Environmental Geotechnics
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Lecture - 52
Swelling, shrinkage and cracking characteristics of soil - 5

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As we have already finished discussion on Swelling and Shrinkage Characteristics, I will continue talking about Cracking Characteristics of Soils. Introduction, some real life scenarios or situations where cracking properties become very important, then a conceptual model which is normally used to understand how cracking takes place in the soils. Linking this model with the tensile strength mobilization or shear strength mobilization of the material which I would like to cover under the sub head of mechanism of tensile strength development; how to determine the tensile strength properties of soils?

Then, the most challenging task which most of us are facing how to analyse the crack patterns which we get when a soil cracks. Followed by a bit of new philosophy that why tensile strength of thin films of the soils should be studied and how would you measure it. The important relationships which have been obtained by the researchers in this concept or the subject followed by what is the remedy, so that the cracking of soil does not take place and that is where the role of self-healing, and self-sealing minerals comes into the picture. I will not go into details of these minerals, just I would like to emphasise their importance and their application in these type of studies.

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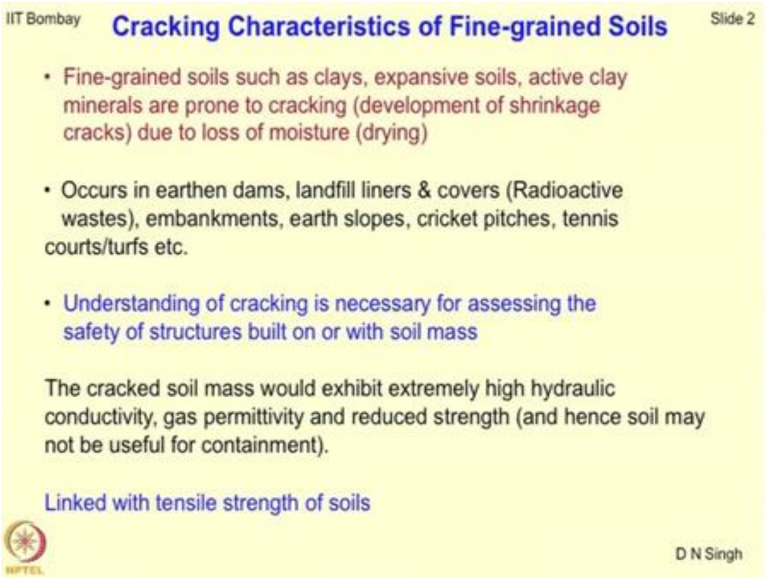

So, the first issue is that every fine grained soil such as clays expansive soils, active clay minerals there are prone to cracking. You might have seen this phenomena is it not and you are aware of how cracking takes place. It is basically due to the development of shrinkage cracks and which is mainly due to the loss of moisture at the time of drying. So, some basic concepts involved in this statements are mostly people are interested in studying cracking patterns in fine grained soils. What is the reason? That is right. So, the basic reason is though fine grained soils are very impervious, but the moment cracks develop effective permeability will be much more, all right.

So, any structure which you are constructing, either with a fine grained material which is prone to cracking would ultimately result in increased hydraulic conductivity and which will defeat the basic idea of using fine grained soils for the construction purpose like back fills, is it not? Or let us say for reclamation of the land or you might have seen we were talking about good backfill materials for isolating the waste from the environment. So, the basic idea of using this tangent minerals of the soils was that they cut off the waste from the environment.

Now, you think of a situation where you are compacting the soil, but after compaction the soil mass exhibits cracks. So, effectively what is happening? The water will percolate in the soil mass and you have basically creating a path of leakage of the waste into the geo environment. So, that is why most of the situation fine grained soils are considered when we talk about cracking phenomena and it so happened that these type of soils are very active, their surface area has a very high, cation exchange capacity is very high, their swelling potentials have we are talking about mineralogy is very active they shrink a lot and so on, and that is the reason that cracks are associated with fine grained material.

The second part of the statement which I have included here is the due to the loss of moisture content. Now, this is also a very important phenomenon. Due to loss of moisture content which I am clubbing as drying could be because of any activity, it could be because of thermal flux, it could be because of a situation where you are dumping waste on a clay liner and this waste is at elevated temperature. So, what is going to happened to the clay liner? Once in it comes in contact with a waste which is having high temperature, the moisture will migrate and because of the migration of moisture out of the soil mass, the cracks will develop.

So, what happens is, all the properties of fine grained soils, they are heavily depended upon moisture content. So, when we study swelling, shrinkage and cracking characteristics, cracking is a phenomena which is an outcome of swelling or shrinkage and most probably because of shrinkage, which is induced because of expulsion of soil moisture from the soil mass. So, under these circumstances that means, if the soil happens to be very active any change in moisture content of the soil because of any reason either mechanical loading or because of thermal loading this system is prone to show or exhibit cracks.

And I am sure now you can realise that why it is important to study this subject in geotechnical engineering. This happens to the most critical and crucial issue related to waste disposal activities which you will be adopting you are recommending for a situation.

What is the occurrence of this phenomena? The occurrence of this phenomena is in earthen dams, landfill liners, their covers, where you are dumping radioactive wastes, embankments, earthen slopes, cricket pitches, tennis courts, turfs and so on. And all the situations forces to understand the basic mechanism of cracking phenomena, so that we can assess the stability and the safety of the structures which are coming upon such type of soil masses. So, it so happened that the cracked soil mass would always exhibit extremely high hydraulic conductivity, gas permittivity and reduced shear strength and hence, soil may not be useful for containment purpose.

Now, it so happens that what is the fundamental properties of fine grained soil? The shear strength. And shear strength is a function of moisture content. So that means, indirectly cracking phenomena should be a function of shear strength of the soil. And when we talk about shear strength they should be under tensile stresses and these tensile stresses are developing because of either the type of loading which is coming on the system or because of thermal gradients.

So, if I ask you this question, what type of loading would cause tensile stresses to develop in the soil mass? Can you give any answer or you can you sight a situation? In a classical bearing capacity theory you assume three types of failures which will is under tensile forces the failure of the system. So, punching is the mechanism where the tensile strength becomes much more prominent. You do a simple cone penetration test. What type of loading you are exhibiting on the soil mass? It is a tensile stress which you are developing in the system because of that the soil is spacing sorry is swelling.

What about the CBR test? What type of test is a CBR test? It is a compressive loading or it is a tensile loading? It is a sort of a punching failure that is the reason the size of the CBR mould and the ratio between the loading pad and the size of CBR mould. You never load the entire soil system all together you know what you do only one-tenth or one-twentieth of the portion is loaded. And how do you find out CBR? Most of the time it is a plunger of a needle type. So, you always define the CBR value of the system and you always correlate with the penetration of this plunger which is having a very infinitesimal diameter as compared to the diameter of the CBR mould, so that you can simulate a punching mechanism, clear?

Now, this is a basic difference between a compressive testing and a tensile the stress testing. So, what you are trying to simulate is, you are trying to find out what is the tensile strength of the soil by doing a CBR test indirectly and thanks to classical geomechanics concept this subject is very well understood. But what people have not done is they have not gone into the micromechanics and the details of mobilisation of tensile strength of the soil, when water moves out or when water comes into the soil mass. So, in short, all the situations basically tells us that tensile strength of the soils makes you know a soil prone to cracking or not.

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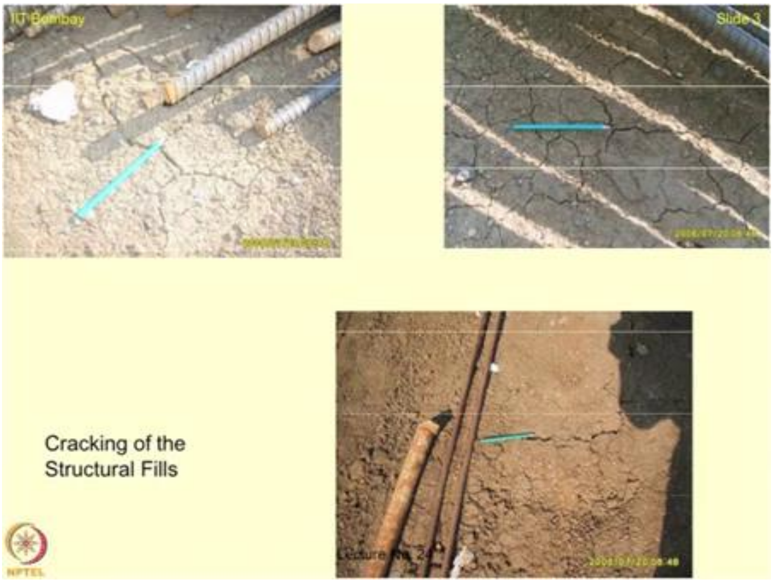

I already show you few real life situations and this is a situation where the foundation pads have been developed by compacting the soil mass and just within few days of compaction, this type of patterns appears on the soil mass. Now you think of a situation just to give an idea about the magnitude of the cracks, one pencil has been kept here I will show you the types of cracks which are developed in the foundation soil. Ultimately the whole idea of isolating the foundations from the environment gets lost.

Look at this situation. That means, these type of situations are going to cause much more ingress of water into the sub surface. And how do we classify this soil system? Is it still intact or it has failed? Truly speaking it is not intact, it has already failed. If you measure a depth of this cracks these cracks may run into meters even depending upon the soil type.

Now, another interesting thing you must notice here is there is no external loading. So, this type of foundation failure has taken place just because of environmental conditions, mostly thermal stresses and humidity, and a very active mineralogy of the soil which was not considered at the time of construction or this type of facility.

So, what are the challenges? Let us say, suppose if I give this problem how would you, what would you do with this type of cracks and what would you like to study, ok. That is one thing, that is a foremost thing you will be studying the mineralogy of the soil and based on that if it is too much of swelling or shrinking type you will not use it for this purpose that is ok, that is very good. Beyond that thickness of the; that is right that means, you will like to quantify the cracks.

Why would you like to quantify the cracks? Not only the thickness you will try to yes; you will like to do the complete tomography of the soil mass in which the cracks have developed, why it is so? We want to find out what is the little extent of the cracks, what is the vertical extent of the cracks, whether these cracks are inter connected or not and so on. Because ultimately, if these type of a situation occurs in a earthen dams what is going to happen? Clear.

So, the issue is once this type of situation occurs as a scientist you would like to analyse what has caused this cracks to develop, ok; what is the extent of the pattern which has got created, how this pattern and cracks are going to affect the fundamental properties of the soil mass, how much deviation the properties we are going to expect because of development of these cracks or this type of situation and in what way it is going to affect your design, clear? And the last, but not the least would be how to stop this type of a phenomena. So, this is the broad scope of the things when we talk about swelling, shrinking and cracking characteristics of the soil.

So, in today’s lecture the theme is cracking characteristics. How to understand whether a soil is going to crack? If it has cracked how would you quantify this cracking pattern, how would you relate this patterns with much more easily known parameters of the soil like shear strength properties strength of parameters and so on. And then how would you remediate this type of situation to occur in future?

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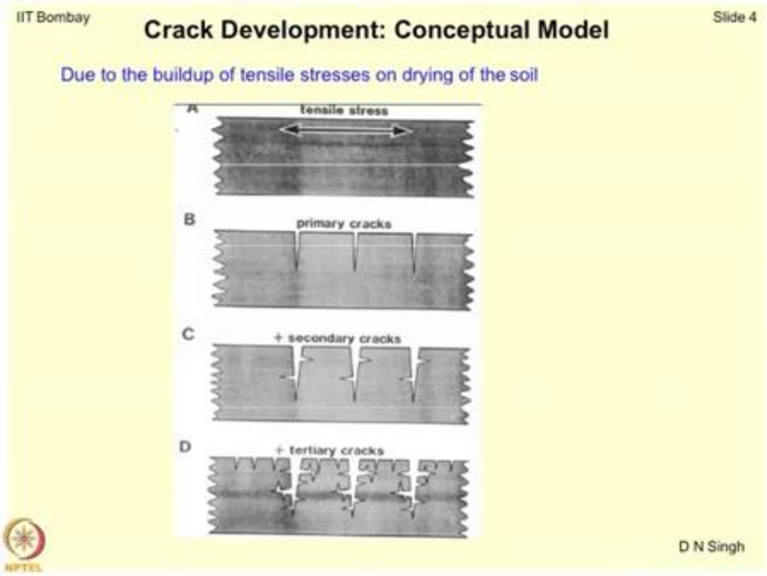

So, what is the conceptual model which can be used for crack development? Basically, the cracking of the soil will take place because of building up of tensile stresses on drying of the soil, whenever they show drought in movies or in any advertisements or in any photo picture. So, I am sure that the pattern the crack is very, clear in your mind and the countries going through this phase they have most of the part of the country are affected by the drought severely. So, its becoming a challenge you lose micronutrients also from the soil because of the cracking of the; the basic mechanism is like this you have a soil mass and tensile stress develop.

This phenomenon is almost similar to the one which you absorb and you boil a fluid or milk, is it not. So, again this is because of surface tension and the moment you talk about surface tension, it goes into the basics of soil suction, capillary action and all that series of the parameters. So, what it is indicates is if you want to study the basic cracking model of the soil you have to link it with the mechanisms of tensile stress development in it.

And tensile stress development can be studied with the help of a suction property which again is commensurating with the movement of moisture out of the soil mass and formation of the capillarity. So, once the tensile stress exceeds tensile strength is this statement, clear? Once the tensile stress exceed, the tensile strength the crack formation will take place, ok.

Now, this situation could happen or could occur in case of a retaining wall also. You just imagine on this phase there is a retaining wall and if your soil is a c-ϕ soil pure cohesive soil it is prone to tensile crack -2 c. root of ka. So, that much amount of primary cracks are going to form. So, what is the; the logic is that this tension crack is developing because of less tensile strength of the material.

Once the primary cracks are developed, what happens? Each one of them becomes a free surface the desiccation, evaporation loss of moisture starts taking place from maximum surface area of the soil. You have an enhanced surface area now because of the primary crack formation that means, soil mass is now much more vulnerable to losing moisture because of environmental conditions and hence the secondary cracks will generate. You have much more surface area into the soil exposed to the environment, what happens? Tertiary cracks develop.

What people are trying to look forward in this century or 21st century is they want to develop mathematical models wherein all this mechanisms can be incorporated easily. And why it is so? Why people are interested in studying tensile strength and cracking characteristics because the type of applications for soils you are having these days are much more different than what they use to be.

See there is a thatched we never allowed a foundation system to create a punching failure. Do you agree with this statement? Wherever we realise a punching may takes place, what did you do? You increase the size of the footing, clear. So, you made it a general shear failure model rather than a punching shear failure model all right or a local shear failure model. This is where you can go slightly deeper or you can play with the dimensions of the footing, but because of the different type of application which we have discussed in the recently you have to think of or you have to give justice to the soil, you have to understand why this mechanisms can be how they can be modelled and why should we study them in detail.

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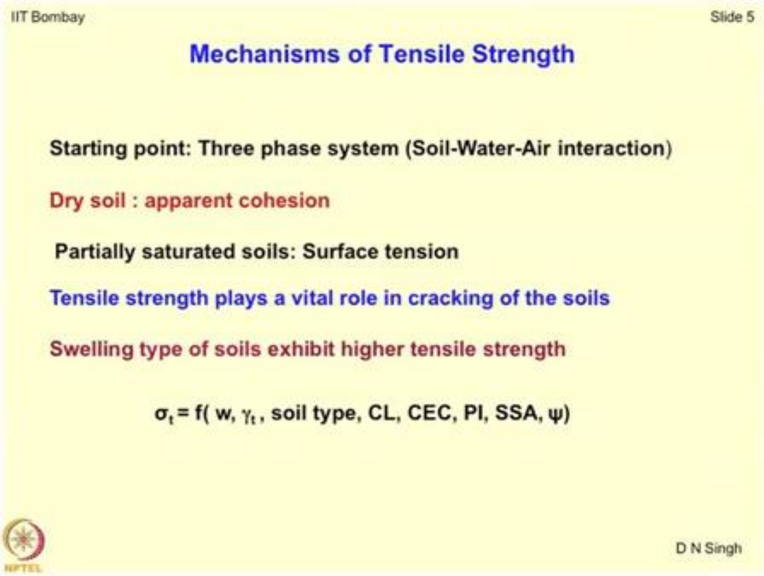

So, the question is what is the mechanism of tensile strength development or mobilisation? You cannot get rid of the three phase system, even if you have saturated soil and saturated soil mass is prone to environmental activities. So, what happens? The soil mass starts losing moisture and once the soil mass starts losing moisture, the system is prone to modify from a two phase system to a three phase system. And the moment is happens soil water interaction starts. You have enough information and knowledge about this interaction by now. So, this is the starting point of the mechanism of tensile strength, mobilization and development of tension cracks or only cracking of the soil in the medium.

When we talk about dry soils, we always talk about its apparent cohesion. Do you agree with this? When you talk about partially saturated soils what happens? Which mechanism governs? Surface tension, capillarity. So, these are the basic mechanisms by which a tension cracks can be modelled or the cracking properties of the soils can be modelled easily. So, tensile strength plays a vital role in cracking of the soils and one should keep in mind the moment tensile stresses are higher than tensile strength of the system, the cracks will develop.

Swelling type of soils will always exhibit higher tensile strength. What is the significance of this? Less cracking will occur, why because they are prone to not allowing water to go out of them. So, more the swelling the chances of cracks developing in it would be less. Its, very trivial situation, the best possible soils which you like to have for filling materials would be c ϕ type of soils and they are the soils which are much more prone to cracking and not the pure cohesive soils. Did you follow this concept? Would you select a pure cohesive soil as a backfill for retaining wall, Why?

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Very good. So, this is number 1, number 2 type.

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Very good. So, cohesive soils cannot be compacted. Number 3 problem.

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Very good, that is right. So, they are more prone to volumetric deformations excellent. Fourth.

In case there is a perched water table, standing water tables is a backfill; less seepage that is right, more porewater pressure, less shear strength. Number 7, more consolidation, clear? And on the top of all this if you use a cohesive backfill material, the type of earth pressures which you get would be much more. Why? No, dispersion of the loading whatever comes on the backfill, clear? They are not good dispersant of the loads. So, these are the issues which create you know a mental block against utilising cohesive soils in backfill.

Now, comeback and read this statement again. Swelling type of soils exhibit higher tensile strength. You agree with this or not, so what we should do? Our profession is to negotiate with nature, to negotiate with nature, to negotiate with materials, to negotiate with soils. And what we are seeing is a material which is good for some activity cannot be used for that and you end up using another material which is not so good for that activity, yes. So, this is where comes the compromise.

So, again you read this statement swelling type of soils exhibit higher tensile strength. So, what should we do? Should we use them for the situations where higher tensile strength are going to occur? Answer is yes. You require swelling type of soils for most of the construction. So, this point again shows that swelling of soils is not a problem, it is a sort of a boon.

Now, you start mixing some coarse grained materials in this and come up to a situation where you get the most optimal parameters which are useful for your design, clear? And this is where people have adopted mixing of swelling clays or swelling minerals with sands to create a system which is most conducive for your design purpose. This is a philosophy of you know designing or optimising the material for a specific purpose.

Now, when we talk about these type of models these models should be giving you tensile strength of the material as a function of moisture content, their total unit weight, soil type mineralogy, their clay content, cation exchange capacity, plasticity index, a specific surface area and total suction of the soil. So, if you put these parameters together you can understand the mechanism of tensile strength of the soil. Is this ok, any doubts here? Truly speaking not.

The first point cannot be ignored. You are changing the phase system of the material itself completely. So, when you are working on saturated soils you are still working up to the shrinkage limit there is only two phase system, that interaction which is very complicated has not started yet, but once you are allow this system to get exposed to the air, formation of tensile stresses, formation of capillarity and the mobilization of the capillary forces, then the dynamics of the of the material is totally different. And this point basically makes you know to study these properties in much more details.

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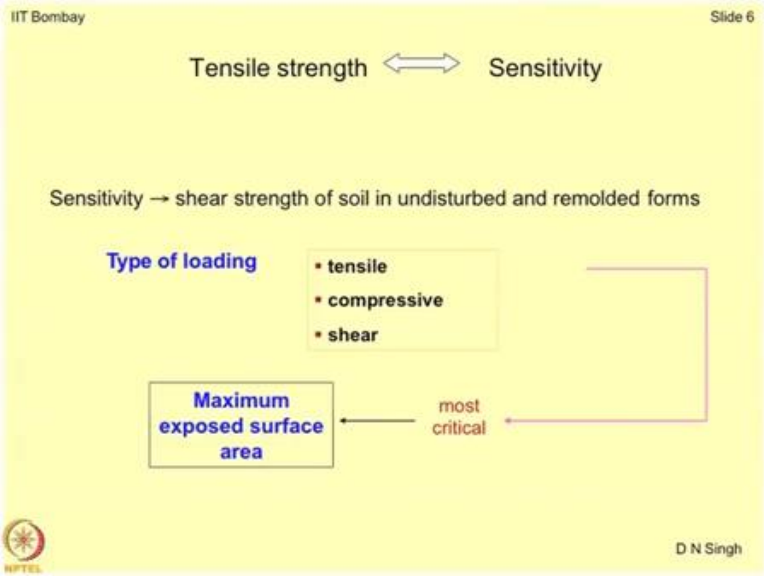

Now, you must have heard about sensitivity of the soils. Is it not? You use it very frequently in classical geo mechanics. What is sensitivity? What is the significance of this statement? Why undisturbed word is so important? Why disturbed word is so important?

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What type of disturbance you are causing? Simple example is even if you hold it in your hands what happens? You have some thumb impression of finger impression on the system. So, what is the tensile strength of this material? Why this impression has you know been created on the material? If you hold a rock piece you do not find any impression on the rocks, why? Clear. So, sensitivity is nothing but related to tensile strength.

So, the question is it was a very vague way of defining sensitivity as the shear strength in undisturbed state and shear strength in disturbed state and find out the ratio between the two. We like, it is very difficult to quantify the statement, what is disturbed state for you may not be a disturbed state for me. So, this concept also forces us to come up with models based on tensile strength theory of the material, clear to show what is sensitivity or to quantify what is sensitivity.

So, as you rightly said sensitivity is nothing but the shear strength of soil in undisturbed and remoulded forms. So, when you say this undisturbed remoulded form, what type of loadings normally you talk about? You talk about tensile loading, compressive loading and the shear loading.

Now, you please focus yourself for few minutes because the entire crux of the thing I am going to explain here. When you talk about type of loading which is tensile in nature, compressive in nature and of shearing type, we normally talk about these three type of situation, either there is a shearing going on or there is a compressive force which is acting on the system or there is a tensile stress acting on the system. The question is which type of loading is much more severe?

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Because we are studying this topic and that is why tensile strength is very important. Yes, answer is correct. Your answer is not correct. Well, we should we should look at the models which will explain that why tensile loading is very critical and crucial. Any idea can you substantiate your statement (Refer Time: 28:39)? What is meant by that critical strength of the soil?

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Sorry.

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Why does not take? You have ignored that strength it is not that material does not have a tensile strength. See most of the houses in village they are constructed out of clay. Most of your ancient civilization buildings they did not use any reinforcement there.

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So, one thing we should appreciate is that we have never bothered about tensile strength of the material much and these are all arbitrary statements. So, let us go into the details of this. The most critical would be a situation where you have maximum exposed surface area. Surface area of what? Surface area of grains; that means, this phenomena also gets correlated with the physical and mineralogical characteristics of the soil mass; is this ok.

Because the activity of the grains is nothing, but the sensitivity. What is the difference between sands and sensitive clays? In case of sands that is difference between undisturbed and remoulded forms will be not much or say you can ignore it. But its more sensitive material is going to show you much more difference in the shear strength in both the forms. What is the meaning of this? The grains are playing a trick. What is that trick? This is what we should study.

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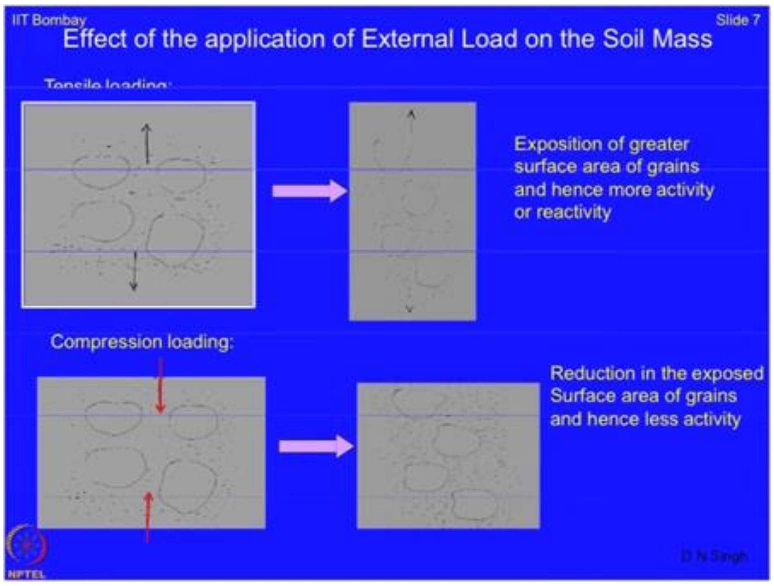

So, when we talk about the effect of application of external load on the soil mass whatever situation normally be considered, one is the tensile forces or the tensile loading and the second one is compression loading. So, you think of a micromechanics model like this. You have a soil mass, and then you are applying a tensile force. What is that you are doing internationally or unintentionally to the clay grains or the particles? You are pulling them apart. So, once you are pulling them apart what is happening to the grains? They are adopting this type of a structure, they get stretched, clear?

Now, when you talk about the compression loading, yes, they become close. So, what is the difference between these two states of the material which you have created by application of two forces which are acting in reverse direction. Something has changed or nothing has changed? What has changed?

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Sorry.

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Which structure is changing?

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Sorry. Grain chips will not change.

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See, this is what is happening. Exposition of greater surface area of grains and hence this type this type of system is going to be much more active. What is happening? Here each and every grain is getting exposed to the environment because of stretching. Now, when you are compressing it with the application of compressive force, there is a reduction in the exposed area of the grains. And what we have been studying till now is the everything or micro mechanism is being controlled by the surface area which is getting exposed to the environment or to a loading condition. Did you get the crux of the mechanism which should be use for defining and differentiating the tensile strength and the compressive strength?

So, it was very easy for the mankind to you know determine the compressive strength of the material. But it is very difficult for us to determine the tensile strength of material. Why? Here you are exposing each and individual grain in the matrix of the soil to react or to act with the external environment which is not going to happen in case of compressive strength; is this part clear? And that is the reason the tensile strength of the material becomes much more complicated complex phenomena.

Now, something that I use in expression where I showed you that tensile strength is quite susceptible to moisture content and your shrinkage property of the soil is also very much depended upon the moisture content. So, a little bit loss of moisture content or little bit gain in moisture in the soil which is of tracking type under tensile loading, its response is going to be much more trivial as compared to its compressive strength response. Is this part clear? And the basic logic is the total surface area which is getting exposed to the external environment is much more as compared to the compressive loading. Now, this model helps in understanding the basic mechanics of the partially saturated soils particularly the shear strengthening.