Environmental Geotechnics
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Lecture – 53
Swelling, shrinkage and cracking characteristics of soil - 6

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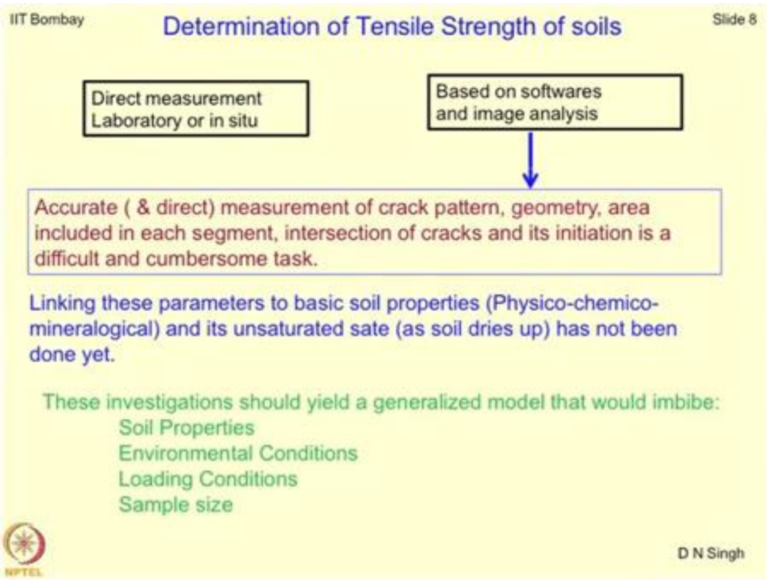

So, the question is what type of test should be done for this purpose to determine the tensile strength of the soil. The first is direct measurements which could be either laboratory or in situ. What type of measurements normally you conduct, what type of tests you normally conduct to determine tensile strength of soils? You must have done this test in determining the tensile strength of geo textiles or geo grids. What did you do? A pull out test, it’s ok? Or in the simplest possible form you can do a triaxial test, a flat jack test in the field. So, these two tests will give you direct measurement of tensile strength under in situ conditions or laboratory conditions. Triaxial testing, direct shear testing or a flat jack test now which is normally done in rocks.

The second type of activity would be based on different types of softwares which are normally used for image analysis. What this softwares will do, they will give you the accurate and direct measurement of crack pattern, geometry, area included in each segment of the cracks, intersection of the cracks and its initiation which is a very very cumbersome task. So, I will be talking about the direct measurements slightly after few minutes.

Let us emphasize on this that based on software image analysis what you like to do is you like to study the crack pattern you like to freeze it geometry area and so on. And then one would like to link this parameters with the basic properties of the soil that is physic-chemico and mineralogical properties. Now, this will make entire study complete. And again you should keep in mind this would be the best possible situation where soil water interaction is taking place, soil water air interaction is taking place in case of partially saturated soils.

And in case of saturated soils, it is soil water interaction which is taking place. Unfortunately, this work has not been done yet. Efforts are on people are trying to link all physical chemical mineralogical properties and how these properties have a bearing on the tensile strength or the shear strength parameters.

So, if somebody takes up these types of investigations, the whole idea is the investigation should yield a generalised model, where you can imbibe all these things that is the soil properties, environmental conditions, loading conditions and the size of the sample. So, this will be the most accurate model which should be used, which can be use for tensile strength determination. Two of my Masters students have done this type of work, one was Ramanna and another one is Sudharshan Shinde. So, I will be presenting some of their findings into this lecture just to illustrate how these properties can be obtained and how they can be linked with overall properties of geo materials.

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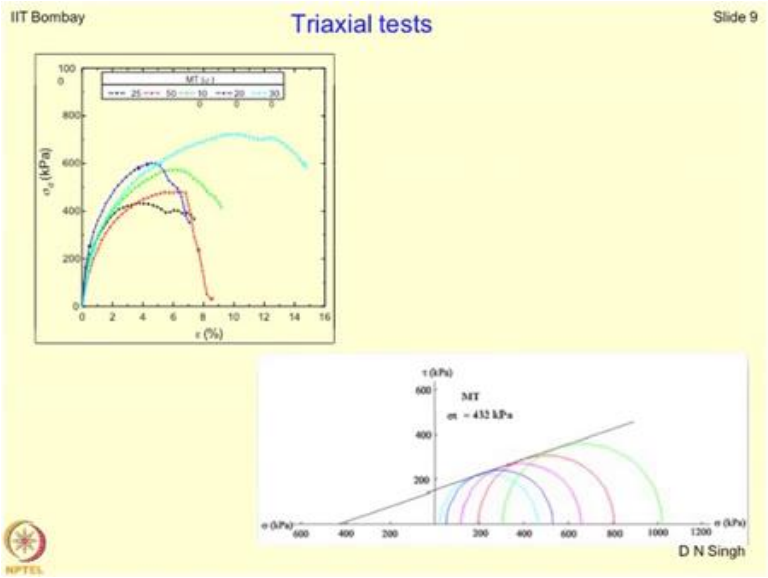

So, to start with the triaxial test which is the most easy form of determining the tensile strength, of course, people debate that this may not be the correct tensile strength or it is may not be the accurate tensile strength of the material. But for all practical purposes, this seems to be the best possible and simplest possible testing methodology which would yield some value of tensile strength which can be used for design purpose.

So, for different deviatoric stress, if you plot with respect to their strain value and if you get the maximum value of the deviatoric stress and if you develop different more circles, the common tangent will cut the y-axis and the x-axis like this, is it not. How would you get the tensile strength now from this graph?

Student: (Refer Time: 04:52).

That is right. So, wherever this envelope touches the normal stress or σ stress value, now this is the value of σ_t. ok? So, as you were saying that the empirical relationships are if you know the UCS value $1/10^{th}$, $1/8^{th}$, $1/7^{th}$ is considered to be the tensile strength, but you cannot ignore it, because even one-tenth of the UCS values are very high value. And if you are ignoring the tensile strength of the material, your designs are going to be much more inadequate.

Why? There could be a situation where the tensile strengths are good enough and you may not require any external reinforcement of the soil. So, unless you measure tensile strength properly you know going for a treatment particularly with geotextiles and geogrids seems to be a decision in a hurry. That means, the material has its own tensile strength you need not to put external elements which are going to take tensile loading.

So you are not doing full justice with material as on date, just by ignoring its capability to mobilize the tensile strength. Is this part clear? If you discuss these things in front of people who are selling geo textile, they will be very angry and the entire market may get disturbed, but yes now the days are coming there people are realizing that you know all those constructions you do not require geotextiles and geo membrane. If somebody takes up see this is how the research governs economy and later on economy governs research.

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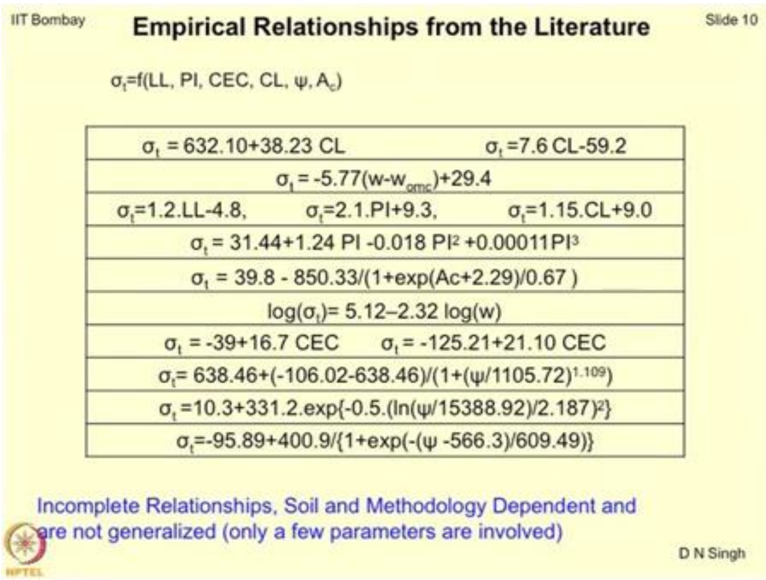

Now, if you conduct these type of tests, some empirical relationships which were developed by Ramanna, they come they can be you know formulated σ_t as a function of liquid limit. Just now we have seen that grain exposure to the environment is the main parameter which mobilizes tensile strength. So, the most important factor is liquid limit, plasticity index, cation exchange capacity, clay content section value and activity of the soil. Better way of defining sensitivity is activity, because activity is at least much more accurately measurable as compared to sensitivity, because there you remould a sample. So, we are disturbing the entire lattice structure and the matrix structure of the soil.

If you go through the literature you will find that there are so many equations which are available. I have tried to compile them here for you just to show you the different researchers who working on different types of soils and by following different methodologies they have come up with so many equations. So, the first category of the equations is σ_t directly as a function of clay content. Not a bad attempt. Because what you will notice is that clay content embeds in itself all the properties like liquid limit positive index, cation exchange capacity, even suction activity. So, these models where you use only one parameter to determine the tensile strength are basically single parameter models.

If you see the second equation, where you will find w- w_{omc}. Now, w_{omc} corresponds to moisture content at omc and another w is only moisture content of the soil at which we are working. Now, this type of philosophy shows any deviation from the OMC of the soil in terms of its moisture content, it is going to get reflected in its tensile strength. So, what is your guess? If you are working very close to OMC, what would be the tensile strength of the material? As compared to a situation we have working on a very dry of optimum of the soil mass.

Now, the question is whatever answer you are giving, the question is it will highly depend upon the type of the soil for a granular material, the response will be different and for a fine grained soil the response will be totally different. That is right so this saves you, correct. So, if you put this rider, these discussion may not be valid, but if you do not put this slider and if you are working on c ϕ soils, then the question becomes very very tricky.

Now, what you can do is you can perform this simple exercise after you go back to your homes, take a proctor compaction curve and find out the variation of σ_t with respect to moisture. Now, you should notice here that there is a negative sign over here. So, what this indicates is you agree, I think you ignored this most of you. If w is more than w_{omc}, the tensile strength is always going to be less. But if w is lesser than OMC, what is going to happen, the tensile strength is going to be more that is right. I said I use the word most of you because there was a divided house all right, you are right Sneha.

Then there are few equations which are based on the liquid limit plasticity index and clay content. You can look at the form of the plasticity index. The cubic equation has been proposed based on the activity, moisture content only, cation exchange capacity and of course, the suction. So, suction is becoming a very important parameter in defining most of the studies which are related with micromechanics model of the fine grained soils and that is one of the reasons that you should measure the soil suction very very appropriately.

Now, what is your feeling if I ask you to choose or select an equation which is the best out of the lot which one you would select and why?

Student: (Refer Time: 11:31).

Very good, but why you can measure it with ease, no, I would say that cannot be the correct answer. Measuring liquid limit is the most easy way or plasticity index is the most easy way or for that matter measuring the clay content is the most easy way, you just take sieve the material find out the clay content, there should be your answer is correct, but the logic is not correct.

Student: (Refer Time: 11:55).

That is right. So, basically when you say measure when you say suction measurement or suction value it is the black box which contains everything overall properties of the soils and what is the most critical issue which is included when you measure the suction of the soil. The migration of water in and out of the soil mass that means, out of all these models, the models which are based on suction analysis will give you the best possible you know idea about the tensile strength in terms of its moisture migration. So, it is a very dynamic phenomena you think of a situation where you are dumping the waste in the field. And again I say use the word these waste are at elevated temperature. What is happening to the clay mass, what is happening to the clay liner its moisture is changing at regular interval and so is changing the tensile strength.

And there will be a situation of tensile strength mobilization which is going to be higher than the cracking stresses and the system will fail, meaning thereby the failure of the clay liners and the GCS is a sequential phenomena induced because of thermal stresses, induced because of the external loading, induced because of the environmental loading induced because of anything which causes moisture migration out of the soil mass. Is this part clear? So, most of these relationships are incomplete, single parameter dependent, methodology dependent, on country, continent, individual dependent and so on. So, people should come up with the models which are more comprehensive.

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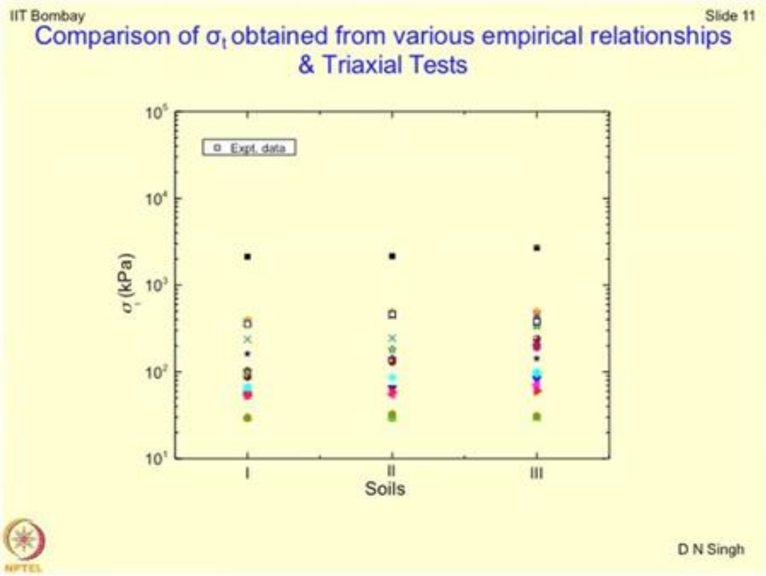

What Ramanna did is he tried to show where the experimental results would be if you use all these equations and your own experimental results. What you will notice is that the experimental results will match with some experimental results which are published in the literature; otherwise most of the equations will give you or mislead you up to an order of 10 power 2. Look at this value and look at this value, there is a difference of almost 100 times, is it not? So, this type of vagueness or non clarity exists still and this is where actually people should contribute. So, very open area where people are still trying to work.

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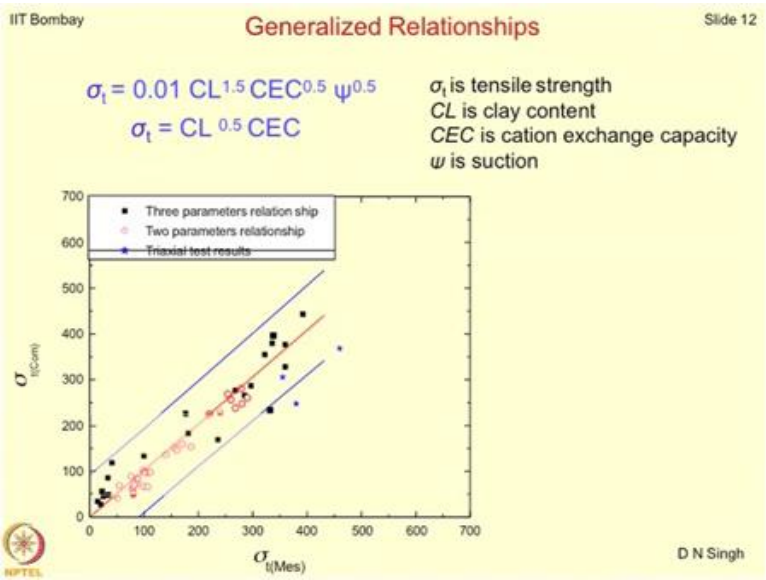

So, then attempts were made to develop some models based on the suction properties, cation exchange capacity and clay content. It is not only a mathematical expression by the way the beauty of this expression is you have physical property coming over here you have chemical property coming over here and you have mineralogical property coming over here. So, when we say it is a composite function of physico chemico mineralogical properties, this seems to be the best possible model which was proposed by Ramanna this work is under review right now, hopefully it should get through, where σ_t is the tensile strength, CL is the clay content, CEC is the cation exchange capacity, and psi is the suction.

And then what he did is he used these relationships, y-axis is computed values of σ_t and cross checked them with the results which are obtained from triaxial. And we find a good 95 % confidence band on the data which are obtained. This seems to be a good study where if you know the suction, measure the suction know the CEC, know the clay content, you can find out tensile strength directly for the soil mass. Is this clear? We need not to go into the all intricacies of measurement of tensile strength which is a very very cumbersome process.

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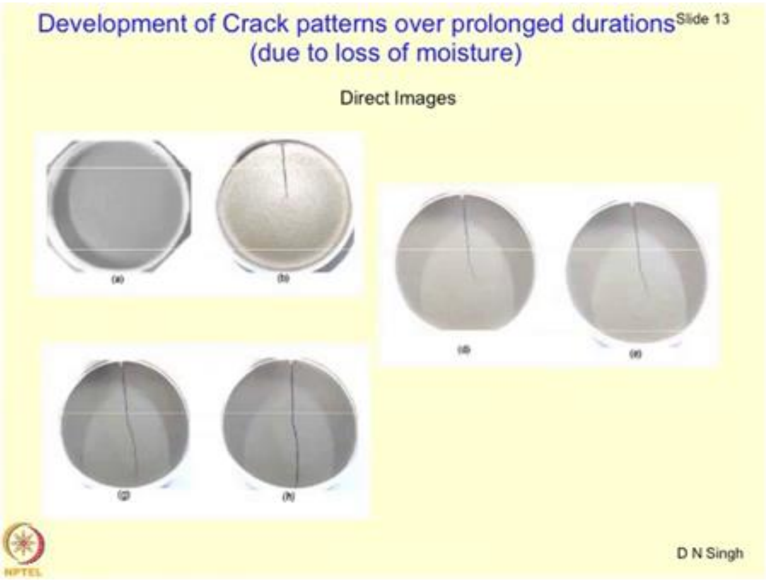

Now, let me share with you a little bit on the development of crack patterns over prolonged durations due to the loss of moisture content. So, the best place to take some direct images. You start from this state of the material, take a soil slurry, put it in a petri dish expose it to drying air drying. What happens, you find a clear-cut crack. Now, this type of crack is a synthetic crack. See the same test we could have done to study the shrinkage limit, but what we have done here is we have either played with the material properties or we have played with the environmental conditions, less humidity, more temperature or more flow of air on the system.

So, what it does is, it causes immediate cracking. Now, these cracks are propagating further. You can see subsequently how these cracks migrate a certain duration. The beauty would have been if you come up with a model where propagation of crack can be captured with respect to time, and ultimately you can say this what is going to happen. So, starting from no crack, bit of crack formation, crack propagating in the medium completely ultimately resulting in a perfect cracking of the soil mass. Now, the time taken from a to h should be how much in your opinion? 7 to 8 days. How did you get this answer?

Student: (Refer Time: 18:00).

Our observation is that the entire thing happens within 7 to 8 minutes that is what I said you can play with the conditions in such a way that you can actuate a crack in a very fast manner. But normally when cracking takes place it occurs within 7 to 8 to 10 minutes that is why the dynamics of the cracking is very important ok. So, this is where the application of image analysis becoming more important.

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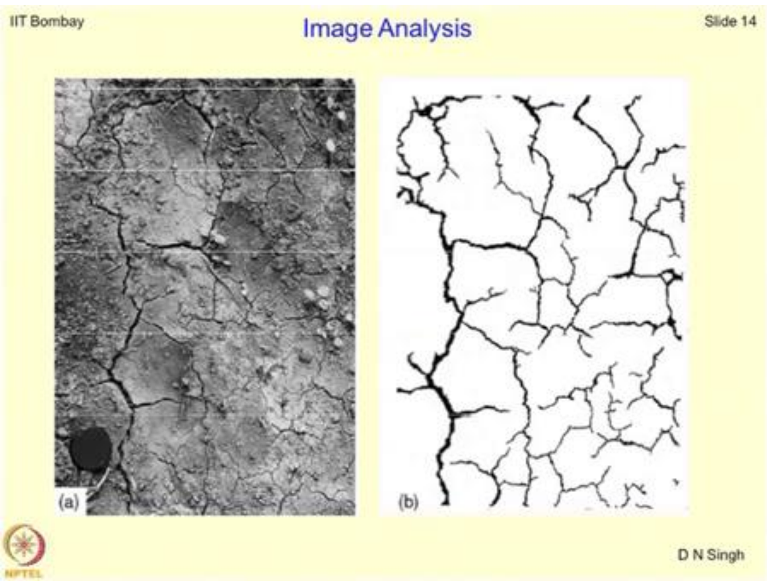

This is the regular phenomena you know you take a photograph of a field or a soil sample, so this is how it will look like. What you can do is this can be converted into a image signal of this type. Now, once you have done this, you can play in terms of Boolean numbers. What you will notice here is the intersection of the cracks can be easily obtained, the lengths of the cracks can be easily obtained, the width of the crack can be easily be obtained, a total area included within one patch of the crack can be obtained easily and ultimately you can map this properties by using some image analysis tool or a software.

And you can link it with physical chemical mineralogical properties to develop a model which will tell you what type of cracking patterns would develop for a given environmental conditions and what will the tensile strength of the material. This work is going on. I can't share much information on this topic right this moment.

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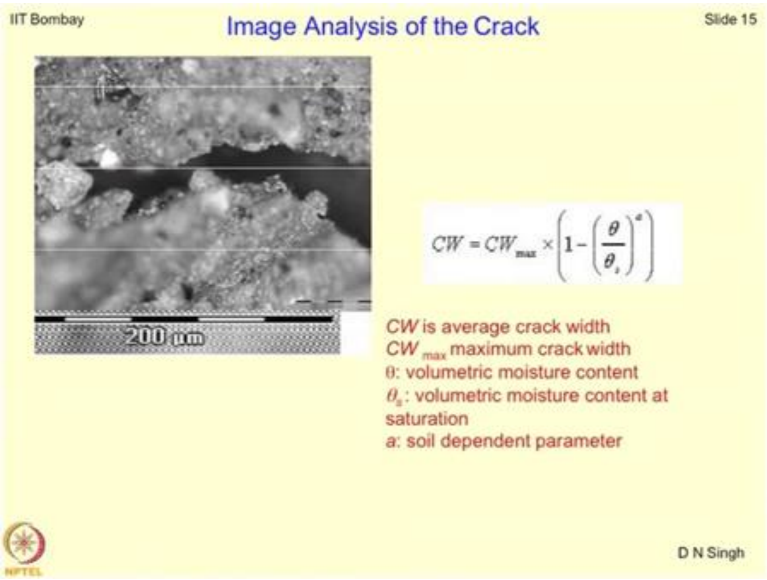

Now, this is a very interesting study where if you magnify a particular crack not the depth; depth could not be studied because for studying the depth we should have a laser beam. And we do not have a facility of laser beam going into the soil mass at this moment, only the surficial analysis can be done. So, what you notice here is that if you capture a crack and if you magnify it several times, where this much scale happens to 200 micrometre you can imagine, this approximately is 200 micrometres.

What people are up to is that they want to quantify the cracks and its propagation. So, CW is the average crack width. What you have to do is at different places you have to find out the crack width which is a direct function of the volumetric moisture content as saturation and at a given time. Now, this is where the measurement of volumetric moisture content instantaneously becomes more important and that is where the application of sensors in geotechnical engineering is also becoming very important.

So, think of a situation where sensors are embedded in the soil mass and they measure the moisture instantaneously when this process is going on because the process is very fast. So, you cannot take out the sample and measure it and keep it back on the weighing balance cannot be done so easily. And a is the some parameter which is dependent upon the soil type.

In my opinion all these studies in again lead to a sort of a classification system for the soils you know and this classification system would be much more complete. Why? Our theta terms are coming here, suction terms are coming here, fundamental soil properties are coming here, environmental conditions are coming here which we were not taken into account earlier while classifying the soil mass. We have classified the soil mass based on its particle sizes, chemical composition, mineralogical composition, shear strength properties, but now if you do these type of studies, the classification which would e which would be developing, evolving would be the best possible classification system for the soil mass.

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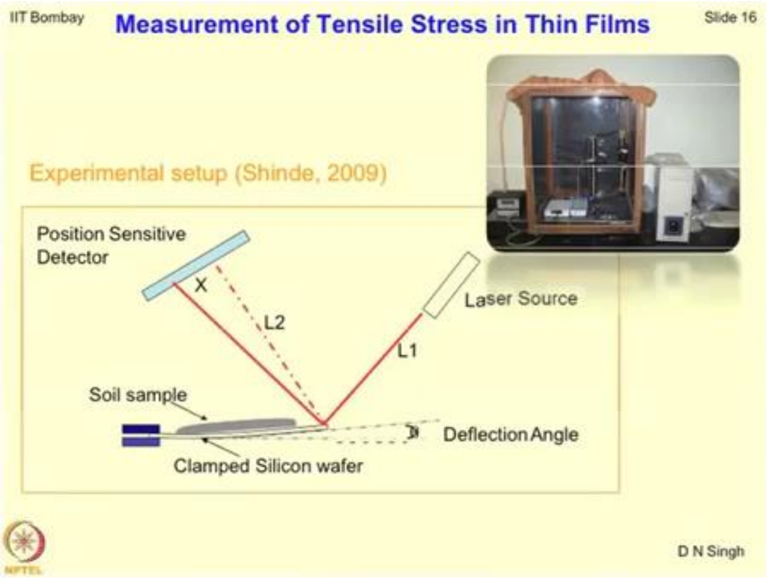

So, this is where actually we went to measurement of thin films of the soil. This process done by my student Sudharshan Shinde in 2009, he submitted his thesis. This setup was developed by Sudharshan where we have a closed chamber. There is a balance, micro balance which can measure up to 0.1 milligram. And you can set up a situation where evaporation takes place at a certain control rate. Use a laser beam here to find out the deflection of a wafer which is made up of silicon.

So, on the silicon wafer which is clamped is a cantilevers sort of a thing, the size of this wafer would be about 1 centimeter by 1 centimeter, on which you put a small drop of the soil. When this soil dries, what happens is the concept of the beam theory simply supported or your cantilever beam when soil dries the bottom surface shrinks and hence the deflection in the wafer is noticed.

So, the only beauty is how would you measure this deflection which is coming because of the tensile strength development in the soil sample. So, this is where you have to use a laser beam. If you drop a laser beam on this wafer, the deviation from the initial to the final condition would be X and X can be measured with respect to time. So, the more and more deformation in this wafer will give higher value of X. Is this correct?

So, once you have measured X you know what type of stresses are going to develop now this becomes a simple thin film theory which is normally used in deformation of clay minerals. Our philosophy was you are trying to understand thin films first and you know because thin films happen to be infinitesimal part of any sample of the soil. So, this is where the effect of size comes into the picture when we talk about tensile strength of the material. Like this we will be having thousands of layers in the sample. So, if you can master each layer wise, what is happening to sample you can study how deep the tension cracks are going in the soil mass.

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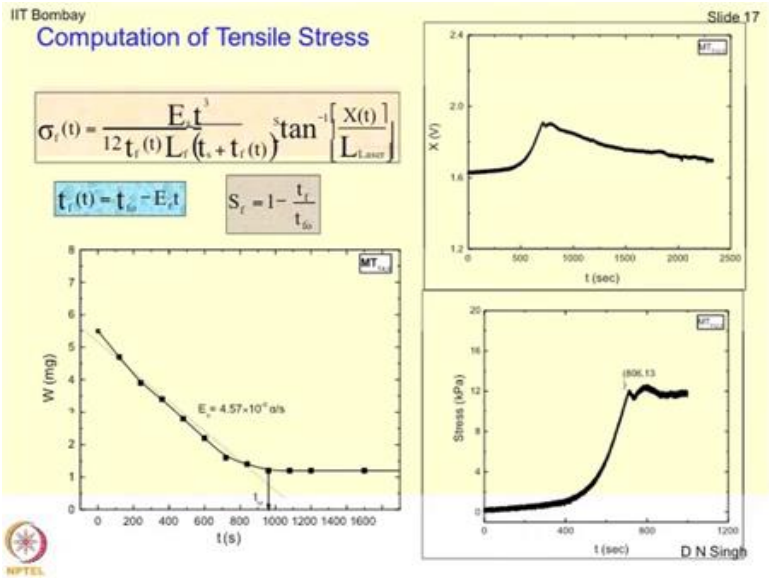

So, then by using this simple equations where σ_t is or the failure strength tensile strength with respect to time is a function of evaporation rate, thickness of the film, final thickness of the film x which we have measured just now I showed you over the length. L is nothing, but this part of the length of the beam. So, then t_f is also changing thickness of the film is changing with respect to time due to evaporation. So, this is the rate of evaporation.

So, the question is how would you find out the rate of evaporation? And then you can find out percentage shrinkage. So, final thickness divided by initial thickness minus 1 will give you the shrinkage of the material. This type of relationship can be established by keeping a sample on a weighing balance as time passes by what happens to the weight of the sample it decreases because of evaporation of moisture from the sample.

So, if you draw this curve and join the initial portion the final portion the straight line, the slope of this line is nothing but the evaporation value. So, this is the rate of evaporation for a climatic condition which can be obtained by simple air drying test.

Loss of weight with respect to time will give you what types of evaporation are going to take place from the sample. We can put the value of E over here and as a function of time what you are noticing is this is the initial thickness of the film minus this component will give you the thickness of the film at a given time. So, from here directly you can compute what is the percentage shrinkage which is coming into system.

Now, once you know evaporation rate, once you know final thickness at a given time, once you know x at a given time, you can directly compute tensile strength. Now, this is the typical graph which will show you what type of dynamics you can notice in the sample. So, if you see that x is nothing but the deflection and the x-axis we have time, so everything happens varies instantaneously you reach a peak after which the system has failed. Substituting this value of x in this expression, you can get the tensile stresses. So, wherever you get the peak, this peak corresponds to the failure of the material is something like your triaxial test or the direct shear test where you get a peak and after which again you get some deformations all right because of the residual strengths.

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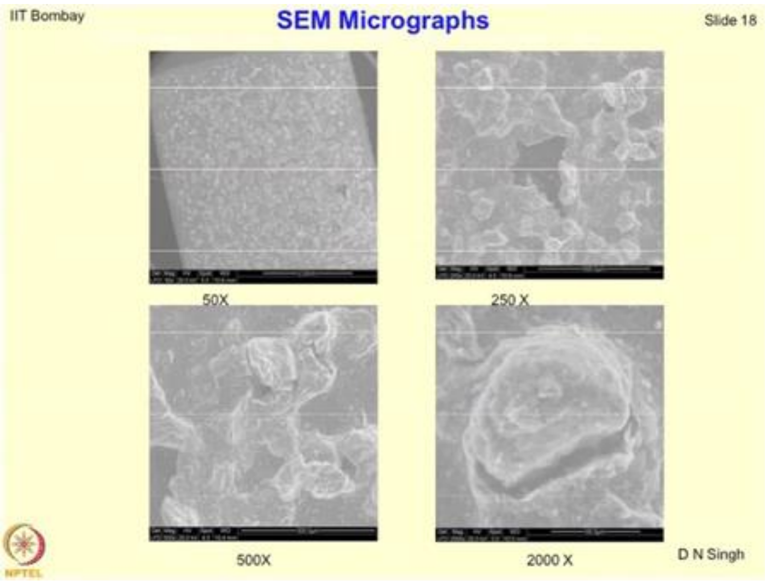

Just to show you what type of changes occur in the sample and the microscopic level, the sample of the bentonite was enlarged 50 times 250 times, now you can see here there is a first initiation of the crack taking place followed by the entire opening up of the you know system the cracks are much more prominent. If you much go much more into this, you will find this type of structure coming here.

So, this is the initiation of the crack you can see how the cracks are developing in the clay platelets. And the most beautiful thing is this where you can see how the clay platelets are getting detached from rest of the material. So, this is how the propagation takes place from a seed, it can it basically looks like this where the entire system will play subsequently ok. I have shown you the micro mechanics model of the cracking.

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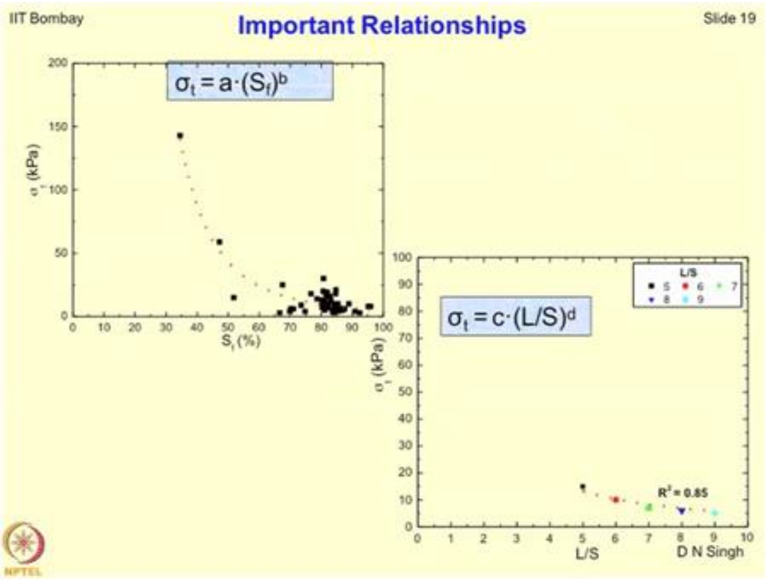

Based on this study some important relationships were developed. The first important relationship is that tensile strength is a function of saturation sorry this is the function of the shrinkage of the film. So, as the shrinkage increases, you remember shrinkage is 1 minus final thickness divided by the initial thickness. So, as the shrinkage increases, the tensile strength decreases. You agree with this trend or no? When you cut a paper and when you cut a polythene which one is easy to cut, what is the meaning of this tensile strength of paper is more or tensile strength of the polythene is more?

Student: Polythene is more.

Polythene is more. So, a new start working on systems where shrinkage is less in a poly disperse material like clay. What is happening at the grain level? If the grains are not free to shrink, you can pull them apart easily. But if you have more and more water in the system, that means, the shrinkage is going to be much more, then what will happen to the tensile strength of a slurry, it will be less. So, on this side, you have dry soils and on this side you have thin films thin soils slurries. So, for a slurry the tensile strength is minimal.

You keep on drying the sample by the time it reaches a perfect state of the sample, you have mobilized more and more tensile strength. Why, the particles have a tendency to come and remain in contact with each other.

Now, if you want to stretch them apart, you have to apply more and more energy or more and more force. So, the tensile strength increases as the moisture moves out of the system, as interaction between the particles increases and so on. So, based on this model, a relationship like this was proposed that σ_t is a non-linear function of shrinkage limits or percentage shrinkage of a sample.

Now, the second graph shows that tensile strength is a function of moisture content L/S. L/S is the nothing but the moisture content. So, more moisture in the system the less tensile strength; less moisture in the same system more tensile strength. So, this was generalised in the form of σ_t as a function of moisture content or L/S in a non-linear fashion. Is it ok?

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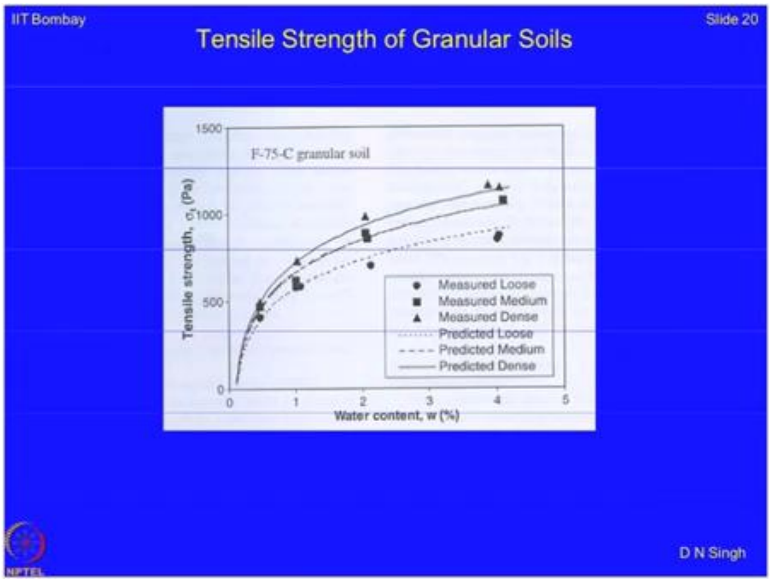

Now, look at the contrary phenomena. When you talk about granular soils and I should confess that we have not done these tests I have got this test results from somewhere. What do you find as moisture content increases the tensile strength increases, but what did you notice in fine grained materials it is a reserve phenomena which one is correct? Both are correct that is right, but then why this trend is correct? Can you give me an example in nature where you find this type of phenomena taking place?

Student: (Refer Time: 32:04).

Very good.

Student: (Refer Time: 32:08).

Excellent.

Student: (Refer Time: 32:11).

Very good excellent. That is correct. So, a wet sand, the moment water comes on the shore, you can walk very easily on the shore on sea on sand beaches, but then when water goes out and the sand dries you cannot even walk there. So, what this water is doing?

Student: (Refer Time: 32:33).

It is acting as a reinforcement in the granular material. Why? In fine grained materials, you already had lot of capillary action clear. So, the tensile strength is mobilizing because of the capillarity. Now, here what happens, here the water goes and reinforces the voids present in the granular structures. And hence you get enough strength getting mobilized out of the system on which you can walk run or whatever good. Is this correct, you agree or no?

Now, if you solidify this material by freezing it, a pure cohesive system when it comes in contact with water becomes a sorry a pure crystal material when it comes in contact with water due to freezing, it transforms to a cohesive state. So, the cohesive strength increases. So, this is how the alteration in properties would take place because of movement of water into it and out of it depending upon the pore structure and the micro structure of the granular material. Is this part clear now?

Another good example is you must have seen kids making castles on the beaches. With dry sand you cannot do anything, but you take wet sand and you can mould it the way you want. Why, because there is enough tensile strength in the system ok and you can bind it the way you want to just by applying a little bit of pressure. What is the significance of this, when you are applying a little bit of pressure you are mobilizing its tensile strength in the presence of moisture. So, what this water is doing?

Student: (Refer Time: 34:28).

Very good, that is right. So, maybe next semester you will study that your sands and slurries of clays, they are identical. It is a paradox by say fact, we will discuss this part next semester.

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Well to end up with this discussion just a bit of idea about how to, you know, remediate the formation of the cracks in the fine grained materials. This is where now the people are talking about self healing, self sealing types of minerals. So, by definition these are the minerals which will possess built in ability to stop swelling, shrinking and cracking properties. Now, this will be a perfect boon. If you can devise minerals like this, all the problems would be sorted out. So, one of you should take up this job become an entrepreneur, develop this type of minerals which will be a boon to all sorts of industry.

These would be nothing but the intelligent minerals. They would understand the response of the environment, climatic conditions in fact what you want them to do and how they should behave in a situation. Their synthesis, characterization and application in various projects related to civil engineering, geotechnical engineering and concrete etcetera would be a challenge. So, if you can develop these types of minerals, you need not to study all these properties swelling, shrinking, cracking. So, geotechnics should head towards this. So, I will end up my discussion on this topic.