Environmental Geotechnics
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Lecture - 49
Swelling, shrinkage and cracking characteristics of soil – 2

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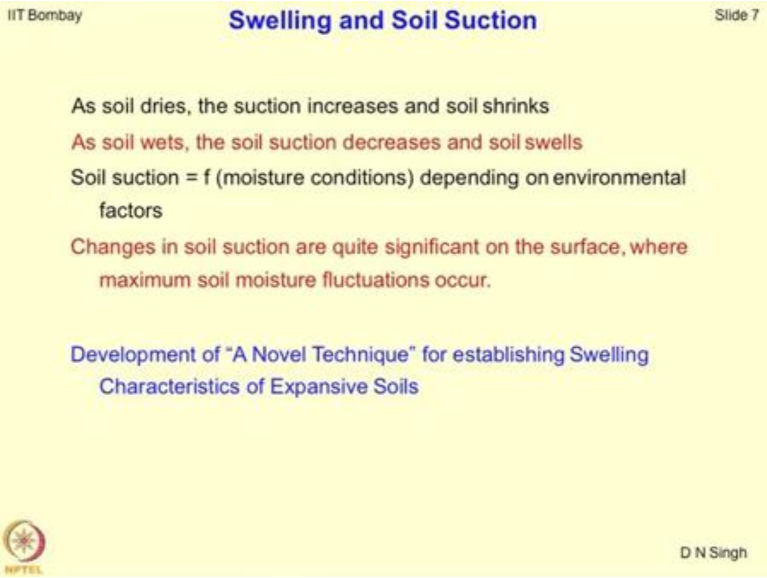

Next concept is how swelling and suction are related to each other. I hope you can understand with this my discussion that swelling is intrinsic behaviour of the material it tries to swell and if a material is swelling and if there is a water in vicinity what is going to happen it has a tendency to take the entire water in to it and this is nothing, but the soil suction also it is nothing, but the negative energy which is present in the pores and the moment you allow it to interact with water there is nullification of negative energy and the soil becomes saturated.

So, as soil dries the suction increases and soil shrinks. Is this clear? This is what actually we do normally when we are finding out Atterberg limits of the clays. So, we always start from a slurry state of the material which is beyond liquid limit you allow air drying of the soil mass and keep on measuring it is volume of moisture content and then you get this craft where as volume decreases, moisture content decreases and beyond which the moisture content becomes constant you get the plastic limit and the shrinkage limit and so on.

However, as soil wets the soil suction decreases and soil swells. So, these are 2 reverse mechanisms. So, soil suction is the function of moisture content which depends upon the environmental factors heat humidity, temperature, climatic conditions, velocity of wind, excessive rain fall, cloud cover and so on ice formation and so on alright. So, changes in soil suction are quite significant on the surface where maximum soil moisture fluctuation occurs and that is the reason why shrinkage cracks will always develop on the surface and then they will travel in to the soil mass.

So, once this theory or the concept is proven that swelling and soil suction are related to each other you can develop a technique or establishing swelling characteristics of expensive soils based on their suction measurement. Some people have already worked in this area and they have shown there is a good correlation between the swelling properties and soil suction which I will be discussing in subsequent lecture today.

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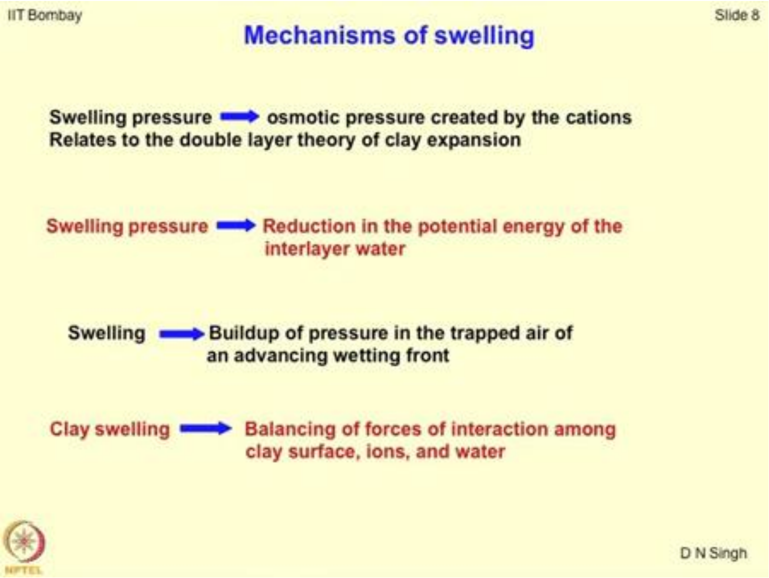

Before we do that let us talk about what are the mechanisms of swelling. So, if I ask you a question in the simplest possible manner how would you define a swelling phenomenon? What would be the answer?

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That is right. Anything apart from this? Actually, you are jumping directly to the may be third sub mechanism the first question is the first instant interaction between the material and the water how should a material recognize again I am asking you this question that it has to interact with something. So, that is mechanism number one. So, when you talk about mechanism of swelling it is a slightly intricate mechanism. This is very important swelling pressure which corresponds to osmotic pressure is created by cations and this relates to be double layer theory of clay expansion.

So, the fundamental concept is unless cations are there unless the osmotic pressure gets generated the swelling pressure will not generate. This is the first mechanism. The second mechanism is swelling pressure is detecting in the potential energy of the inter layer water. Why it is so? What capillarity does? What surface tension does? Surface tension will reduce the potential energy or it will increase the potential energy. It will reduce the potential energy; that means, you think of 2 grains of the soil which are wet and this thin layer of water what is trying to do.

It is trying to act like an elastic band or your rubber band. So, the tendency of the rubber band is to bring both the grains together because of the surface tension clear. So, this type of mechanism generates the swelling response of the material. So, truly speaking what is swelling? Swelling is nothing, but an opposite reaction to the surface tension. You agree with this and as you said rightly swelling is nothing, but the buildup of pressure in the trapped air of an advance wetting front.

So, as water moves from external surface to the inner surface there is a gradient of pressure within the soil mass itself and to equilibrate this there would be a swelling exhibited by the soil sample or the soil mass. Is this ok? So, first issue talks about the physico chemical mechanism. The cations will be having more parking space on a system which is having more surface area which are very fine in shape clear and osmotic pressure is also going to come because of chemical interaction.

So, that means, the first interaction would be mostly physico chemical, but of course, you cannot say that mineralogy is not going to picture. So, this happens to be a physico chemical mineralogical interaction. When you talk about the reduction in potential energy of the inter water layer what type of mechanisms are controlling here? What type of the parameters are controlling here the entire process? These are also electromagnetic forces which are acting between the grains which again will depended upon physico chemico and mineralogical properties and the buildup pressure in the trapped air of the advancing wetting front this happens to be a simple physical phenomenon.

So, most of the time in classical geomechanics you will notice that swelling has been defined by this simple equation and not much weightage has been given to one and 2 mechanisms. You have not talked about the mineralogy, you have not talked about the chemical processes which are going through this, you have not talked about the type of electromagnetic forces which are acting between the particles and the particle and the water system.

So, unless you break these bonds the swelling will not take place or the reverses shrinkage process; that means, they should be enough energy within the system so that the grains come in contact with each other. So, this is where actually you have to talk about the micro mechanisms of swelling and shrinkage and in absolute terms you cannot simply that if the certain amount of pressure is developing that would be equal to the swelling pressure and this is where you have to understand the difference between the intrinsic and the potential expensive behavior of the soil mass is this logic clear now any questions?

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That is right correct.

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How to?

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Well they are already included. When you say reduction in the potential energy of the entire layer system why this reduction energy is taking place because half of the energy or certain amount of energy is now diverted towards interactions with the environment. So, this is a sort of a nullification of the energy which is present in the system or the negative energy which is present in the system in the form of soil suction. The simplest possible answer to your question would be a loose soil mass a well compacted soil mass which one is going to show more swelling properties. You do free soil index test.

And then you do swell potential test also which one is more reliable? Which one?

Swelling.

Swelling say it with confidence. Why FSI is not a very good parameter of why is not a very reliable parameter?

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That is most simple answer would be in soil you do not find anywhere loose possible state of the material is it not. So, you are trying to stimulate a situation which is more realistic and then when you are compacting the sample what you are doing you are inducing more and more negative energy in to it in the form of suction. So, you are testing the response of the material for swelling under the worst possible situation when it is heavily compacted; that means, when suction values are extremely low or minus means very high. Is this ok?

So, these concepts can be further modified when you see that clay swelling is nothing, but balancing of forces of interaction among clay surface, ions and water and then you can say that the swelling is a wonderful example of soil, water, air interaction. So, all those concepts which you have learnt till now can be put together here to identify the swelling response of the clays. I hope you will appreciate this point what are the methodologies classical for identification of swelling type of soils.

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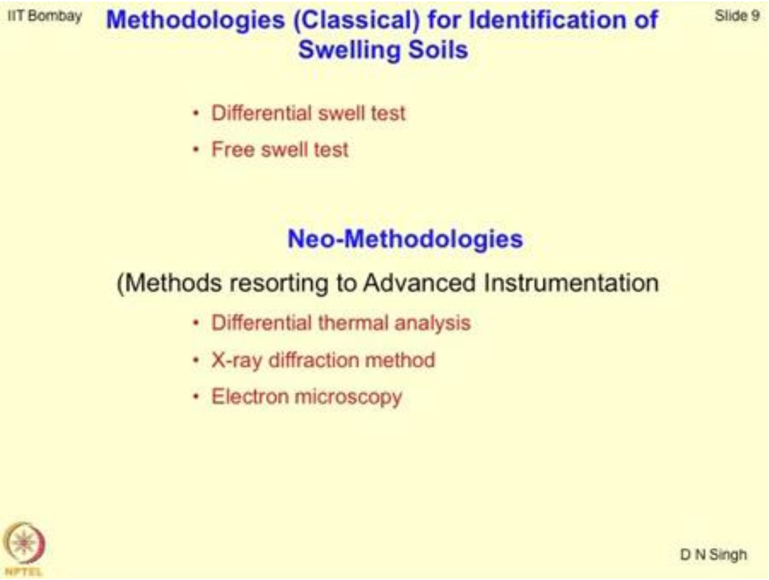

So, you do differentials swelling test and you do free swelling test, what are the neo methodologies methods resorting to advance instrumentation? Any guess what methods can be utilized for determining the swelling type of soils? Differential Thermal Analysis you remember or you are forgotten DTA, TGA Thermo Gravimetric Analysis, Differential Thermal Analysis.

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Suction will not come to this category. X-ray diffraction method you can identify the minerals and you can easily say that if this mineral is present the swelling potential would be so much, free swelling index could be so much and so on.

Electron microscopy; you can see the type of minerals which are present in the system you can do the quantitative analysis and you can always make sure that what will be the swelling response of the material; alright.

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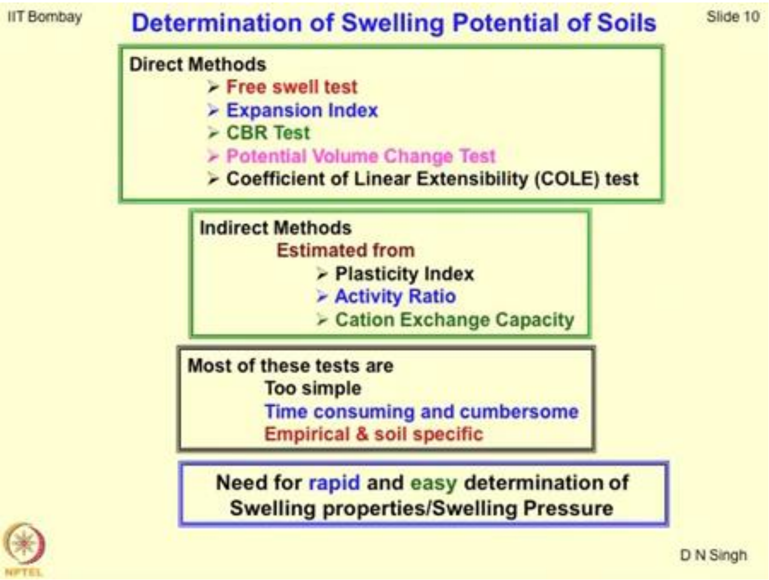

So, what are the direct methods which are available for determination of swelling properties or swelling potential of the soil. The first one is free swell index test. You keep the sample in water and in kerosene which is a which one is a polar?

Water is a polar.

And which one is a non polar fluid kerosene. So, why do you put them in water and kerosene?

(Refer Time: 12:45) water to polar liquid is just having to (Refer Time: 12:49) and this helps get thing making it what will say it.

I am simply asking you why do you put in both the fluids?

(Refer Time: 13:00) differentiating (Refer Time: 13:02).

So, you are differentiating between what?

Volume of (Refer Time: 13:08).

Volume is a macro term what is that you have differentiating with the material is a interacting with?

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Exactly. So, the material is interacting with something which is polar where hydrogen bonds will form easily and, in another case, this type of mechanism is not going to take place. So, one is a inert environment another one is in active environment. So, that is why you get the potential of the material to interact with something in 2 different environments. You do expansion index how much the material expands delta h upon h in any oedometer test CBR test will give you a direct method of determination of the swelling potential of the material. Is it not?

You soak the sample after compacting it and find out the volumetric deformation of the material which is nothing, but potential volume change test and the co-efficient of linear extensibility. This is what is known as COLE index or COLE test. What are the indirect methods? The indirect methods are you can estimate by using π. Is this ok or not? You can find out from activity ratio and you can find it out from cation exchange capacity.

Sir we can find this (Refer Time: 14:34).

Rather than finding out separately the best would be

Plasticity.

To use plasticity index. Why it is so? Which one is more reliable liquid limit or plastic limit or plasticity index? See in engineering behavior, negatives are more important than positives you always have a - b very rarely we will give weightage to a plus b why? It shows too much contrast between the properties. So, higher the value of LL- PL or lower the value of LL- PL it tells you something about the material; that means, these are the two contrast characteristics of the material clear.

So, if you use plasticity index this gives you a better information about the swelling potential of soils; however, most of these tests are very simple, time consuming and cumbersome, empirical and soil specific. So, this is where you require something which can be employed to get answers easily and you can find out swelling potential or swelling pressure of the material quite precisely and easily.

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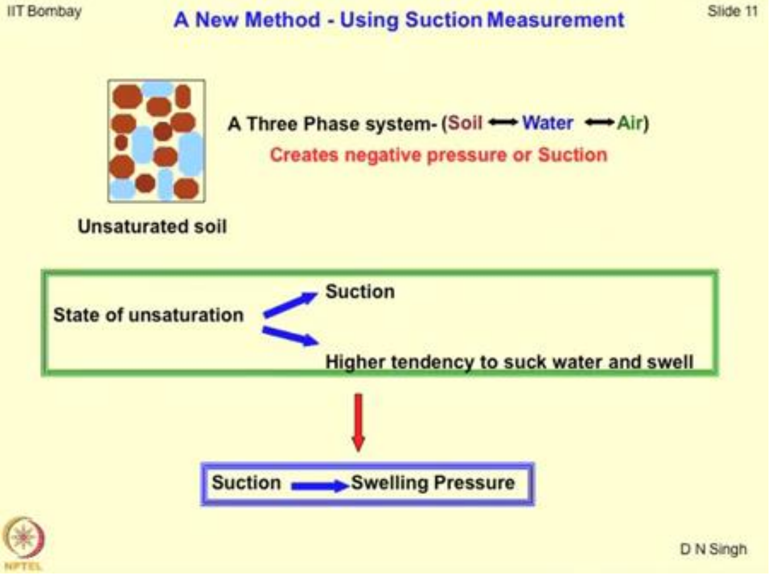

Just to remind you the basics the methodology was developed by one of my masters of student Vikas Kumar, where we use the soil suction measurement it is a simple 3 phase system of unsaturated soil, you have soil water air interaction is taking place and because of this interaction the negative pressure gets generated in to the soil mass clear, because there is a menisci between air and water and soil and water.

So, the differential between the two is nothing, but your suction value. So, state of n saturation gives raise to suction in the soil and when suction generates there is a higher tendency to suck water and swell. What this corresponds to is that if you know the suction you can find out very easily the swelling pressure of the material. So, this is how we said that this is a new or model technique to determine swelling properties of the soil just by measuring it is suction properties. So, you need not to do at the test.

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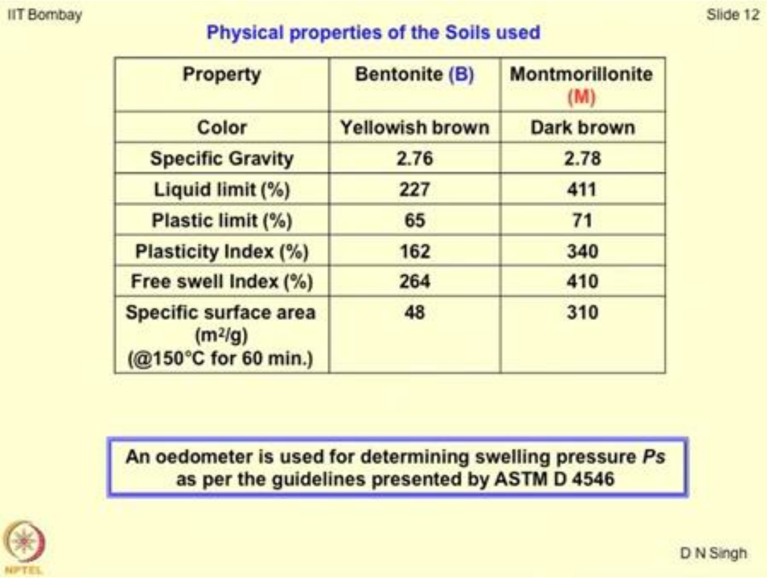

Just to give you an idea what type of soils were used we used bentonite and montmorillonite, B is for bentonite, M is corresponding to montmorillonite. A specific gravity are all most same, but look at the liquid limit contrast and the plastic limit contrast and the π and of course, they have free swell index and the specific surface area, alright. So, these are two extremes of the soils which were used for these studies to show the methodologies validity and oedometer test for perform to determine swelling pressure Ps as per the guidelines provided by ASTM 4546.

(Refer Time: 17:46) what is significance (Refer Time: 17:48).

Well it is a very interesting question.

(Refer Time: 17:59) sample is (Refer Time: 18:01).

Suchit I think you should respond to their question because you are also talking about negative FSI or someone else for talking Ramanna, what is your guess? Why you are getting negative value of FSI? First of all, what is the significance of negative FSI? My answer to this question when Ramanna asks me this Ramanna was my master’s student who have completed in 2007. Go it at the mineralogical level what is your guess? A mineral may react with water, it could be a endothermic reaction or exothermic reaction? Got it. When you dissolve some powder in water it may produce heat like calcium.

And the same time when you take this material dissolve it in water what happen it becomes quite cool; that means, it is a sort of a endothermic reaction. So, you have to go in to the thermo dynamics of the system to understand why FSI could be it is not negative frankly speaking is the minerals which are getting altered to a different state. FSI negative has no meaning. What it indicates is the reaction between the minerals and the water is in a different manner. So, you cannot again compute or you cannot again compare the two responses.

Sir, the reason in swelling of sample in clay is that it got to randomly oriented and more whites are there. So, it is swell and it (Refer Time: 19:49).

Both slightly more in to the micro mechanics we have discussed so much now double layer formation you know all those things forget about the grain orientation only. It has something to do with the energy balance. If system shows positive energy release it is always going to bounce back. If it shows negative energy release what is going to happen it will show you a compress behavior that is it. So, it has something to do the thermo dynamics of the whole system.

So, what you do is next time when you do these experiments put them in a calorie meter. So, if you are too much interested in reading this work you refer to Gaurav’s thesis, Gaurav Gupta who has measured the temperatures which get released at the time of interaction or Srinivas you wait for some time and when he starts his work then you can mintage with him, but to give you an answer quickly it is because of the thermodynamics of the system which is controlling the entire process, you should never report FSI negative ever, clear.

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Try to understand the chemical compassion and mineralogical compassion of the soil on which we have working. It could be a bentonite and where the type of processes which are controlling are endothermic.

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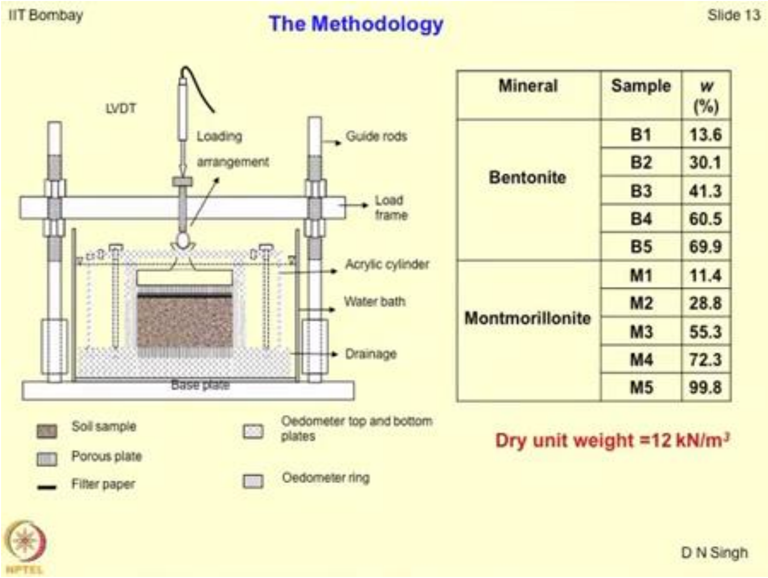

Are you talking about this in your thesis negative expand no ok. So, this is the conventional methodology which is normally used. You have an oedometer ring and places sample at a compacted density and then measure the deformation of the sample and known both the sides of the literal you do not have any deformation of the material.

So, if you test bentonite and montmorillonite samples their designated as B1, B2, B3, B4, B5 and montmorillonite as M1, M2, M3, M4, M5. We have different moisture contents you can be convinced that we are working in the driest of optimum to the OMC and driest of optimum to almost up to OMC because a liquid limits are very very high here and if you maintain the same unit weight of the material dry unit weight as 12 kilo newton per meter cube.

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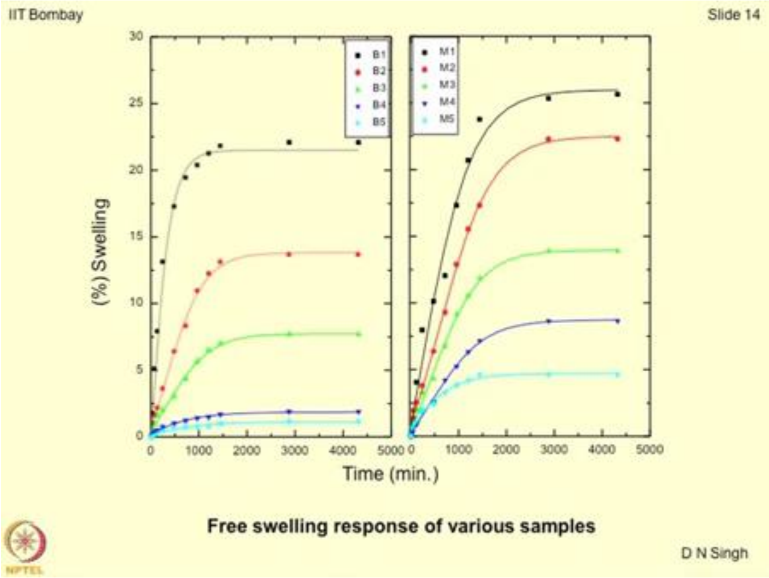

This is what the response would be. I thought of showing you this response two reasons you can compare the response of bentonite and montmorillonite yourself and you can see that there is a substantial amount of difference at every stage of you know swelling.

So, with respect to time if you do this test almost up to 4,000 minutes what will notices that after initialize there is a constant percentage swell in the system. So, it every stage of the test you will notice that the montmorillonite is a much faster response as compare to bentonite. The slope of the curves are steep higher values and so on. So, these are the free swell response of the materials.

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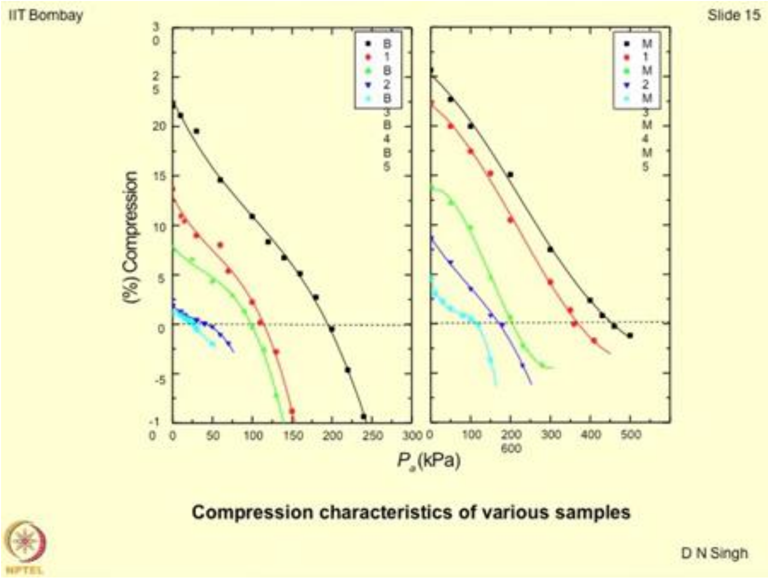

And there is a conventional swelling potential test when we perform after the material as swelled completely you compress it by loading the system and wherever this curve cuts the 0 percent compression line this gives you the swelling potential. So, for different compression states you can notice here B1 to B5 is the increasing order of moisture content. So, what is the meaning of this the driest possible sample shows much more higher swelling potential as compared to the sample which is having more moisture and the same trend is valid over here also these are driest state of the material and this is the most wet state of the material.

So, this is how the swelling potential changes from all most 100 kPa to 500 kPa approximately fivefold almost. Now the question here is that is there any way to isolate the material when it is interacting with nature directly. See you can perform this test in the laboratory, but once you have compact to the soil mass and you leave the system to interact with the environment there could be rapid change in the moisture content or there could be rapid rise in the moisture content. You know because of the fluctuation of water table or because of the interaction with rain water and so on.

And if this cycle repeats what is going to happen ultimately. It is going to result in distresses coming over the structure. So, all this information cannot be imbibed in these classical graphs. Do you agree with this? Because these graphs correspond to a initial compression state of the material and with a continuous interaction with water.

So, what is the meaning of the, significance is that these types of test are not real representation of the material property and it is potential to show the response when it comes in contact with the environment directly.

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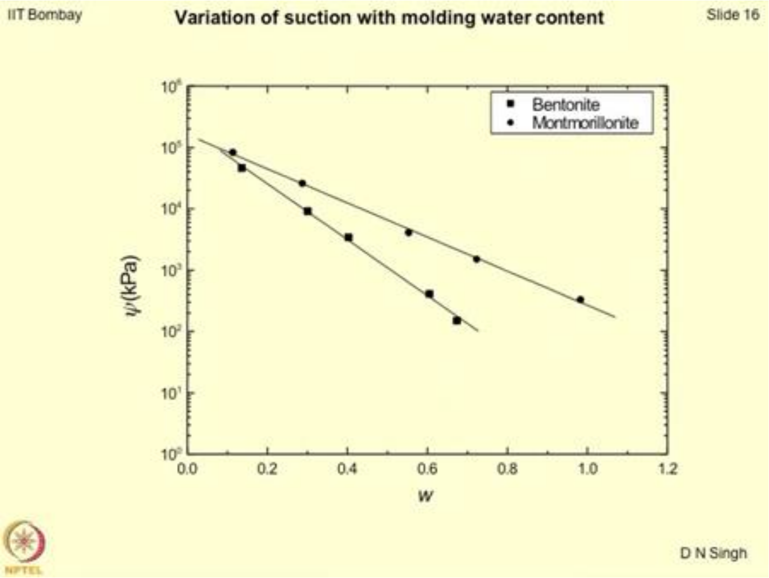

So, if you measure the suctions at sequential stages of the drying of the material what will notice is it is a typical SWCC curve you are plotting suction with respect to moisture content alright. So, this is another application of soil water characteristic curve that from the slope of the SWCC curve you can determine it is swelling potential and I hope you will appreciate this point that SWCC is a unique curve. So, for every soil the swelling potential would be unique value particularly, if you are suction ranges or the moisture content ranges are well defined.

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Results from the study

Mineral	Sample	w (%)	P_s (kPa)	Ψ (kPa)
Bentonite	B1	13.6	194.26	46000
	B2	30.1	114.80	9100
	B3	41.3	99.22	3400
	B4	60.5	44.69	410
	B5	69.9	27.69	150
Montmorillonite	M1	11.4	454.17	83000
	M2	28.8	369.26	26000
	M3	55.3	201.77	4070
	M4	72.3	169.83	1500
	M5	99.8	113.73	330

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Just to give you an idea about what I presented in the previous graph if you compare the suction values and the swelling pressures for different samples as the moisture content increases the suction value drops and hence the swelling pressure drops the same is valid for montmorillonite also ok.

But what will notice is that the residual suction in case of montmorillonite is much higher than bentonite. Residual section means at 100 % moisture content also this is almost 2 times that of the bentonite.

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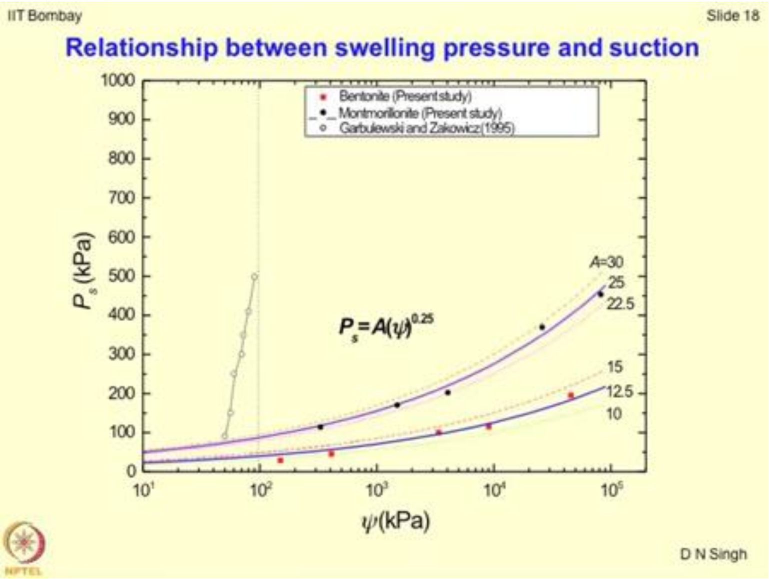

Now, this was something which was proposed by as if you plot on y axis swelling pressure and if you plot on the x axis the suction you get a typical or a peculiar relationship like this which is non-liner curve what it indicates is as suction increases what happens for swelling potential. The swelling potential or the swelling pressure increases non-linearly and the generalized form of the equation can be given as this where A is a co-efficient and 0.25 is also a co-efficient or a constant term. Now value of A corresponds to the co-efficient what different minerals.

So, basically the best thing would be if you can characterize the minerals based upon their A value. Did you get this point? You test several minerals and then try to establish these curves and then come up with the values of A which are peculiar numbers. So, once you have this peculiar numbers of A your characterization of the soil mass based on it is swelling potential is over and what you have been trying to emphasize here is that the swelling potential is a phenomenon which is physico chemical mineralogical in nature. And hence a characterization scheme based on suction all swelling potential measurement would be a good characterization scheme for classifying the geomaterial. Now the boundaries over the real curve A is nothing, but the confidence limit.

So, the value of a may vary with in ±5% or 2.5% and so on. Now this is what actually you are trying to show that some results which are given by other researchers do not match at all and the reason is that these people have not measured suction in the higher ranges. So, this was done in 1995. So, we came up with the methodology which is much better for measuring suction and determining the swelling pressure.

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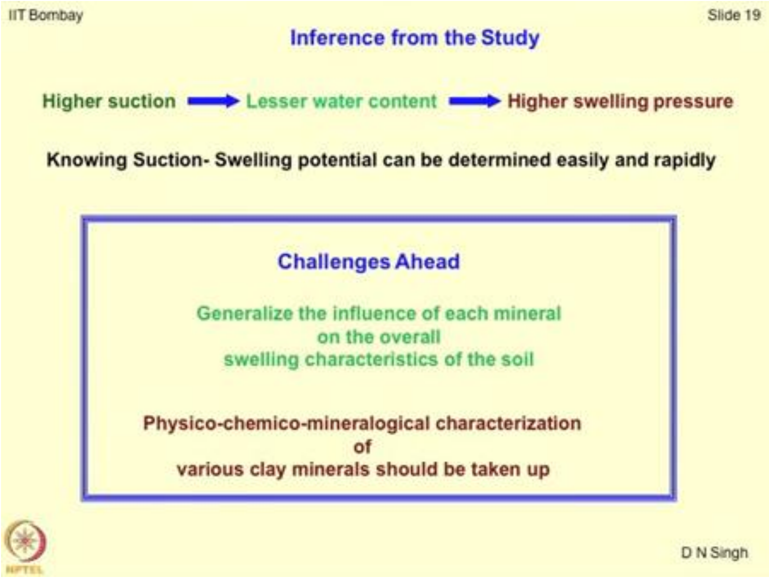

So, what is the inference from this type of studies? The inference that higher suction less water content higher swelling pressure. Knowing suction swelling potential can determine easily and rapidly and this is where I feel that there are lot of challenges which have to be taken up by people. You have to come up with some solutions generalize the influence of each mineral on the overall swelling characterization of soils. What had been shown here is for 2 minerals that is bentonite and montmorillonite.

But in normal soil natural soils will constitute of different minerals in different compositions so; that means, if you keep on varying the composition of different minerals you think of a multi scale multi phases of the minerals which are present in the soil mass and then come up with some generalize model where you can ascertain some weightage factor to ψ_w function alright. So, either you can determine the composition of the soil or if composition of the soil is known then you can find out the total potential of the soil and need not to emphasize again that physico chemico mineralogical characterization of various clay minerals should be taken up to do this work.

But good thing is because bentonite and montmorillonite as the 2 minerals which are quite prominent if they have been studied well and if you think that other minerals are going to contribute that effect should also be included in this type of studies.

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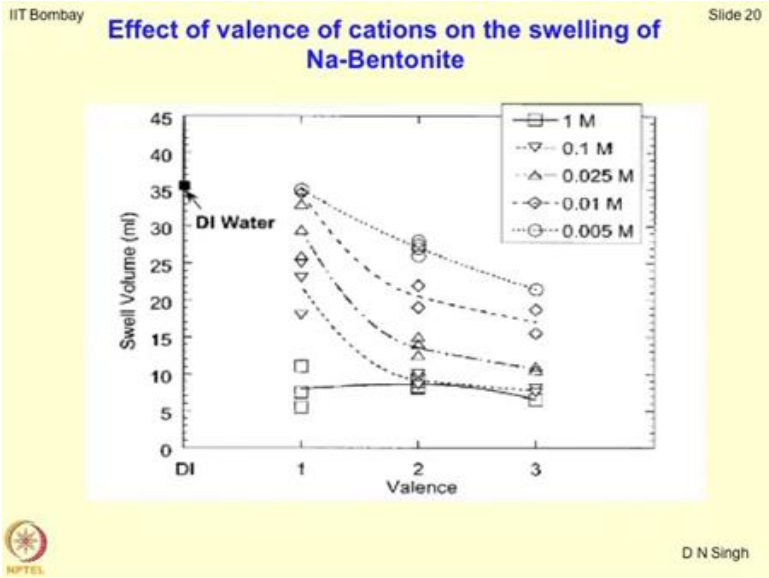

Some typical response of the parameters just to show you how swelling potential or will vary with respect to valence of the cations which are present in the soil mass. So, normal trend is more the valiancy what will happen to the swelling it will be less because the bonding is too strong. Is it not? Ionic bonding or covalent bonding is very strong for all sorts of molarities.

DI corresponds to distill water or deionized water. So, if you put the system in to the deionized water the swelling volume will be this much; however, if you change the valiancy of the solution or the cations with different molarities the normal trend is as valiancy increases the swelling volume will decreases. So, let me ask you a question if I give you a sodium bentonite and a calcium bentonite all right which one will show you more swelling.

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Very good. So, hydraulic conductivity will more in which sodium or calcium bentonite?

Calcium bentonite.

That is right. So, if you have understood these two concepts I think most of the things are clear.

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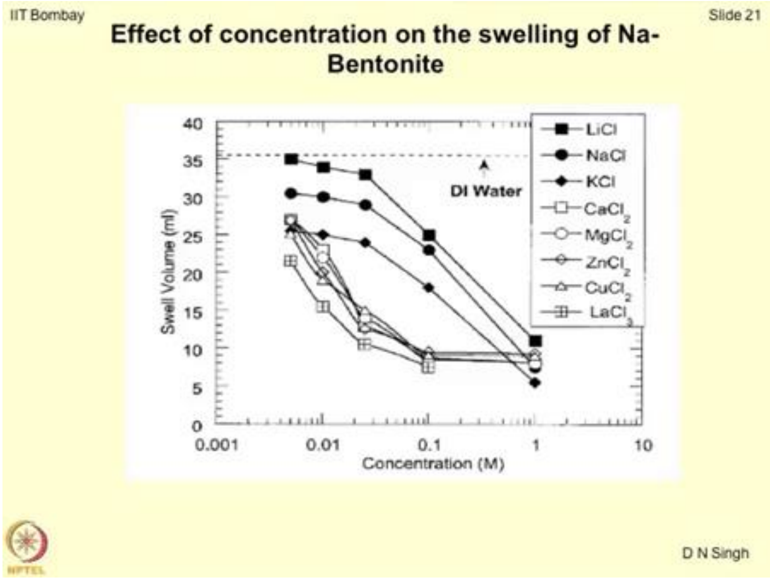

Effect of concentration of fluid on swelling of sodium bentonite. What is your guess if the concentration is more what happens to the swelling volume? See this could be because of the osmotic effects. So, as you keep on increasing the concentration of the solvent or the solute in the solution the osmotic effects get reduced and if osmotic effect gets reduced the swelling phenomena will get sub sided. So, if concentration is more the swelling will be less.

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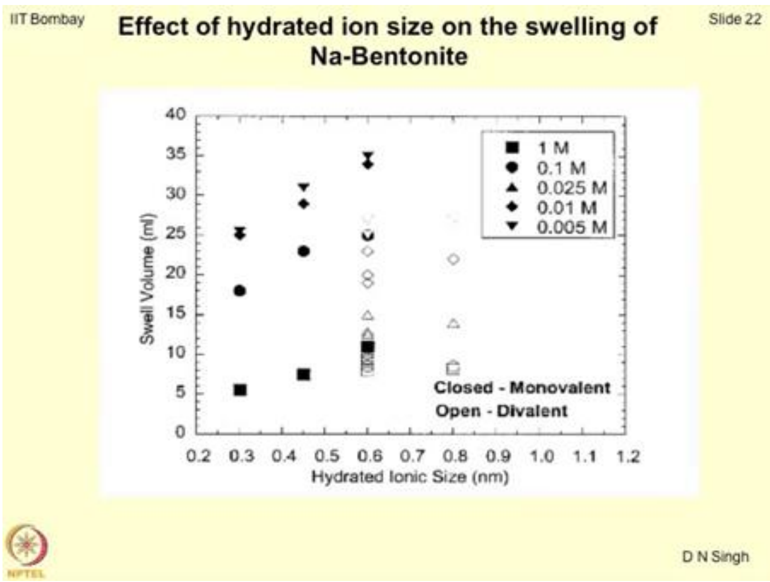

What about the hydrated ionic size? If the size is much more of the hydrated ions. What about the swelling volume? More the size of the ion more the swelling up to a certain limit beyond which there will be a drop, although this is a very random type of a study.

But still in general as long as the size of the ions is smaller the swelling volume will be more. So, these are the few studies which I have been reported in the literature. Of course, this will depend upon the type of system which you have adopting whether a monovalent or a divalent and what is a molarity of a particular solution, alright. Anything you have to ask oh one more slide is there I have forgot to show you the effect of pH on swelling.

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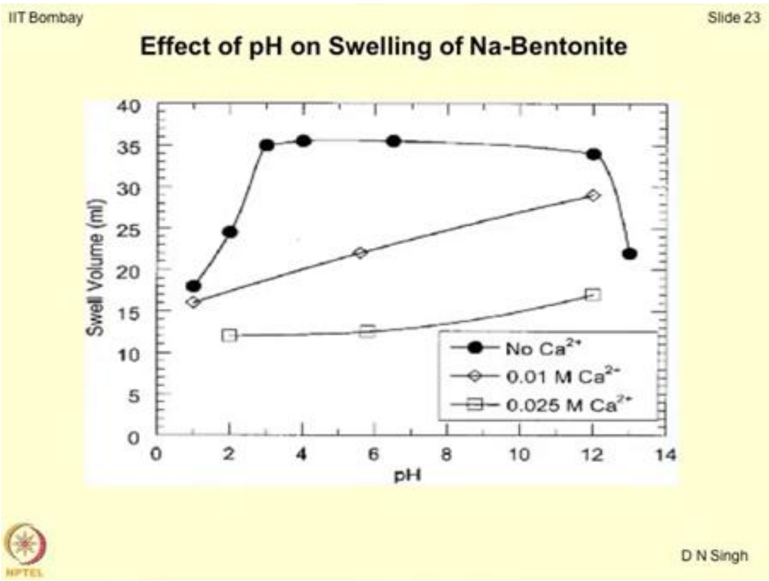

If pH increases see beyond neutrality again it is depends upon the type of cations which you have and their molarity. So, what cations are doing and the molarity. It creates it is different type of a dispersed structure. So, if the grain structure I think you are talking about this Niraj grain structure is it not. So, at micro level if you alter the grain structure the swelling potential will get affected. So, a dispersed structure will swell much more as compare to a flocculated structure or so reverse.

Dispense structure will always swell much more that is the whole idea of compaction. When you answer something you should think before you before you reply see that is why I have been telling you FSI test is nothing but a sort of a flocculated structure which is not reliable, but when you compact the soil mass you take a sample at a dry density when you go closed to the OMC then your suction values are more than then you are you know swelling potential will be very high and so on.

So, a more ordered structure will always show you much more swelling as compared to a flocculated structure. Flocs will not show you much of swelling as such. Then the question is if what is the role of pH? If you add a substance which creates more acidic environment or more basic environment, what is going to happened to the swelling of the material? How to define acidity by the way?

So, more acidic environment is always you have more swelling is it not, more volumetric deformations in the system as compared to the basic environment. That is the reason that acidic environments are much more aggressive than the basic environment. Now the question is can I alter the state of grain structure by changing its pH. Answer is yes because that is what you are observing here.

Even if you look any portion of the graph as per of the system is more acidic the deformations are going to be much more as compared to the basic portion. Now how would you change the pH of the solution, by adding some contaminant either acidic contaminant or basic contaminant. So, the best way to nullify the effect of swelling would be to add acids or basis bases. So, how do you stabilize your soils?

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That is what lime does it induces more basicity clear. So, the moral of the story is you can alter the state of the material by adding chemicals in to it and the same chemical may give you different pH value also and then by of course, applying some external energy. So, that the grains become more ordered or not.

The response of sodium bentonite is more unstable as compared to calcium bentonite that I think you are aware of. So, that is the reason whenever you come across bentonites you differentiate first between sodium or calcium and then you connect to hydro with them. I think which you are asking about the stabilization effect what type of bentonite will be using sodium bentonite or calcium bentonite or deep whole stability.