Environmental Geomechanics
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Lecture No. 48
Cracking characteristics of fine-grained soils-I

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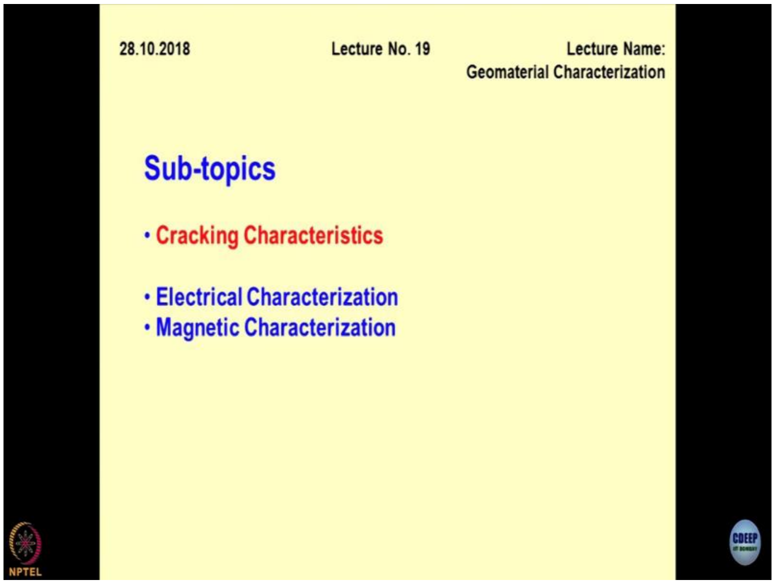

We have been discussing the geomaterial characterization and in particular thermal characterization. So, as discussed last time, one of the real-life application of thermal characterization would be the formation of heat-induced cracking of the soils. And this is a big challenge for geotechnical engineers to overcome and design the foundations and the structures so that they do not get exposed to the environment even after the thermal cracking occurs.

So, in today's discussion, I will be elaborating about the mechanisms what thermal cracking is all about? What are the mechanisms of cracking of soils and how to quantify the cracking characteristics and how to use this information in the practice of geotechnical engineering and of course, this will be followed by electrical and magnetic characterization, mostly the cracking is associated with the fine-grained materials.

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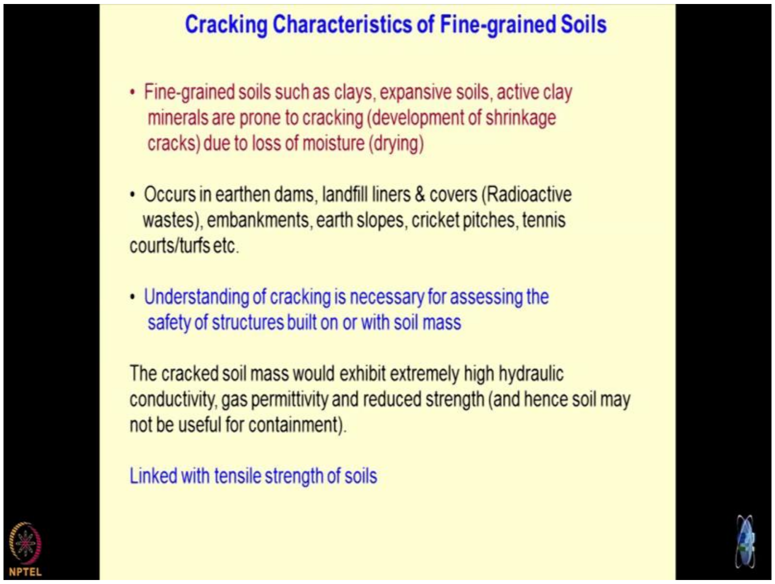

Such as clays or the expensive soils where the mineralogy is very active or the clay minerals which are active in nature, when we say active minerals the tendency of the minerals is to react with water or the environment and in the process, they shrink and swell. So, shrinkage is because of the expulsion of the moisture and when the drying takes place. And the swelling is the reverse process when the minerals come in contact with water; they have a tendency to adhered the water onto their surface. In short, the swelling and shrinking cause the cracking to occur.

That means there will be a limit of swelling and shrinking process before the cracking occurs. So, cracking is something which is the ultimate effect of the swelling and shrinking process. These type of situations become very critical when we talk about the clays which are used as a core of the earthen dams, sometimes landfill liners also and the landfill covers, these could be the liners and covers for the radioactive waste repositories also as we have discussed embankment, slopes in the sporting world.

Normally this concept is used quite a lot, where they apply the concepts of cracking of soils and how to migrate it, how to remediate it, particularly in case of cricket pitches and tennis courts. In fact, my research in the cracking of fine-grained soils and so I started with my association with the BCCI when we were doing this pitches for World Cup 2011, and then I found that this idea became so intricate that I guided almost 2 PhDs on this. And we devised a lot of philosophies and the facilities, which can be utilized for characterization of fine-grained materials. It is a very interesting topic to study by geotechnical engineers as well as the people who are associated with these type of projects. Now, another thing is that when you construct something on the soil mass which is prone to cracking, the safety of the structure becomes a very very important issue, most of the time in the realm of environmental geotechnology, where we talk about the permittivity of the compacted soil mass.

The big question would be after the soils crack, particularly the fine-grained soils, they become more porous, more conducting, sometimes we also call this as a secondary porosity of the material. So, after cracking the material becomes highly conducting and this could be an alarming situation when you deal with the liners or the covers for the landfills. So, imagine a situation where the thermal gradients are coming from the landfill, and they are getting exposed, or the clay liners are getting exposed to the thermal gradients which are coming from the landfill, where a lot of chemical reactions are occurring.

And if these liners crack, the chances are that the environmental water will migrate through the covers which have been designed as well as the liners through which the leachates will go into the environment. As far as the conventional geomechanics is concerned, the tracking is going to because of the loss of bearing of the strata. And sometimes if the tracking tendency is too much, then differential settlements also might prevail in the system.

It so happens that the cracking of the soils is linked with the tensile strength of soils. And I am sure you will realize that in conventional geomechanics, we have not given much weightage to the tensile strength of geomaterials all the test which are performed are related to the compression of the soils, and we rarely talk about the tensile strength of the soils, but it has been realized in the recent past that the tensile strength of the soils is the one which controls their stability rather than the compressive strength.

And hence, it becomes very important to study the mechanism of crack formation in the fine-grained soils and which is attributed to the tensile strength mobilization. This also necessitates the development of instrumentation and the hypothesis which can be utilized for determination of tensile strength of soils.

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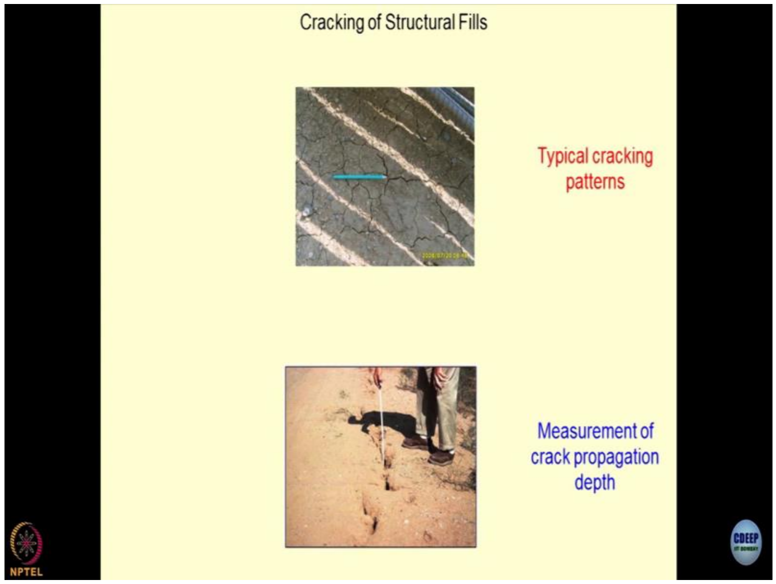

I had another interesting encounter with the geomaterials which used to crack, and this is an example of a large structural fill which was created somewhere close to Bombay, in Gujarat. Soils in Gujarat are quite, active because of the mineralogy and this case happened where the structural fill was created. And unfortunately, there was a flash flood and because of the flash floods several hectares of the area which was structurally filled up with the soils cracked, and then this became a very interesting case to study. So here what I have shown is, if you look at the pattern of the cracks, which get developed on the entire structural fill, the basic idea of compacting the soil to create a structural pad gets defeated number one, you can always say that this was a poor choice as far as the material is concerned to create a structural fill and Yes, that is true.

So, the contractor need not be paid for this type of filling because he was supposed to be extra cautious while selecting a material as structural fill material. Now in short ones these type of cracks developed, we do the third dimension mapping also of the cracks, and we try to realize that how many portions of this compacted fill has become debunked if you have done a structural analysis of the retention schemes, particularly the retaining walls and the retaining walls which are exposed to desiccation cracking.

The simple question which is asked is what is the earth pressure before and after the development of the tension crack. And I am sure you have done this analysis to show once this structural crack develops, the soil is not in touch with the retaining wall at all. And hence, the earth pressures are going to be different than the earth pressures which are going to be under full contact of the backfill with the wall.

So, this is where it becomes very important apart from knowing what the amount of seepage which is getting induced into the subsurface of the backfills because of the crack formation is, and if the depth of the cracks is quite high, the situation might become quite alarming as well in simple words. If this type of situation occurs somewhere, the structural fill has lost its integrity, and hence you cannot accept this type of a situation.

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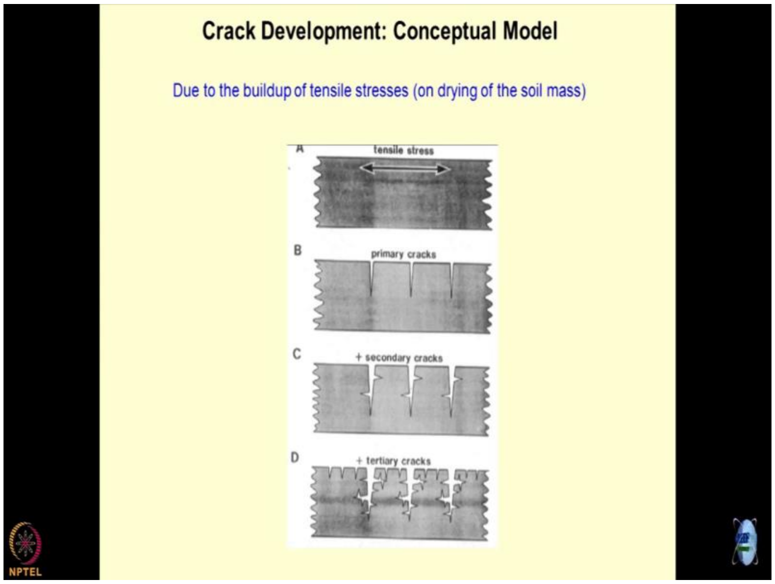

Now, if you think about the conceptual model that why soils crack, the tensile stresses which develop in the system to be blamed for cracking of the soils and tensile stresses develop due to the desiccation of the soil mass or the drying of the soil mass. So, I am sure you must be realizing that this is a situation which does not occur because of the mechanical loading of the soils.

The situation occurs because of the thermal loading of the soils, and thermal loading causes expulsion of water from the soils or the drying we call this as desiccation also, and then the tensile stresses mobilize if the tensile stresses are higher than the tensile stresses which are at the limiting stage of cracking, the soils will crack otherwise they remain within the permissible limit. So, this type of models is normally used. You have a thin layer of the soil which is fine-grained material clay, and this is where the tensile stress is developed, because of the heating, because of the stretching of the clay layer.

There will be primary cracks which were developed, air enters into the system, and this system does not remain at equilibrium because of the development of the primary cracks, these cracks multiply in the form of the secondary and tertiary crack and the whole system which was compacted as the backfill material becomes quite pervious and loses its structural stability. So, this is a simple model, which is used to define the cracking characteristics of the soils.

Now, the question is how would you determine the tensile stresses in the material and how would you link it with the thermal effects and the desiccation effects which might be happening because of the environmental conditions. And that is the reason this subject is now becoming quite important to be studied by all those who are in the practice of geotechnical engineering as well as geoenvironmental engineering. Now, if I change the context and if I say rather than heat drying the soil mass, there is some chemical activity which is occurring in the system and because of that, there could be an internal heating process which is going on.

So, this is equivalent to the situation when the soil mass was getting heated up from the outside or externally heated. So, truly speaking the source of heat generation is not very important, this could be within the system, this could be outside the system, what is important is that how the moisture gets released from the pores and that process causes the cracks to develop.

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So, if we talk about the mechanism of mobilization of the tensile strength, this is a complicated process, we have to again start with the three the phase system. And if you remember we have talked about the soil, water, air interface or the interaction all the three phases interacting with each other, which is the main reason for the mobilization of the tensile strength of the fine-grained materials and this is where we assume that in case of the dry soils, we have apparent cohesion, if you remember the shear stress versus normal stress relationship or the failure envelops of the soils.

I hope you will realize that the initial portion is an OC material OC response where the C remains constant, and then there comes the point of sigma p prime pre-consolidation pressure and beyond which the material becomes NC. So, if you plot tow versus sigma relationship, so, you will get an OC response followed by NC response on the shear strength profile and the point of intersection of these two responses is the pre-consolidation pressure.

So, for less moisture soil, we consider them as the dry soils, and we consider this as the apparent cohesion. Apparent cohesion could be the over consolidation, the value of the shear strength which is associated with the soils. However, when we talk about the partially saturated soils. This is where the capillary phenomena take an important role, and we talk about the surface tension, and surface tension is nothing but suction in the soil.

So, the best way to model the mechanism of mobilization of the tensile strength would be to bring in the suction parameter. I think now; you can realize that why conventional geomechanics does not talk about the tensile strength of geomaterials because there forcefully we have saturated the soil samples, we have made sure that the soil does not remain under the unsaturated state. However, the tensile strength is going to get mobilized when the soils become partially saturated, or they tend to become unsaturated.

This is an interesting fact that the soils that swell exhibit higher tensile strength. So, that is the arrangement of the water retention system on the on those minerals of the fine-grained materials. So, more the holding capacity of the moisture, more the swelling pressure, and once the swelling pressure is very high, the tensile strength of the material is going to be high. Now, what we do is, we try to relate the tensile strength by with so many parameters.

So, tensile strength is a function of the moisture content of the soil. It is γ_t, now γ_t basically indicates the total unit weight of the material, which is a function of specific gravity and soil type corresponds to mainly texture and CL is the clay content. So, higher the clay content higher this σ_t value, cation exchange capacity, then plasticity index, specific surface area and the suction matrix suction. So, all these terms put together would create the sigma t value.

Yes, please. That high swelling pressure, swelling soils have more tensile strength means when we study that suppose compaction curve, so the dry side supposed to have more swelling tendency so they should have more tensile stress should develop, I think no you are not correct if you plot γ_d vs W and the suction pressure with develops as a function of moisture content, you will realize the maximum amount of suction is at the OMC. So, what you are thinking is a totally reverse process.

So, if you plot γ_d vs W and if you plot the porewater pressure versus w. So, if this is the OMC, what you will realize the suction pressure is going to be maximum at the OMC. So, what this indicates is that the degree of compaction also plays a very very important role. And I hope you can easily follow this concept by the fact that the more the compacted a material would be you have expelled out most of the air which was present in the soil mass and hence the suction is going to be much more so as you compact the soils the suction builds up.

A reverse process is like this, the more compacted the soil, the more the suction present in it. But suppose if I fill or if I saturate the entire system then this suction gets lost and hence the shear strength decreases. So, this is the complete cycle which you have to consider. The simple logic is the more I compact the soils, the more suction gets build in because I have expelled air from the pores.

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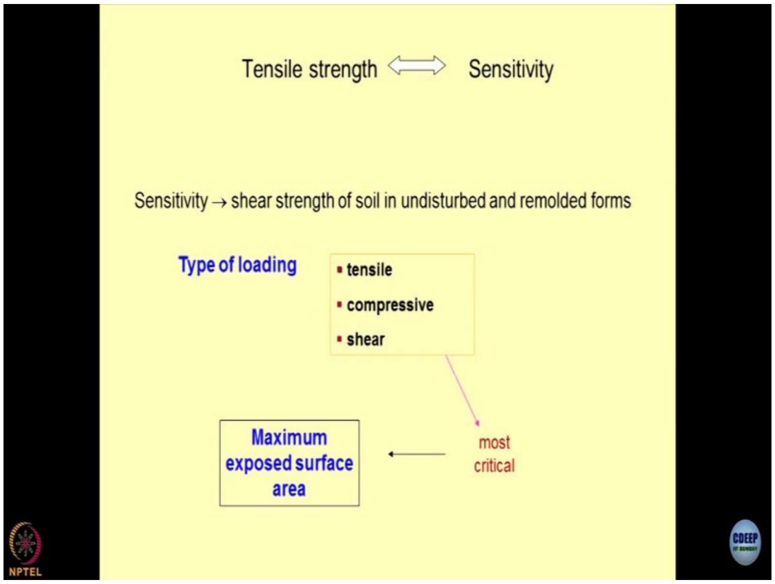

Now, this is the tensile strength which also influences the sensitivity of the soils. In conventional geomechanics, we have talked a lot about the sensitivity, and we have ascribed sensitivity to the ratio of the shear strengths. We say sensitivity is the shear strength of soils in its undisturbed state to the remoulded state. So, one of the ways of looking at the tensile strength could be If I use the concept of sensitivity and if I talk about the shear strength parameters associated with the soil mass in its undisturbed as well as the disturbed state, remoulded state.

Now, this is where the type of loading becomes very important. So, when we are talking about the tensile strength, we have to understand what type of loading the soil mass is undergoing through. So, there are three types of loading which normally we talk about tensile strength, tensile stresses, compressive stresses and shear stresses. Under no shear condition, if I consider what tensile and compressive stresses due to the sample, this becomes a critical situation, and then we have to try to understand what tensile and comprehensive loading does to the arrangement of the grains in the soil system.

And this is where I would like to introduce the concept of the maximum exposed surface area, which is responsible for tensile and compressive loading. And ultimately it gets linked to the tensile strength; if you really want to understand how exposed surface area influences the tensile strength of the material, we have to go into the micromechanics of the system. And the micro mechanics looks like this.

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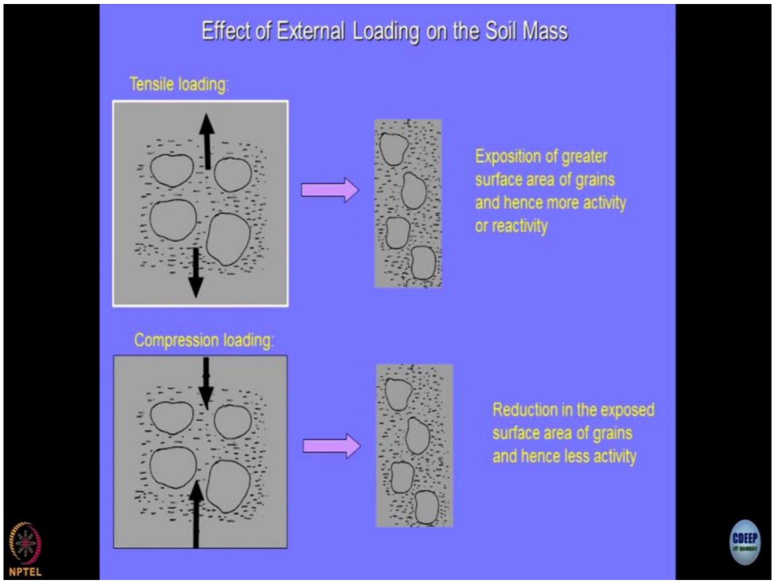

So, if you start with, let us say tensile loading or the compressive loading, and these are the grains, which are in the soil mass, and if I stretch it, what is going to happen, when I stretch it, all the particles get repelled from each other. That means, in other words, each particle is now free to exhibit the 100% surface area to the environment. So, this is a case when tensile loading causes, exposure of the grains to the environment.

So, the more you stress the material, the particles get stretched out, and they are free to now interact with the environment. The environment could be water, contaminants, which are present in the liquid phase, gaseous phase, sometimes solid phase also, bacteria. So, all these are the attributes of the environment, what happens in case of the compression loading, I think you can realize when the compression loading occurs, the particles come closer to each other certain amount of their surface is getting hidden because of the compressive forces.

That means, when we talk about the compression loading, we are not doing justice with the material modelling, because when you bring particles together to each other, there is sort of a shadow effect. So, each particle is shadowing the certain fraction of the surface of another particle. So, what it indicates is the fundamental difference between tensile loading and the compression loading is that exposure of the surface gets changed and hence we are not really modelling the grains.

The way we should have modelled them for finding out what should be the response of the loading on the geomaterials, particularly the fine-grained materials. So, this is a very convincing model which has been used by people to put forth this analogy or the philosophy that why tensile loading should be considered for characterization of the soils. So, truly speaking, the tensile strength is a parameter which can be utilized to characterize the geomaterials.

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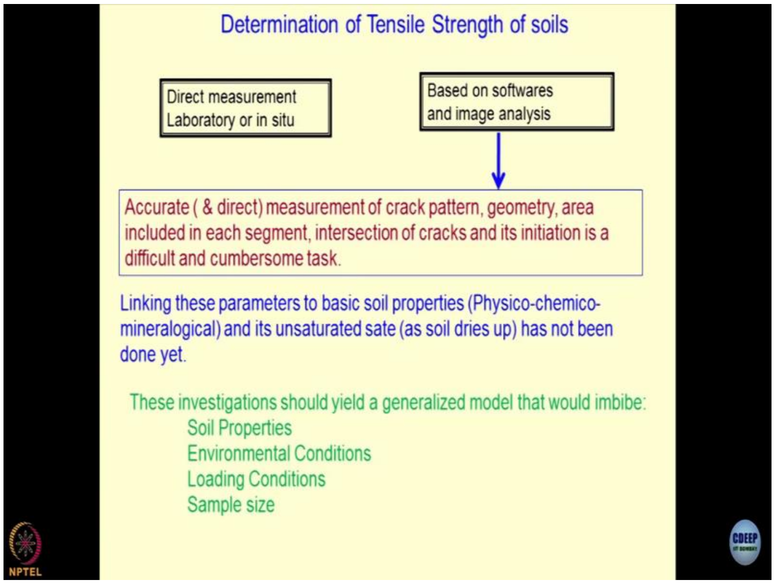

So, the question is, how would I go ahead, how would I obtain the tensile strength of the soils having done all these things with all convincing statements that tensile strength is the most important governing parameter as far as the geomaterial characteristics are concerned?. There are two techniques which can be utilized; one is the direct measurement either in the laboratory condition or in the field condition. So, the type of photographs which I showed you where the entire backfill has cracked I can do the image analysis and I can find out how the tensile strength is getting mobilized,

Sometimes we use software or the image analysis packages, and we get the information. However, this is a very complicated process and one of my PhD scholars who is a faculty member, now at IIT Mandi, Dr. Uday Kala, he was the person who started imaging of the cracks, which he developed in the fine-grained materials and this was his PhD thesis, where we have taken soil samples, which after desiccation crack or we have accelerated the cracking process by creating the environmental conditions in the laboratory.

So, we did the simulation. So, when you do these type of software-based image analysis thing, we get accurate and direct measurement of the track patterns and their geometry. The area included in each segment, I will show it to you intersection of the tracks and its initiation in a particular soil mass I hope you realize that the whole system is very dynamic, because the cracking pattern is a function of time and the moment soils get exposed to the environment, desiccation starts evaporation starts, and there could be a situation where all of a sudden the entire soil mass may crack.

So, if you want to capture the whole process of cracking of the geomaterials, you have to utilize the modern gadgets where the entire sequence of desiccation can be video graphed and then you can discretize the events and then you can stitch them to see how this whole situation has got developed and created. Another interesting or the big challenge would be having all these parameters known that is what type of cracking pattern is what type of geometry the cracks follow, what is the area included in each segment of the crack, what is the line of intersection of the cracks.

Can I link all these parameters to the basic soil properties, because our hypothesis is that soils are very intelligent materials?. So, they do not just crack for this fun sake. And another thing is the crack pattern is a unique fundamental behaviour of a given soil mass provided the environmental conditions are maintained. So, using these hypotheses, what we have done is, we have linked or tried to link the parameters which we have listed over here with the physical, chemical and mineralogical characteristics of the soils.

And the way the suction profile gets developed in the Soil mass. The suction profile gets developed in the soil mass when the soil gets dried up expulsion of moisture. And this expulsion of moisture is because of the heating, which is a coupled phenomenon. So, now I am sure you are dealing with a situation which is a dynamic situation. Everything is a function of time here. Until now, you have not talked about the material property as a function of time. Here, the moisture content in the soil mass is a function of time; the suction in the soil mass is a function of time.

The crack width and the depth and the geometry of the track pattern itself is a function of time. What we did is we have selected soils have known properties, exposed them to known environmental conditions, we call this facility as an environmental chamber. Where we can create different types of temperatures and humidities over a period of time, so, I am sure you are getting a feel of how environmental loading can be simulated on the soil mass.

The way you used to do consolation test, where you started with one sigma value, and then you keep kept on doubling it after a certain time when the dial gauge readings become constant. When we talk about the environmental loading, we have to have a specialized setups where we exposed the soils to different temperatures, humidity, wind velocity, solar cycle, and so on, and then we simulate the loading conditions on this, and these loading conditions are the thermal loading and of course the size of the sample, because you will realize that the analogy is from the consolidation test, if you take the oedometer sample after the consolidation is over, the porewater pressure is not going to be uniform within the sample. It is going to be less at the two edges where the porous stone was kept, and the porewater pressures are going to be maximum in the centre of the sample isochrone concept. So, the sample size plays a very very important role.