Environmental Geotechnics
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Lecture – 42
Thermal Characterisation – 3

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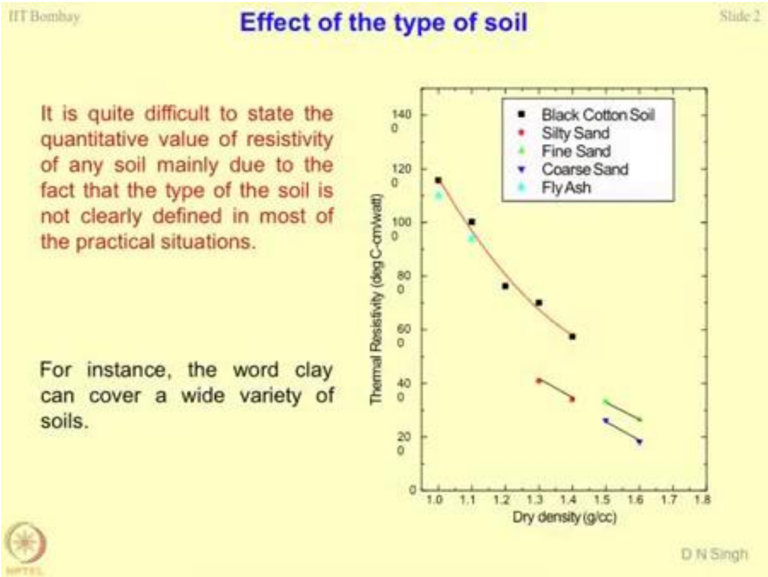

Now, by this time you are aware of the thermal properties of geomaterials that is thermal resistivity, conductivity, diffusivity and specific heat. So, the parameters which influence these properties; the number one parameter is the effect of the type of the soil. So, it is a very very random way of defining, but still it is quite difficult to state the quantitative value of the resistivity of the any soil mainly due to the fact that the type of the soil is not clearly defined in most of the situations.

There are two things associated with type of the soil, one is the origin or the composition and the second one is when we use the word type of the soil is understood that we are talking about its size fraction. So, state of the art is not sufficient enough to address the origin of the soil and how it influences the thermal properties, but yes enough work has been done wherein people have talked about the green size fraction distribution or effect of grain size on thermal properties.

So, this is where actually most of the time the confusion arises when we say word clay is difficult to connote it to certain properties unless you have particular because clay could be because of the minerals or clay could be because of the size fraction. So, before you use this word you have should be careful that what is the connotation; whether the clay corresponds to the mineralogy or the clay word corresponds to the size fraction.

But, in short if you look at this relationship, they should answer I think Sneha's question you are asking or someone else was asking in the previous lecture what is the relative ranking of thermal resistivity's of the soil, is it not? So, if you plot on y-axis thermal resistivity the units are °C. cm/watt with respect to dry density (γ_d). So, the first trend which is clear from this figure is that as dry density increases the resistivity drops down this is because of better contact between the grains; grain to grain contact increases because of good compaction or dry density is there high.

Now, if you look into trends what you will notice here is that the finest grain material that is the black cotton soil shows maximum resistivity alright followed by the fly ash which is a silty material. So, clays and silts mostly show very high resistivity followed by you will see that these two graphs or the trends are for sands; so, coarse sands and the fine sands. So, this is how you can make out the influence of the size fraction of the soil on thermal resistivity ok.

But, most of the time you will notice that the natural soils which are available for construction purpose or industrial applications they will constitute mostly clays and hence the resistivity will be very high. So, the biggest challenge is that how to drop or how to decrease the resistivity of the soil mass so that you can do some construction related to either air conditioning ducts, buried pipelines, cables and so on. I hope this answers the question that what is the influence of type of the material or the fraction size on resistivities with respect to dry density.

Now, some one of you should have ask this question that why these trends are not available beyond a certain limit of dry density. Why this graph is hanging somewhere here only? The reason is it is very difficult to compact clays beyond 1.4 g/cc. So, these are all experimental findings. So, in laboratory you cannot compact the material more than 1.4 g/cc. However, you can extrapolate the trend and what you should observe here is that this graph will become asymptote after certain density.

Now, it is a very interesting way of understanding how grain to grain contact influences the resistivity because when you plotting dry density it is understood that you are filtering out the effect of moisture content and either this is the driest possible state of the material or even if you are studying the density total density you are normalizing the total density with respect to moisture content. So, your $\gamma_d/(1+w)$ term is nothing, but γ_d.

So, the tendency of the material is to achieve a constant thermal resistivity which is nothing, but the resistivity of the minerals. Now, this concept can be utilized again for characterization of minerals; not soils, the minerals and you think of a situation where the resistivity's of individual minerals is known and then you can come up with the model to find out what is the mineralogical composition of the soil. So, that would be something very interesting. And, this is where actually people need to do research alright.

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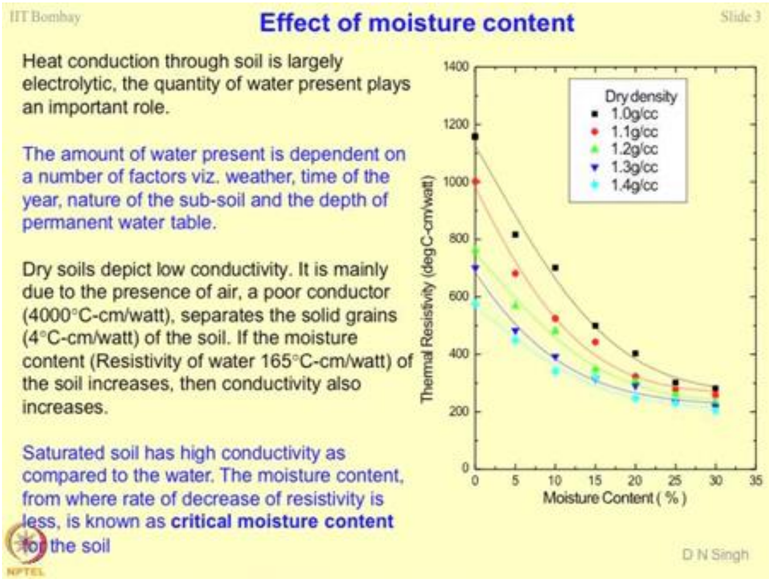

The second major factor which influences thermal resistivity is moisture content. So, what is the philosophy behind this type of mechanism? Why moisture content controls the resistivity? So, heat conduction is mostly through the pores or the pore solution which is present in the soil or the porous media. The reason is resistivity of minerals is very high as compared to the pore solution; so, most of the thermal conduction takes place either because of advection or because of advection convection.

So, when you talk about the fluids the heat transfer is convective in nature. So, even if you are talking about partially saturated soils or fully saturated soils beyond a certain limit the conduction gets exchange with convection convective currents alright. So, heat conduction through soil is largely electrolytic, the quantity of water present in the soil mass will play a very important role. Now, why it is so? Why water is so important? The amount of water present is dependent on a number of factors that is the weather conditions, the climatic conditions, time of the year alright, nature of the subsoil and the depth of the permanent water table, fluctuation of the water table.

So, this is why this study or you know this subject becomes very important in day to day life particularly in the scenarios where waste is being disposed and this takes as a component or the attribute associated with it as the temperature being very high. So, in what way these temperatures are going to influence the geoenvironment of geometrical fundamental characteristics becomes a very important issue.

Now, this is the logic that most of the time dry soils will depict low conductivity or very high resistivity. It is mainly due to the presence of air which is a poor conductor and if you look at the value of conductivity of the air resistivity sorry, this will be 4000 ℃.cm/watt and this is separating the solid grains and the resistivity of the solid grains would be 4 ℃.cm/watt of the soil.

Now, if the moisture content of water is assumed to be 165 ℃.cm/watt. So, as you increase the moisture in the dry soil what happens the resistivity will drop down and what you will notice is that beyond a certain point if you keep on changing the moisture content of the soil, a situation comes beyond which the resistivity becomes constant or remains constant and that is a resistivity of the water as under 65 ℃.cm/watt. A bit of an explanation I had given in the previous lecture where I was talking about the influence of water and water is coming on the top is the influence of the matrix of the soil mass.

So, that is the reason saturated soil will have high conductivity as compared to water. Because now there is an effect of water as well as the conduction through the grains. Now, this philosophy becomes very important for the people who are trying to study thermal impedance of the soils. In our country particularly people have not worked in this area, but the way you talk about electrical impedance it is nothing, but resistance of the circuit which you might be studying. Similarly, if you can find out the resistance offered by a soil mass for the passage of heat so, this becomes thermal impedance.

So, thermal impedance is becoming a very important parameter which most of the colleagues from power engineering or electrical engineering you know sub subject has power they need this input from civil engineers. So, if they know the thermal impedance of the soil, they can design their cables properly. So, you may like you can understand there is a big challenge for the profession to give the feedback to electrical engineers who can then come in the picture as far as the design of the cables and everything is concerned.

So, the moisture content from where the weight of decrease or resistivity is less this is known as critical moisture content of the soil, I will just show you what is the significance of this. For a given soil if you conduct several test corresponding to different dry densities by changing the moisture content these types of relationship will be getting.

So, here you can see many things. First of all, the effect of density, if density is more and this section density is less. So, as density increases what happens to thermal resistivity? It drops down. So, the top most curve corresponds to very loose state of the material, the bottom most part of the curve shows corresponds to dense state of the material. So, more density; that means, in this direction the γ_d is increasing. So, bottom most line corresponds to higher dry density as compared to top portion. This is point number 1.

The second thing is for a given γ_d what is the influence of moisture content? So, what you will notice is as moisture content increases the resistivity drops down and the logic air is getting replaced by water which is having less thermal resistance. So, this drop is too high a very rapid up to a certain limit, and beyond certain point you will notice let us say about 25 % or so, you will notice that more or less the RT value becomes constant. Can you correlate it with something else in geomechanics? This magic number of 25 % in terms of moisture content OMC; OMC of most of the soils is about 25 – 30 %. Is it not silty soils and all.

So, there is a philosophy that if you know this type of relationship you can again find out the OMC indirectly and I am sure you will agree that compaction process is not a very very you know the size methodology to characterize the soils. However, this method happens to be a very precise method of characterization. So, there is a school of thought which proposes that thermal properties can also be used for compaction characteristics of a soil. Why it is so? One of the parameters is this γ_d and this is nothing, but the moisture content. So, truly speaking if you plot R_T variation along the proctor compaction curve; you got the point? Because this is nothing, but the γ_d versus w (%) for a given resistivity;

you will be getting the resistivity contours for the material in a 3-dimensional plane and that graph can be utilized for most of the problems related to your industrial design and applications.

There is another interesting thing which comes out of this type of relationships that beyond this point where the drop-in resistivity seizes and the resistivity becomes almost constant, now this is what is known as critical moisture content. So, this point somewhere close 25 or somewhere close to OMC would be a critical moisture content point. Why do we say that this is a critical point? Now, this is a point beyond which the soil mass is going to exhibit a very high resistivity for a unit drop in moisture content.

On the left-hand side of this graph or this point sorry on the left side of this point unit dropping moisture content is going to get exhibited in increase resistivity alright. So, the issue is if you know this moisture content and if you can maintain this much amount of moisture content under in-situ conditions, please understand what I am saying. If you know this point very precisely and if you can maintain the situation where the moisture content of the soil does not go less than below this moisture content, thermal instability will never occur. So, this is the best way of avoiding thermal instability; otherwise what is going to happen?

The resistivity will increase during summers because of there is lot of moisture and that is the time when most of the cables may burn if they have buried in the mass. So, this look like a very simple relationship, but the implications are several. Of course, these graphs are blind of the mineralogy. So, that requires more and intensive studies from researches like all of us to make very comprehensive picture which can be utilized in the most precise manner. Is this ok?

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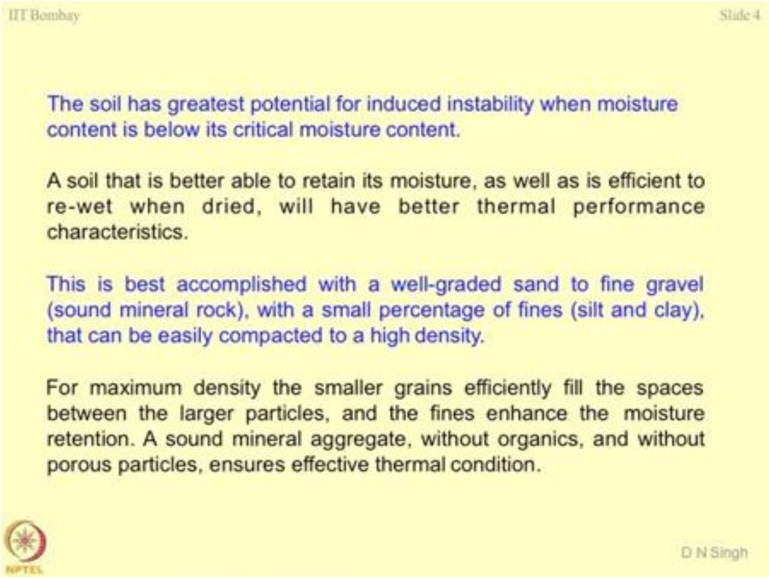

So, the soil has the greatest potential for induced instability when moisture content is below the critical moisture content. This is what I have explained just now. A soil that is better able to retain its moisture as well as efficient to rewet when dried. We will have better thermal performance characteristics. See this is the era of infrastructure. Everywhere in the country people are talking about infrastructure. So, infrastructure development is supported by not only soil most of the power plants development; about 80 power plants are being constructed in the country big power plants.

So, the main issue is thermal instability. You are generating power, but that power cannot be you know transported or cannot be conveyed to different places. Why? Just because the local soil conditions are very poor. I mean can you imagine the extent of the problem? If you are producing any other product you can always transport it either by using railways or airways or transport of anytime, but when you are transporting current electricity then it becomes very crucial issue. So, this is where the concept of rewetting and drying of the soil comes in to the picture.

And, that is how this thought came in the mind let’s study the wetting and drying cycles which Sneha is going to educate us on by the end of this semester. So, what happens to the material when it gets dried up and then it becomes wet and the cycle goes on. So, what type of hysteresis comes into the picture, what type of material properties losses can be estimated and so on, how material behaves, how material is going to exhibit itself becomes a big question mark.

So, in all these projects as I was telling you sometime back a term known as FTB is very important, Fluidized Thermal Bed. So, Fluidized Thermal Bed is nothing, but an artificial system by which resistivity of the soil can be maintained below a certain value so that it does not shoot up because of changing moisture content. So, either by adding the different type of materials into the native soil you can design an FTB or by adding simply moisture in the soil mass you can create FTB depending upon the situation and the requirements.

So, this is where I written a soil that is better able to retain it moisture is very good because not looking the moisture. So, if it is not using moisture, I hope you can appreciate the point there will not be any drop in the moisture and hence thermal instability will never take place. So, this calls for selection of fine-grain materials, because fine grain materials can only retain moisture, but the issue is if you are using fine grained materials the resistivity's are very high. So, this problem becomes a design problem.

So, a soil that is better able to retain it is moisture as well as is efficient to rewet when dried, we will have better thermal performance characteristics. This is best accomplished with well graded sand to find gravel with a small percentage of fines that can be easily compacted to a high density. So, what do you require? You require good possible densities, very high moisture contents, less fine contents. So, you add some coarse materials in the fine-grained material to create a good FTB material and then compact it better.

So, for maximum density the smaller grains efficiently fill the spaces between the larger particles; theory of compaction. So, a well graded soil can be compacted better as compared to a uniformly graded soil or a poorly graded soil and the fines enhance the moisture retention. So, this is a very interesting problem, the moisture should not come out of the matrix at the same time heat conduction should be through the soil mass at a proper rate.

Now, this again becomes a you know what do you call it as a coupled phenomenon or the heat migrates moisture does not migrate. So, you have to test the soil mass to understand what is the susceptibility of the material towards thermal gradient and at what degree of compaction with moisture content thermal instability may occur? Is it part clear? So, basically, we are talking about γ_d, moisture content, type of the soil and its compaction and the minerals. So, a sound mineral aggregate, without organics, and without porous particles, ensures effective thermal condition.

These are the philosophies based on which most of the time soils at power plants or the base facilities where thermal gradients are very high are designed and that is the importance of the environmental geotechniques geo mechanics where you can select the materials you can talk about these attributes otherwise in classical geomechanics you cannot really consider this effects.

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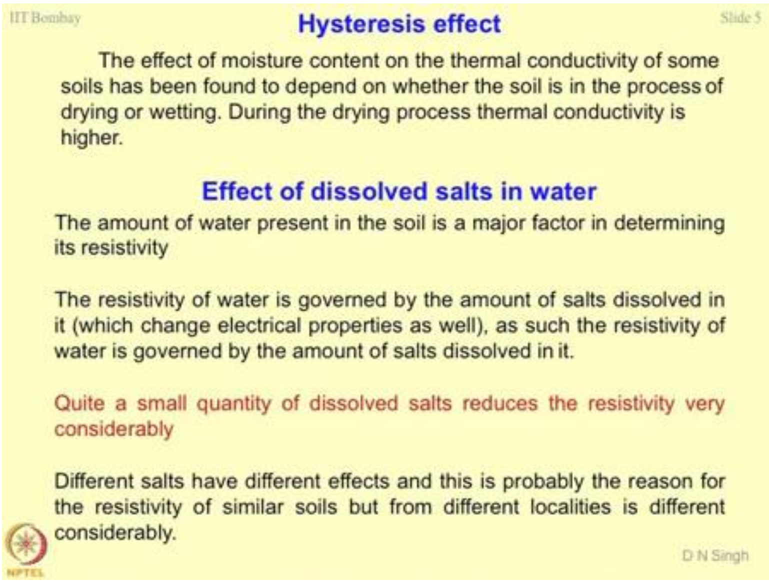

Then comes the hysteresis effect. Not very clear to researchers how hysteresis can be you know correlated with the fundamental properties of the soil as on date, still people are trying to study this, the effect of moisture content on the thermal conductivity of some soils has been found to depend on whether the soil is in the process of drying of wetting and it is understood that drying process will result in more thermal; what resistivity or conductivity? Yeah. So, during the drying process the thermal conductivity is decreased.

But then this has to be studied properly; what really happens if the microstructure to the soil mass. Another reason for studying this phenomenon would be why cracking occurs in the fine-grained materials. So, why fine-grained materials crack? So, it is a very big issue in geotechnical engineering about the cracking and the tensile strength of the soils. So, if time permits, I will introduce these concepts also in this course a little bit. I think there is a mistake, during the drying process thermal conductivity should be, yes. So, you should have told that then, you should have pointed this out very clearly how can I go as caught free. So, during the drying process thermal conductivity should be low. Then comes the effect of dissolved soils in water. What is your gut feeling if more dissolved soils are present what will happen to the resistivity?

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Why?

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Thermal gradient will not (Refer Time: 23:13). Let us see. It has something to do with the pore solutions again. So, the amount of water which is present in the soil is a major factor in determining it is resistivity alright. So, the resistivity of the water is governed by the amount of salt which are dissolved in it which change electrical properties as well. So, this is where again the compact situation comes where the pore solution and the moment you add more salts into it, its dielectric constant changes. So, if its dielectric constant changes, its thermal properties are also changed.

Why do you add salt in ice? Yes, you are quite close to the correct answer. Any other attempt? Why do you add salts in ice? To lower the freezing point alright. So, if you lower the freezing point in what way it will going to help you?

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Sorry?

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It will not melt very easily, clear? So, when you are adding some water some salts in the pore solutions of the soil what is going to happen? Its resistivity is going to change definitely. Now the question is whether it is going to be higher or lower? So, quite a small quantity of dissolved solid reduces the resistivity considerably. You agree or no? Correct, why?

Simple logic is the density of fresh water is more or brine solution is more? So, that is the best possible answer. So, the moment you add salts to a solution water, what happens to its density? It increases a little bit and that is the reason the conductivity will increase and the resistivity will reduce. This is what my logic. Your logic is also correct, but then when you talk about the ionic interactions and the thermal effects, mobility may increase that is true because of heating up.

So, ionic conductivity will increase because of elevated temperatures and hence resistivity drops down, that is logic. That logic is also correct. Now, the issue is that different type of salts will affect you know resistivity or conductivity in a different manner. So, different salts have different effects and this is probably the reason for the resistivity of similar soils, but from different localities is different considerately. So, if you take sand from the Rann of Kutch or if you take sand from central part of the India where do you expect resistivity will be less.

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Yeah, because you have more brine solution there, correct.

Salt water.

Salt water is there too much. These concepts can be utilized for thermography and then based on thermography you can estimate whether the soil mass is contaminated or not with the help of thermal cameras. So, nowadays thermal cameras are becoming very you know potential tools particularly on the airports they are checking whether somebody is having swine flu or not you must have read in newspapers. So, you can identify in a crowd how many people are suffering with flu or temperatures or the fevers and so on.

So, same concept you can utilize for determining the extent of contamination of the soil by using thermal imagery or by using thermal cameras. They call these zones as the heat zones very high thermal zones. So, you can find out in the buildings where the leakage is taking place, where the plaster is not intact by using thermal imagery.

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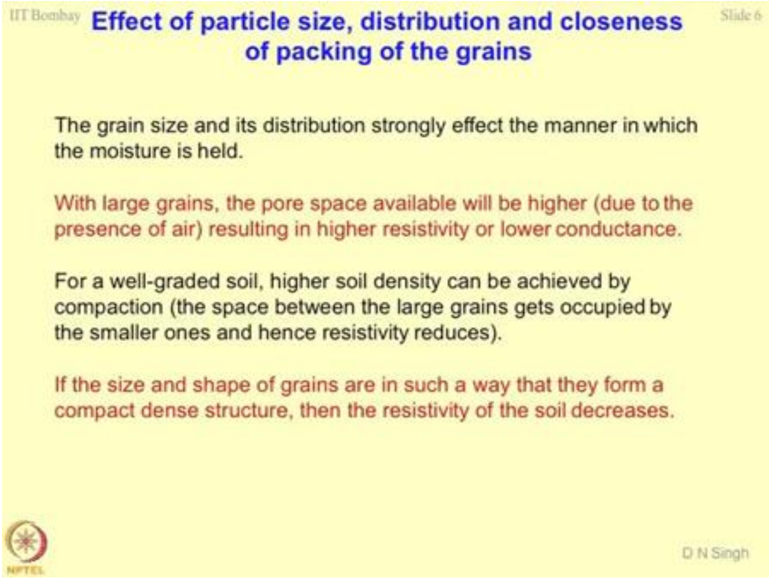

Now, other parameters which effect thermal properties would be particle size, the distribution, their packing, closeness and the grains themselves, yes.

You have mentioned that quite a small quantity of soils and the thermal resistivity reduces. What about the increase in the concentration of the salts?

Any guess from the audience? No? If you keep on increasing the concentration there could be a situation where precipitation of salts may take place and the moment precipitation takes place the resistivity's may go up again. It is a good question, but you have to study it.

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Yeah?

Student: Stimuli versus concentration of salt content.

Yeah.

Relation.

Yes.

Can you just.

How it would be? So, what is your feeling? If you plot on y-axis resistivity, on x-axis the concentration of the salt how the curve should be?

First decrease.

First it should decrease it should come up to a certain optimal point and beyond which again it should increase, that is right. Most of the graphs in engineering practices you are identical alright. But, to my knowledge I have never come across any this type of study was a good idea somebody can consider this while examining the soils and coming up with some generalized relationships.

So, grains anything else? Ravi Teja. So, we are talking about the effect of particle size, distribution, closeness of packing of the grains. So, this is where the grain size and distribution strongly affect the manner in which moisture is held and hence it will be responsible for thermal properties of the soils. You have seen in the previous graph that if the grain size is more the resistivity is less and if grain sizes less resistivity is very high. So, with large grains the pore space available will be higher due to the presence of air. You cannot compact it so well, resulting higher resistivity or lower conductance.

For a well-graded soil, higher soil density can be achieved by compaction that is the space between the large grains gets occupied by the smaller once and hence resistivity reduces. This is a simple concept all of you are aware of. If the size and shape of the grains are in such a way that they form a compact dense structure, then the resistivity of the soil will decrease. It is ok?

Now, comes the question what is the influence of soil fabric on thermal properties of the soils. If you remember soil fabric is nothing, but arrangement of the grains. So, what is your feeling, intuitive feeling? Flocculated structure or disperse structure which one of the two will show you more as resistivity and less resistivity?

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Why it is so?

Sir (Refer Time: 30:56).

This has to be studied. And, if somebody is studies this then he can easily correlate hydraulic conductivity with thermal resistivity. See basically the question is how to characterize porous media, clear? You want to understand how porous media is behaving whether it is water flow, contaminant flow, heat flow, electricity flow, magnetism flow or radio activity flow? So, at the end of the day why people are studying all these things is so that the small modules can be put in place to answer big issues.

How water at elevated temperature having more contaminants in it, these contaminants are radioactive in nature and are active contaminants are going to flow from one point to another point or they are going to degrade the geoenvironment in what way. So, these are the biggest possible issues.

So, in isolation you cannot study these parameters, but yes to start from somewhere you have to first isolate the issues, understand the behavior, put them together, make a modular structure and then see that what is the overall effect. So, my question to you was at how soil fabric influences the thermal response of the material. Well, I am not sure about the answer, but I will go by your answer. Some of you are saying that dispersed structure will show you more conductivity, less conductivity and somebody saying dispersed structure.

Now, let me ask you a question. As far as the dispersed structure is concerned and flocculate structures are concerned which structure shows more viscosity in terms of water. Why?

In dispersed structure sir the grain to grain arrangement is laminar and they are having negative charges which is not allowing the water to flow from that as it is a dipolar liquid.

Yes. So, which structure should be more susceptible to temperature change? Flocculated structure or dispersed structure? If you change the temperature flocculation may not take place. You agree with this or not?

Yes, sir.

A simple example is when you make jellies in your home, why do you keep it in the fridge overnight or say few hours? A jelly which you take normally as a desert what it is? It is dispersed structure; it is a flocculate structure? So, how many of you had got dispersed structure? So, how many of you are sure about it or you are guessing?

Sir, sure about it.

Sir actually, bentonite slurry also is the same case. When we make the bentonite slurry it loses the strength, but if we keep it for sometime it would gain strength which is called thixotropic.

You are completely wrong.

A dispersed structure is always because of compaction. The basic philosophy actually you are too much away from the basic concepts. Never lose the basics. You start from a flocculated structure, you keep on compact the soil, you will attain a dispersed structure. See, this is a correct answer. So, all your logic is completely wrong. So, if you are not compacting any system, we just loose it in keep it in loose form in a water, everything is in a flocculated way. Now, you start compressing it and then whatever the residue is that could be a dispersed structure, clear?

Now, this process itself is the function of temperature. So, when I ask you the question soil fabric in fact, I would like to study the influence of soil fabric on the thermal properties of soil, but then this is a very big question. First of all, you have to talk about the mineralogy; second you have to talk about these parameters which are physical in nature and by the time you reach to the soil fabric you know the entire concentration of the study is over.

So, it will take lot of time for people to understand how soil fabric influences and most of our papers which we submitted reviewers are asking this question that why do not you study the effect of fabric structure of the soil. So, it is not so easy to answer as on date. I am sorry for that, but I thought let me talk to you and you may give me some ideas so that we can study our, we can conduct our say further ok. So, for that time do not bring the soil fabric structure in to the picture alright. So, apart from fabric structure this is how the grain structure is going to control the process.

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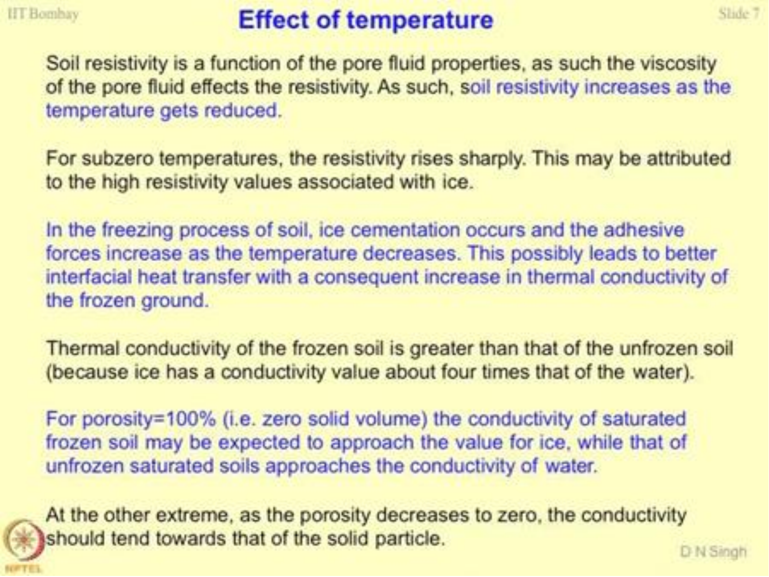

Effect of temperature. Now, what is going to affect the temperature maximum, raise or drop in the temperature? Again, is the pore fluid you agree or no?

Why? Whether it is gaseous form or whether it is liquid form, the changes will be much more, why it is so? Coefficient of thermal expansions are very high for liquids as compared to minerals, clear? So, a bit change in the temperature of the fluids which are present in the pore structure is going to alter the properties completely. So, soil resistivity is the function of pore fluid property, clear?

As I said, viscosity pore fluid will get affected very easily and hence the soil resistivity will increase as a temperature gets reduced, this at the macro level. So, we talk about the fluid where the density is changing because of change in temperature, clear? Now, see I am basically adding more and more complexity into subject. This you must be realizing; so, the moment your fluid properties change particularly the rheological properties. So, viscosity changes, its density changes. So, at elevated temperatures that definitely going to get reduced and hence what will happen to resistivity? It should be less.

Now comes your four-phase system of soils or the geomaterial where you have ice also in to the picture. As I said we are lucky that we do not have to deal with pore phase soil and geomaterials in our country in most of the part of the country except for maybe Himalayan ranges. So, for sub zero temperature, the resistivity rises sharply. This may be attributed to the high resistivity associated with the ice. Ice is having more resistivity towards thermal flow more or less? What floats in water? Ice or water floats on ice?

Ice.

So, if you think about the crystals of ice so, that gives one idea about how the resistivity contrast would be in the same phase. Now, this is the important explanation in the freezing process of the soil ice cementation occurs and the adhesive forces increase as the temperature decreases. Is this part is clear?

This possibly leads to a better interfacial heat transfer with the consequent increasing thermal conductivity of the frozen ground. The subject which deals with ice mechanics and geotechnical engineering there you have to take these concepts and put them in place to answer day to day life problems. Particularly those of you may get a chance to work in permafrost and heave and thaw process because of the permafrost formation and temperature fluctuation and all.

Did you have a question that we do not talk about the influence of environmental conditions on geomaterial response as such? You have been from you might heard that Indian military they are posted at Kargil, is it not? So, they also need shelter, basic amenities, infrastructure. So, we are not doing research in that direction. 6 months let us says it is frozen completely, again cycle comes it is a thawing process, correct most of the places and then this situation is much worse in the western countries where the temperature fluctuations are too much particularly Canadian continent, Scandinavian continent, Norwegian continent and so on. So, this. Yes, please?

Sir, there is an increase in the thermal conductivity, sir, in the frozen state. This will occur in a subzero temperature, but we are not considering the effect of temperature there itself. The temperature is getting reduced and reduced. So, I think there will be a.

Temperature getting reduced, where?

Subzero temperatures below 0, sir. So, I think there will be a limit to that temperature; there will be temperature limit where there will be what to say that conductivity itself will not be there.

Repeat your question again now.

Of course, the thermal conductivity increases sir, but what will be the possibility of a presence of an existence of a temperature, heat, presence of heat in that subzero temperatures. I think there will be a limit for that?

No, there cannot be any limit. See, there is a process and there is a material which is exhibiting some property. So, it is a super imposition of the mechanism on a mechanical property that is it. Now, your question is there could be a variation in temperature. Yes, there can be. Now, how heat flux is going to migrate from one point to another point let us say within subzero temperature itself. So, top surface is - 40 and by the time you reach few meters below the temperature could be normal or they could be much less than 0.

Yes, sir.

So, there is a temperature gradient and this is because of a climatic condition. Now, how heat is migrating into this type of a system? A good example of this if you remember I had cited in the class particularly in the extraction of gas hydrates. So, if you.

Did you remember? The biggest challenges how to extract the gas hydrates which are at -40, -50, -80 °C. So, this is where you have to heat these hydrates, you have to provide certain amount of thermal energy in such a way that only certain amount of hydrates come out and you can trap them easily. If you apply the heat in a in a step function what is going to happen? The entire thing will melt there only and you cannot extract anything.

So, what you are saying is a very good example of this type of situation where the temperature variations are taking place and there is a thermal flux which is migrating into the porous media. I am not giving answer to your question, but I am just giving you a sort of analogy, there we have the question which are asking can be implied directly.

Sir, as temperature increases the water will dissipate vaporize then air will come?

Water may not vaporizer. So, let us say that state of the material alters.

Ok, sir.

Unless you go beyond let say 100°C.

Ok, but sir yes sir. But sir resistivity there will be some water and some air, but if the temperature increases the air will come more air than water.

Provided if you are allowing.

Sir.

Air to go out, if they you allow the air to go out.

There are lot of ifs and buts I am provided they are lot of constrains. So, we are not talking about all those constraints right now. We are just talking about how the parameters influence or they get influenced by a physical phenomenon, I know that there are lot of ifs and buts alright. So, basically crystallization in what way it is going to influence the porous media, characteristics in terms of resistivity.

Now, if you can map this you can locate where the gas hydrates are and this is where the roles of geotechnical engineers would be, like when you are doing like say in-situ venture test and you think of a situation where your venture test is conducted along with temperature measurements. So, you have a thermal probe also attached to the venture. So, you are getting shear strain parameters corresponding to a in-situ temperature condition and then let us talk about how undrained shear strength changes over a temperature change. So, these are more real life and practical problems for oil industry, for people who are more interested in gas hydrated studies and so on.

Now, thermal conductivity of the frozen soil is greater than that of the unfrozen soils. Why it is so? The simple logic is there is no air, clear? So, any other form of a fluid which is getting frozen and crystallized will show you lesser resistivity as compared to air. So, this is the simplest possible logic because ice has a conductivity value about 4 times that of the water. Now, this another interesting thing. Basically, when we talk about porous media characterization we are talking about the porosity. So, there are two situations of porosity; one is tending to 100 %, what is the significance of this? Yes, or the second situation would be porosity tending to 0.

So, the first situation is porosity for 100 % that is the zero solid volume the conductivity of saturated frozen soil may be expected to approach the value of the ice, while that of the unfrozen saturated soil approaches the conductivity of the water. Here you should, I do not know whether you could follow this fallacy or not when we say zero solid volume, why it is so? It is no more your skeletal soil which we are talking into or you are taking your account exactly. This is the crystallized form of the water which is present in the soil matrix.

The whole idea of giving you this concept was that to maybe train your mind for going ahead with three-phase to four-phase to multiphase models for the soil system. Like these are the challenges in our profession people should come up with now different phases systems and more reliable you know models which can be used for volume mass relationships; like your G. w = S. e is valid only for a very ideal situation and you know the limitations alright. Now, this is at the other extreme, as the porosity decreases to zero, the conductivity should tend towards to the solid particles. So, the skeleton comes in to the picture.

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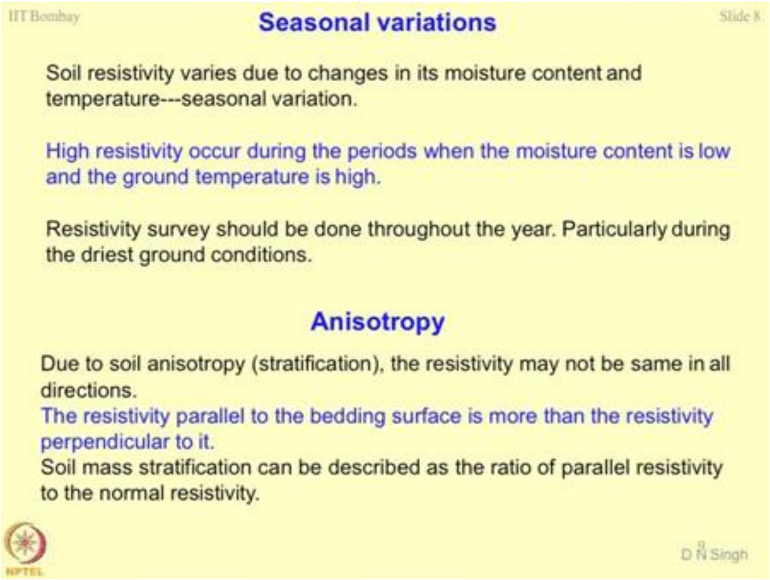

Seasonal variations, very difficult to quantify, but in most of the projects you have to study the seasonal variation effect particularly where you are conveying a fluid from one point to another point or where you are conveying electricity from one point to another point. A good example is cross country pipelines for your gasolines or petroleum products, 75 % part of the pipeline is in the desserts just imagine the temperatures where you are passing the crude oil, is it not? And, you are aware of the cavitation process? What is cavitation in pipes?

Pressure (Refer Time: 48:10).

Not corrosion, there could be a pressure, yes.

Sir, pressure of the flowing fluid will be if it becomes less than the vapour pressure of the fluid, then cavitation takes place.

That is a cavitation process. So, these types of situation may occur because of very high temperatures. Clear? So, if cavitation takes place in the pipe somewhere you can convey the fluid first of all, pipes may also burst and so on. So, seasonal variations are also very important. Soil resistivity varies due to it. Have you ever seen that the pipelines are you know protected with some?

Casing.

Casings; they are not only the concrete casings.

Yes.

But they are protected with casings made up of some thermocol or particularly your air conditioning ducts. So, it is nothing, but the insulation which you are doing for the pipelines. So, soil resistivity varies due to changes in the moisture content and temperature which is nothing, but the seasonal variation.

High resistivity occurs during the periods when the moisture content is low and the ground temperatures are very high. So, resistivity survey should be done throughout the year, but it is difficult. So, the best possible value which you can use in your designs would be the most the worst values. In fact, that is the driest possible state of the material and then you may talk about the affect of wetting of the soil and how much resistivity will dropped per unit you know intake of moisture into the system.

Anisotropy; I think you are talking about anisotropy sometime back. So, in what way anisotropy influences the heat flow or the thermal properties of the soil mass? What is meant by anisotropy? Vinil?

Variation in the property of this like layered.

Correct, stratifications because of stratification the properties may not be same in all the directions. So, that is what is basically anisotropy. Due to soil anisotropy that is a stratification the resistivity will not be same in all the direction. Where do you think that this type of studies would be useful? Rocks? Kunal Singh you are from engineering geology.

Can be possible, sir; sedimentary rocks.

Why do you want to study stratification in subsoil?

Flow of it stratification is a type of fracture. It can increase soil strength decrease sorry rock strength.

No, my question is that why do we require anisotropy to be studied? Why it is so important?

The strength depends on the anisotropy.

Any mechanism for that matter. See permeation you are right some of you are talk about the permeation of fluids let say. Permeation, strength you know their bearing capacity in fact, for that matter you know.

Shear strength.

Shear strength you talk about be a weak layer underlined by yes by a hard layer or strong layer and vice versa and so on. So, anisotropy detection is also becoming very important. Unfortunately, there is no way in classical geo mechanics where you can define the anisotropy of the subsurface except for either utilizing the.

Seismic, sir.

Seismic studies or thermal studies or electrical studies; so, this is where all the three studies will require properties of the geomaterials so that the modeling can be done properly. So, this is the good style of studying how much anisotropy the soil mass is. The basic concept is parallel to the bedding the resistivity is always less; resistivity is less conductivity more and when you talk about perpendicular to the bedding the resistivities are very high.

So, if you understand this now you should be able to understand the effect of fabric structure on properties of the soil mass because fabric structure is nothing, but sort of a stratification particularly when we talk about dispersed structure. So, if you study the anisotropy you know map the parameters which you are getting from here into the soil fabric structure. A good way of doing this would be you define soil mass stratification index and this is nothing, but the ratio of the parallel resistivity to the ratio of it should be normal resistivity.

Another logic is that why normal is always more because the compaction densities will be more in the perpendicular to the bedding as compared to parallel to the bedding because you always compact where deposition takes place in the perpendicular to the bedding plane. So, these concepts can be utilized for tomography of the subsurface, is it not? Or subsurface profiling.

So, as I said there are three methods either by geo physical methods which again will use, either thermal energy field or electoral magnetic field. So, if you know the thermal property and electrical properties of the soil mass you can correlate your results in getting the stratification of the sub surface. Is this part clear?

We discussed lot of basics today.

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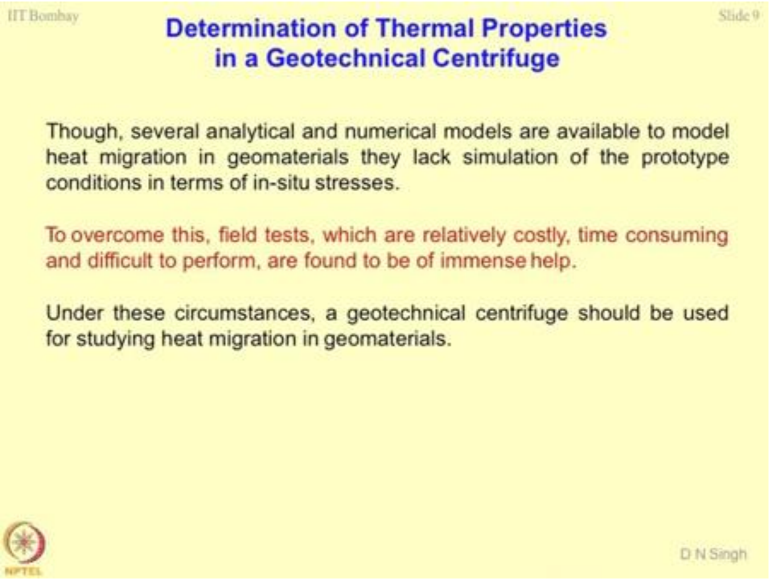

Now, let me go through very quickly through the rest of the lectures determination of thermal properties in a geotechnical centrifuge. You have any doubts from the previous lectures or shall we go ahead and finish this off? The first question is why do you want to study this phenomenon in a geotechnical centrifuge when you have everything readymade that analytical tools are there, numerical tools are there lot of investigations are done in-situ testing are done and so on.

So, the reason answer is though several analytical and numerical models are available to model heat migration in geomaterials. They lack simulation of the prototype in terms of in situ stresses. I am not sure whether you are aware or not, but the biggest question is always spent fuel which comes out of the atomic reactors where should be stored. So, that is where you go and go in the deep in to the sub surface in the rocks, make tunnels over there and then charge them with atomic waste, clear? Now, this is how the India is also adopting this strategy.

Now, when you do this what is going to happen to the rock mass which is surrounding this waste? There would be thermal stresses that is the right word is it not thermal stresses. Now, because of thermal stresses the mechanical stresses becoming insignificant. The rocks are famous for arching action. There will not be any mechanical loading up to that point, but then thermal stresses becoming very important. So, then the question is if I give you a problem that below the ground let say 50 meter what is the influence of let say all these parameters which you are studied on overall transmission of heat from one point to another point?

So, these are the problems which require either real life simulations where you have to really dig out a whole at a depth of 50 meter, do some experiments. These are known as hydro-thermo-mechanical models and do the probing of the area and see how it is migrating from one point to another point and come up with the models. Is it not? Thermal behavior of the rocks, but that the rocks can sustain this much temperature or not how heat is migrating from one point to another point and so on or you take the rock course bring them to the laboratory conducts centrifuge modeling, you save time and you are more sure about what type of analysis and simulation you are doing.

So, to overcome this type of difficulty people have done field studies, but then field studies are very expensive, very time consuming and difficult to perform. So, what to do? In order to overcome all this people have gone for centrifuge modeling, so that at least you can simulate the stresses which are going to come on the system in the form of mechanical stresses or you are simulating the prototype in-situ stress conditions and how these conditions are influencing the heat migration in the geomaterial.

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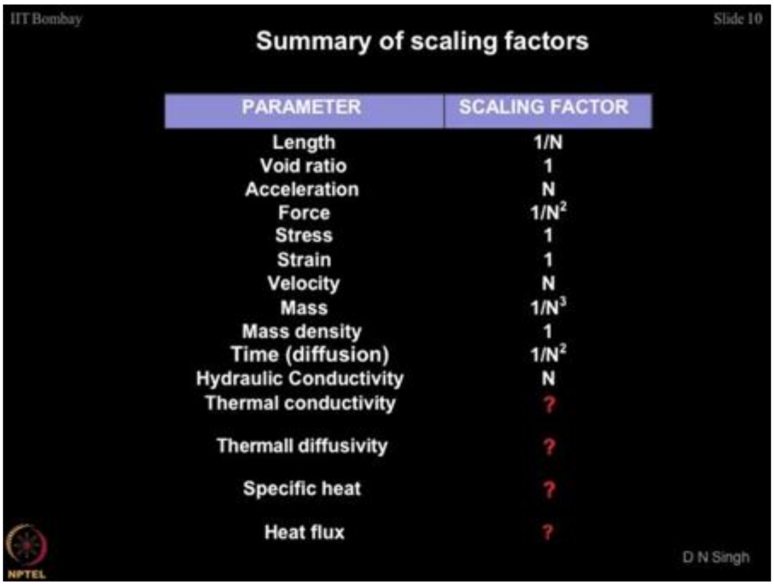

Now, let me ask you a question because you are doing this course also. I am sure that you are aware of the scaling factors or length, void ratio, the acceleration, force, stress, strain, velocity, mass, time of diffusion, hydraulic conductivity and so on. Is it not? But you have come across the scaling factors or thermal conductivity, thermal diffusivity, specific heat and heat flux; why? Because you are doing centrifuge modeling and you should be knowing the scaling factors for this phenomenon also.

So, that is there the issue is before you take up centrifuge modelling of heat migration you have to understand what are the scaling factors for thermal properties of geomaterials; that means, thermal conductivity, thermal diffusivity and specific heat how it gets modeled and what is your gut feeling? It will get modeled or it will not get modeled?

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Yes, it should. But unfortunately, it is so happens it will not get modeled and let us see how it can be ascertained. So, this is the question to a researcher that what really happens to the material when it goes into centrifuge.

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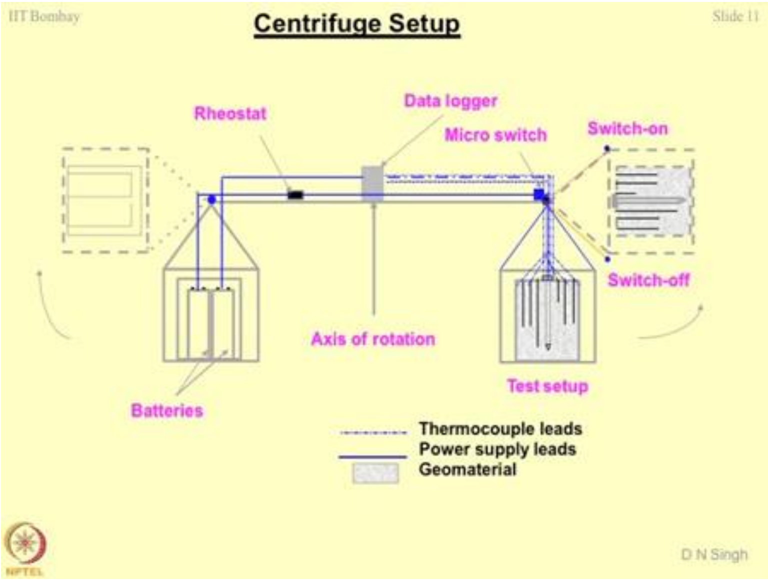

So, the doctor Krishnaiah, he was my PhD scholar he did this work. He used this setup which have been developed by him. These are the buckets of the centrifuge where they entire setup is placed you can see the thermal probe which you are discussing in the previous lecture and in this setup, there are lot of thermocouples are embedded. So, these thermocouples will be measuring temperature in r z domain, r is the radial distance from the centre of the rope and z is the depth below the sample surface.

So, truly speaking what you are doing is you are doing temperature modelling in r z t domain, the t is the time. So, as a function of time at a given point in the radial direction and at a depth of z, what is the temperature value. But because this happens to be axisymmetric case the z becomes insignificant. So, it is only r and t which are the important parameter and you are finding out temperatures associated with a radial distance at a given time.

The counter weight was used as a battery for supplying the power to the system and the duty of the system is there was a switch and this switch when the bucket swings are not connected to the circuit, but in flight the switch gets connected to the bucket and the circuit gets complete. So, this was the simplest possible way of doing the experiments. We saved lot of money and the experiments perform like this.

So, in flight the switch gets attached to the bucket, circuit gets completed, heat starts flowing in to the thermocouple and you can measure the temperatures, clear? A simple method and then we are data logging the temperatures over a period of time.

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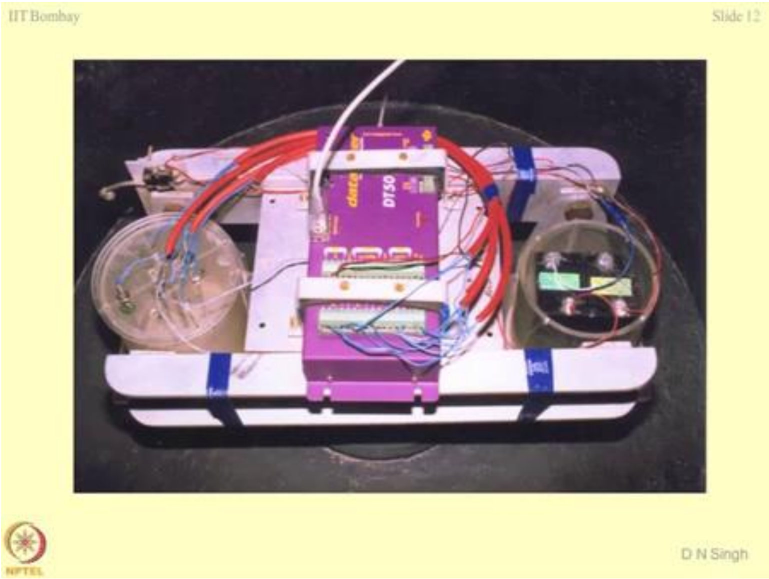

Now, this is the whole assembly in the centrifuge where you have the data logger attached to inside of the batteries in the countable counter, balance and this is the centrifuge setup and this is the switch which I have been showing you when the circuit is connected to this switch. So, the moment the bucket is in the flight it gets connected and this current start flowing.

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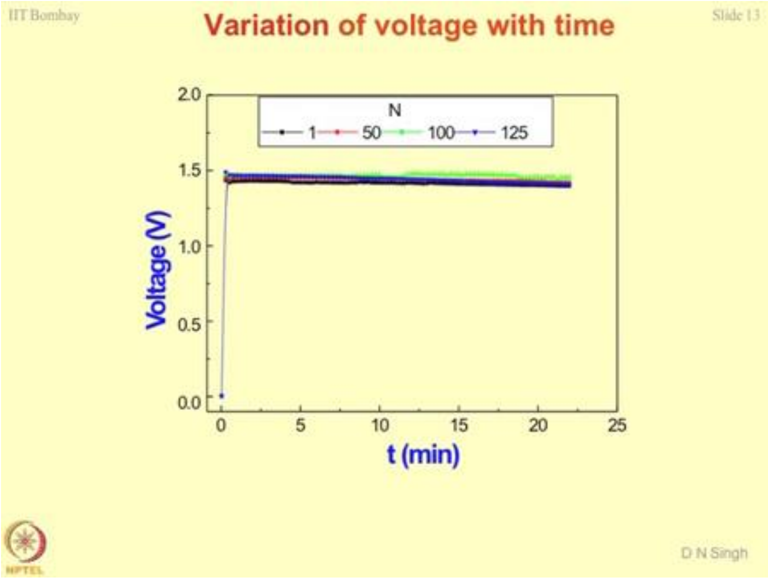

Now, this is how the flux modeling was done; voltage versus time in the centrifuge to show that the flux remains almost constant. So, the first question was what is the scaling log of flux? There cannot be any scaling log for the flux, because the flux is a form of energy. It cannot be created; it cannot be destroyed. So, this is what is getting frozen from here that the voltage remains constant practically over a period of time. A little bit of drop in voltage you are seeing because of the draining out of the batteries over a period of time.

So, the best way of doing this was that you conduct experiments in less than 6 to 7 minutes time as the voltage remains practically constant and ignore this portion of the curve. So, if you are performing your experiment within 5 minutes, 6 minutes there is no problem; flux remains constant.

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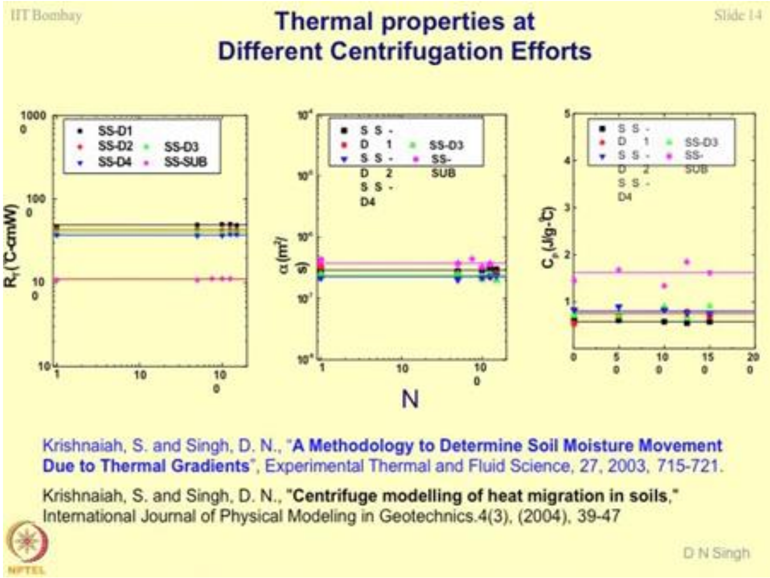

Now, this is what I have been asking you, if you conduct at different N values, different test to obtain R_T on different soils what will notice is the R_T remains practically constant. So, is the case with thermal diffusivity and so is the case with specific heat. So, all these parameters remain almost same. This work was published in these two journal papers, if you are more interested you can refer this, the Centrifuge modeling of heat migration in soils, International Journal of Physical Modeling in Geomechanics, 2004.

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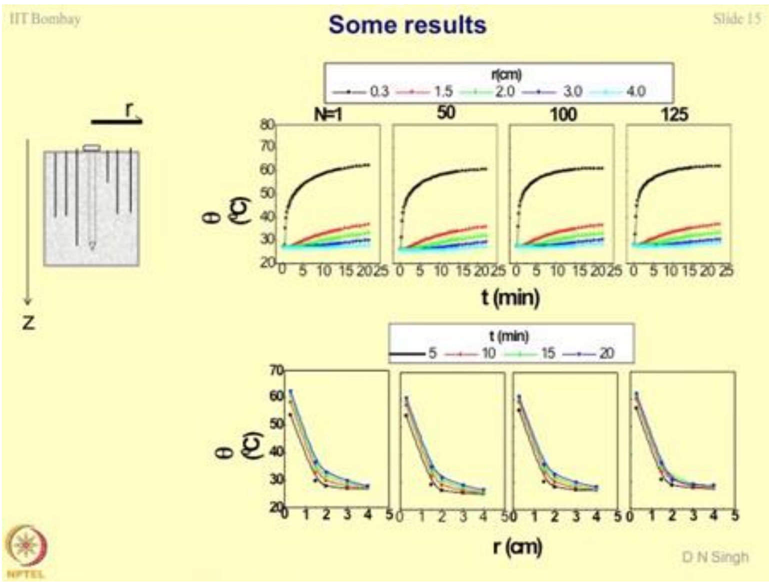

Now, if you do this test and as I said that you are doing modelling in r and z domain. This is what the results would be. On y-axis you have temperature going up and x-axis is time. So, for a given centrifuge apart at N equal to 1, 50, 100, 125, if you do the temperature profile with respect to the radial distance r, what you will notice is that this is how the temperature increases from the nearest point to the extreme point and you are measuring temperature from this.

So, these types of temperature profile you can obtain when you do centrifuge modeling and then the second thing would be how temperature is varying from this point to this point. So, if you plot it with respect to r, variation and temperature the moment you go from center to the extreme out the temperatures will be dropping down. So, these are the basic raw results which you will get from the centrifuge models. Now utilizing these results, you have to see what can be done.

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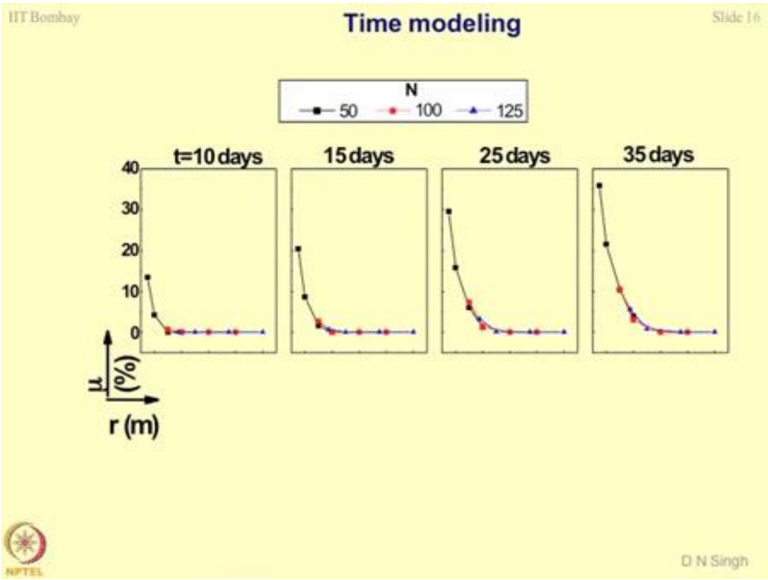

So, the answer is that I would like to do the modeling of time, but I could not. So, whether the same phenomena can be observed after certain time or not. So, if you define the y-axis, the percentage increase in temperature that is initial temperature minus final temperature divided by initial temperature with respect to r, what we will notice is the maximum rise in temperature is near to the probe and as you move out of the probe the percentage increase in temperature is less. So, this is what the time modeling is and for different N values you will see the results fall perfectly on the any curve that is what the modeling of the models is for time.

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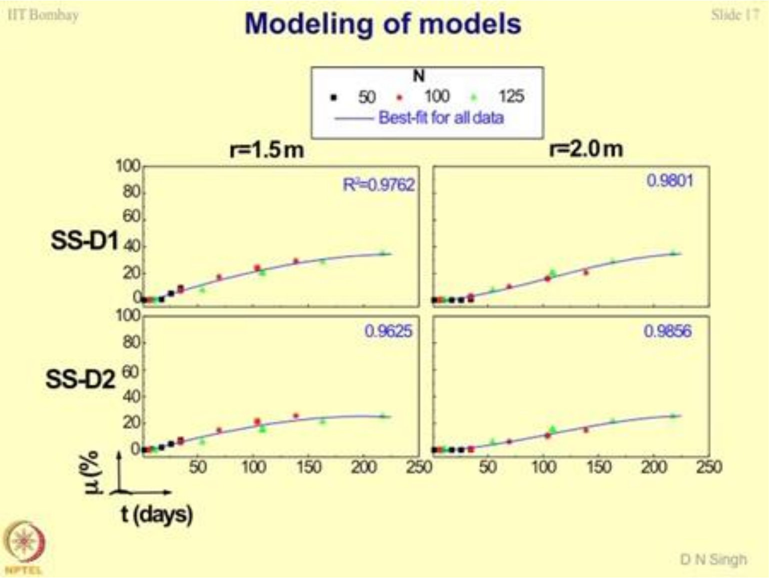

Now, this is the modeling of the model exercise when you talk about the N value. So, for any N value or the centrifugation effort you will notice for different type of soils corresponding to different distance you will have a unique relationship, this shows that modeling of models is valid heat migration analysis alright.

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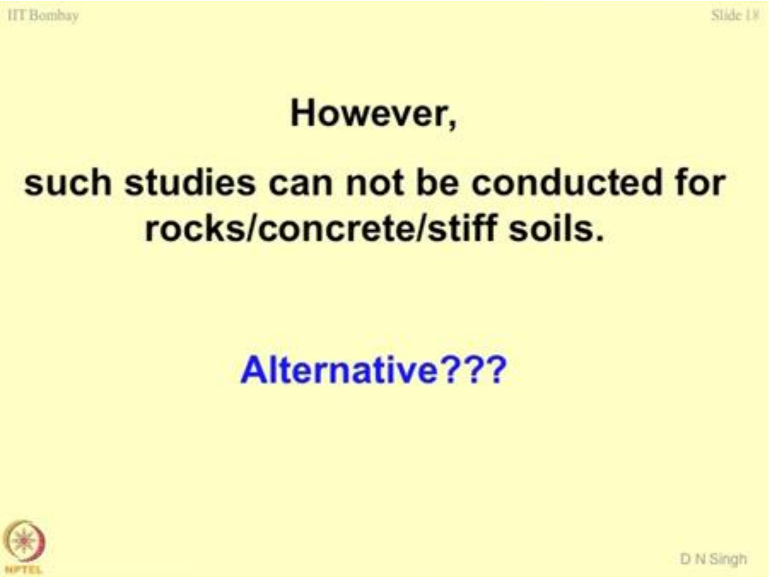

Now, this was again another issue that these types of studies cannot be conducted in rocks and concrete and the stiff soils. The reason is you cannot insert the probe, you cannot insert the thermocouples. So, what you should do? So, this is where the best way would be to go for numerical modeling using ANSYS.

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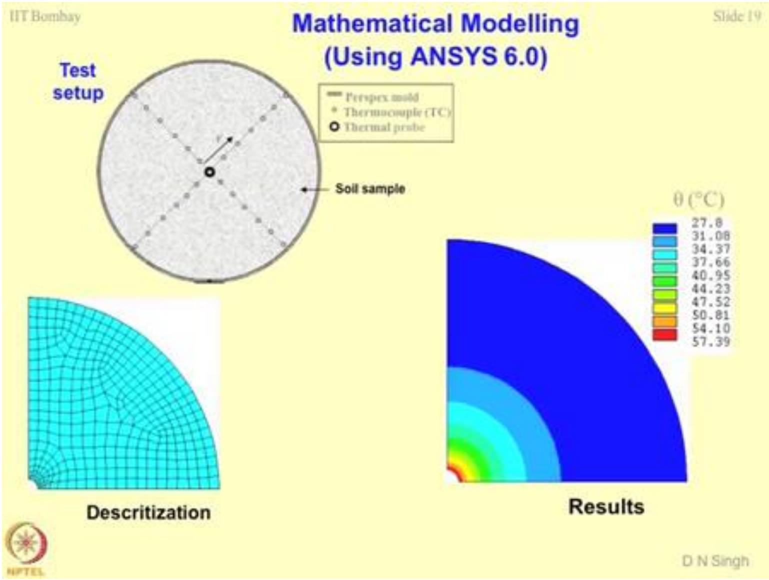

So, this is the test setup. This is the top view; this circle shows the probe and in the radial direction you have thermocouples embedded in the samples and then what you are trying to do is you are taking the one-fourth of the one-quadrant of the sample and then digitizing it or discretizing it. So, once you develop the discretize model to solve this by using ANSYS you will get these types of thermal profile.

So, close to the normal probe the temperatures are going to be very high and as you go down in the outer sides of the sample the temperatures would be quite less. So, 57.392 almost 27.8 which is the room temperature, so, this type of thermal gradient has been imposed on the soil sample under in-situ conditions. You can always debate the validity of the results, but issue is at least these types of test give you some values which are close to a physical phenomenon which is going to happen in nature.

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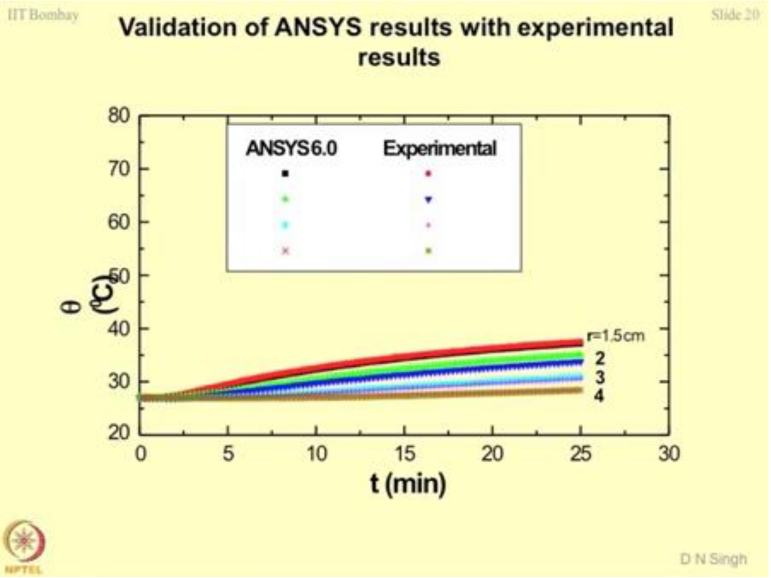

And, then if you match the results of ANSYS with the experimental studies where you are putting on y-axis the heat temperature and on the x-axis the time. So, for different radial distances you will notice that the experimental result and the ANSYS result they will be matching with each other. So, this gives more confidence in the type of exercise which is being done.

So, what is remaining now is that we have answered two questions the properties remain same. So, there is no modeling of models of the properties and the thermal flux. But, still one question is that what about the physical time of the heat migration?

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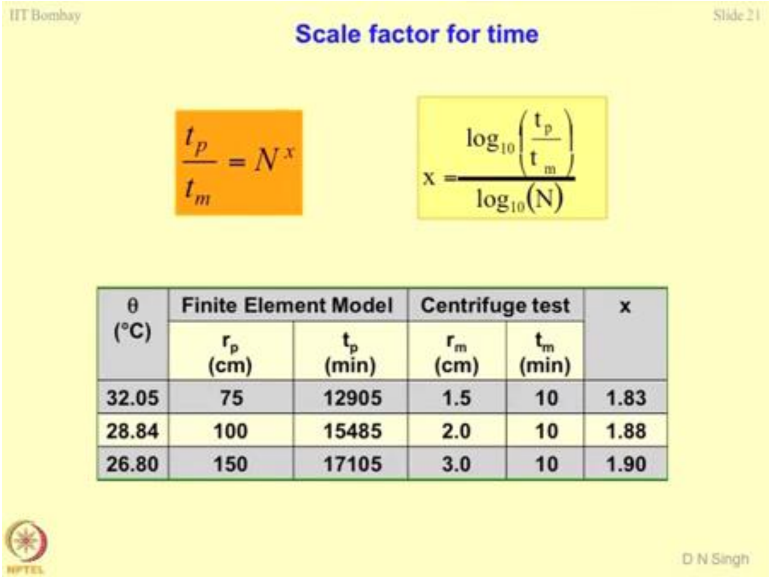

So, that is where actually very intelligently you can take help of numerical models and you can then scale them for time. So, what is known as time scale factors for the mechanism that is prototype and model if you put like this. So, $t_p/t_m = N^{x.}$

where x is unknown scaling log. So, if you take the log on both the sides x will be $\log(t_p/t_m)/\log N$. Now, this table summarizes the entire study.

So, if you have initial temperatures which are known you do the finite element analysis for a distance of r p and t which is nothing, but the prototype and then you have the models in the centrifuge. So, essentially the logic is that because on rocks, concretes and the stiff soils you cannot do these types of studies. So, we want to generate confidence in the ANSYS models. So, once ANSYS model has been validated with respect to field conditions using ANSYS you can validation centrifuge results and hence you can find out the time scale factors ok.

So, if you know the centrifuge test times which are known you can put this in this equation and then you can get the x parameter. So, how do you read this expression now $t_p/t_m = N^2$ alright. 1.8, 1.8, 1.9 is nothing, but 2. So, do you agree with this law, $t_p/t_m = N^{x2}$? What is the meaning of this? Hydraulic conductivity gets modeled N times because it is a advective flow and this is a diffusive flow it gets modeled N square times, clear?

So, even if you do a consolation test in the centrifuge what should be the scaling law for consolation process, consolation time, in fact? It should be N times or N square times; it should be N square time because that is a diffusive process for water or the pore pressures. So, these types of studies can be done and the whole idea was to show in-situ modeling with you know mathematical modeling and the mathematical modeling vis a vis the laboratory experiments and centrifuge.

So, with this I will close the discussion on thermal properties.