Environmental Geomechanics
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Lecture No. 47
Thermal characterization-III

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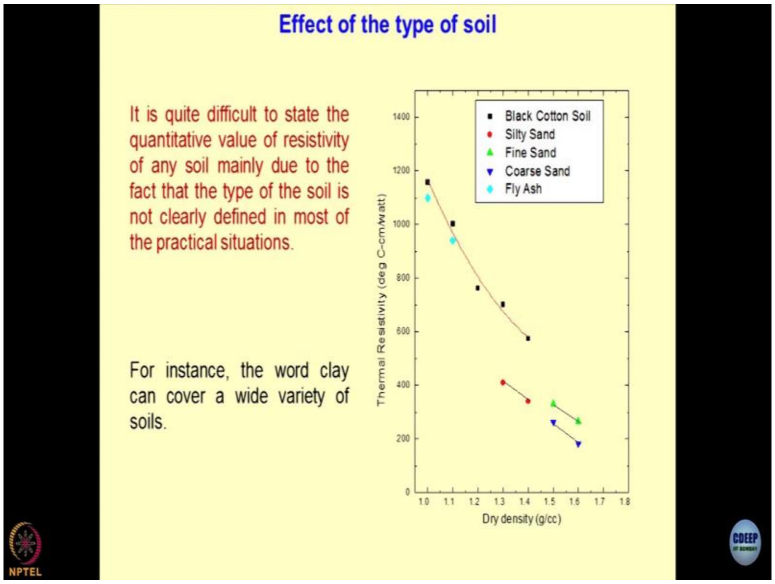

So, let me quickly go through the effect of the type of the soils as I discussed thermal resistivity is quite sensitive to the type of the soil and what I have shown over here is that how clays, sands and the silts they compare with each other. So, clays have maximum resistivity, and this is followed for the sands and silts for the same dry density overall trend remains the same as the density increases thermal resistivity will drop.

So, this answers your question we were asking that fine-grained material because of the clay minerals are highly resistive, for the same density. Another question to complicate the statement would be clay cannot be compacted. So, your hunch was that you would compact something and you will create a barrier system. Now, this becomes a very interesting and complicated problem. If you are dealing with the clay minerals, how would you compact them to a certain γ_d, that itself is big engineering?

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So the effect of moisture content is like this, as I was talking about earlier, that thermal resistivity. When plotted with respect to moisture, the trend is, as the moisture content increases, thermal resistivity decreases, look at the effect of density. So, the higher the density the resistivity drops. So, starting from low density to higher density, the trend is resistivity drops and then ultimately converges at a given point, which is around 200-400 cm/W. And this is approximately 165.

So this comes out to be the resistivity of the water. There is one more concept which is known as critical moisture content. Similarly, when you design thermo activity structures, you have to make sure that the moisture content does not drop even by one unit. you want to understand this fact, you should look at this graph carefully from this point onwards where the point of tangency or the point of constant nature of this graph starts on the left hand side even a small unit of drop of moisture content will rise the thermal resistivity suddenly.

So, this point where the thermal properties of the material become constant is known as critical moisture and what is done in real life is either people maintain the moisture by irrigating the structures, or you devise these type of thermal barriers. So, this is becoming a big subject, most of the thermal power plants which have come outcome up in the recent past require, these type of knowledge for designing their buried pipelines buried cable systems.

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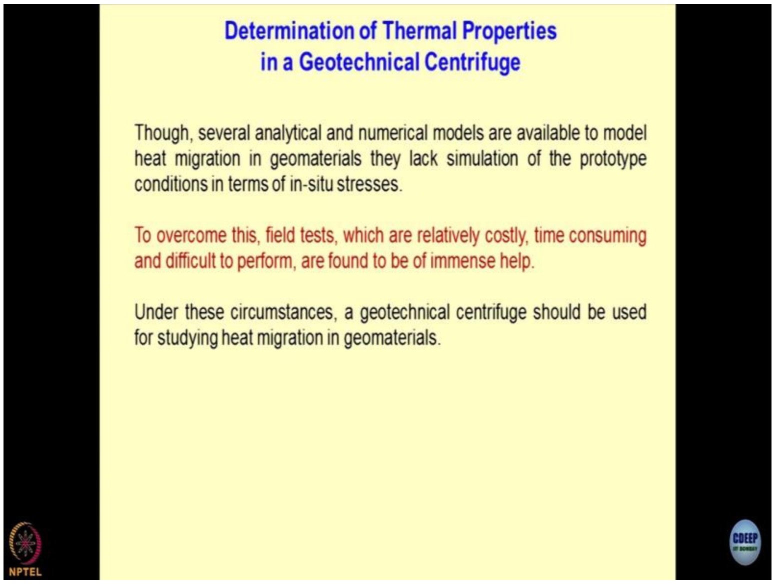

Then we went on modelling the whole thing in the centrifuge because this is the fashion at that time, everybody wanted to study what happens, to the soil properties when you spin the sample at a very high g value. And the reason was that when you take the samples from the field you cannot imbibe in them, the boundary conditions and the stress conditions, because once you are taken off the sample from the ground, the stress conditions do not simulate what they were. So, there has been interesting in researchers that they wanted to study the influence of in-situ stresses and how these in-situ stresses would influence the thermal properties of the geomaterial. And that is where the centrifuge modelling came in the picture; we used a small geotechnical centrifuge.

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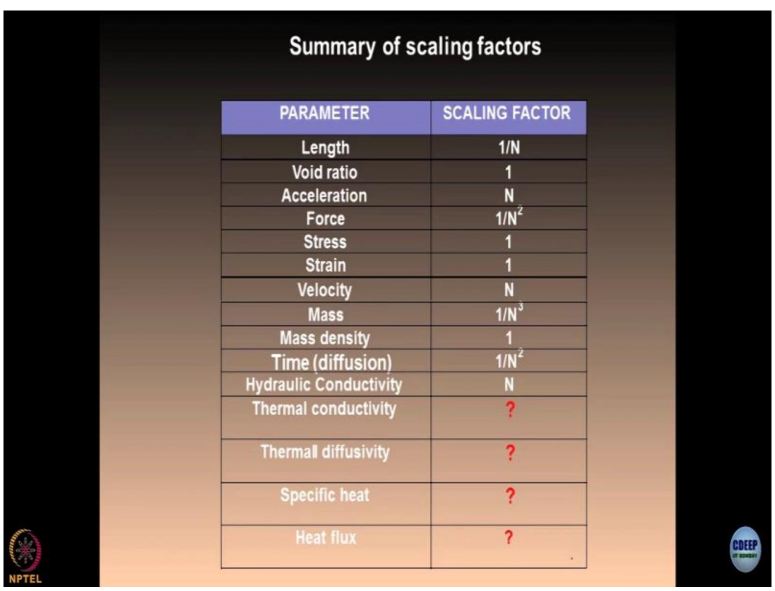

And then we wanted to do these tests. This whole exercise was done by my PhD scholar, Dr. Krishnaiah. When he started this test, the scaling factors for length, void ratio, acceleration, force, stress-strain, velocity, mass, density, diffusion time, hydraulic conductivity was known, in fact, hydraulic conductivity determination was done by my another PhD scholar, one Prof. A.K. Gupta, but we were not having any clues about how heat migrates in the centrifuge.

This was the first effort I would say, made by the researchers and that too form a group. So, you are not aware of how these things will get scaled. So, his contribution was to give an answer to this question of how thermal conductivity, thermal diffusivity, specific heat and heat flux gets modelled or scaled in the centrifuge.

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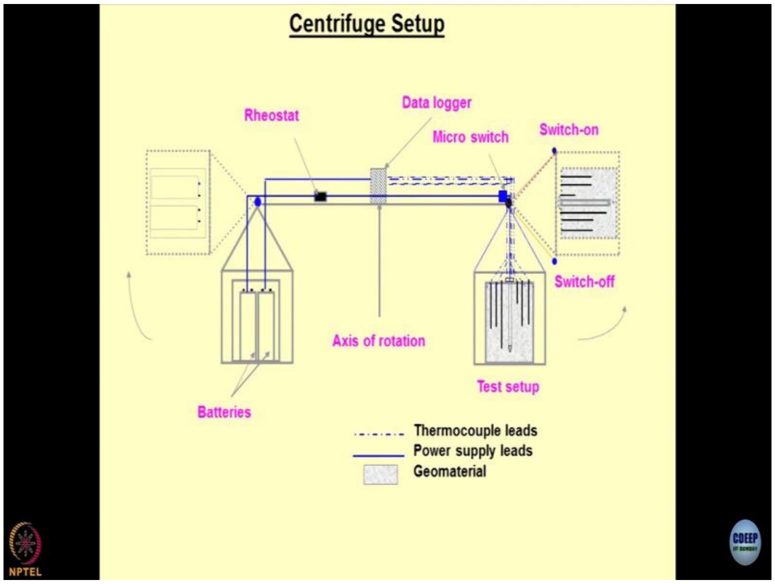

So we created a system like this, which have become a technological solution for doing heat migration studies in the centrifuge set up what you are observing here is that this is the axis of rotation of the centrifuge. It is a beam-type centrifuge, this is the sample which is instrumented with the thermal probe and different thermocouples, and for batteries, we have used another bucket, and we have used them as a counterweight

This concept took me to realize maybe 3, 4 months that rather than keeping the battery separately and creating another counterweight, we can use the batteries as a counterweight, but the problem is when the centrifuge is in spinning condition, how would you pass the current through the sample or through the thermal probe. So, we devised a switch, which under a stationary condition remain disconnected from the body of the sample.

So, what we have done is this bucket of the centrifuges we have taken as a conducting material, and this switch under one g does not remain in contact with the bucket. The moment it goes in the flight, there is a contract between the switch and the bucket circuit gets completed, the probe gets heated up, heat migrates, I have different thermocouples, and I can measure the temperature. This was an exciting design of the experiment, which was published in the International Journal of physical modelling in geotechnical engineering.

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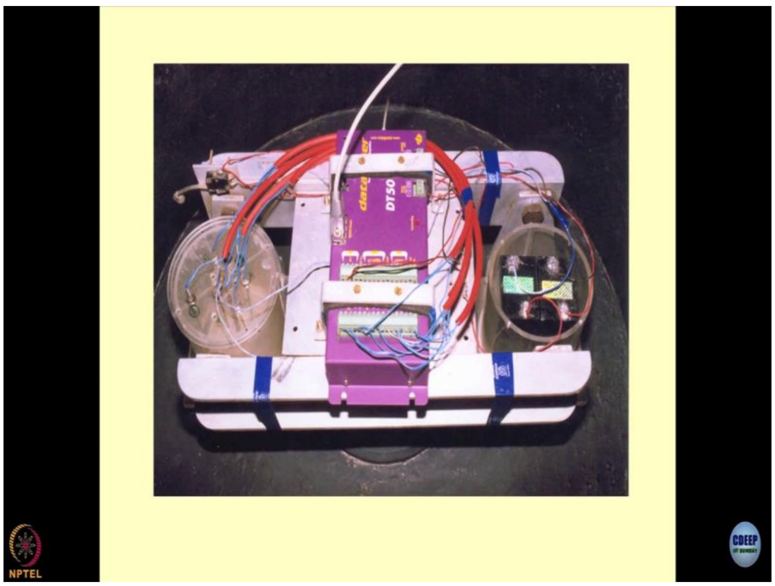

This is how it looks like this is the data logger which was mounted on the centrifuge itself these are the batteries, this is a sample, and this is the switch if you are interested in seeing how this was done and if you want to read the philosophy and the whole work how it has been done, please go through the paper which was published by Dr Krishnaiah.

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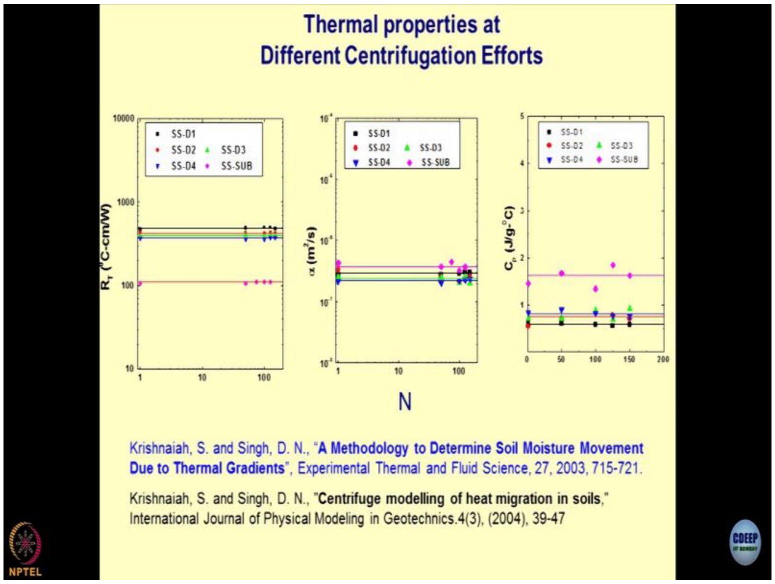

Now, these are the results which we get in the centrifugation, if I plot N values, R_T values corresponding to different N values for different states of soils, what you will observe is that R_T does not get affected. Similarly, diffusivity does not get affected; the specific heat does not get affected. Fine. So, this is the answer we got to the question of what happens to the thermal properties when they get exposed to centrifugation or higher g values.

This paper was published by Krishnaiah in Experimental thermal and fluid sciences in 2003. A method to determine soil moisturizer movement due to thermal gradients. These are simple experiments, which were done with good planning and later on, they became path-breaking exercise. There is another paper, which we have published as I was discussing centrifuge modelling of heat migration in soils by Krishnaiah and myself in International Journal of physical modelling in geotechnics that was published in 2004.

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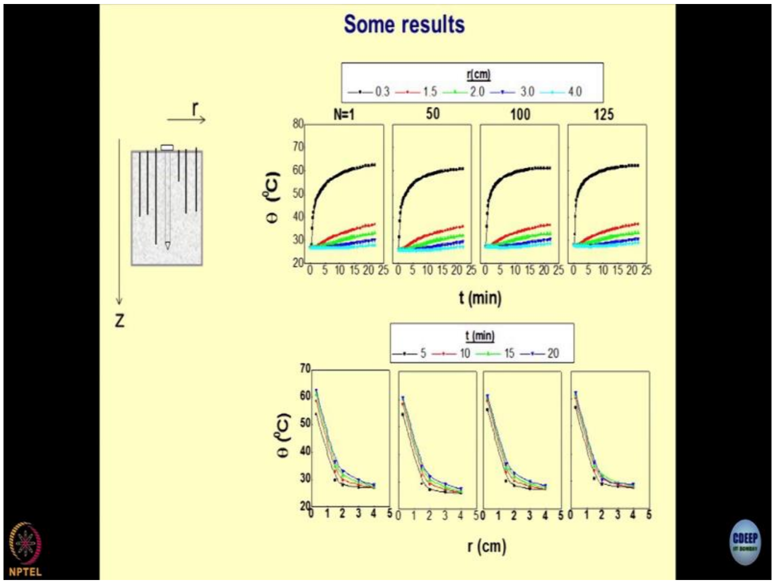

Analysis of some more results, which I wanted to share with you that if this is the sample of the soil, the thermal probe is embedded in it, we have different thermocouples at different r different Zs. Remember, the heat is being monitored at the tip of the thermocouple. So, by this arrangement, we have varied r, and we have varied z. So, if you plot how temperature varies with respect to time for different thermocouples which are placed at different r values, this is how the thermal profiles would be.

Another way of plotting this would be temperature as a function of r forgiven. So truly speaking, these are the thermal profiles. In other words, these are theta as a function of r, z and t, and that is what we wanted. So, once the thermal regime which has been set in the soil mass, we can do numerical modelling, and we can get other parameters. Those of you who are aware of centrifuge modelling, there is something known as modelling of models, that means whatever the testing conditions are, the result should not be dependent upon the testing conditions.

That means if I am doing a test at 50g, 100g, or 125g ultimately, the results should be overlapping each other, and that is what we have shown over. So, mu is the percentage increase in the temperature as a function of radial distance from the thermal probe, and then we have done time modelling for different days. And what we observe is the results are unique and the profiles which you are going to get define the state of heat migration in the geomaterials, easy way to read this would be at a certain distance from the thermal probe, the temperature rise is maximum, as the radial distance increases, the thermal change in the sample becomes less.

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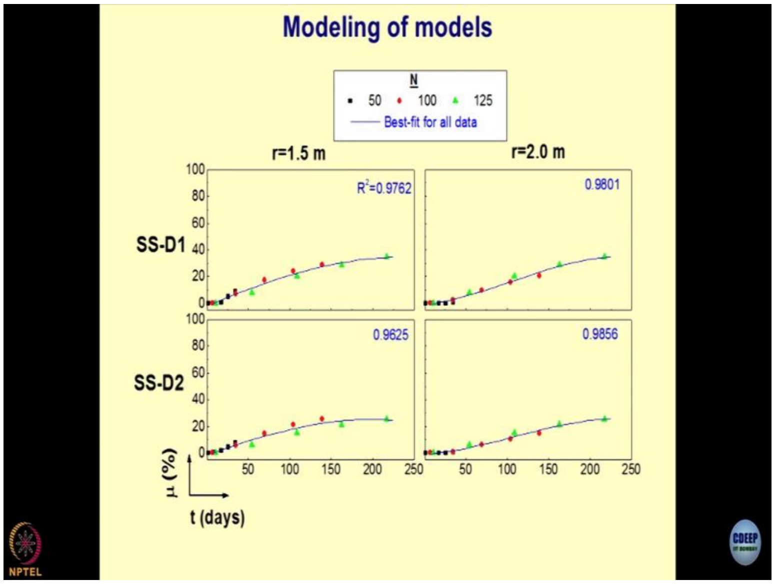

This is the modelling of models for different N values. So, for different soil states, different types of samples, if you compare the results at different radial distances for different N values, again you will realize that if I plot percentage increase in the temperature with respect to time, the relationships are unique. So, both and modelling that is the g level modelling and the time modelling gives that unique results. So, this is how we showed that centrifuge modelling could be done for studying heat migration in the geomaterials; later on, we extended this to the numerical modelling.

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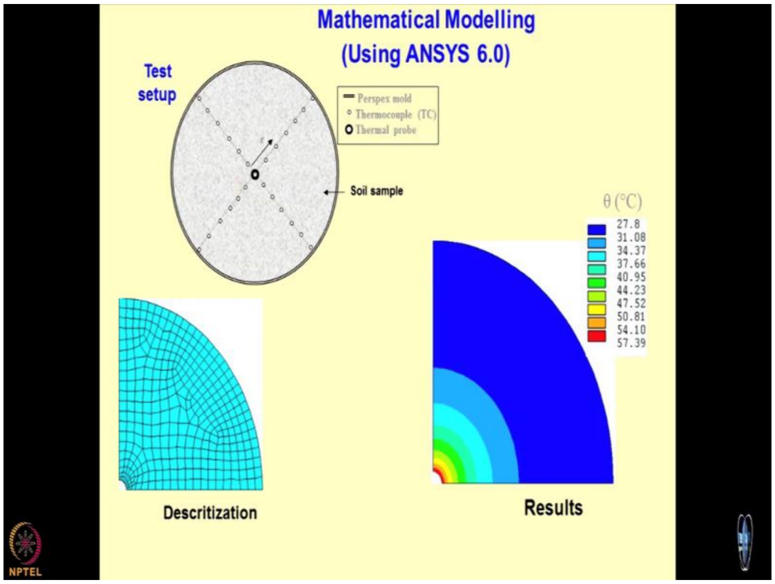

By using ANSYS. So, this is the model from there I have got the results, and the central portion shows the thermal probe, and there are thermocouples which are installed in the radial directions diametrically. So, as far as the numerical modelling is concerned, we will do only one-fourth of the domain of the soil mass because there is asymmetry. So, if you take out the one four-quadrant or one quadrant of the sample, this is how the discretization has been done, this surface is the contact between the thermal probe and the soil mass through which the heat is migrating into the domain.

So, again the statement of the problem is same I want to find out theta as a function of R and t because z is not coming into the picture and these are the results which you will be getting. So, this is the thermal profile which has set in the soil mass. Now using this thermal profile, what we have done is we have again try to find out how the.

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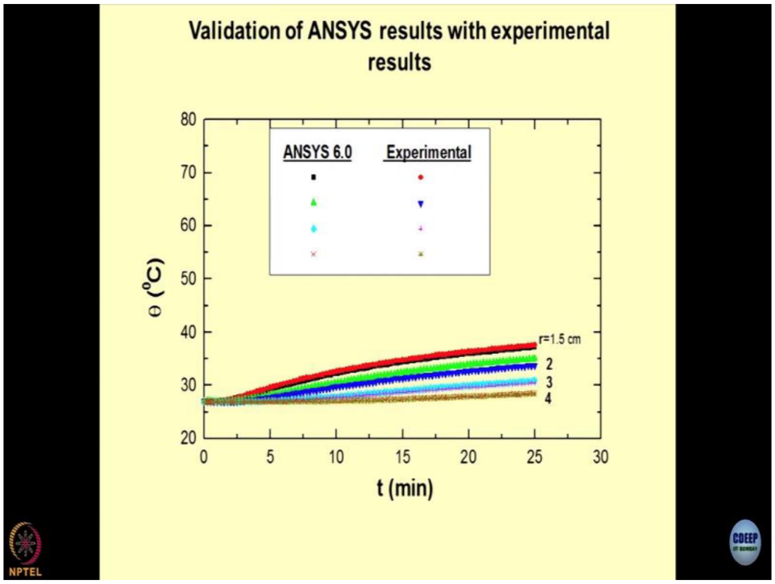

Time of heating gets scaled. So, if you plot the results of the ANSYS and the experimental results which we have obtained for different radial distances and time, you will see the overlap quite well. So, this is the validation of your experimentation or the validation of the mathematical code which you are using or the validation of the parameters that you have selected for making a mathematical model. Fine.

So, all these things have been taken care of. The idea was to extend this type of philosophy to the materials which are very stiff and through which the thermal probes cannot be inserted so easily like concrete. So, once I have trained mathematical model vis a vis the results which I got from the soil samples, I know what parameters have been used this can be extended to the concrete.

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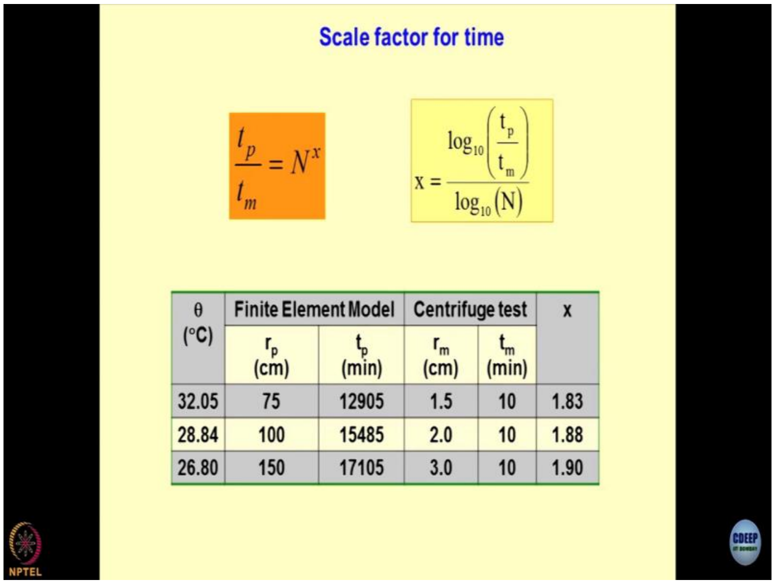

So, this is how the scale factor for the times was obtained p corresponds to the prototype m correspond to the model. So, time taken by the heat front to move in the prototype and time taken by the heat front to move in the model gets scaled by N is the centrifugation effort, and X is some constant, which is the time factor. So, if you do this exercise where you use the FEM results and the Centrifuge test results, what you will realize is that x comes out to be approximately 1.8, which is approximately 2. So, this is how you can find out the time factor for heat migration through geomaterials.

N square times the time in the model indicates that this is a diffusion process. So, if you revisit this series of the time factors which with which we started now, you will realize that the time of diffusion is one upon in the squared times whether it is contaminant diffusion or whether it is the diffusion of the heat, hydraulic conductivity gets modelled N times that means, in the model the hydraulic conductivity is N times higher than the prototype. So, this is how heat modelling exercise was done.

And this is an exercise which was just to show you that how various situations can be dealt with to come out with simple solutions to the problems what I have done is in short duration, I have tried to show you how thermal properties can be determined by creating simple experiments, philosophies, and how to use them in giving the answers to the questions.