Environmental Geotechnics
Prof. D. N. Singh
Department of Civil Engineering
Indian Institution of Technology, Bombay

Lecture - 40
Thermal Characterisation- 1

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Thermal Characterisation; Where I will be talking about importance of thermal characterization. What are different methodologies, which are used for characterizing geomaterials based on their thermal response and of course, the methodologies which have being used for determining thermal response or thermal characteristics. So, what are these properties or the characteristics?

Then, what is the influence of various soil specific parameters on thermal properties or characteristics of the geomaterials? Now, this will be followed by some discussion on centrifuge modelling of establishing heat flow in geomaterials. And of course, the last one would be electrical characterization. So, let me ask you a question here that, why we are studying or why we are characterising geomaterials?

Do you remember that why we started characterising the geo materials or you have forgotten? What is the basic idea of characterising geomaterials?

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Yeah; so, his answer is that the based on the characterisation, you can identify the soil that is the bottom line. The whole idea of doing this exercise is that we should be able to identify the material based in its response. And if you remember, when we are talking about the response of the material, we have discussed different energy fields.

So, the most common which everybody is using in the classical geomechanics is mechanical energy field. Then, we spent the enough time on chemical characterisation. And now, we are graduating to thermal characterisation followed by electrical characterisation. So, the basic idea is as you rightly said by adopting a suitable characterisation scheme you want to understand, how a geomaterial is going to perform under a given circumstances. So, the circumstances are a very big word. In our discussion or the point of view of our discussion, the circumstance is corresponding to a different situation or a loading condition.

So, we have been talking about mechanical response of the material, load deformation characteristics, stress strain, relationship, how air dish was changed, how strain changes, how stresses changes and so on. Now, continuing this concept, if I use chemical flux, it becomes chemical energy field. We have seen how porous media is going to respond to or in other words it you know the response; we can find out what type of loading is taking place into the geomaterial.

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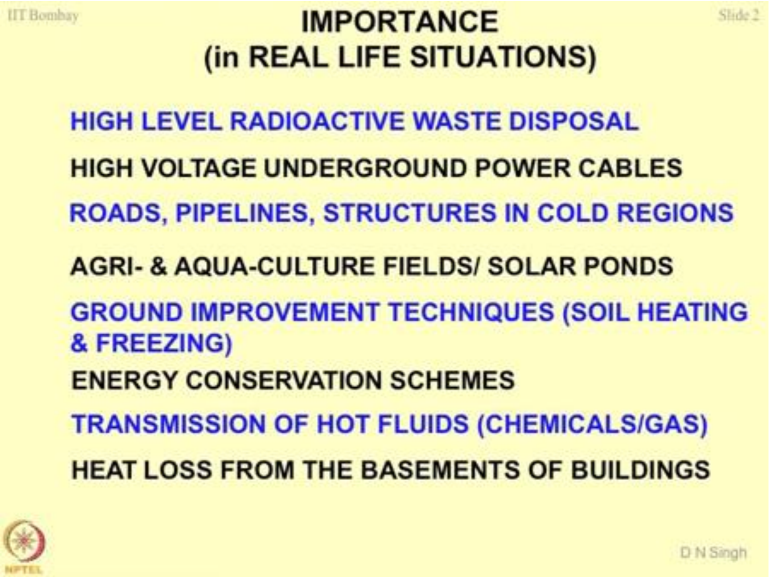

So, when we talk about thermal characterisation, this characterisation is becoming very important because of several real-life situations which we encounter in field. Now, what are these real-life situations, which are now challenging our profession as such? The first one is high level radioactive waste disposal. The stability of the geomaterial itself is under question mark, is under a big threat if the thermal flux is very high.

So, now by this time we have enough idea about how these types of wastes are going to create problem to the geoenvironment. So, when a high-level radioactive waste come in contacts with geomaterials, how this geomaterial is going to behave, if at all it remains intact or if it does not disintegrate? If it disintegrates that is a different issue all together and response does not come to the picture.

So, that is what we say, thermal flux is very high, but under normal circumstances when, you are dumping a radioactive waste in a depositary which could be a either soil or which could be intact rock mass. You have to establish the heat bearing capacity of the depositary or the material. So, you should note the word heat bearing capacity. Intentionally, I am using this word heat bearing capacity because still now, we are talking about the bearing capacity which is related to be mechanical loading. So, in this situation it becomes important to understand how geomaterial is going to respond to a thermal flux or thermal loading.

The second situation is high voltage underground power cables. The more and more and industrialisation is challenging our profession because most of time high power transmission of current is underground. Now, when you expose underground environment or geoenvironment the thermal fluxes, how these thermal fluxes are going to change the properties of geomaterials is the very big question. And unless you establish this you cannot use the concepts of classical geomechanics properly.

A good example of this characterisation would be thermal cracking of soils. So, because of the excessive heat generates because of transmission of electricity in underground power cables. There could be a situation where, a soil cracks completely and once the cracking takes place, the system will expose to the environment or for percolation of water and so on.

So, this situation is also becoming very important in most of the industries or in present a civilisation. We talk about roads, pipelines, structures in cold regions; they also required some input about the thermal response of the material all right. Sometime back I had given you an idea about the design of foundations in Antarctica or in the cold regions where the permafrost is quite active. So, you have to estimate the properties of the geomaterials exposed to the different temperature conditions. So that you can understand how stable the system would be and hence, you can design the foundation system and so on.

When, you talk about the roads, I think it is understood the most of the time your thermal stresses cause wrapping stresses into the concrete sleepers or the concrete pavements. So, you should understand how the situation can be dealt with pipelines. So, these pipelines could be conveying crude oil or some volatile materials like any substance chemicals or may be petroleum. So, if the nm temperature rises too much, what is going to happen to the crude oil or the chemicals, which are being transmitted through pipelines? They may become unstable. So, you cannot transmit chemicals from one point to another point if you do not take into account, the thermal properties of the geomaterials in which the pipelines are buried.

Similarly, there could be an extreme condition, where the ambient temperature goes below 0. So, what it is indicates to? The pipelines may burst or the fluid itself may get frozen into the pipelines again chocking them bursting. So, the problem becomes quite multiple and that is the reason that in environmental geotechniques or geomechanics people are trying to understand the response of geomaterials for thermal loading.

Most of the time, when you deal with agriculture or aquaculture; so, this is where, the concept of solar pond comes what type of aquaculture should be adopted in a certain region; all right or the growth of some bio-organisms which are quite useful for either agricultural purpose or a medicinal purpose or for purpose or whatever.

So, this is where, you have gone for energy balance the energy which plant receive from the sun the solar energy and how whether it gets retained into the system or not has to be studied. So, agriculture and aquaculture fields or the solar ponds are also attracting lot of attention on geotechnical engineering and there was the time when, we were collaborating with TERI TATA Energy Research Institute for designing their solar ponds and specialized bricks by using some typical type of soils where, the energy efficiency factors are very important.

Ground improvement techniques; so, in ground improvement techniques particularly, when you are talking about the techniques related to soil heating and freezing. This is where; the thermal properties or the response of the geomaterial for thermal flux becomes very important. Remember, I have given an example that if you are doing tunnelling in fractured rock mass or in highly pervious soils the best option is you freeze the soil. Is it not? So, by freezing the soil what you are doing?

You are decreasing the permeability and hence, you need not to adopt pumping out methods to drain out water from the tunnels or some excavations and so on. So, these types of methods are very handy in advanced geomechanics these days. Similarly, you can think of soil heating procedure and soil heating can be used for remediating the lands, which are contaminated with organic materials.

So, the best way would be to heat the soil mass and then, what happens? All the vapours go out into the ambiance; you may collect them in a controlled manner. So that then, the environment does not get contaminated much. So, these are the applications where, you know our focus or our attention is really required.

Energy conservation schemes; I have already talked about this when, you have talked about the solar ponds; different type of refrigeration units, different type of bricks for the air conditioning purpose and all. Energy is becoming a big commodity. So, you think of the bricks, which are very energy efficient. So, you require very less air conditioning as compared to outside ambiance.

Transmission of hot fluids that is the chemicals and the gases; this also i have discussed just now. There could be instability in the material, which is being transmitted in the pipelines when the temperatures go beyond a certain point or if the heat is not getting dissipated in the geomaterial easily or efficiently.

Heat loss from the basement of the buildings, now this is becoming a very big issue in most of the metros where basements are becoming very important places for several issues; particularly multiplexes, good hotels, recreation activities and so on. So, this is where you require maintaining the ambiance properly in the basements ok.

So, this is where, again you have to talk about the geomaterial and the basements structure thermal stability. So, all these issues show? That yes, the thermal response is becoming a very important factor. Sometimes back, I had given you a logic or may be even of the situations where, if you are designing a foundry; all right foundry unit; what type of foundation it should be adopted? Where the temperatures are going to be very high? Or the forging unit for that matter or it or a furnace.

So, if you design a furnace on this soil without talking into; without taking into account these thermal properties; the thermal cracking may take place. So, these are the situations I think we can see the empty number of situations where, the thermal flux plays a very important role in talking about the stability of the geomaterials.

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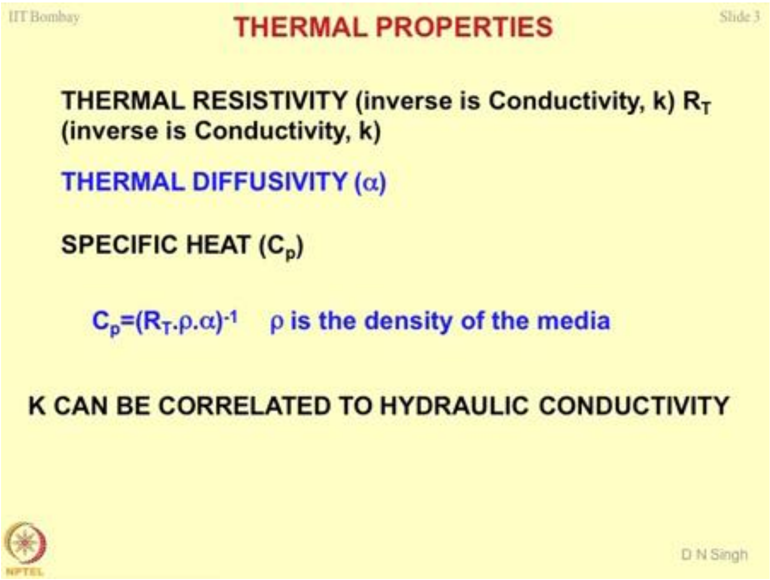

So, what are these thermal properties, how would you quantify the thermal response of a geomaterial? The first parameter is thermal resistivity, which is the inverse of conductivity k and thermal resistivity is denoted as R_T, which is the inverse of conductivity k. The second parameter is thermal diffusivity; how easily heat diffuses from one point to another point in the system? Do you remember we were talking about diffusion of contaminants and in pore pressure theory we talk about the diffusion of pore water? So, here we talk about thermal diffusivity.

So, coefficient of consolidation is nothing, but pore pressure diffusion process. D_i is nothing, but diffusion coefficient in terms of chemical contaminants. Here, we are using the term thermal diffusivity. The form of the equation of the expression will remain same. The third parameter is the specific heat, which is denoted as C_P, which is the heat restoring capacity of the system.

Now, let me ask you a question; can you correlate thermal resistivity with some very well-known geotechnical engineering parameter or for that matter thermal diffusivity and a specific heat? A Specific heat of water is very high or very less.

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It is your guess or you are sure about it.

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Why it is so high?

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Your answer; your logic is not correct, but answer is correct. So, heat capacity of water is high and normally it is 1 unity. So, my question to you is can we use these three terms in characterising the geomaterials?

How did you define hydraulic conductivity? Hydraulic conductivity is the ease with which, water can migrate into the porous system. Now in equivalent form if I use the term rather than saying hydraulic conductivity, if I say thermal conductivity. So, this is nothing, but thermal conductivity k. So, this is small k is equivalent of hydraulic conductivity of the porous system. Now, this concept can be utilised for determining hydraulic conductivity of unsaturated soils; how? In your classical geomechanics experiments like falling a test, what you are doing? You are allowing water to go into the porous media.

But suppose, if I want to create unsaturated state of the soil by expelling what are out of the porous media; it is a reverse process. So, how I am going to do this. If I impose a thermal flux on the soil mass, what this thermal flux will do? It will expel the water from the porous media; clear. So, expulsion of water is nothing, but unsaturated hydraulic conductivity ingress or movement of water into the soil mass is nothing, but saturated hydraulic conductivity. So, this concept has been used by doctor Hanumanth Rao for his

PhD thesis and he has shown how these methods can be used in creating unsaturated state of the soil and determining unsaturated hydraulic conductivity of the soil.

So, what I wanted to demonstrate here is that these three terms are related to each other and they get mapped over the density, ρ. So, C_P is a inverse function of multiplication of thermal resistivity, density and thermal diffusivity; clear. So, if diffusivity is more, the specific heat is always less because heat has the tendency to get diffused faster. Similarly, if resistivity is very high, what is going to happen? This is going to be less.

So, this is where I say that conductivity can be correlated to hydraulic conductivity and the logic, I have given you just now. So, these three parameters become very important to characterise a geomaterial when this geomaterial is getting exposed to a thermal gradient. Is this part clear?

So, you can think of a characterisation theme for the soils where R_T, k, α, C_P are known and you should be able to identify what is the constituent of the soil. This again is very challenging work because measuring these properties is a matter of few minutes, but you take any of your classical geotechnical engineering experiment which takes not less than few hours.

So, this is where; you know these philosophies are becoming very handy and you can characterise a soil mass quickly. So, I will show you in the latter half of the lecture today and how these parameters can be utilised in characterising the soil mass.

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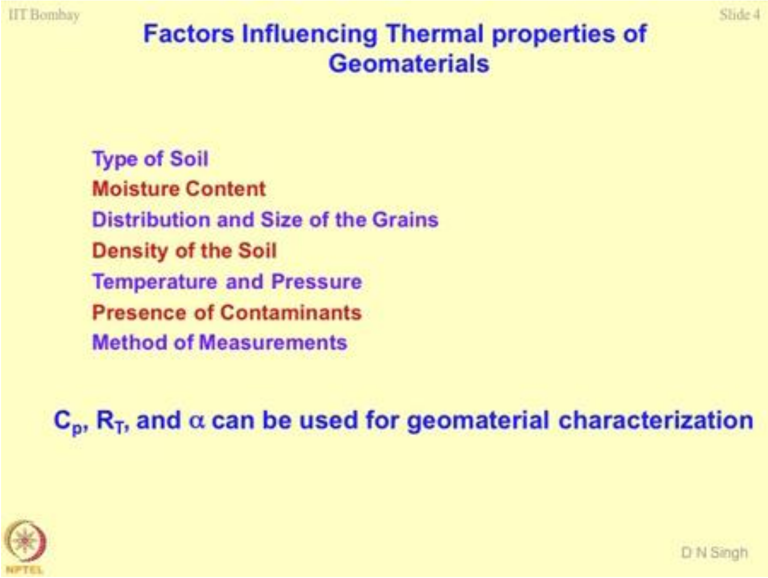

Let us talk about the factors which influence the thermal properties of geomaterials. The first one is of course, the type of the soil; whether a soil is a clay type of a soil, it is a sandy type of a soil; whether it is a rock material; whether it is a mixture of the combination of the two; whether it is saturated or not. So, moisture content becomes very important.

What is your intuitive feeling? If moisture content is more, resistivity should be more or less.

Less.

Yes, right; why?

Specific heat (Refer Time: 18:55).

No, please think it again. I asked you a trivial question. If soil is dry, what is there in the pores? Here, what about the thermal conductivity of air? It is more or less? It is less. So that is the reason, for dry soils the thermal resistivities will be very high and for wet soils thermal resistivities would be less. Of course, when you say this type of the soil the distribution and size of the grains plays a very important role. Now, what is your feeling for fine grained soils the resistivity should be more or less?

more.

Why?

Sir, these fine-grained soils are used for a ceramic coating on a space shuttles and all those things to have a very high thermal resistivity.

Your answer is correct; logic is wrong. Well, the answer is correct that if the grains are very fine the resistivity is going to be much more. Minerals are good conductor of heat or bad conductor of heat.

As compared to what? First of all, you should ask that question otherwise, question is incomplete; alright. So, truly speaking minerals are bad conductors of heat ok. So, when we talk about the minerals, which are of very fine platelets. Their resistivities will be much more ok, but when we talk about the coarse-grained materials certain amount of minerals gets replaced by air and the resistivity of the air is higher than the minerals, but lesser than water.

So, that series comes into the picture and hence, you will notice when you work on fine grained soils the resistivities are going to be much more. Now, why it is important to study the resistivity of the soils? If you burry a cable, which is conveying certain amperage. Amperage means certain amount of current is getting passed through this cable and if resistivity happens to be very high, what is your imagination? What you are going to happen to the cable? You think of a situation where, all about the cable the temperature rises too much because of passage of the current. So, what will happen? The cable itself may melt.

Melt.

Alright and once the cable melts, you cannot convey any current from one point to another point. So, this is situation where, you require a system which dissipates heat which is getting generated in the soil mass or in the porous media because of conveyance of the current very quickly. So, resistivity for a good deposit in which the cable trenches should be laid should be very less.

In technical terms, this is what is known as ampacity of cables; that means, the ampacity of the cables should be very high. So, whatever current is being input in the cable the same should come out at another end 100 kilometres 200 kilometres 500 kilometres away. If there are looses because of resistivities of the soil you know you are losing energy, you are losing money and so on. And that is why most of sites are selected based on; normally, they are geotechnical parameters. The major issues by industrialisation is the thermal resistivity state of the soil and that is one of the reasons why most of good companies in the country would not establish their basis in most of the part of the countries, because the ground conditions are very poor; a classic example is of Hyundai.

Hyundai earlier wanted to come and settle down in Kerala, but it could not. Apart from some political reasons because the ground conditions were really very bad all right and they selected another place where, the you know chainage; all along the chain as the resistivity values were either not changing too much or good enough for laying a good cable line. Another good example is your cross-country pipeline from Gujarat to; where?

Iran

Iran yes, that is a very big project which is going on in India right now; Seacon India limited is doing that work. So, this is where actually the type of the soil moisture content distribution of the size and the grains of the soil becomes a very important parameter and finding out whether a project is feasible or not because there is a limit to modify the soil based on its thermal properties and when you say modification of the properties, it is understood that you are trying to lower the resistivities; clear?

So, in a region like Bombay, or most of the coastal regions where, you have clays the thermal resistivities are very high. So, you have to modify the entire root of the pipeline of the buried cable, kilometres long by inserting a good material, which is known as a good backfill material or fluidized thermal bed material FTBs. If you work sometimes in this area you will come across a word which is known as FTB fluidized thermal beds. So, fluidized thermal beds are designed to reduce resistivities of the soil mass. There is a paper by Dr. Kolay and myself in ASCE where, we have designed fluidized thermal beds using fly ash and clays. It must be in 2001 or 2001 ASCE. Another parameter is density of the soil

Now, what is your intuitive feeling? If density is more, the resistivity should be less or more. How can if density is more resistivity can how can it be more. If density is more, the air will be less; the point to point contact will be more alright. So, the resistivities are going to be less. Temperature and pressure; temperatures and pressures are also going to affect the resistivities. Do you remember the linear resistance equation as a function of temperature rise, RT equal to R naught plus 1 plus alpha into delta theta; so, the movement temperature rises, what happens to the resistance? The resistance increases; if resistance increases, what happens to the current or the same voltage? It will drop down.

So, you think of a situation where you are; excuse me, where you are designing a industrial unit and where you want to convey certain amount of voltage or a current, but because of very high resistivity of the geomaterial the temperature of the cable increases. So, if temperature of the cable increases, what happens to resistance? So, resistance increases and then, what happens to your current passing from one point to another point? It drops down. So, all these issues are very important when you design industries in problematic soils, alright; is this ok?

Presence of contaminants, the presence of contaminants can also influence the resistivities of the soils. Method of measurements, what type of method of measurement is being implied to measure thermal resistivity? So, because these issues are quite young, you know in historical time. Young in the sense they are not more than certainly 25-year-old issues. So, still people are trying to establish the methods, the methodologies the interpretation of the parameters and so on.

So, that is what I say that the method of measurements play a very important role in coming across the properties of the material or establishing the properties of the material. Now, all these parameters indicate that a specific heat, thermal resistivity and diffusivity because they depend upon these parameters, they can be utilised to characterised them; in the best possible manner.

A good example of this type of characterisation is if you go through the published work by Bibuti das, who did his PhD. he has characterised concrete based on their thermal properties. So, that was also very interesting way of characterising the; you know durability of concrete or the porosity of the concrete based on thermal flux.

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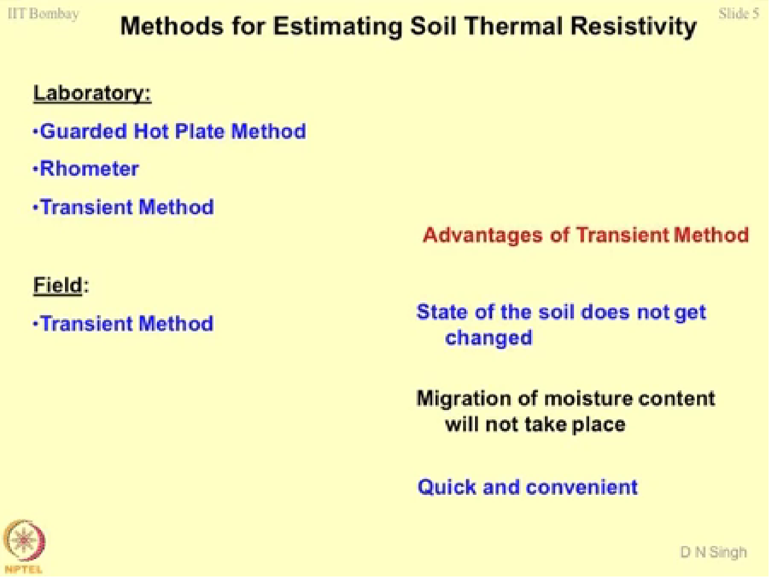

Now, let us talk about the methods for estimating soil thermal resistivity. The first method is grouped as laboratory method and the second one is field method. So, within laboratory method it is a guarded hot plate method, which is normally not used these days. The reason is this was the technique, where you have a hot plate like the one which you use for making chapattis at home; is it not?

So, you have a hot plate, put the material on the top of that and then, let there be a thermal equilibrium which itself is under question mark and their system is exposed to the environment. And then, measure the temperatures which are building up in the material. So, I think you can understand that this is a very crude way of defining a parameter, but yes it has been recorded because there was lot of experiments done by people, using graduated; guarded hot plate method.

Another one is a Rhometer, what is a Rhometer? What is meant by rho? Rhometer is basically a viscosity measurement equipment. So, if you can measure the viscosity of the system under elevated temperatures you can always find out what are its thermal properties because viscosity is highly linked with temperature. So, again this method happens to be a very crude way of defining the thermal properties.

Now, under these circumstances the transient method becomes the most handy and useful method. And our group has done lot of work in transient method; so, most of the findings of my students I will be presenting into this presentation and showing you how transient methods can be utilised for determining all the three parameters simultaneously. As far as field measurements are concerned, you cannot do guarded hot plate method. Of course, some people have tried by inserting a hot plate into the soil mass and then, heating it and then, using the temperatures in the geomaterial.

So, what are the advantages of the transient method? The first; first of all, let me ask you a question, what is meant by a transient method? See, our saints and sages they used the word life is transient; what is the meaning of this word? Not limit; not permanent. Transient means something which is momentary. So, this is just for few moments. So that means, the transient method uses the philosophy that you heat the soil mass for a certain moment; clear. In technological term this is also known as pulse of heat or pulse of heat flux being imposed on the geomaterial.

Is this part clear? For a certain movement; so, certain for moment could be 1 minute, 2 minute, 5 minutes, 10 minutes, but not more than that much, not more than few minutes say 20 minutes, 15 minutes. Now, within this duration the moisture may change, if your heat flux is too much. So, the basic idea is you do not want the moisture content of the soil mass to get changed; is it not? Otherwise, it will be creating unsaturated soil of the material.

So, the beauty of the transient method is you can control the flux intensity, you can control the temperatures and you can control how moisture is migrating along with the heat, which is the coupled phenomena; if you remember sometime back, I had coined this term. Coupled phenomena is the phenomena where, the moisture migrates from that porous media as well as the heat migrates into the porous media. So, both the things are migrating simultaneously and hence, this process is a coupled process.

So, idea is this method gives me or gives a researcher or a practitioner a good control over state of the soil. You can play with a flux; so, that the moisture does not change at all. You can apply the flux for the certain moment; so that no major changes are undergoing into the system. So, migration of the moisture will not take place and of course, this is a very quick and convenient method of determining thermal properties of geomaterials or the porous media.

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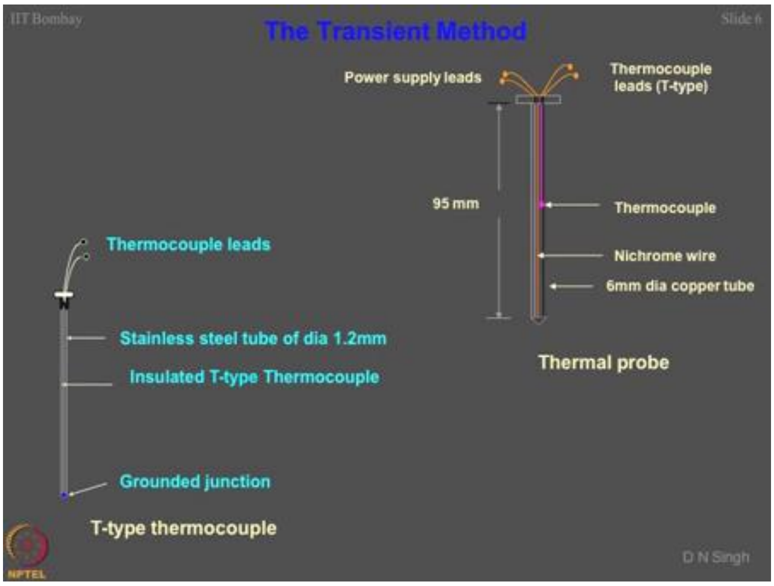

So, what is a transmits, the transient method? The transient method is based on a probe like this. The basic intension of showing you all these techniques is to make you realise that people like you have done all these few years back.

So, this was devised by my one of his students Gangadhar Rao that was in 1996 or 97 I suppose long back. And now, we have monopoly in the entire word, I should use the word a thermal measurement; nobody does this so precisely; except for us.

Say, good scope is to see that there is lot of scope of instrumentation in geotechnical engineering. And instrumentation can be done by all of us; you need not to import anything from anywhere. So, it is a simple copper tube of 95 mm length and diameter about 6 mm. And in this tube, we have installed one Nichrome wire and the tube at the end has a conical shape. So that it can be inserted in to the soil mass very easily. And ultimately, what you do is you put a thermo couple inside the probe.

It is a T- type thermocouple and then, connect it to some readout units; so that you can measure what is the temperature at the surface of the probe when, it is inserted in some geomaterial. And then, these two leads are power supply leads. So, through this the power is supplied through the Nichrome wire. So, it is a simple law of heat flux:

$Q = i^2 . r$

Where, i is the current; r is the resistance of the Nichrome wire. Now, the basic idea of having this copper tube is that your having an isothermal surface; that means, the temperature all along with tube body is same and then, this becomes a typical axis symmetric case of heat flux all right; that means, the temperatures are going to vary only in the r direction; where, r is the radial distance of a point from the middle of the probe; is this correct? Now, this is a thermocouple; yeah. So, here you can see this, the Nichrome wire passing through and this is a thermal couple which is connected to the read-out unit from where you can measure temperature.

And this is a typical thermocouple, which is inserted inside. So, you can understand that in 6 mm diameter probe we are inserting everything. And this probe now we are actually marketing to the Norwegian electricity board; yes. So, this is our copyright and at the end of this thermocouple there is a grounded junction which you can see over here. So, this is the point which reads the temperature. So, the both the things are fitted in the system. So, once you lower down this probe in the material, you can measure temperature on the surface of the probe. Now, why I am emphasising is that you are measuring the temperature on the surface or at the contact of the geomaterial and the surface of the tube or the copper tube because this becomes a boundary condition.

The radius of the probe becomes a boundary, which is a isotherm where you are measuring the temperature; you got the point. So, if I use differential equations to solve this; I will be knowing at least one point where the temperatures are measured. So, if it is second ordered differential equation what I need to do is I need to measure temperatures at two points in the soil mass. So, one point happens to be on the surface of the probe and the contact point of the material and another temperature I can measure in the geomaterial somewhere at a distance of r. So, if I know the two temperatures, if I know the two r values, I can solve any differential equation. I hope this concept is clear.

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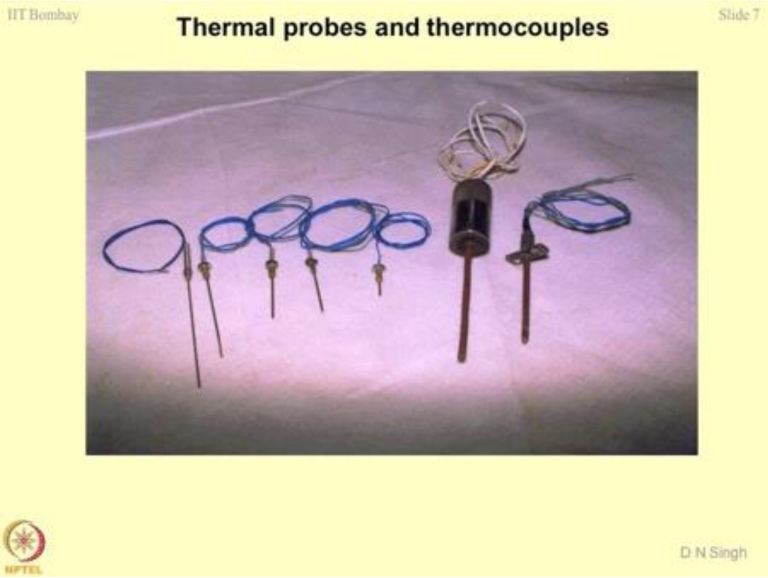

Well, this is a closer look of the thermal couples, which have been used and the probes which were developed; alright. So, these are the probes, which we are been using quite a lot in our day to day activities. This your cross-country pipeline between Jamnagar to Iraq, some place this was also done by us. The whole mapping of the soil mass for the thermal resistivity approximately, 1500-kilometre-long distance.

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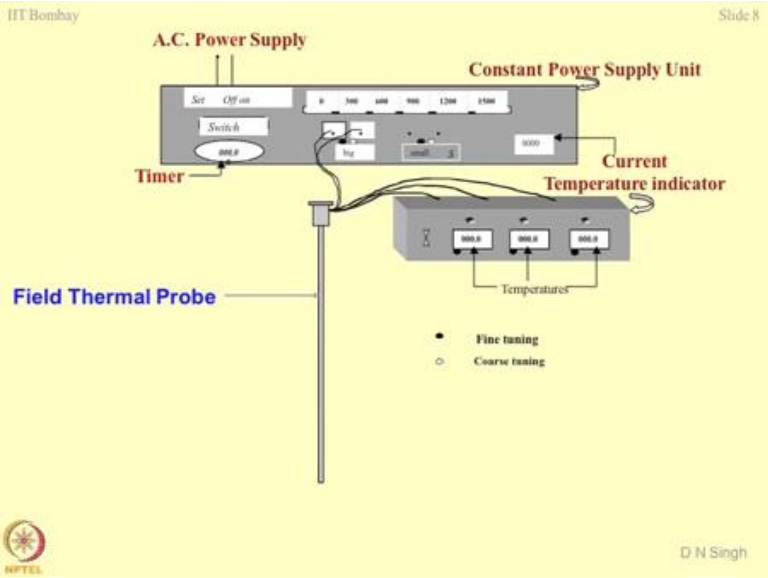

Now, this is the field probe, which was developed by my another student known as David; this is the one metre long field probe. This can be inserted into the soil mass and you can probe the temperature profile of the soil mass up to a depth of 1 metre. This is the electronic circuitry, which you have power supply, the timer, the constant power supply and the temperature read out units.

So, only thing is that there are three thermal couples installed within this 1 metre where, you can measure the temperature and you can find out the contrast in the thermal properties of the geomaterials even layer wise; so very useful tool which, we have been using quite a lot in our day to day activities.

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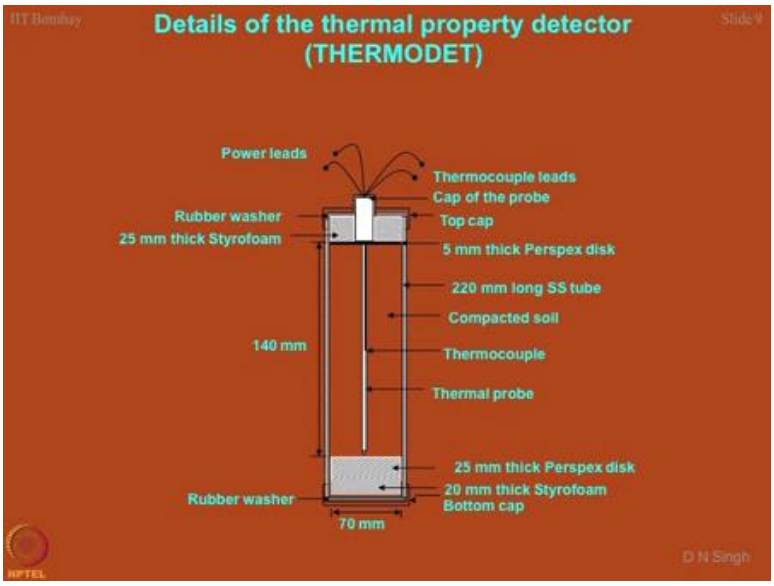

Now, this is the device which was developed by you know my PhD scholars' doctor Krishnayya, who is now JNTU HOD Civil Engineering department Anantapur. So, this is thermal property detector. So, thermal detector we call this device as thermodet; it is a tube about 70-millimetre diameter; hollow tube both the ends are you know cl with the help of a Styrofoam. And in this Styrofoam, you can fix the thermal probe which, I have showed just now.

The beauty of the set up is that you can fill up the soil mass in the powder form or in the core of the soil in this space and you can insert the probe, alright. You can apply current; so that the entire material gets heated up inside and then, you can measure the temperature over a period of time. Now, this is what is known as heating cycle. Another way of interpreting the results would be you pack the geomaterial in this system along with the thermal probe and the thermocouple and keep the entire unit in a oven. I will show you the results, what we have got. So, what happens? The entire system gets heated up to a certain temperature. And then, we can use this device for measuring the temperature inside the material. Now, this again is the heating cycle; later on, you can take out this device from the oven and put it in a water bath ok.

And then, this is the cooling cycle. So, still I can measure the temperatures within the soil mass for the cooling. I will show you that how these two different mechanisms have been utilised in interpreting some parameters, which are related to the soil mass admixture. Particularly, this device was used for finding out the thermal properties of admixtures and cements. And this project was basically done for Taiga Atomic Power Plant for designing their roof shells and the atomic shells, where they had some specifications for thermal resistivity and we have done this job for them.

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So, working principle is almost same. Now, these are the photographs of the devices which were developed. This is a laboratory thermal probe; this is the dummy rod. So, you make a proper sample. Use the dummy rod, which is slightly lesser than diameter than thermal probe. You create a dummy hole and then, fix this probe into that and then, you can go ahead with your experiment; very simple device. This is extended form of the the laboratory thermal probe; which is field thermal probe where, we use a mould of 1 metre length and diameters about thirty centimetres. This device was used for measuring the sandy soils particularly and gravelly soils and gravels. Because you can appreciate the point that gravels cannot be tested in this type of a setup. So, you require almost a 1 metre long rod to check the thermal conductivities of gravels.

This paper was published in ASCE. So, you can refer it whenever you need. And this is the device is thermodet which I have shown you just now. This is the unit made up of stainless steel; thermal probe which is inserted in to it. This is the temperature read out unit and this is the power supply unit which heats up the Nichrome wire. So, these are very simple devices, which can be used or which can be developed as per your requirement for doing various geotechnical investigations. And based on the findings of these results we developed one software which is known as DDTherm.

The first D corresponds to my student name David and another D corresponds to my name and then, this is the thermal property detector. So, we use the software for finding out the thermal properties of a geomaterial. If you know the basic ingredients of the soil like organic components, inorganic components, particle size distribution, density moisture content, state of compaction; you have to just need to put this in the software and gives the resistivities.