Environmental Geomechanics
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Lecture No. 45
Thermal characterization-I

We have been talking about geomaterial characterization, and which is quite prolonged you must have realized. And what we did is we studied the physical characterization, morphological characterization, mineralogical characterization, and then we spend a lot of time on chemical characterization. There is a misconception that environmental geotechnology deals a lot with the chemistry. But I am sure that you will realize that without chemistry, nothing is possible in today's world.

See, even if two people meet we say no there is good chemistry jelling them together. So, this is the fact that Life biosciences have become very important. Similarly, the applied chemistry is becoming very important because the environment is all about how the chemicals are influencing it.

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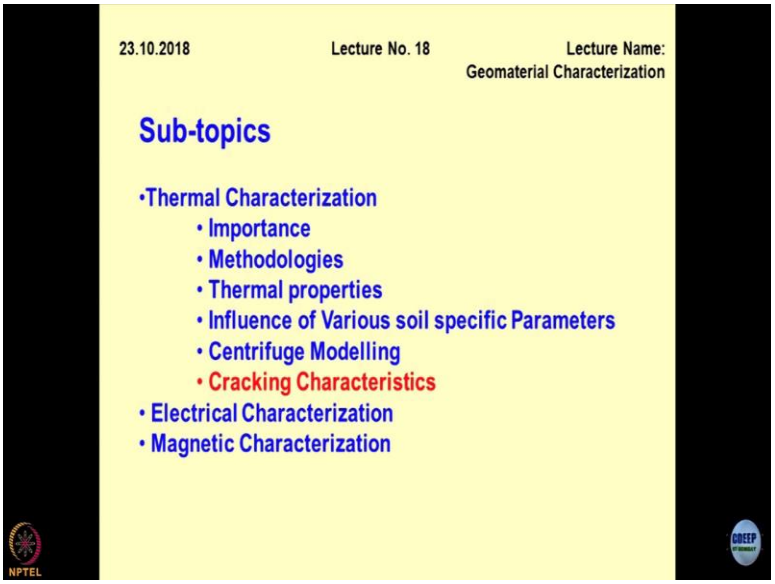

Now, in this context may be the next in series is the thermal characterization and which is quite a physical phenomena most of you must have studied the concepts of heat migration through materials, we are going to extend this information and knowledge to the heat migration through geomaterials. But before we do that, it is important to understand how to characterize geomaterials based on their thermal properties. In other words, when geomaterials are exposed to thermal gradients or thermal field, how do they respond?

So, it is important, we will be studying methodologies which are used or employed for thermal characterization of geomaterials. What are the thermal properties of importance? Then influence of various while parameters on thermal properties of the geomaterials and followed by a bit of centrifuge modelling. And one of the applications of thermal properties in geomechanics and environmental geomechanics is the cracking characteristics of soils.

So, I will spend some time on discussing the cracking characteristics which are nothing but an indirect implication of the swelling and shrinking characteristics of the soils and this is where I will also try to emphasize on the fact that gone are days when swelling and shrinking characteristics of the size used to be unwanted properties in the contemporary application of geotechnical engineering and environmental geotechnology.

If the soils are passive, they are not selling and shrinking. They are not supposed to be good material. So, the context has changed completely and having done this, we will come back to the electrical characterization and magnetic characterization.

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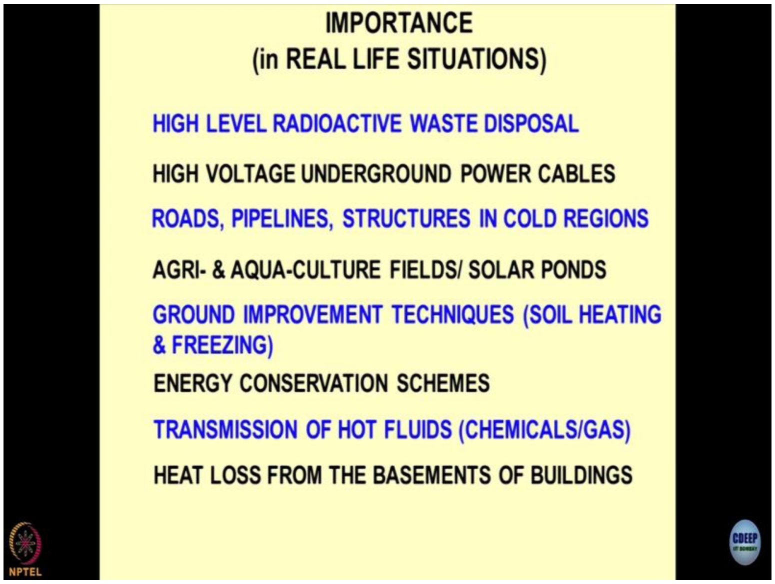

So, to begin with, the thermal characterization of geomaterials, what is the importance and what are the real-life situations where you will be using these concepts, some of these situations are listed over here? So, the first and foremost is the high-level radioactive waste disposal, which we have discussed quite in details in the initial lectures of the course, and I have been citing this example, since then that the modern-day geotechnical engineering is more towards thermomechanical coupling and hence the thermal effects become very very important.

When we deal with the geomaterials which are going to contain the toxic waste or radio nuclear waste, high voltage underground power cables, the more and more industrialization is taking place in the country. The more and more need is to electrify the industries as well as the societies as well as the housing colonies and so on. The infrastructure you may say, and this is a high voltage underground cables are becoming a part of the modern-day civilization.

And apart from power electronics guys, the best possible solutions to how to lay the power cables in the soil mass can be given by the geotechnical engineers there were many projects which I have been leading dealing with in the country and abroad, where these type of situations were dealt with by our research group and us and then I will show you some of the case studies where how these situations were answered different types of roads, pipelines structures in the coal regions, they require the concepts of thermal properties of the soils, particularly in the cold regions, where their freezing and thawing is an absolute problem.

People are talking about the installation of the geomaterials, so that the structures or the infrastructure which is coming on the top of these type of deposits, does not get distressed when freezing and fine actions take place. The most important of these type of infrastructures would be the real the airstrips in the cold regions. And I am sure you must have realized that including India, rest of the world is also facing a severe problem of creating airstrips in the regions which are extremely cold, where the freezing thawing action is extremely important and very critical for the safety of the infrastructure.

Then comes the Agri and aquaculture fields and the solar farms. You will be surprised to know that the design of the solar plants is based on the thermal properties of the geomaterials because the whole idea is to grow the aquaculture or agriculture and unless the proper temperatures are maintained within the ponds, you cannot grow shrimps you cannot grow lobsters and whatever. So, this is what the demand is in present-day society.

So when you design these type of ponds, the thermal properties of the geomaterials particularly the foundations of the ponds become very important, they should not be allowing heat migration taking place through them to maintain the optimum temperature for the culture of aquatic life. Then ground improvement techniques, including the soil heating and freezing, which requires a lot of concepts of the thermal properties of the materials.

I think I have cited some examples also, when you are working in the highly fractured rock mass and when the tunnelling is being done, where the highly fractured rock mass might allow the groundwater table to get activated and the seepage occurring into the tunnel shoots. This is where the ground improvement can be made by freezing of the geomaterials; the rocks particularly brick making is an example of how the clays or the soils react to thermal fields.

And if you go to the history and particularly stories of the World War II, there was a time, and the airstrips were made overnight by heating the soil from the top and making sure that the influence zone of the heater which is heating the surface is about 300 to 600 mm. So, this is how you can cast the roads under in-situ conditions, different types of thermo active structures, which people are talking about these days require concepts of thermal properties of geomaterials, particularly energy conservation schemes.

So, thermal piles are a good example of heat exchangers which are being designed. This is also a good example of why somebody should be studying the thermal properties of materials, the transmission of the hot fluids, most of the time transmission is done underground. So, similar, this is a similar situation as of the power cables where you are trying to convey the power, electric current and in this case

This could be air conditioning duct, or there could be some chemicals which are either going into the industry or coming out of the industry, under all circumstances you want to minimize the heat losses. A good example would also be pipelined where you might have to do thermal insulation of the pipelines. So that the cavitation does not occur in the pipeline, I hope you will know what cavitation is?

So, imagine a situation where you are pumping hydrocarbons through the pipelines. And these pipelines are passing through very high climatic conditions, very extreme climatic conditions, extreme temperatures, like deserts, Rajasthan, parts of the Rajasthan and so on. So, the chances are that the hydrocarbon might get vaporized because of extremely high temperatures, and hence the cavitation may occur and was the cavitation occurs.

You cannot convey the fluids further. So, the subject is becoming very important and very relevant to contemporary geotechnologists. And I hope the importance of infrastructure which is being done for sustaining the society, the present-day society. Another interesting example is the heat loss from the basement of the buildings, mostly cold storages which are designed or which are constructed to save the cost of the air conditioning the best thing would be to isolate these type of structures from the environment and hence, the basements have to be insulated. This is also valid for the hydrocarbon tanks, which are installed in the tank forms very close to the coastal areas where the import-export of the crude oil takes place or different type of chemicals occur. So under those circumstances, also, you would like to make a foundation system which is thermally insulated.

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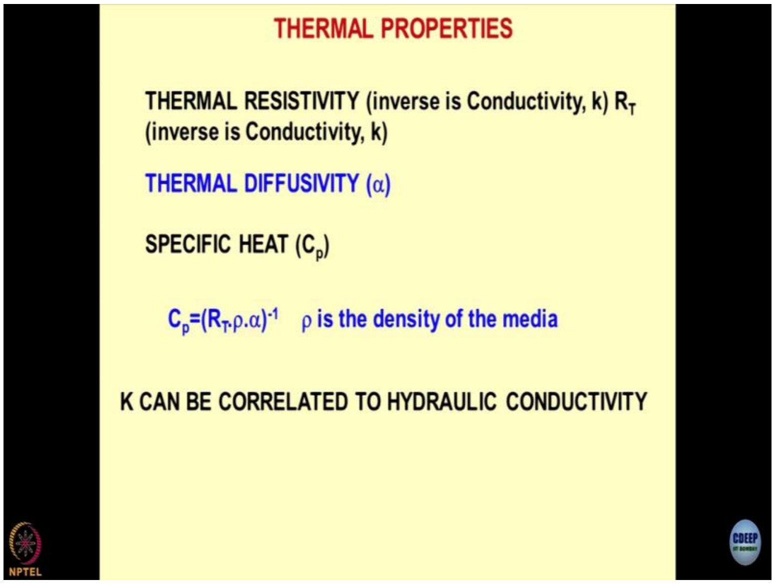

So, I hope it is clear to you that there are a lot of applications of why somebody should be studying the thermal properties of geomaterials, it is a very contemporary subject. Now, there are three properties which I would like to find out or define for the geomaterials, and these are thermal resistivity, thermal conductivity, which are related to each other in the inverse form. So, thermal resistivity is $R_{T,}$ and the inverse of this is thermal conductivity k second is the thermal diffusivity how easily the heat gets diffused from one point to another point.

If you remember when we were analyzing the energy fluxes, and this is a second-order differential equation which I was talking about, we were discussing the similarity between the diffusion coefficients. And one example I had given to you was the similarity between α or C_v the coefficient of consolidation. So, thermal diffusivity is a similar sort of a term which indicates how easily the heat flux can diffuse.

From one point to another point in the geomaterials, the accumulation of heat is not a good idea why, because if the accumulation of the heat flux takes place, the temperature of the geomaterials will rise. And once the temperature rises, the chances are that the moisture will be lost. Coupled phenomena heating induced moisture migration and which will ultimately result in the cracking of the soils. So, this is what we will be discussed subsequently, after studying the thermal properties of geomaterials.

The third parameter is the specific heat of geomaterials has defined a C_p, in you 10+2 in physics I am sure you must have done this. If you want to know what is the discharge Q. So normally what you do is $m \times C_p \times \Delta\theta$ is not where m is the mass of the material C_p is this specific heat multiplied by the change in temperature, and that is a heat flux which is either going into the system or coming out of the system.

I am sure you will realize that there is no conventional tool or equipment which is available in the market which can be utilized for determining k, R_T, α and C_p. So, our research group was quite active in this context since the early 21^{st} century, and we have been doing a lot of work in this area. And in the process, we came out with the design of instruments and design of methodologies followed by the experimental work.

This is a big challenge to determine these properties like thermal resistivity and thermal diffusivity and specific heat, and in today's discussion, I will give us some idea about how these properties can be obtained by simple instrumentation which has been done by my research scholars, and I am going to present this to you today, there is a relationship between these parameters, that is the thermal resistivity R_T, ρ is the density of the soil mass or the media and find the diffusivity and that this specific heat is C_p. So C_p is $1/(R_T \times \alpha \times \rho)$.

So, if two parameters, the third one can be obtained because the density of the soil media can be obtained very easily. So, if the density is known, still I have 3 unknowns, so, out of the three unknowns, I have to obtain at least 2 parameters to obtain the third one. So, normally the practice is that by connecting heat migration experiments, we obtain R_T directly which can be opted inverse of R_T will be the connectivity which can be obtained in and then diffusivity is obtained. If you want to find out specific heat either you obtain this mathematically, or there are some other equipments like if you remember.

We have talked about differential scanning calorimeter, DSC. So, that can be utilized to obtain the specific heat of the material or you can do simple calorimetric experiments which you might have done in your class 10th and 10+2, if you remember, you take some amount of the material and then heat it in a calorie meter and then find out how much time is required for the temperature to sustain itself and so on. It is so, interesting to see that all these conductivities can be related to each other, and a good example is that hydraulic conductivity can be related to the thermal conductivity.

So, this concept has been utilized by us in determining the hydraulic conductivity of unsaturated soils, because, as you must be aware of that it is very difficult to create an unsaturated profile of the soil number one, number two, there are no instruments which can give you the unsaturated hydraulic conductivity of the geomaterials. So, under these circumstances, the best thing would be if I heat the soil mass slowly and if I create an unsaturated soil state or unsaturated geomaterial state by allowing the moisture to migrate out of the sample.

This is how I am creating an unsaturated state of the material. And then if I observe how the moisture moves out of sample over a given period of time, I can compute hydraulic conductivity. So, this is very intricate work. I have guided two PhDs, and the best one I would be saying is of Dr Hanumantha Rao the faculty member at IIT Bhubaneswar now, he is a pioneer in this area, and he did a lot of work-related to unsaturated hydraulic conductivity determination of the soils by slow heating of the samples.

What you have to make sure is when you are applying thermal flux to the soil samples or the geomaterial, they should not crack, and the cracking would occur because of loss of moisture. Fine. So, this is an interesting philosophy, which has already been exhibited to be working by our research group and there are papers which are available in the repositories.

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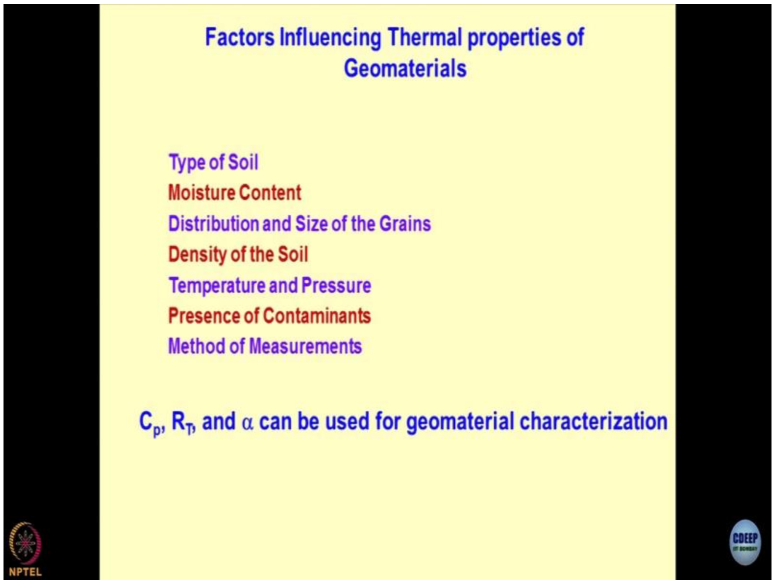

So, coming to the factors influencing thermal properties of geomaterials, this is a big series of the parameters which influence thermal properties, number one is the type of the soil definitely, the texture of the soil plays an important role, then is the moisture content because I am sure you must be exposed to this fact that heat migration through air is going to be less as compared to heat migration through the liquid phase is this correct or not? Water is a better conductor of heat as compared to air.

So, the moisture content in the voids plays a very important role. Imagine a situation where the pores are filled up with air only, and if you heat the system, in the second situation, there could be partially saturated soil where you have some air some amount of moisture, and then you heat it, and the third situation could be I have the pores which are fully filled up with water-saturated soils. So, heat conduction is going to be much faster in the saturated state of the material as compared to the dry state of the material.

Then comes the distribution and size of the grains because this has something to do with the density of the material. So, uniformly distributed soils will create a dense matrix. This is a well-known fact though if particle to particle contact is better, the heat conduction is going to be good as compared to the situation where particle to particle contact is not good. Fine. So, the distribution and size of the grains indirectly control the density, and this density is directly controlling the heat migration through the geomaterials.

So, more the density, the resistivity is going to be less. So, the density of the soil plays an important role, temperature and pressure. I am sure you must have come across this concept. When you are doing your 10+2 physics, you take a resister and pass a current through it, and when the temperatures are increased what happens resistance, the resistance also increases and that is the reason we are quite bothered about designing the power cables.

So, imagine the power cables are buried in the soils and soils exhibit very low thermal conductivity or very low thermal diffusivity. So, what is going to happen when you pass the current through the cables, the soil mass in the vicinity of the power cable attains very high temperature and when the soil mass at a very high temperature what is going to happen to the cable itself the resistance will increase and if there is an increase what happens to the power I squared times R.

So, first of all, they will be losses of the current you cannot pass the current because of very high resistance. So imagine from one city to another city if you are trying to transmit current because of elevated temperatures of the soil or less diffusivity of the current in the soil mass, the temperatures of the cables will rise, they may get burnt for this is a very trivial situation, or even if they do not get burnt, the current-carrying capacity which is known as ampacity of the cable wires or the cables decreases, we call it as ampacity.

So, the current-carrying capacity gets affected. So, it is a very intricate subject I am sure you must be realizing and what is the role played by the geotechnical engineers I am trying to emphasize all the time, presence of contaminants depends what type of contaminants are present in the geomaterials. In what phase this could be liquid, this could be solid, this could be a gaseous phase, and they would have their own influence.

This concept or this factor has not been investigated much, until now. It requires a lot of understanding and a lot of experimentation, first of all, to put things together and then to frame the thumb rules. Method of measurements, it depends upon what type of measurement method you are trying to use or which is being employed for conducting the studies. I will be talking about different methods; also, another interesting thing is the way we are utilizing these properties that is the thermal resistivity, diffusivity and specific heat, I want to utilize them to create a classification scheme of the soils.

And the beauty is that this type of a classification scheme will include physicochemical, mineralogical, chemical aspects associated with the geomaterials, I hope you can understand this. So, depending upon the minerals, whether the minerals are acting as insulators or good conductor of heat that is the fundamental nature of the mineral, a good classification system can be created.

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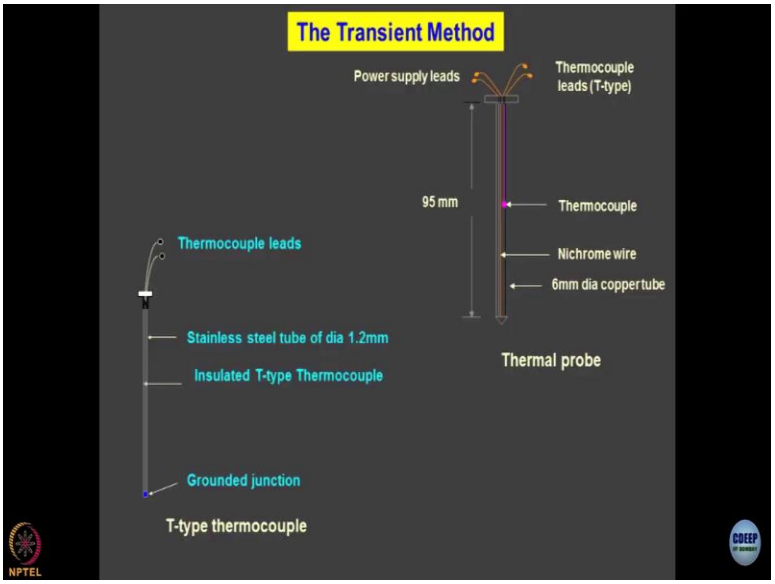

So, let me talk about the transient method, which is what we have practised much in our laboratory and which turns out to be a quite a decent method to find out the thermal properties of geomaterials. Transient is something which is short-lived momentarily. So, what we do is we apply a heat pulse of very small intensity for a very short duration to the geomaterials. And the idea is simple. We do not want any distortions and geomaterials to occur. Fine. Distortions first thing is moisture content.

The second thing is if the minerals have their inherent thermal expansion coefficient, I hope now you can realize where I am heading to, because of the expansion, when they export are exposed to high temperatures. What will happen there is a distortion in the matrix which is going to occur, so that means under these circumstances the initial state of the material is not going to be same as the final state of the material.

So, you will measure the properties of a different state of the material. So, these are issues which have helped people to talk about the transient methods where low-intensity heat flux is applied for a short duration, 1 minute 2-minute maximum. The idea is to measure how this heat pulse migrates into the geomaterials. So, this type of approach was developed by my student in 2000. In fact, before that 1995, I would say, one Mr Gangadhar Rao was there, he created this thermal probe. He was the person who was working in this first project, which I handled for cable Corporation of India.

That time there was a big supply of cables which was being done, and the installation was being done for different industrial application. And people were clueless about how to find out the thermal properties of soils. So, we were the first in the country and maybe a significant part of the world to tackle this problem. So what you see over here is that this is a copper tube of about 95 mm long, it is a hollow tube, and then we got this fabricated, we put a nichrome resistance wire inside, and we fixed it at the bottom, and then we put a thermocouple inside the probe. It is a T type thermocouple, and the probe is ready.

Now if you buy this instrument, this will not be costing you less than few lakhs, and the commercial versions of these instruments will cost you about seven to eight lakhs these are available in the market. Unfortunately, we could not patent, and we could not fabricate this thing is at that time for a better supply of the heat which gets generated through this nichrome wire, when you connect this to power. What we do is we fill up space in the tube with a something known as heat source-sink fluid, this is an oil of high thermal conductivity.

So, what the whole idea is that you replace the air which is inside the tube with the heat sink fluid. So, this system becomes a monolith. And what you are observing is that the other end is tapered. So, I can insert it into the ground very easily, just by tamping it. And then this thermocouple gives me what the temperature of the thermal probe is, this is a copper tube, the surface is going to be an isotherm

The moment I put this whole thing in the soil mass, the temperature of the copper tube and the soil mass attains equilibration, and that is what is measured over a period of time. These are the thermocouple leads which were used, so the thermocouple is grounded at the junction at the bottom of soil this tell us to do 1.2 mm diameter and this is the body of the insulated T type thermocouple. All these things were done in house at the time.