soon as we like studied that as SWCC curves I was thinking about that gravimetric water content determination with that in the oven-dry method. That is not correct, because we cannot ever get rid out of the whole moisture content from the soil.

Because of whatever suction we apply, there will always be water content remaining. And with these new techniques, the contemporary techniques, the first one that we have used, so can we get that accurate value, like the real moisture content, because in clays, no matter how much you keep on oven drying, as soon as the suction is there, you cannot get the real water content value. Whatever value we get. So, is that a good option? Because it is a quick method in our lab, I also saw. You just have electromagnetic rays, and it gives you the right value.

So, the answer to your question is the simplest answer to your question is please read this paper where we have spelt out all our sentiments, and a lot of emotions also, that what should be done and what should not be done and unless you read this paper, I am sure you will not understand what the difficulties are associated with determination moisture content. So, what I said is that earlier this parameter was not taken very seriously. But now, if you read the history of the development of as SWCC, you will realize that is SWCC is also utilized to differentiate between the types of moisture which are present in the soil mass. **"Professor - student conversation ends."**

So, when you talk about types of moisture which are present in the soil mass, the precise determination is very very important. So, coming back to your question that for as SWCC oven drying method is not going to help you are right but then what is the way out.

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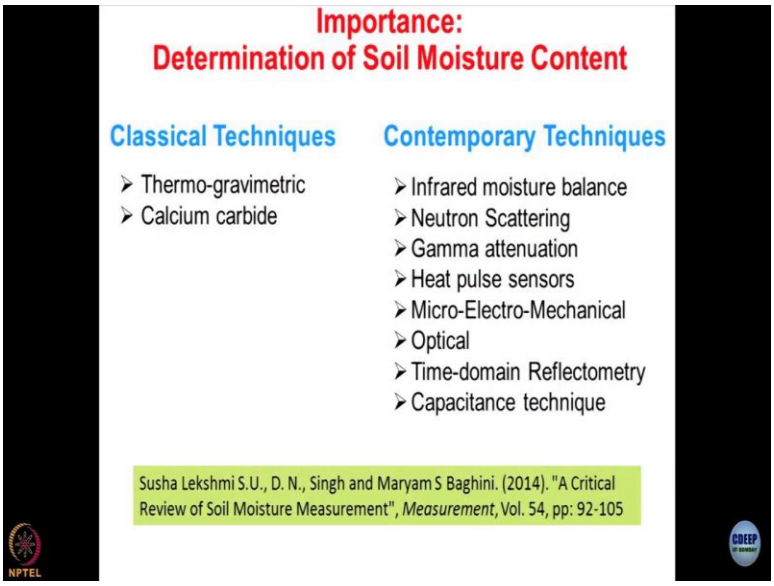

This is one question. You can use some of these techniques like infrared and all which can be of some help. Still, people are debating on the methodologies. And remember, when you will go through this paper, you will realize that the organic matter which is present in the soil plays a very big critical role when you heat up the soil. So, the oven method of determination of the gravimetric moisture does not appear to be a very precise method, particularly for the soils which are organic in nature.

Yes, because the soils would disintegrate, soils would get burnt, or the soils which are contaminated with organ with, let us say organic matter or volatile organic matter. So this is a big issue. I think my suggestion is, whenever you get time, please read this. So, what I am trying to show here is that even computation of the volumetric moisture content is not such a simple task, because the porosity has to be determined.

And I am going to discuss; the methodologies is which can be employed for determination of porosity separately. Earlier also had emphasized on the determination of the porosity to remember when we were talking about the contaminant transport, and the electromagnetic response of the geomaterials, how the current passes through the material, how the heat migrates through the geomaterial is everywhere where we have to talk about the porosity of the geomaterials.

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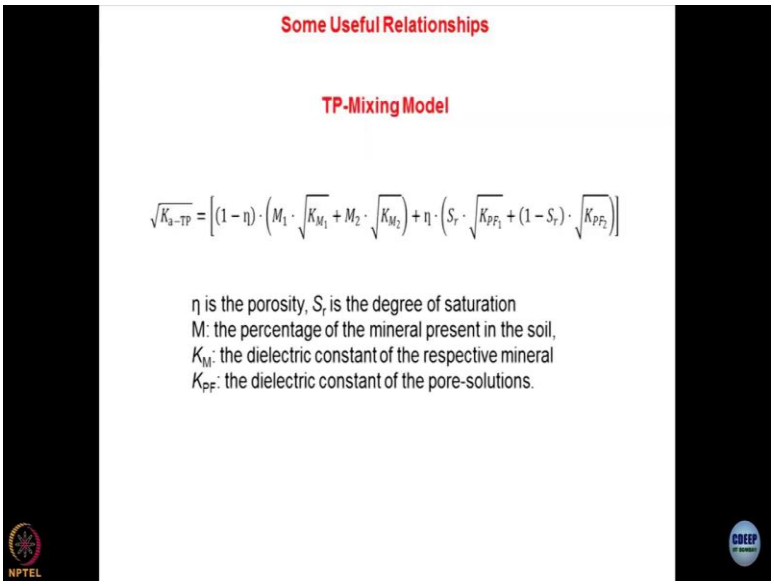

Sometimes people utilize the TP mixing model; these are the several phases of the soils which are taken into account while talking about its dielectric constant. So, the TP mixing model is known as the multi-phase mixing model. And what it talks about is, there is a relationship like this which is used for a two-phase system. Eta is the porosity of the geomaterial Sr is the saturation, degree of saturation, M is the percentage of the mineral content.

So, what you have to do is you have to get XRD results, and by using some software which normally is known as the expert high score you have to find out what is the percentage of a mineral which is present in the soil mass. This is what is known as quantitative analysis. So, once the M_1 and M_2 correspond to two types of minerals which are present in the soil, K_M is the dielectric constant of these minerals and K_{PF} is that pore fluid.

So it is a very interesting philosophy to understand the equation the way it has been developed. Truly speaking, this is the dielectric constant of the mineralogical phase one multiplied by its fraction plus a dielectric constant of phase 2 multiplied its fraction and 1 - porosity will give you the solid contents, correct and porosity multiplied by saturation and one minus saturation will give you the pore fluid content.

So K_{PF1} is the pore fluid 1 one K_{PF2} is the pore fluid 2. And the two types of pore fluids normally we air and water. Now, suppose if I put saturation equal to one, fully saturated soil. So, what is

going to happen?. The second component vanishes because this becomes 0, fully saturated material. So, this happens to be the pore fluid water, this is air, and then we have 1 - porosity into mineralogical fractions multiplied by the dielectric constant.

So, these type of models are being utilized, and people have been successful. Now, the biggest question would suppose if somebody wants to extend this model to a three-phase system or let us say a multi-phase system of geomaterial like hydrates, gas hydrates. Then this becomes really very very complicated because the saturation term itself would be having two components three components sometimes So, this could be water saturation, this could be hydrate saturation, this could be gas saturation.

So, now we are working on this model, how to utilize the TP mixing model and extend it to a multi-phase system where you have several minerals you have several types of fluids, which are present in the system. And this is a very contemporary research area on which I would like to work for another 5, 6 years. It is going to be quite complicated, but very interesting analysis can be developed, which is going to tell you under in-situ conditions, what exists in the sediments, any type of alteration, mineralogical, physical, chemical, bacteriological can be detected by using probes what I to do is I have to simply measure the dielectric constant.

And then relate it with the phases of the materials which are present in the system. Now, this is what we could achieve in the realm of magnetic characterization of soils. So, still, a lot has to be done. Our understanding is very limited, but I have intentionally covered this subject in the class is that this is where the research has to be done. And imagine, as I said, the processes which are occurring in the geomaterials can be only deciphered or depicted or captured by using these techniques. There is no other technique.