Unsaturated Soil Mechanics
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Week - 12
Lecture - 35

Volume Change Behaviour of Bentonite and Kaolin Clay

Hello everyone, we have been discussing the Volume Change of Unsaturated Soils. Let me summarize the basic difference between montmorillonite rich clays such as bentonites and kaolinite rich minerals such as kaolin. Even though both are clays most of the particles are less than two micron size but the behavior is completely different under the application of load when the soils are wet or when the soils are saturated.

One soil exhibits swelling, another soil exhibits collapse. So, the swelling behavior of bentonite is due to the montmorillonite mineral in the soil and collapse behavior is due to kaolinite mineral in the kaolins clay. So, these two phenomena are physicochemical, the volume changes in these two clays is due to physico chemical in nature. Let us quickly go through what difference it makes between montmorillonite and kaolinite.

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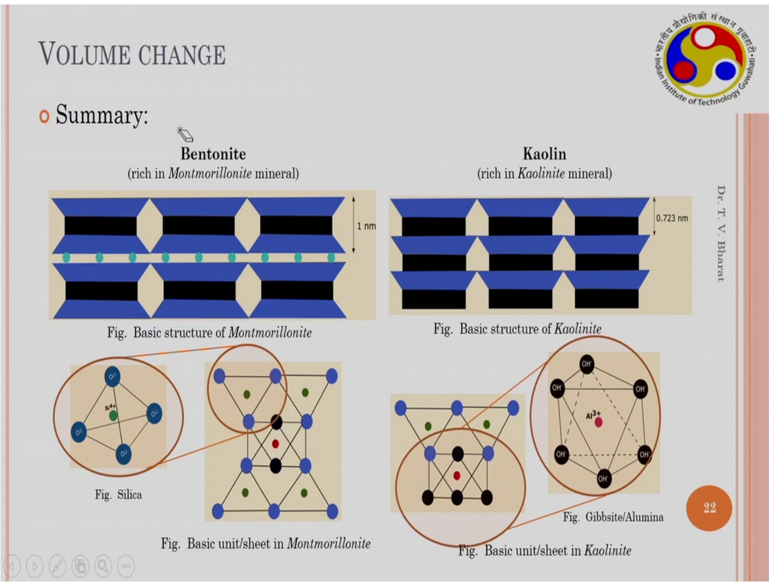

VOLUME CHANGE

- Summary:

Bentonite
(rich in *Montmorillonite* mineral)

Kaolin
(rich in *Kaolinite* mineral)

Fig. Basic structure of *Montmorillonite*

Fig. Basic structure of *Kaolinite*

Fig. Silica

Fig. Basic unit/sheet in *Montmorillonite*

Fig. Gibbsite/Alumina

Fig. Basic unit/sheet in *Kaolinite*

This picture is the basic structure of montmorillonite; bentonite clays contain high percentage of montmorillonite mineral. So, you have silica and alumina so, these are this is 2 is to 1 mineral because 2 silica sheets are attached to 1 alumina sheet. The alumina sheet is sandwiched between 2 silica sheets and this is 1 basic unit and such basic units are attached together with weak bonds. You have here water molecules and some exchangeable cations also might be there in the inter-layer. So, such different basic units are sheets together is called one montmorillonite. The montmorillonite consists of such basic sheets attached in this manner.

So, when the soil is wetted or when the soil is saturated the water can enter into the interlayer space. So, the layers can expand, so the expansion can take place in between these two this distance can increase so that layers can expand. And also the hydration of individual cations, exchangeable cations that takes place and hydration of inter layers and hydration of external surface takes place and after that diffuse double layer should form, this causes expansion of the mineral.

So, here this is a basic unit of silica, silica consists of silicon psi 4 plus and surrounded by 4 oxygen atoms O 2 minus and this is attached to an alumina sheet. So, this is a gibbsite or alumina Al 3 plus which is surrounded by 6 OH minus ions, so this is in 3 dimensional view. And combination of one silica and alumina sheet plus another silica in case of montmorillonite.

In case of kaolinite only one silica and alumina are attached this is that is why this is called 1 is to 1 mineral and one montmorillonite is called 2 is to 1 mineral. So, this 1 is to 1 mineral this whole thing is together is called one sheet. So, one sheet is attached to another sheet by strong bonds like hydrogen bonds. Water cannot enter between these individual sheets, so because the bond is very strong, so therefore, expansion due to wetting does not take place in kaolin or kaolinite mineral.

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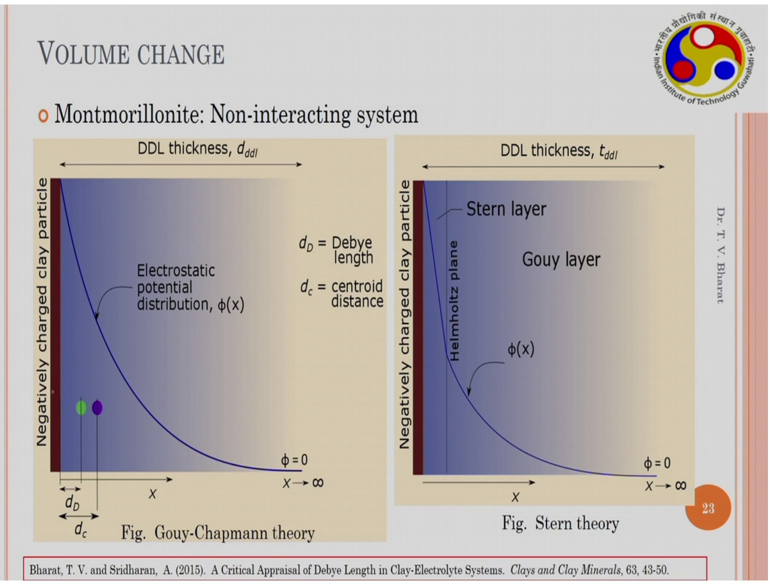

VOLUME CHANGE

- Montmorillonite: Non-interacting system

Fig. Gouy-Chapmann theory

Fig. Stern theory

Bharat, T. V. and Sridharan, A. (2015). A Critical Appraisal of Debye Length in Clay-Electrolyte Systems. *Clays and Clay Minerals*, 63, 43-50.

So, in case of motmorillonite, so the clay particles are negatively charged because you have silica on both sides and the specific surface area is very high. So, the montmorillonite generally has a specific surface area of 800 meter square per gram, but depending on the percentage of montmorillonite that is contained in given clay the specific surface area varies. So, the cation exchange capacity is also significantly high this could be as high as 100 to 110 milli (Refer Time: 04:57) per gram.

Such a high values of surface properties montmorillonite will have, so the generally the bentonite clays will have very high values of cation exchange capacity and specific surface area. So, therefore, the surface potentially is very high. So, the potential distribution happens around the clay platelet when this is completely saturated. So, this is a diffuse double layer or film water film that is formed around individual clay platelet. So, this is a electrostatic potential distribution phi of x or you know non dimensional form its can be written as y of x.

So, there are several theories whether the electrostatic potential distribution happens in this manner or there is a linear variation up to certain distance and after that it distributes it has a Boltzmann distribution depending on different theories. One theory Gouy Chapman theory assumes that there is a Boltzmann distribution around individual clay particles and this is how the distribution is. And in Stern theory there is a Stern layer of thickness equivalent to hydrated exchangeability cationic size and beyond that the distribution is similar to the Gouy Chapman theory. So, when the clay particle is saturated along with the clay platelet there is a film that is surrounded by this clay platelet.

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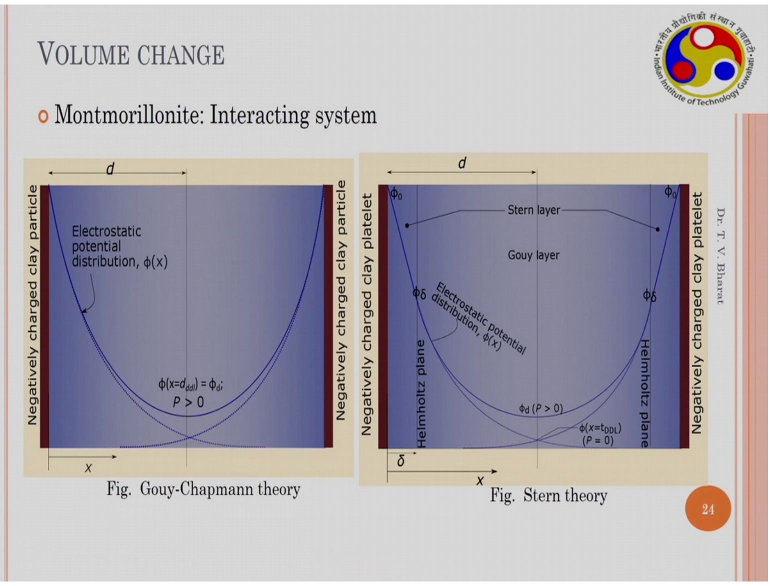

VOLUME CHANGE

- Montmorillonite: Interacting system

Fig. Gouy-Chapmann theory

Fig. Stern theory

So, therefore, when two individual clay platelet us approach each other. There is a repulsion between the positive diffused double layer and another positive diffused double layer from the other particle. So, due to this repulsion the particles go away from each other and under gravity the particles will be arranged to just one on each other and the interaction is close to 0. But however, when there is a force or external pressure is applied on individual particles. So, the particles approach each other potential at the mid plane at the mid distance will start increasing.

So, these dotted lines are electrostatic potential of individual clay platelet us but due to the interaction this is a potential distribution that develops. So, this potential is a phi d r, in non-dimensional form this is u. A non-dimensional mid plane potential this is related to the osmotic pressure that is generated due to the interaction of these two diffused double layers.

So, the osmotic pressure that is developed within the clay platelet us is related to the external mechanical force or pressure that is exerted. So, at equilibrium the pressure mechanical pressure that is exerted is related to the osmotic pressure that is generated due to the given mid plane potential. If the mid plane potential goes to 0 r approaches to

0, then the osmotic pressure is 0, then this is under 0 external load condition, so that is free state. And in case of stern theory we have a linear variation of potential up to the delta distance and beyond that you have the Boltzmann distribution and this is how the mid plane potential varies.

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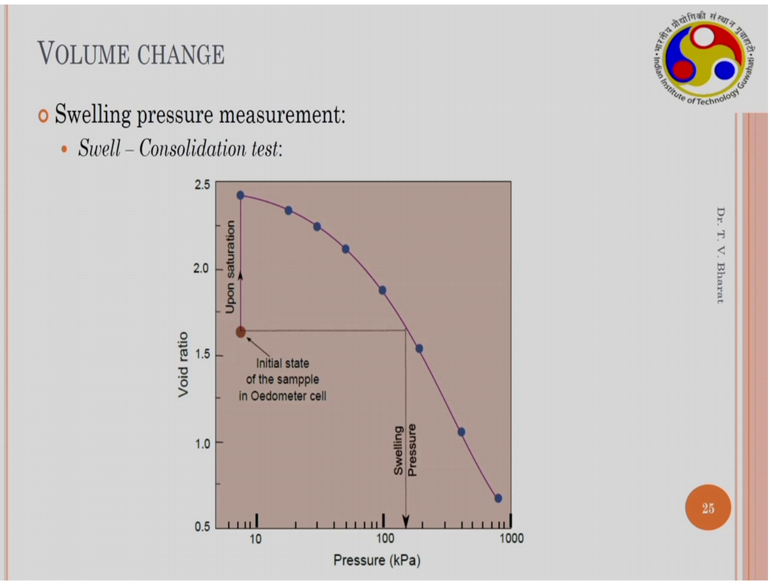

VOLUME CHANGE

- Swelling pressure measurement:
  - *Swell – Consolidation test:*

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So, now knowing this we can easily understand that if you place a soil, bentonite soil in a beaker volumetric flask which has water soil swells and it occupies huge volume. This volume is of the sediment volume is significantly high and this can be compared with the sediment volume that is occupied with clay in the presence of kerosene. So, this sediment volume is significantly high this explains that the soil can swell enormously.

So, because it can swell under confined environment it exerts swell pressure on the surroundings which can be measured. If the volume change is not restricted then it exhibits swell potential and how the swell potential varies with time we have seen earlier and the swelling pressure can be obtained by different techniques. One technique is swell and consolidation initially the sample is taken and this is void ratio versus pressure plot.

So, initially the sample is taken in oedometer cell and when this is saturated it swells or the void ratio increases and this is the at equilibrium void ratio, under some (Refer Time: 09:57) pressure say 6.25 kilo Pascal or 5 kilo Pascal. Then this is consolidated by applying loading and this consolidates in this manner.

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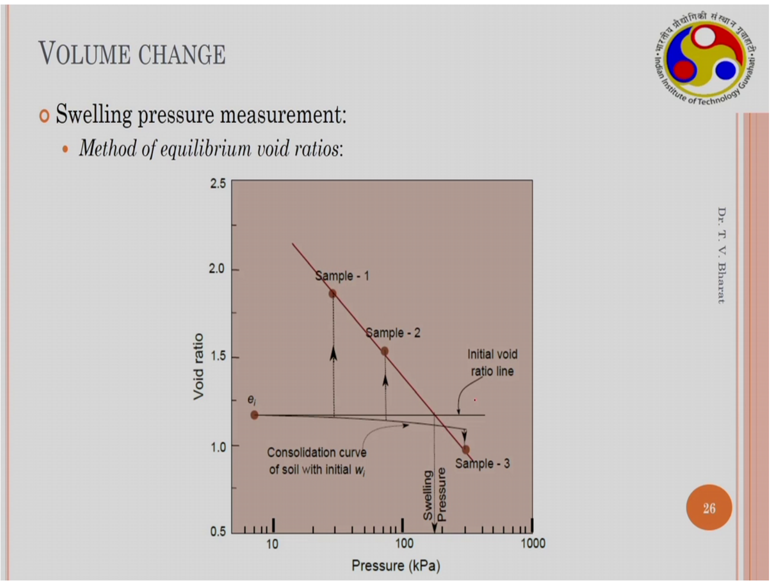

VOLUME CHANGE

- Swelling pressure measurement:
  - *Method of equilibrium void ratios:*

When we draw a horizontal line and the corresponding swell pressure can be obtained similarly a method of equilibrium void ratios can be used where the initial soil sample is compressed in this manner under different loadings and this is saturated at different pressures at different mechanical loading. Then it exhibits swelling nearly below swelling pressure value and when the mechanical load is more than the swelling pressure it starts collapsing or volume decreases. So, when you join this straight line combining all these the equilibrium void ratios after its fully saturated state wherever this line crosses the initial horizontal line extended from the initial void ratio that corresponding pressure is swelling pressure.

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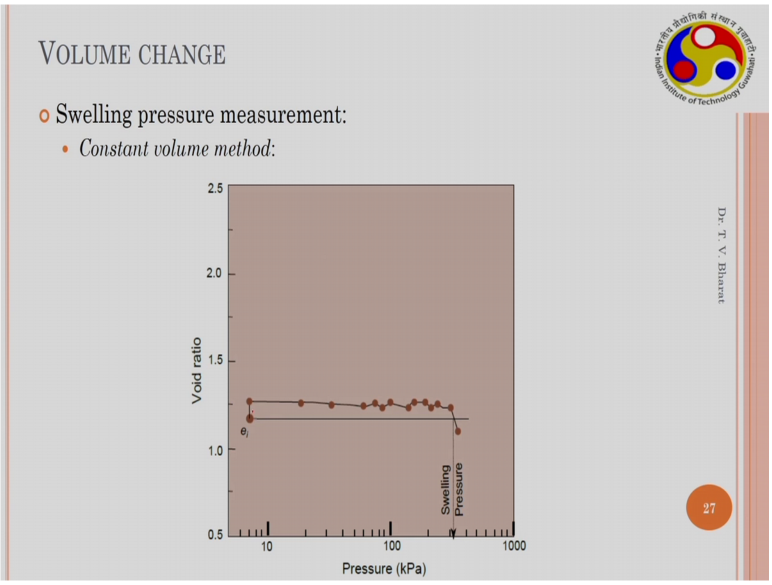
VOLUME CHANGE

- Swelling pressure measurement:
  - *Constant volume method:*

So, the last one we have seen constant volume technique. Here soil is a wetted or saturated and it starts increasing it is volume then you apply small load, then it decreases its volume and this is how a constant volume is maintained. And it starts decreasing it is volume below the initial void ratio if the applied pressure is more than swelling pressure. So, in these techniques we can measure the swell pressure.

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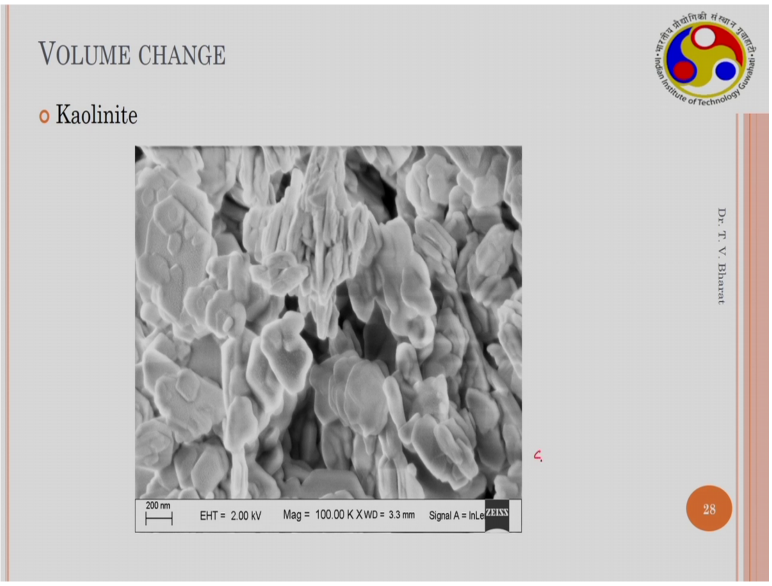
VOLUME CHANGE

- Kaolinite

So, in case of kaolinite this is a picture from scanning electron microscope. Scanning electron microscope provides the particle associations, so in this manner this size is around 200 nanometers. So, the scale is 200 nanometers, so this much distance is 200 nanometers. And here you can clearly see that the particles are arranged in card house manner. So, huge wide space is available in between this is macro pore volume. Similarly here different particles are arranged in this particular manner and this is the wide space, this is the wide space and this is the wide space, so these are macro pore volume.

And here you have one aggregate so, this is not a single particle it is an aggregate of different platelet us. So, here in between these platelet us whatever the volume pore volume that is exist that is micro pore volume so, this clay has exhibits double porosity. So, under applied load the card house structure cannot be broken and it maintains the card house structure, but macro pore volume slightly decreases. So, when this is saturated the macro pore volume collapses and particles would get arranged into face to face manner which reduces the volume essentially.

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- Kaolinite – Volume change

$IEP_{edge} = 6.05$

So, it again depends on the pH of the environment as explained earlier. So, when kaolinite is taken in and placed in volumetric flask of volume 100 ml at one particular pH, pH is around 3. So, the volume of the sediment is this much. So, the volume of sediment decreases with increase in the pH in this manner this is 6.05 or something and this is 4.97, like that it decreases. And once it crosses 6.05 the soil exhibits a dispersive nature here you have a clear solution.

Here even though you wait for several months the soil will not settle. So, this is a dispersed sediment and this is a clear sediment which is flocculated these are all clear and this is at a higher ph say a 7.17 or something where you have a more dispersive sediment available and this is a higher pH 7.36 or something. And here you have more dispersive solution and as the pH is increasing more and more dispersive solution is available, soil becomes dispersed.

So, at lower pH lower than I selected point of the edge the particles are arranged in edge to face or shifted face to face manner. So, they settle immediately and then they form sediments clear sediments like this and beyond IEP edge the particle arrangement is face to face and they form dispersed sediment in this particular manner. So, the particle arrangements would change depending on the pH environment also the pore fluid concentrations or the presence of salts in the pore solution and based on that the particles get arranged into different manner, like face to face, or shifted face to face, edge to face or different arrangements they undergo and which causes change in the volumes.

Similarly, the low soil it exhibits collapse due to the mechanical behavior there may be some bond like Van der Waal forces etcetera they exist between individual quartz particles, silica sized quartz particles and clay bridges exists between individual platelet us because of the negative pore water pressure. As soon as this negative pore water pressure is absent due to wetting the entire structure collapses so, that is in low soil.

So, as the behavior of individual soil varies depending on either physicochemical characteristics of individual clay or due to presence of suction or presence of some clay content etcetera. So, developing generalized constitutive surfaces or generalized constitutive models still people are working on developing generalized constitutive surfaces relating suction, degree of saturation, mean stress that is applied load and volume change, specific volume. So, this will be the generalized surfaces can be developed by controlling suction and observing what is the degree of saturation under what load this is done and what is the volume change. Such constitutive surfaces are built by conducting control tests.

Thank you.