Environmental Geotechnics
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Lecture – 51
Swelling, shrinkage and cracking characteristics of soil – 4

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What are the factors which influence shrinkage phenomena? The first factor is initial bulk density. You must have noticed density is a parameter which keeps on changing in both shrinking as well as swelling. In most of the classical geomechanics concepts what do we do? We maintain bulk unit rates constant over a period of time. You agree with this or not? But, all these problems are problems related to time effect.

So, density is changing, porosity is changing, the pore structure is changing, the grain structure is changing, the mineralogical properties are changing, the chemical properties are changing and surface property is also changing. The clay content, organic carbon content. So, truly speaking with this organic content, but most of the time carbon also is associated with organic matter. So, what organic matter does in soil? If you have more organic matter or more carbon it will result in what?

Student: (Refer Time: 01:35).

Yes, very good, correct. So, water handling holding capacity becomes more. OMCs will be very high of the soil, but it is difficult to compact a soil with more carbon in it. So, dry densities cannot be achieved very high. Is this correct? What is your understanding if clay content is more, shrinkage will be more or clay is less shrinkage will be more? Ok let us let us lump all the minerals as clay minerals, then what is your feeling? If clay content is more shrinkage should be more or less? Chepauk is famous for what? Chepauk?

Student: Cricket stadium.

Cricket stadium, not stadium it is a pitch. It is famous for what? Whenever test matches are played they use to be over in 2 days or 3 days at the most, why? Because second day or third day pitch use to crack, it used to shrink. So, these are shrinkage cracks which develop on the top of the surface. So, what I should do there is more clay content more shrinkages going to take place. How to reduce clay content? By adding more silt fraction or sand fraction, alright.

Now, if you keep on adding more and more silt and sand fraction you cannot grow any grass over it. So, think of a pitch without any grass, what will happen? It will become a slow pitch or a fast pitch. It will become a slow pitch. So, it may not qualify as a pitch for a good cricketing pitch. Another issue is more clay content can you grow some vegetation? Why? The tendency of the clay minerals is to absorb water in them and they will not release any water to the plants ok. So, it is an interesting problem.

Cation exchange capacity becomes very important when you talk about shrinkage. What is your feeling if cation exchange capacity is more shrinkage should be more or less? Why more? (Refer Time: 04:09).

So, you try to answer one question how soil would understand whether it should swell or it should shrink? Directly do you do you get this point? Is this a valid point or not?

Student: (Refer Time: 04:31).

Because of the?

Student: (Refer Time: 04:33).

Alright, but we a we are always studying the response exhibited by a system when it comes in contact with some external disturbances. See, this is what the theme of the entire story is what we have been discussing since last 22, 23 lectures, is it not? So, this where the question is how would you ascertain that this soil is doing to show more shrinking or this soil is going to show more swelling? Is the question valid or not?

Sangeetha, you agree with the question? So, what should be the answer? See, the same soil, yes, whether it should show swelling or whether it should show shrinking or do you think that there should be something like first this happens and then this happens or vice versa. Like can we say that certain type of soils will only with swelling type of soils and certain type of soil would be only shrinking type of soils? No, I agree with you. Yes?

Student: (Refer Time: 05:51).

Kavitha it is not so it is not so easy.

Student: (Refer Time: 05:56).

Mineralogy is a black box. All chemical physical properties are black box. Now, what is you know actuating a certain phenomena you can lump at the most as the environmental factors. So, this basically again points out to the fact that if water moves into the system by any chance, this would be swelling and if water comes out of the system, this is going to be shrinkage. So, what is the meaning of this? How you are going to train the material to behave like a swelling type of a material or a shrinkage type of material? Just by controlling the moisture content. Is this ok?

So, if you maintain the moisture content of the soil and if you do not allow it to come out or you know in increase further you can get rid of swelling and shrinkage problems. So, ideally you could have coated soils with some paints to make them you know totally cut off or sealed; cut off from the environment.

Cation exchange capacity, I do not think would be a very important or direct parameter which would be influencing shrinkage, but yes because cation exchange capacity is the property of a mineral and if it is certain beyond a certain limit definitely mineral will be active. So, environmental condition should be much more important than at least these factors.

This is an interesting parameter mica-smectite content. This I am sure you might not have heard about yet. Smectite is nothing but a clay mineral like vermiculite, smectite – mostly people use it in different industries, medicine, cosmetics even all your cricket turfs smectite is the one which is used. So, you have to balance between the mica and smectite content. If you can balance between these two minerals then you can get rid of shrinkage phenomena.

Liquid limit is an important parameter. What is your feeling liquid limit is more shrinkage would be more or shrinkage would be less?

Student: More.

Yes, more free water, easy for it to go out of the soil matrix. So, more liquid limit, more shrinkage. More liquid limit, more swelling just like human beings. The same person behaves in a different manner in a given circumstances ok. Presence of salts, what is your understanding? If you increase the salts or decrease the salts what will happen to shrinkage or swelling phenomena? When you do stabilization, why do not you do a stabilization with sodium chloride? The first answer is already sodium chloride is present in marshy clays or soft clays.

So, if sodium chloride was stabilizing the soils there was no point in adding it from outside. So, what we do, you inject calcium hydroxide in it, clear? So, simple understanding is calcium being a divalent cation replaces sodium from the soil mass. This is where cation exchange capacity comes to the picture. So, calcium gets attached to the clay minerals displacing all sodium ions, clear and soil becomes stiff. So, this is how presence of salts and the type of the salts can control the system and it makes system more you know stable.

Initial water content. So, what is your intuitive feeling initial water content?

Student: (Refer Time: 10:25).

Yes. Again, may be you can use the concept of free water more initial water, more free water, more free water goes out of the matrix more shrinkage takes place. If I add salts in the pore solution what will happen to evaporation rate?

Student: It will decrease.

It will decrease. So, that means, presence of salts may retard shrinkage phenomena.

Student: Rate of retard.

Rate of retard, exactly. So, they may retard the process of shrinkage. pH of the pore solution either you know acidic or basic. More pH should create more shrinkage or less shrinkage. That is right. So, more basic solution would create less shrinkage that is right. Now, what are the remedies? As we discussed during the course of discussion of these factors the false remedy of nullifying shrinkage phenomena would be we use some soil cement. What is soil cement? Any cementing material added to the soil even lime stabilization would also be a sort of a soil cement.

Nowadays lot of commercially available soil cements are available Oz Crete, terracrete and so on. What companies are doing is a big business. They would take minerals and you augment their properties in such a way that each gram of this mineral will equilibrate the soils and hence you can form a soil crete is nothing but the soil concrete or a soil cement.

You can reinforce the soils for nullifying the shrinkage or tension cracks. Why do you reinforce soils? To nullify the tensile strength of the soil. Vegetation is the simplest possible example. Now, can you correlate vegetation of the soil and slope failures? More vegetation less.

Student: (Refer Time: 12:43).

Why?

Student: (Refer Time: 12:46).

Exactly. So, what these roots are doing?

Student: Reinforcing the soil.

Reinforcing the soil, that is true. They are binding the soil together in a holding the soil together, in other words apparent cohesion of the soil becomes much more ok. So, on a sandy soil if you can generate or you can if you can grow some vegetation so, effectively a frictional material or sandy soil becomes a cohesive soil.

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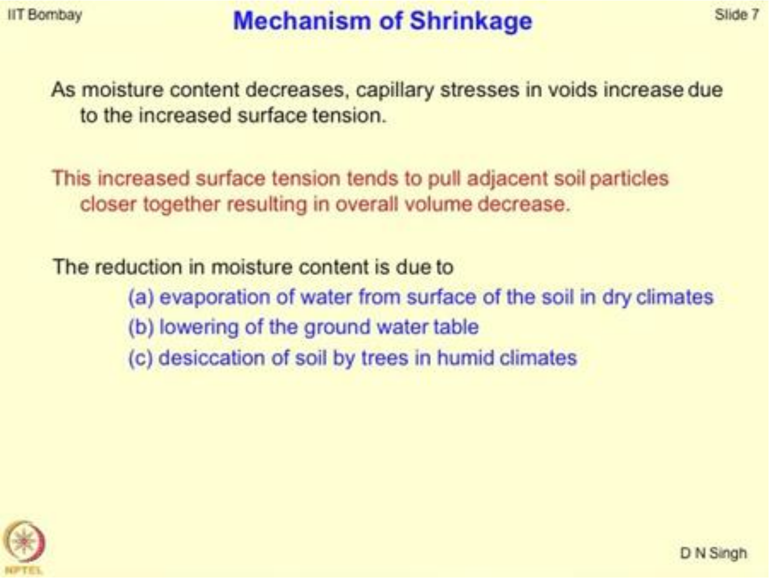

Now, let us discuss the mechanism of shrinkage. The first and foremost point is that as moisture content decreases, capillary stresses and void will increase due to the increased surface tension. You must have done this somewhere. Have you used this concept in determining shrinkage limits of the soil? Can you assimilate this easily? What do you do in determination of shrinkage limit of soil? You took the pat, dried it in air. What air drying is doing? It is creating more and more surface tension in the material.

So, as moisture content decreases, capillarity stresses get induced in the voids and it is because of the increased surface tension. This increased surface tension tends to pull at the sense while particles closer together resulting in overall volume decrease. A typical model of the capillarity is where you have a capillary tube and the water film is uplifting the water in the capillary. The reaction of that force comes on the soil particles and soil particles become more and more densely packed.

What are the causes of reduction in moisture of the soil mass? Evaporation of water from surface of the soil in dry climates; lowering of ground water table; and desiccation of soil by trees in humid climates. So, more the humidity more the shrinkage cracks. More humidity will cause more desiccation and more desiccation will cause more evaporation of water and more evaporation of water will cause more shrinkage crack will develop.

Student: (Refer Time: 15:22) atmosphere is already saturated (Refer Time: 15:27).

So I should I should use the word fluctuation in humidity let us say. So, more fluctuation in humidity will result in more shrinkage cracking of the material. Fluctuation is important. Yes, fluctuation in humidity.

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See this is how the response of any active soils which you must have studied. In 0 hours if you start from this state of the shrinkage limit test after 24 hours, 48 hours, 72 hours, 84 hours.

Student: (Refer Time: 16:07).

So, this is the most stable state of the material which is arrived at after 84 hours. So, it takes 84 hours of air drying to achieve the most equilibrated state. Actually, basic intent of doing this study was to see what type of cracks are developing in the system which I will show you in the next lecture. Today I am just trying to show you the stable state of the material there are no cracks appear in the system and what you want to do is we want to in fact, freeze the images over a period of time to see how volumetric strains are developing in the material when it dries.

So, it is a case of strain hardening or strain softening? So, I am sure that now you can correlate strain hardening effects in soils because of their drying or because of their shrinkage. Is this mechanism clear now little bit?

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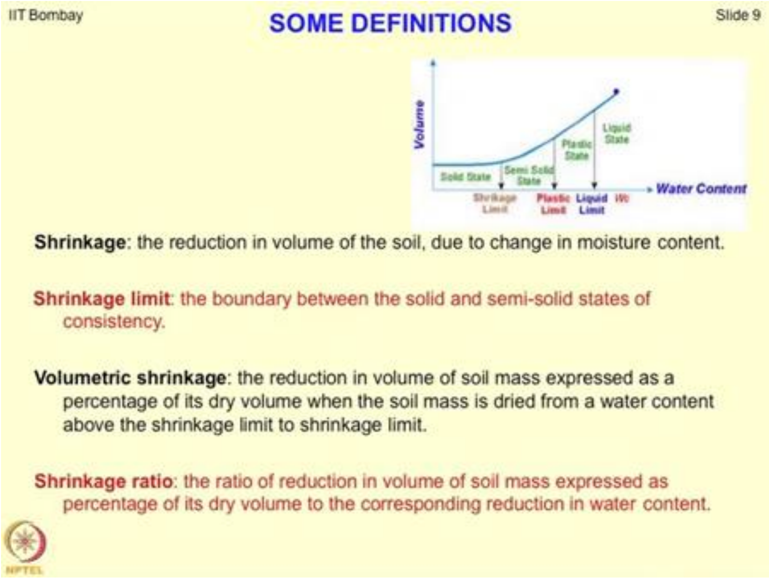

The definitions which are used you can recognize this graph very easily. You plot on y-axis volume of the entire system, x-axis is water content. What we do? We start from a driest possible state of the soil and we keep on adding water. So, we traverse always from this end to this end. In normal practice there is a there is a paradox. I will repeat again. In normal practice what do you do? You always traverse from not for finding out Atterberg limits, a normal practice compression curve let us say. What do you do? You always start from the driest part of the soil you add a little bit of water, add a little bit of water, add a little bit of water; that means, you always traverse from this to right hand side, clear?

But when we talk about determination of Atterberg limits what do we do. We follow a reverse path. So, is this true or is this correct? Most of the geotechnical engineering applications you will notice that we always add certain amount of moisture to the soil. But, when it comes to finding out the limits and see we very proudly say the liquid limit is this, plastic limit is this, shrinkage limit is this which is based on a totally opposite phenomenon. Ok, keep this in mind. So, it is a research idea on which many of us are working.

Coming back to the issue if you start from a slurry state of the material which is nothing but liquid state, little bit loss in moisture you know you transform to plastic state, plastic state to semi stolid state, semi solid state to solid state and then you define liquid limit, plastic limit and shrinkage limit.

So, shrinkage is nothing but the reduction in volume of the soil due to change in moisture content. What is shrinkage limit? The boundary between the solid and semi solid states of the consistency. What is volumetric shrinkage the reduction in volume of the soil mass expressed as a percentage of its dry volume when the soil mass is dried from a water content above the shrinkage limit to the shrinkage limit. These are classical definitions. What is shrinkage ratio? A shrinkage ratio is the ratio of reduction in volume of the soil mass expressed as percentage of its dry volume to the corresponding reduction in water content.

Did you ever notice one interesting thing? You might have used this graph quite frequently if I extend this portion of the straight line, straight line portion of the graph and if it intersects somewhere here, did you get this point? The straight-line portion of volume versus moisture content relationship if it intersects somewhere over here in the y-axis what would be that ordinate? If you project the straight-line portion on y-axis what will be the value of y axis? See you say this is volume. Volume of what? No, volume of solids and correct. So, this whole thing when you describe you know this whole axis this value is nothing but total volume of.

Student: (Refer Time: 20:43).

Air and solids. If you want to differentiate between the volume of solids only you have to extend this line to get V_s. So, V_s plus V_a will give you the total volume of the dry soil. This is another fallacy in classical geomechanics. Do not give due weightage to the soil skeleton and its volume. You always say that this is the solid state of the material, what is the meaning of solid state of the material ok?

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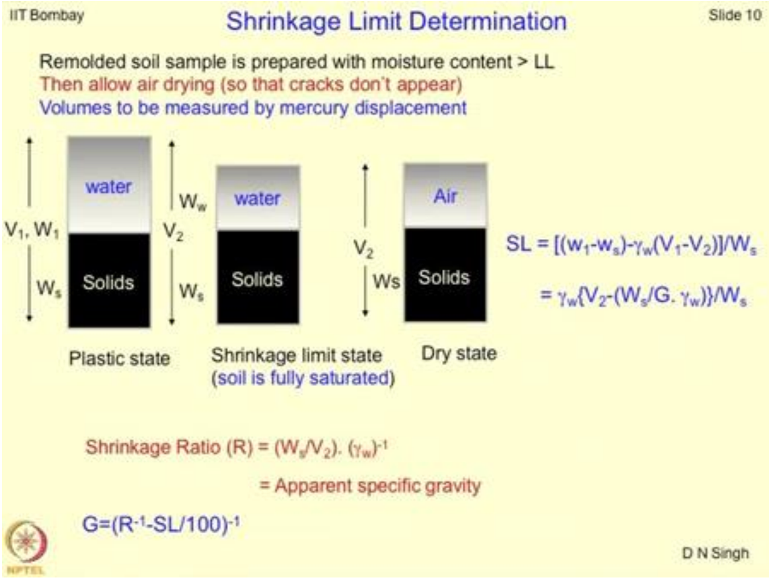

So, with this in view, if you determine the shrinkage limit of the soil you take remolded soil and always it is prepared at liquid moisture content more than liquid limit. Allow it for air drying so that cracks do not appear. Volumes to be measured with the help of mercury displacement technique.

Now, this is a simple depiction of plastic state of material. You have water, you have solids, the total volume of the system is V_1. The weight of water is sorry weight of the entire system is W_1, weight of solids is W_s. From this state what do you do by slow air drying you come very close to shrinkage limit and the condition is that no crack should appear on the surface of the soil mass and soil mass is still saturated. So, there is a reduction in volume from V_1 to V_2, the weight of solids remains same. What has happened to weight of water? It has reduced from W_1 to W. What should be the third state of the material? The third state of the material is completely dry state.

So, these are three states of the material which are more of interest when you are trying to understand its susceptibility to shrink not swell. So, at this state the volume remains constant V_2 and then you have solids as W_s and certain amount of air comes and sits over here. So, now, I can define shrinkage limit which is by using simple volumetric relationship, weight volume relationship, you get relationship like this. So, weight difference multiplied by unit weight of water multiplied by volume difference divided by the weight of the solids which are present. This is also equal to unit weight of water multiplied by final volume minus this relationship divided by W s. So, you can use both the equations to get shrinkage limit of the soil mass.

What is shrinkage ratio? The shrinkage ratio is R which is equal to W_s upon V_2 into inverse of unit rate of water. Do you think that this is a specific gravity term also? So, this is known as a specific gravity which you can represent in this form 1/ (R- SL). 100. It should be inverse of this. It should be $G = (R^{-1} - SL)/100$, the entire thing inverse. This should be 1 upon this term. That is what it should be 1/ G. No, the way you define this is this is W_s into upon volume and $1/\gamma_w$. So, this becomes your gravity term a specific gravity term. See, G. γ_w will be nothing but weight upon volume. Here there is a correction, this should be G^{-1}. So, this is how you can correlate shrinkage limit and shrinkage ratio and the specific gravity.

Now, what is the significance of this. I can check the specific gravity value of the soil if I know shrinkage ratio and shrinkage limit. So, these type of equations are also used for calibrating the methodology which you are using for determining the specific gravity. So, ok. So, this term is also defined as apparent specific gravity.

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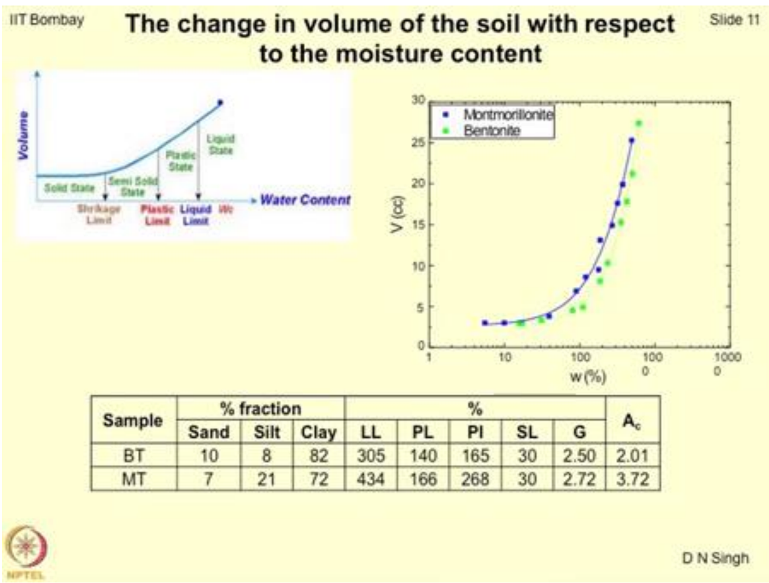

Sample	% fraction			%					A_c
	Sand	Silt	Clay	LL	PL	PI	SL	G	
BT	10	8	82	305	140	165	30	2.50	2.01
MT	7	21	72	434	166	268	30	2.72	3.72

Now, coming back to the same graph which I was showing you. If you perform some experiments in real life the question is how these graphs can be simulated? Now, this is a typical response of a Montmorillonite and bentonite material with these properties. Bentonite shows a liquid limit of 305, mononite shows a liquid limit of 434. What you notice is that drop in volume is very very fast and there is no way to get intercept, you know, of this graph onto the y-axis.

What is the significance of this? You are starting from a state of material which is almost a slurry. Let us say L/S equal to 100 or 1000; 1 gram of soil and 1 liter of water. So, truly speaking the solids do not exist or they are insignificant. So, when we have been talking about L by S all the time and you must be wondering why L/S becomes so important when we talk about soil water environment interaction. It is a state of the slurry which is also going to contribute to the shrinkage and its overall volumetric deformation pattern deformation pattern.

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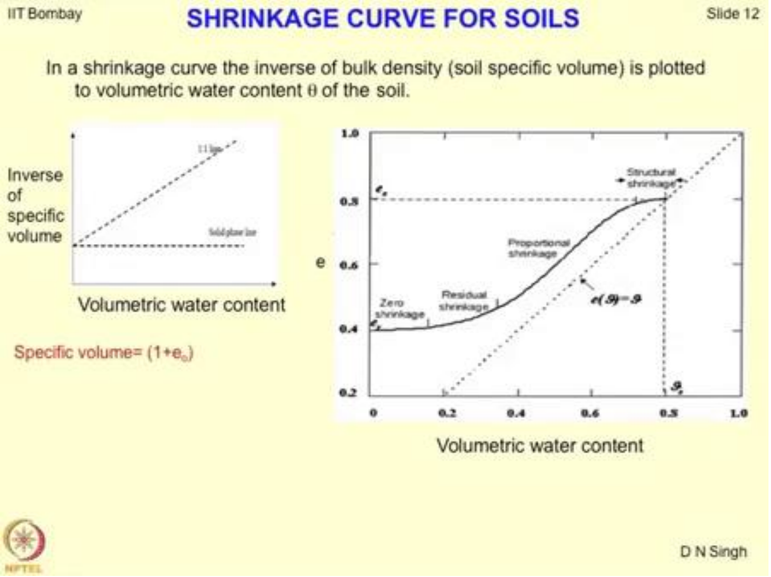

So, shrinkage curves for soils, it is normally plotted by using inverse of specific volume and volumetric water content on a 45 degree line. What is inverse of a specific volume? A specific volume is 1 plus e naught. So, in your consolidation equation when you write CC upon 1 plus e naught, so, 1 plus e naught is nothing but a specific volume. So, you normalize it with the volume of the soil which is being considered for consolidation test now this would be a typical wide ration versus volumetric water content response.

So, this is a 45-degree line which is getting mapped over here. Void ratios are function of moisture content, ok and these phenomena is valid for swelling also. So, when you plot swelling graphs the void ratio should be changing as a function of moisture content.

The point of interest here is to understand what type of shrinkages are appearing in the system. So, you may have certain structural shrinkages which are very important for the stability of structures which are founded on the on the soil mass. You may have some residual shrinkage which is a sort of a inherent property of the material and this much volumetric deformation you are going to expect for any volumetric moisture content of the soil mass.

There is a certain range of proportional shrinkage, where e is directly proportional to volumetric water content and followed by zero shrinkage of the is more stable state of the material. Now, this graph can be correlated easily with e versus log sigma prime relationship because the volumetric moisture content itself is a function of the external pressures which are applied and if more over the pressure is developed the recitation would be more and so on. It is a very loud thinking.

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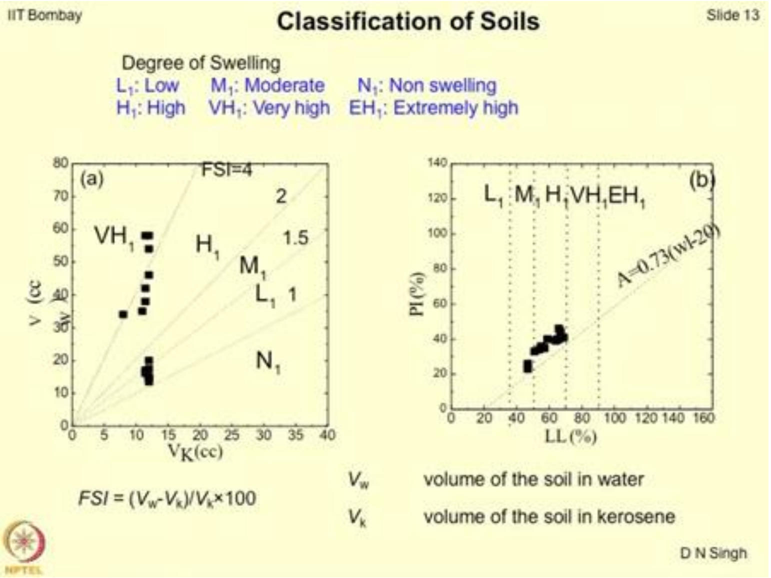

Now, just to show you what is the application of these studies this work I have taken from Ramanna's thesis. It is not published yet where degree of swelling has been defined as low, moderate, non-swelling, high, very high, extremely high. The idea was that to develop a classification scheme based on a swelling and shrinking response of the material.

So, this is where we have used FSI Free Swell Index property. Volume k is volume of the soil mass in kerosene, volume w is the volume of soil mass in water and then you can see here the zones of you know swelling properties of the soil mass. So, non-swelling is the it is found somewhere over here. So, volume in kerosene is much higher, but volume in water is much less. Try to map your soil on this type of relationship and see whether the minerals are peculiar or not.

So, you have plasticity index versus liquid limit nothing but A-line and based on the liquid limit you can define it as low to extremely high response of swelling. Of course, FSI is given by this equation that is V_w minus V_k upon V_k.

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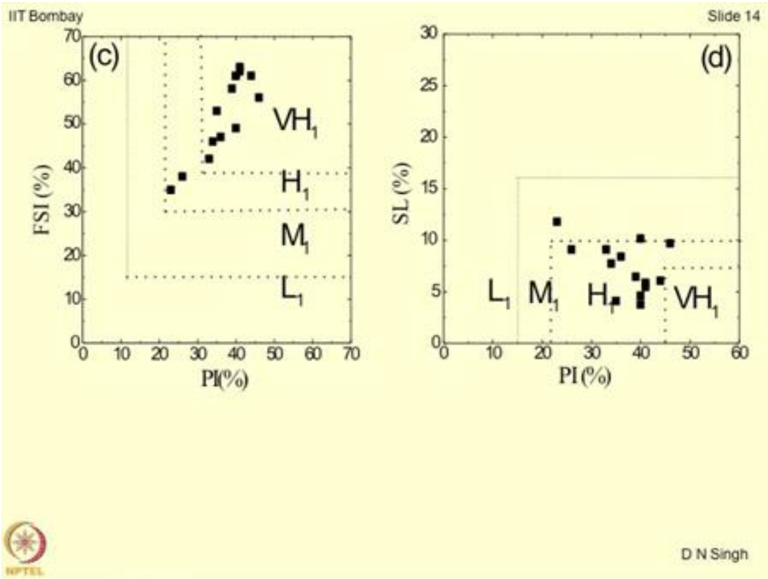

This is another way of looking at the classification scheme. If you plot free swelling index with respect to plasticity index more FSI should correspond to very high swelling and very low FSI should correspond to very low swelling. You can use shrinkage limit also with respect to plasticity index and then you can get some relationship between very high response of swelling to low response of swelling.

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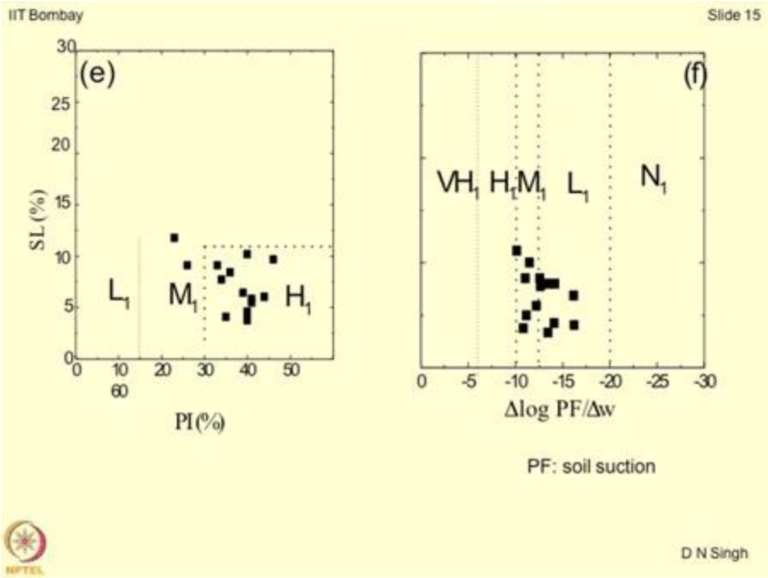

Now, this is where I wanted to introduce the concept of suction with the shrinkage limit. If you measure the soil suction change in soil suction on a log scale divided by change in moisture content it is nothing but the slope of the SWCC can be correlated with shrinkage limit and you will notice that very high suction would induce more shrinkage in the system as compared to low suction.

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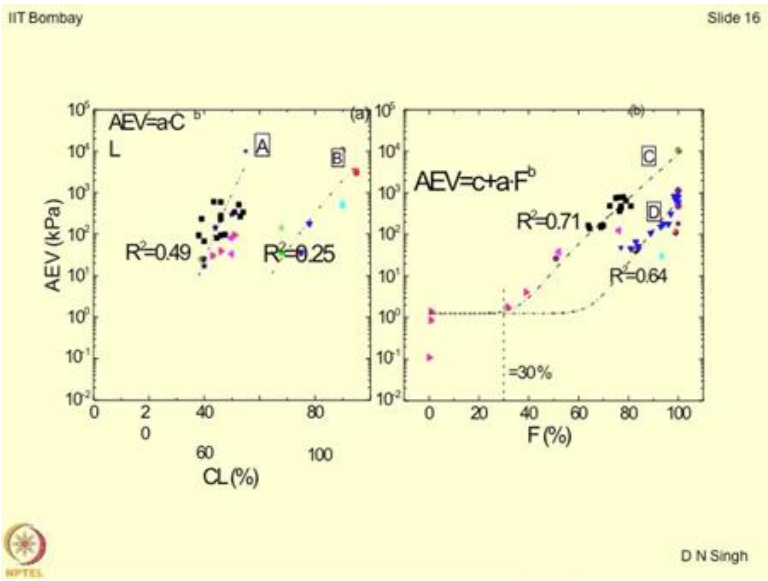

Now, if you go to the parameters of suction, there is a air entry value which can be correlated with the clay content and you can get a relationship between clay content and air entry value like this. Air entry value and the fine contents can be correlated here. What you will notice is that for most of the soils if you analyze the air entry value would be very high for the soils which are swelling type as compared to soils which are non swelling type.

So, in our opinion this type of a classification scheme is very useful for differentiating between swelling and non-swelling type of soil just by looking at their air entry value.

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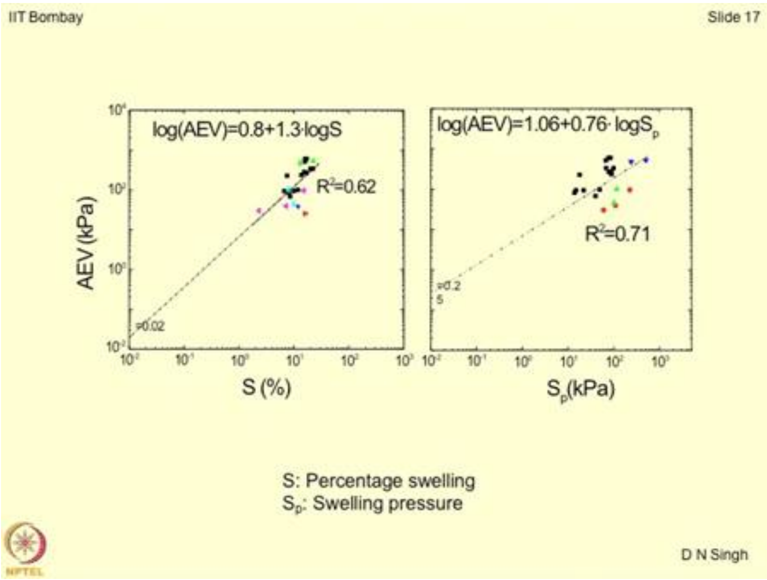

Air entry value can also be plotted with percentage swelling. So, more the percentage swelling you have more air entry value and this relationship can be extended further to swelling pressure. So, just by knowing the air entry value which you can get from SWCC you can obtain its swelling pressure easily. This seems to be a sort of a linear relationship.

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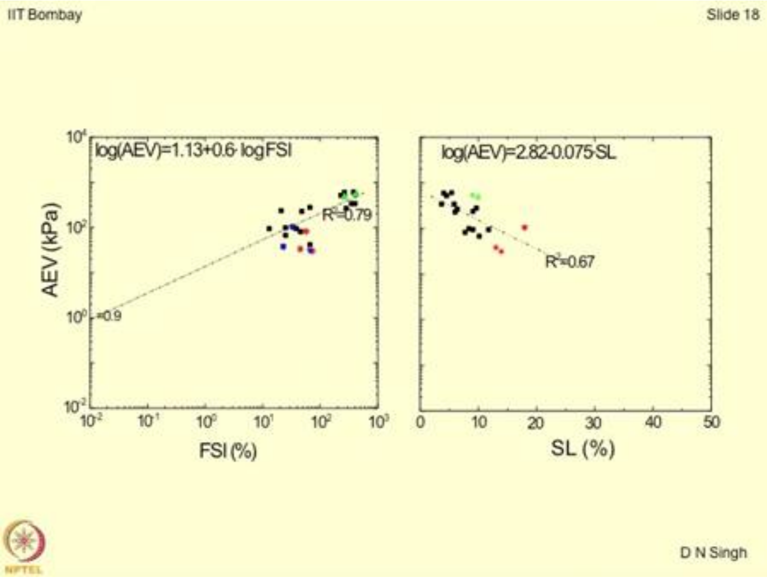

FSI is a very great term. So, still you can try to develop relationship between air entry value and free swell index. So, more the free swell index more the air entry value you can use this type of relationship. However, air entry value and shrinkage limit they map exactly opposite to each other. The reason is simple, air entry value talks about the suction properties, swelling properties and shrinkage limit should be opposite phenomena to this. So, this is how you can interlink the swelling response and the shrinkage response together.

So, unfortunately this work is not in still a conclusive state where you have to still do lot of work to get. You must have noticed that in most ranges of the FSIs we could not get any data, in other words the soils in this range do not exist. So, we may think of creating some synthetic soils and train soils with FSIs which are very less alright and then it has their air entry value and so on.

And, this was just to show you as this relationships can be very powerful relationships interlinking the mechanisms.