Environmental Geotechnics
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Lecture – 30
Geomaterial characterization – 10 (Assessing soil contamination)

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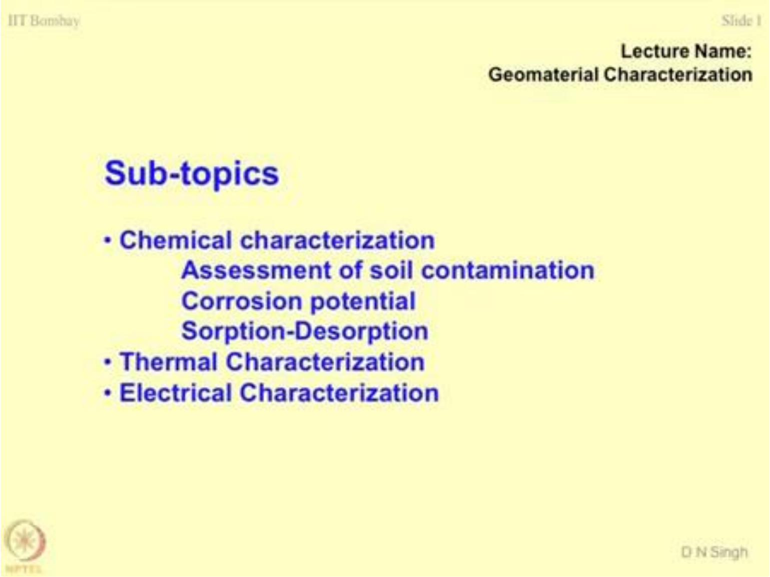

Lecture Name:
Geomaterial Characterization

Sub-topics

- Chemical characterization
    - Assessment of soil contamination
    - Corrosion potential
    - Sorption-Desorption
- Thermal Characterization
- Electrical Characterization

We continue with Geomaterial characterization with sub topics as chemical characterization. Well, this is taking too much time as you can appreciate a lot of things to cover under this sub-topic. I like to include assessment of soil contamination in today’s lecture. It is a good example of why chemical characterization should be done and how chemical characterization can help you in determining the extent of contamination of the soil.

We will continue our discussion on corrosion potential of the soil followed by sorption-desorption is not coming in picture yet. It takes too much time to reach to sorption desorption, followed by thermal characterization and electrical characterization of the geomaterials.

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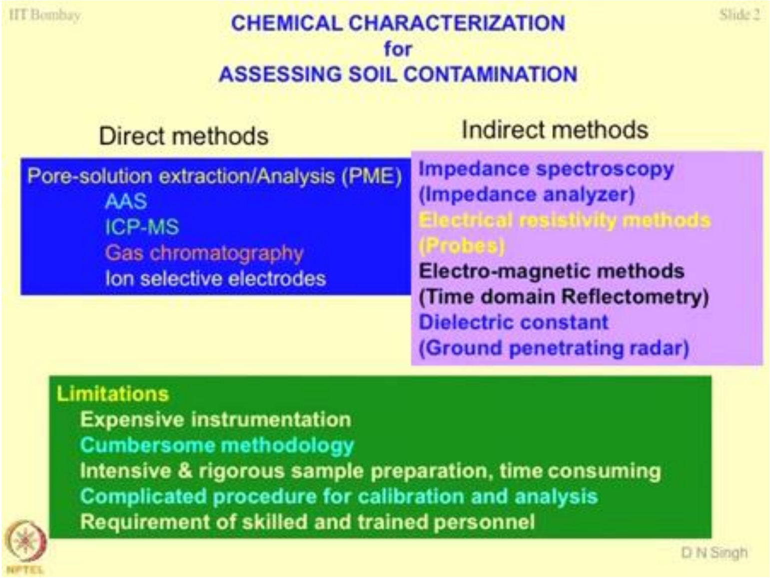

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Slide 2

CHEMICAL CHARACTERIZATION
for
ASSESSING SOIL CONTAMINATION

Direct methods

Pore-solution extraction/Analysis (PME)
- AAS
- ICP-MS
- Gas chromatography
- Ion selective electrodes

Indirect methods

Impedance spectroscopy
(Impedance analyzer)
Electrical resistivity methods
(Probes)
Electro-magnetic methods
(Time domain Reflectometry)
Dielectric constant
(Ground penetrating radar)

Limitations
- Expensive instrumentation
- Cumbersome methodology
- Intensive & rigorous sample preparation, time consuming
- Complicated procedure for calibration and analysis
- Requirement of skilled and trained personnel

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So, let me start with chemical characterization for assessing soil contamination or you may also call it as determination of extent of contamination of soil mass because of chemicals. In previous class we have been talking about pore solution extraction, it truly speaking there are two methods of determination of soil contamination or accessing the soil contamination: one is direct method and second one is indirect method. So, in direct method basically what is done is you take out the pore solution from the soil sample and for this we have discussed quite in details lysimeters, centrifugation and pressure membrane extractor.

So, this comes under the category of direct determination of extent of contamination of the soil mass. Now, these methods are always coupled with the analysis in terms of finding out the elemental composition of the contaminant by using atomic absorption spectroscopy, ICP-MS inductively coupled plasma, mass spectroscopy, gas chromatography; particularly if the contaminants happened to be hydrocarbons then you can go for GC.

There is a new technique known as GC-MS also that is Gas Chromatography coupled with mass spectroscopy. And then of course, ion selective electrodes which can be used to determine the extent of contamination of the soil mass. A good example of ion selection or selective electrodes would be cylinder sensors of that matter even the pH sensor. So, you take a slurry of the soil, filter it out and the solution if you measure the pH and if pH happens to be different than the neutral you can access that yes there is some contamination present in the soil.

So, these methods may have limitations in the way that they may be quantitative, they may be semi-quantitative or they may be only qualitative. So, particularly ion selective electrodes though they give you the concentration of ions; truly speaking the soil fall under the qualitative way of determination of soil contamination. However, AAS, ICP-MS, gas chromatography there will be more of quantitative analysis. So, the pore solution which we are extracted by using different methods can be quantified by using these techniques and then you can say that soil is contaminated or not.

What you require is they should be some guideline associated with each element or the prescribed limit. So, if the concentration is well below the prescribed limit, you can say the contamination is within the limits or the soil is not contaminated. If it overshoots the value the idea is that the soil is contaminated. The second category is indirect methods and these are the methodologies which are normally used to determine soil contamination. The first one is impedance spectroscopy; I have given you some idea about how impedance analyzers can be used utilized for developing equivalent circuits of the soils if you remember.

And, then using the components of the circuits you can say with confidence whether soil is contaminated or not. Of course, this requires lot of basics of impedance spectroscopy which I may talk when we are discussing electrical properties of the soil mass. The second method is electrical resistivity methods by using probe. So, you must have study in undergraduate different methods of electrical resistivity for determining geophysical method, that is right the extent of clay ion, presence of water table, hard rock and so on.

So, this basically works on the principle of electrical resistivity, sometime we also say that these are the probing methods. So, with the help of different probes you can say by confidence that the soil mass happens to be contaminated. Because, there will be a contrast in electrical resistivity of the soil which is contaminated and which is not contaminated. Electromagnetic methods where you use electromagnetic wave to determine the extent of contamination of the soil mass particularly TDR probe. So, a TDR probe or a Time Domain Reflectometry probe will give you the moisture content, volumetric and the TDR level.

So, TDR level happens to be a function of dielectric constant of the material. So, by using dielectric constant of the material, you can determine whether the soil is contaminated or not. And, this concept is normally used when we talk about advance instrumentation schemes like GPR, where the ground penetrating radar works on the principle of dielectric contrast of the soil mass. If you remember sometimes, I had talked about the k_{diff} value for determining SSA of the soil, a Specific Surface Area of the soil is a function of k_{diff}.

So, this is nothing, but the k_{diff} of k_{hm} corresponding to hygroscopic moisture content and k_{dry} corresponding to dry soil. So that means, with respect to dry soil the dielectric constant of a contaminated soil will be different. So, by measuring or mapping this contrast in dielectric properties you can say that whether soil is contaminated or not. For your information dielectric constant for water is very high, 81 and dielectric constant for air is very less 2 or 3 or 1 sometimes yes. So, this is the scale in between normally we work either we work with fully saturated soils.

So, k is very close to 81 and or we work with the dry soils where k is very close to 2 or 3. However, all these methods have their own limitations so, these limitations are mostly in terms of you know instrumentation or the cumbersomeness which is involved with the methodology itself; sample preparation is a tough task, cost is the tough task. So, this is what I have written here, that limitations are that these methods are quite they depend on the instrumentation which is quite expensive, very cumbersome methodology, intensive and rigorous sample preparation and very time consuming.

Particularly, when you deal with direct methods where you have to extract sample, calibrate the sample or the machine on which you are working and then find out the extent of concentration of contamination. They also deal with complicated procedures for calibration analysis and requirement of skilled and trained personnel is a must. So, looking at this, there is a question in the mind of researchers that can we simplify that things.

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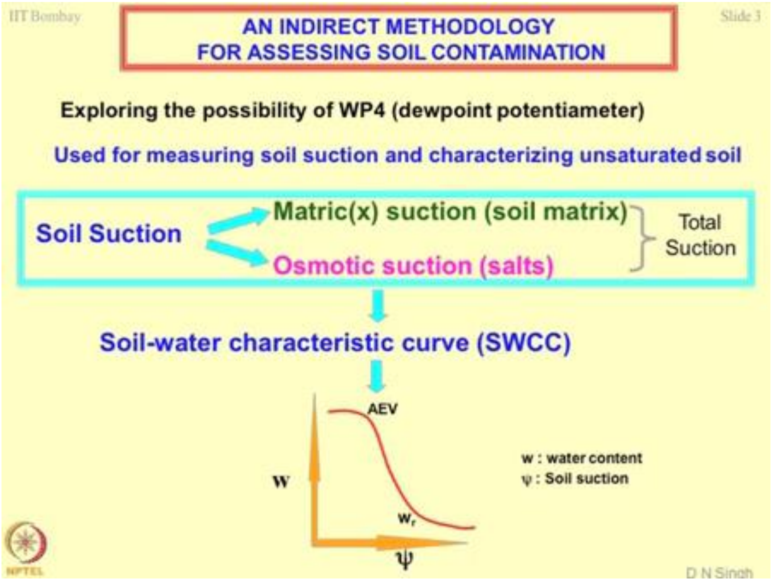

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Slide 3

AN INDIRECT METHODOLOGY FOR ASSESSING SOIL CONTAMINATION

Exploring the possibility of WP4 (dewpoint potentiameter)

Used for measuring soil suction and characterizing unsaturated soil

Soil Suction → **Matric(x) suction (soil matrix)** / **Osmotic suction (salts)** } Total Suction

↓

Soil-water characteristic curve (SWCC)

↓

w : water content

ψ : Soil suction

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So, this is where what we did is we try to develop a new method and this method is shown to be working for assessment of soil contamination. This work was done by Dr. Sreedeep my PhD scholar, this is where we use the possibility of WP4. So, WP4 is an instrument which is known as dewpoint potentiameter, when you come for doing your laboratory experimental geotechnics on 8th October you will be using this equipment to determine suction of the soil.

So, I thought I will cover it here so, that you can follow what you do better in the lab. So, this is where we explore the possibility of WP4 dewpoint potentiameter. This potentiameters are nothing, but psychrometers and all psychrometers work on the principle of relative humidity.

So, this equipment is you used for measuring soil suction and characterizing unsaturated soils. Now, when we talk about soil suction there are two components associated with the suction of the soil. The first one is known as matric suction; some people also call it as matrix suction both are same. So, when we talk about the matrix of the soil; that means, grain to grain contact of the soil then this is known as metric or matrix. So, this suction corresponds to the capillarity of the material. So, this is how we call this as soil matrix; there is another component associated with soil suction which is osmotic suction.

So, this contributes or this contribution is because of the salts which are present in the soil mass. Now, these salts could be in a dry form, they could be in a liquid form or they could be even in a vapour form. So, osmotic suction is nothing, but the presence of salts in the soil which contributes a sort of a negative tension in the soil mass which is known as osmotic suction. So, put together matrix suction and osmotic suction is known as total suction. What it indicates is total suction can be obtained with the help of WP4 that is dewpoint potentiameter. Now, once you are measured this you can develop soil water characteristic curve.

So, what is soil water characteristic curve? It is a relationship between the water content on the y axis and on the x axis is suction soil suction. So, this psi corresponds to total suction, now if you look at this curve what it indicates is for the driest possible soil the suction is maximum, is it not? And for the saturated soil the suction is minimum. So, corresponding to this point you will notice that suction is minimum because, this corresponds to maximum moisture content. So, normally this is what is known as a drying SWCC curve. We always start from a saturated state of the soil and we keep on exposing it to drying either in air or in the psychrometer.

So, slowly and slowly moisture moves out of the sample and then suction generates. So, if you see this curve from this point to this point you are transiting. Now, this is what is known as a drying cycle, the SWCC can also be generated if I do a wetting cycle. That means, a starting from the driest state of the soil mass; that means, from the tail end, if I keep on exposing it to a humidity chamber. So, the tendency of the soil is to take some moisture hygroscopic moisture alright and then the suction will start decreasing.

So, when you develop a wetting cycle curve called as SWCC, it will be traversing in this direction. Now, your senior Seema is working on and Sneha is going to talk about; what is the relationship between wetting and drying cycles of SWCC. Now, can you imagine where this type of concept can be used, not you let others think. Why it becomes so, important to talk about wetting and drying cycles of the soil? That is very good correct, you got the point; you can differentiate between swelling, non-swelling soils just by developing this relationship.

So, how easily the soil will expel moisture from itself can be studied by simple test on a WP4. Otherwise I am sure you will agree with me that finding out swelling potential and identification of swelling type of soils is a very cumbersome process. It would take you at least 3, 4, 7 days depending upon the potential of the soil. So, this happens to be a very quick technique to determine how to differentiate between active soils and passive soils, that is right. Another point which I wanted to emphasize here is hysteresis concept which I had asked you sometime back. There should be some energy stored between the wetting cycle and the drying cycle.

So, the question is that what this energy does to the system whether it is making system unstable or stable. So, the perfect soil would be where there is no difference between a wetting and drying cycle. But then this is a hypothetical soil which you would never get in the nature. So, the basic idea in the mind is can we use this SWCC relationship for determining or creating a scale, activity scale of the soil where you can say with confidence that if activity so, much the hysteresis is going to be less or more or vice versa. So that means, just by looking at the relationship between SWCC of wetting and drying cycles I should be able to estimate the potential of the soils to swell or to react with the environment.

So, this is one of the examples what I am talking about that when we say assessing soil contamination, contamination is going to interact with the soil when the soil is going to be very reactive. For a passive soil effect of contamination will not be much. So, this with this philosophy what we did is we developed indirect methodology to determine the extent of contamination of the soil mass. Is this part clear? Any doubts or any suggestions?

Sir, regarding this slide, the curve which you have shown sir, we can have a down moving type of a draining cycle, upward going type for wetting cycle.

That is right.

Just those sort of thing

Correct you are right. So, if I defend myself by saying that my soil has no difference between wetting and drying, I will be getting a unique curve alright. But your point is well taken yes, it should be, but actually the biggest question in the mind is what is the difference between the drying and wetting SWCC; unless she answers Sneha and Seema I cannot draw two lines on this curve. So, this is a big question right now and I do not want to mislead you.

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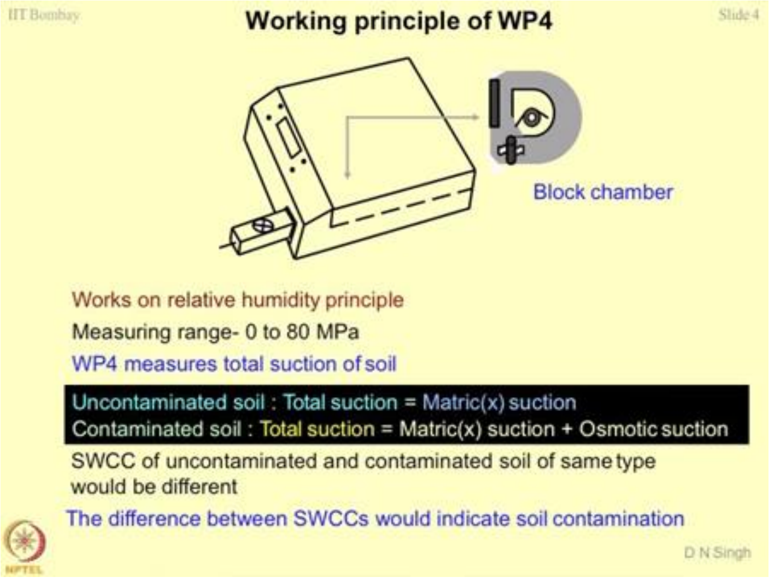

Working principle of WP4

Works on relative humidity principle

Measuring range- 0 to 80 MPa

WP4 measures total suction of soil

Uncontaminated soil : Total suction = Matric(x) suction

Contaminated soil : Total suction = Matric(x) suction + Osmotic suction

SWCC of uncontaminated and contaminated soil of same type would be different

The difference between SWCCs would indicate soil contamination

So, big challenge, well the working principle of WP4 it’s basically a compact unit which contains a block chamber. And, in this block chamber you have an eye over here which is nothing, but a lens and then there is a fan associated with this. So, because of the movement of the fan the sample is kept in this tray and it can be pushed inside; that means, essentially this sample goes and sits just below this chamber.

Now, because of the movement of the fan what happens? There is a vapour pressure equilibrium. And what this device does? It basically senses the amount of vapors which are getting condensed on the lens by using an infrared beam. So, infrared beam basically tells you what is the amount of moisture which is getting condensed on this lens. Because, of this the name of the technique is chilled mirror technology; that means, whatever gets.

Chilled on the mirror.

Chilled on the mirror or fogged or condensed on the mirror this is what you are measuring, clear in terms of volumetric moisture. So, this is also known as a psychrometer, it is known as WP4 potentiameter; you must have seen the spelling of the equipment, it is not potentiometer, it is potentiameter. So, it measures the potential which is negative and due to suction. So, it is a relatively simple device which has been used quite a lot by my students and myself for measuring the total suction of the soil mass, that is the matrix suction as well as the osmotic suction.

So, this device works on the principle of relative humidity and the measuring range is minus 0 to minus 80 MPa mega Pascal, it is a big range. The latest equipments they are now working up to 0 to 300 MPa. So, that way ours instrument is quite absolute you may say. Incidentally you know who were the people who have used this instrument first, which profession they might have used this type of instrument? Any guess? Sorry.

Agriculturist

Yes, you are right agriculturist particularly botanist. Now, can you think a bit more and say what is that they were measuring?

Probably the melting point, melting point of.

That was the answer for agriculturist, for biologist and particularly plant pathologist the size of a stromata on the leaves. So, basically if you keep a leave here, you can find out what is the respiration rate of the plant, respiration rate or evapotranspiration also you can find out from this. So, this had applications mostly in agricultural sciences. Then Dr. Sreedeep went and spend some time in your Kerala University of agriculture. They were the first in the country to have this instrument.

So, we learned from them and we adopted this technology and then we used it in our profession geotechnical engineering. As I said that WP4 measures total suction of the soil; now important thing here to notice is if you are working on uncontaminated soils, the total suction would be equal to matric suction only because there is no osmotic suction term coming into the picture. However, if you are working on contaminated soils, the total suction will be matrix suction plus osmotic suction. So, this was the key to attack on this problem, you can differentiate between you know contaminated and uncontaminated soils just by measuring their suction.

Now, what you are going to see in subsequent slides is a very intelligent thinking which was done by Dr. Sreedeep and let me show you how you can simulate a situation where, from a contaminated soil and uncontaminated soil can be created. Now, can you think of something, some procedure by which you can create unsaturated uncontaminated soils starting from a contaminated soil. When your clothes become dirty what do you do? You wash them clear. So, you keep on washing the soil unless it becomes uncontaminated clear. Now, this concept was used to differentiate between a contaminated state and uncontaminated state of the soil.

And, then we formulated a methodology which can be used now to determine the extent of contamination which is present in the soil mass, is this clear? So, the basic principle is the SWCC of uncontaminated and contaminated soil of the same type would be different. So, this is the key; the difference between SWCC's would indicate the soil contamination. So, these also becomes a very quick or rapid technique to determine whether the soils are contaminated or not clear. Rather than waiting for all those methods where you have to extract the pore solution, you have to do ICP, ASS analysis or gas chromatography and all, it takes lot of time.

So, this becomes a very rapid technique to differentiate between contaminated uncontaminated state of the soils and of course, you can quantify also the type of contamination which is present.

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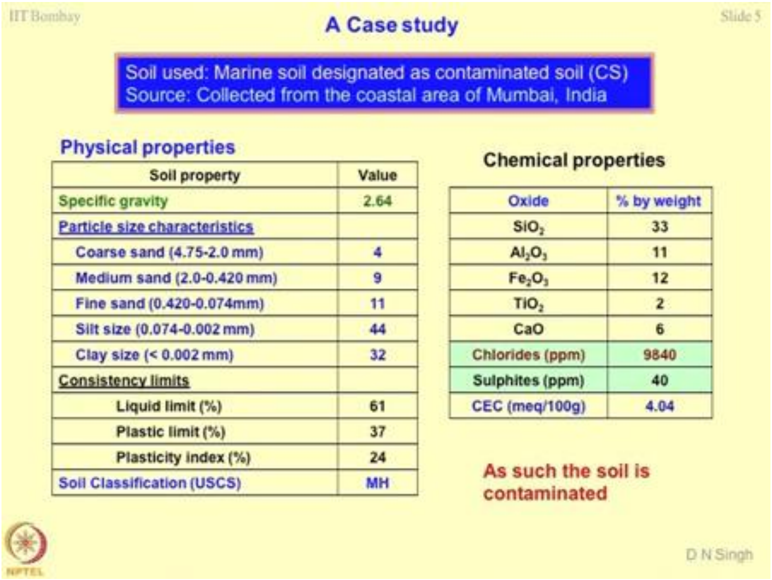

A Case study

Soil used: Marine soil designated as contaminated soil (CS)
Source: Collected from the coastal area of Mumbai, India

Physical properties

Soil property	Value
Specific gravity	2.64
Particle size characteristics	
Coarse sand (4.75-2.0 mm)	4
Medium sand (2.0-0.420 mm)	9
Fine sand (0.420-0.074mm)	11
Silt size (0.074-0.002 mm)	44
Clay size (< 0.002 mm)	32
Consistency limits	
Liquid limit (%)	61
Plastic limit (%)	37
Plasticity index (%)	24
Soil Classification (USCS)	MH

Chemical properties

Oxide	% by weight
SiO_2	33
Al_2O_3	11
Fe_2O_3	12
TiO_2	2
CaO	6
Chlorides (ppm)	9840
Sulphites (ppm)	40
CEC (meq/100g)	4.04

As such the soil is contaminated

So, this is where an electro uses a case study where we use the soil which is of marine origin as a contaminated soil. Now, what is your guess, why I say that this soil is contaminated a marine soil?

Soil salt intrusion.

Sorry. It is not intrusion; the soil has lot of chloride ions or the chloride content itself is very high. So, here we are suppressing the mineralogy and we are simply talking about the chemistry of the soil. That means, for the same type of soil we are seeing the effect of contamination and this soil was collected from the coastal area of Bombay. Physical properties of the soil and chemical properties of the soils were determined, specific gravity is 2.64 which is of any normal clay. These are the particle size characteristics, liquid limit and ultimately this soil gets classified as MH. What is the MH?

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Highly.

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Sorry.

Highly compressible silt.

Highly compressible silt, from where compressibility is coming in soil classification?

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There is no way you can define compressibility by using USCS.

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High.

(Refer Time: 23:41).

Plastic. How do you name MH soil?

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M is for silt, H is for?

High plasticity.

High plasticity, high plasticity silt that is it; compressibility is not coming into picture. I wish somebody develops a classification where, a number corresponds to even the compressibility state of the material that would be the ultimate in our subject. And of course, the chemical composition is like this; here you will notice that chlorides are 9840 is a typical marine clay.

If you collect from Bombay region you will find that the chloride contents may go when up to 15000 ppm; ppm is nothing, but parts per million and sulfides are 40 high, but not so high and cation exchange capacity of the soil is 4. So, moderately active material you can say; now because of these chlorides which are present you can say that soil is contaminated. So, what we did is we started with this soil and then we subjected it to repeated washing to nullify the contamination effect.

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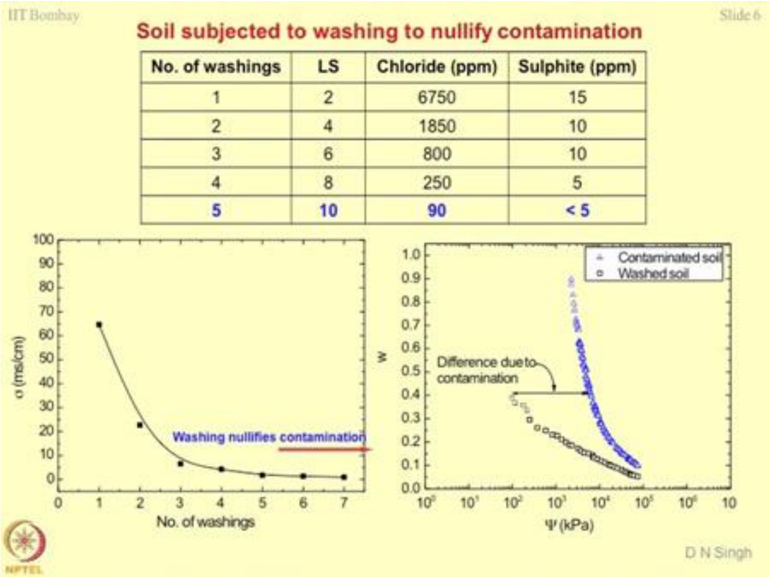

Soil subjected to washing to nullify contamination

No. of washings	LS	Chloride (ppm)	Sulphite (ppm)
1	2	6750	15
2	4	1850	10
3	6	800	10
4	8	250	5
5	**10**	**90**	**< 5**

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So, this is the program which was followed, you keep on washing the sample repeatedly consecutively. So, what happens? The first washing liquid to solid ratio is 2, the second time you make it 4, 6, 8, 10 alright. So, when you are washing it repeatedly, the concentration of chloride ion keeps on decreasing. So, from 9000 something it came down to 6000 up to 90 in the 5th wash and the sulfide content reduced from almost 40 to 5. So, this state of the material we are saying as uncontaminated.

So, what we have done is a contaminated state of the material has been converted into a uncontaminated state. And, we wanted to see what is the difference between the soil water characteristic curves of these two materials.

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Now, this is where electrical conductivity was measured of the soil corresponding to number of washing; that means, every stage of washing of the sample the conductivity of the solution was measured. And, what you will notice is that the conductivity of a solution keeps on decreasing. So, after approximately 5th wash you will say that they are not much of difference. And, hence we have a stopped watching over here. It was saying by the 5th wash the soil becomes almost uncontaminated. Now, if you look at the soil water characteristic curves of the soils, states of the soils on y axis I have plotted moisture content and on the x axis I have plotted suction value.

So, what it indicates is the blue curve corresponds to contaminated state of the soil. First of all, do you agree that this curve is correct or these results are correct or is there some ambiguity? Well, there is no ambiguity by the way; the only thing is I have transformed x and y axis. Why? If you take any moisture content; so, for a given moisture content what you will notice, this suction of a contaminated soil is higher than suction exhibited by uncontaminated state clear.

So, this difference between the two SWCC’s corresponds to the osmotic suction, is it not? Because, by definition a contaminated soil will show you both matrix as well as osmotic suction. However, this soil or this state of the soil will correspond to only matrix suction. So, the difference between the two is nothing, but osmotic suction. So, incidentally this methodology happens to be one of the best methodologies to find out the osmotic suction of the soil also.

Now, you may perform this test when you come to the lab for your experimental geotechnics course. Is this part clear? And, another intelligent thinking you can do is that whatever wash is coming out from each washing that can be analyzed further for elemental analysis. So, this will give you the total elemental composition of the contaminants which are present in the soil mass. So, this seems to be a good technique for determining and differentiating the state of contamination with uncontaminated soils.