Unsaturated Soil Mechanics

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Week – 11
Lecture – 33
Swelling Behaviour of Soils

Hello everyone, we have been discussing the volume change behaviour of unsaturated soils. So, previously we have discussed, how the suction controlled volume change behaviour can be obtained in suction controlled consolidometers and isotropic consolidation tests in suction control tri-axial tests. So, mostly the behaviour of such soils under controlled suction are analyzed for developing constitutive relationships and for understanding the stress state of the soil at any given condition, under loading condition and the change in the volume, how to obtain the change in the volume with degree of saturation and change in the water content and suction can be combined into constitutive modeling. And, say continuous behaviour of the soil from wetting to drying or drying to wetting can be model.

Today, we will discuss few topics related to initially, we will discuss constitutive model, which is a given by recent researchers on how to incorporate the volume change also into suction water content relationship. And, after that we will start discussing about Swelling of Soil.

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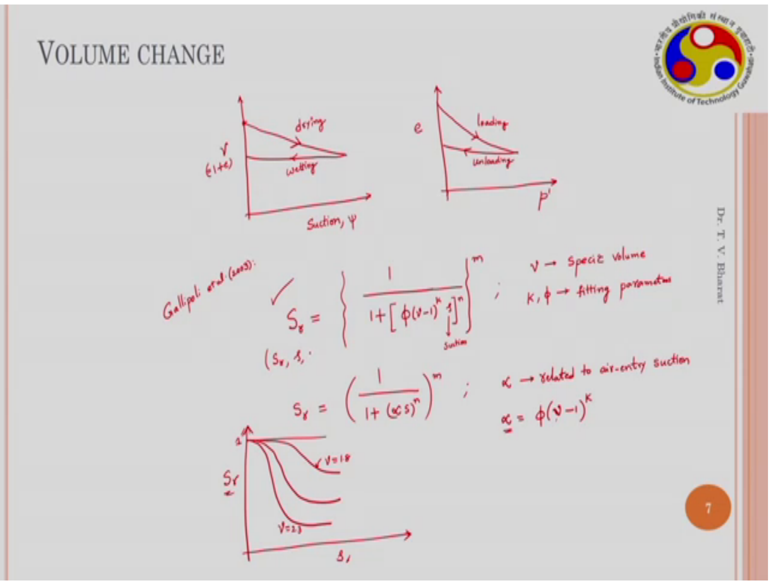

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Gallipoli et al. (2003):

$$\checkmark \; S_r = \left\{ \frac{1}{1+\left[\phi(v-1)^{k}\,\underset{\text{suction}}{\underset{\downarrow}{s}}\right]^{n}} \right\}^{m} \; ; \quad v \rightarrow \text{Specific volume} \quad k, \phi \rightarrow \text{fitting parameters}$$

$(S_r, s,$

$$S_r = \left(\frac{1}{1+(\alpha s)^{n}}\right)^{m} \; ; \quad \alpha \rightarrow \text{related to air-entry suction}$$

$$\underline{\alpha} = \phi(v-1)^{k}$$

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As we have seen earlier, the specific volume which is represented as v or nu with suction follows in this particular manner initial the specific volume maybe somewhere here, then the suction is 0 that is fully saturated state. As the suction increases this, when it is dried it follows this curve and when it is wetted.

So, this follows this relationship this curve. So, this is similar to void ratio and load or effective stress has a load or effective stress increases the soil compresses as a load is released or when the unloading is taken place the soil expands, but it does not come to the original condition. So, the behaviour of soil under unsaturated condition is very similar to the soil in the saturated condition qualitatively because, during drying and wetting.

So, this is loading drying is similar to loading and wetting is similar to unloading. So, here it is 1 plus c, the specific volume is 1 plus c. So, these 2 are related. So, now, there is a constitutive relationship given by Gallipoli etal in 2003 to modify to incorporate volume changes also in suction water content relationship. So, he has proposed this relationship the degree of saturation is this is a 1 by 1 of 1 plus or relationship is the vengeance equation is modified by incorporating the changes in the volume.

So, here the nu is a volume change or a specific volume and here psi and phi are fitting parameters. So, as we represent psi for suction let me use a different parameter here k k and psi are the fitting parameters and s is suction. So, if you compare original (Refer

Time: 05:01) equation, which is written as 1 by 1 plus alpha s over n whole power m. So, here alpha is a fitting parameter related to the air entry suction or 1 over air entry suction is the function of or related to air entry suction.

So now, alpha is substituted with phi times specific value minus 1 power k. So, as the air entry of the soil changes with change in the pore geometry, when volume of the soil changes the air entry of the soil also changes because, if we consider initially saturated soil, when it is dried the volume of the sample changes, but degree of saturation remains same. So, as the water release from the soil system, the void ratio decreases. So, therefore, air does not enter into the system.

So, it is before alpha is related to the alpha, which is the parameter, which is related to the air entry value is related to the void ratio. So, as the void ratio is decreasing the saturation can be kept constant until certain value and beyond the rate decreases. So, therefore, if this is plotted as degree of saturation versus suction, it is seen that for a given controlled volume specific volume, it is seen that for high specific volume, it exhibits this behaviour for high specific volume, this is 1. For high specific volume, it exhibits this behaviour and for moderate it exhibit this behaviour as a specific volume decreases maybe, 1.8 or something this exhibit this behaviour and this is at constant specific volume. So, this is at 2.3.

So, under constant specific volumes the relation between degree of saturation and suction follows this relationships pattern, using this particular equation. So, it defines the surface so, soil water characteristic surface in degree of saturation s and nu space with three dimensional space.

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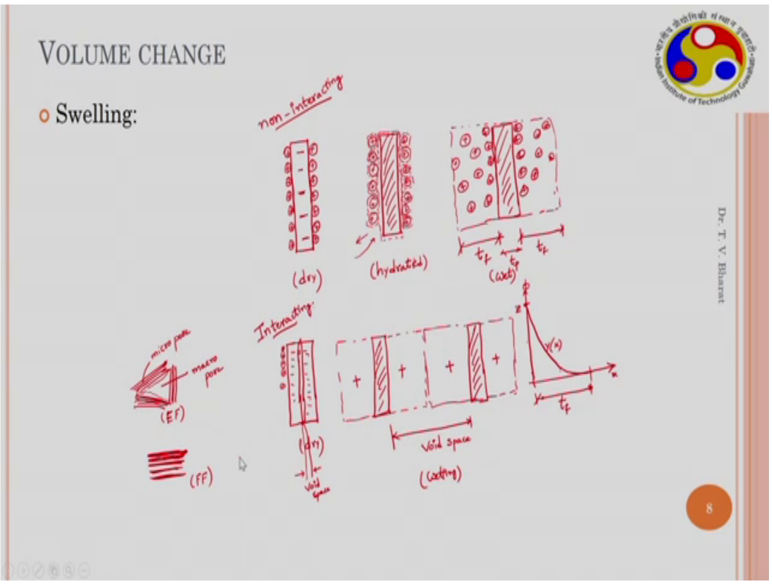

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- Swelling:

So, most of such relationships are very useful for understanding the continuous behaviour of soils from wetting to drying or drying to wetting and how they behave in a cyclic manner, they can be modelled using such relationships. And, critical states soils mechanics theories require such kind of a relationships such relationships too. And, let us understanding, how the swelling of the soil takes place during wetting, we must have heard that there are swelling soils or expansive soils. So, these are the soils when there wetted or saturated the volume of the sample increases. So, the volume of the sample increases because the expansive soils contains clay minerals. which are mostly the (Refer Time: 08:35) mineral or (Refer Time: 08:36) mineral. The particles of these minerals are kaolinite, the particles of these minerals contain negative charge on the surface due to isomorphous substitution.

Due to the isomorphous substitution so, the silica may be replaced by the alumina. So, the alumina is alumina replaces the silica in tetrahedral sheet. So, this causes net negative charge on the clay surface. So, due to this negative charge on a surface clay particles acquire positive ions these are cations on its surface, during the exposure to the environment after they formed. So, these are the exchangeable cations, exchangeable cations means so, these cations can be replaced with another cations. So, they can be removable or exchangeable not removable exchangeable. So, the alumina we fine so now, so when this particular particle is hydrated. So, then or when water is absorbed, the water is absorbed from the atmosphere. So, they get hydrated. So, there is a thin film around clay particle that is formed and the ions also get hydrated.

So, these broken lines are the hydrated or the broken lines show the hydration. So, generally these layers are multiple layers like more number of multiple layers can be formed around these cations and the surface. So, the particle when this clay particle is completed wetted, there is a diffuse double layer or a water film that is formed around the clay platelets. This is a clay platelet and the water, when it is available in the bulk solution. So, generally the ions straight diffuse away from the clay particle. However, the clay particles try to hold ions around the surface because, they have affinity towards these cations. Therefore, water enters into the surface of the clay particle, when water enters these ions gets distributed around the clay platelet, in this particular manner.

So, the concentration in the outer layers is very less. So, the concentration of these cations are very high near the surface, these are all in hydrated stage only. So, this is individual film thickness. So, this is another film thickness around clay platelet. So, this is particle thickness clay platelet thickness. So, initially this so, this is at dry state. So, this is hydrated particle and this is completely wet are saturated particle. So, here if you see the potential, the electrostatic potential to presented, may be with phi with the distance if you see so, it distributes in this particular manner.

So, the potential is higher here at the surface, in non dimensional format can be represented with z and which decreases, which is the function of x distance from the particle surface, this is distance from a particles surface. So, this is a particle if this is a particle is an distance from the particle is x then the potential drops, the non dimensional potential drops in this particular manner and which goes to 0 at bulk solution and diffuse regular interface. So, this thickness is your t f film thickness.

So, now when particles are at dry state, when they are compacted the particles maybe interacting in this particular manner. So, this is one particle and this is another particle. So, particles are if there is a small water that is available then there will be held in this particular manner and then where very close, very close to each other. They may have surface exchangeable cations particles are very close to each other, but as soon as this is a dry state. So, this is a non interacting system. So, this is interacting system.

So, when the soil is completely wet. So, you have 1 clay platelet and you have film thickness around individual clay platelet and that is one particle and you have another particle. So, this is positive ion double layer and this is also positive ion double layer. So, because of the repulsion between these 2 double layers the particle distance increases and which is the void space. So, initially the void space is this much only and now the void space in complete wetting is this. So therefore, when the clay is wetted so, the particles distance increases. The particles distance increases because, the diffuse double layers form around the clay platelets and this is a thin, there is a film that is formed around clay platelets, because of this these diffuse double layers triple each other and void space increases.

So, this is a idealized situation, but the clay platelets at dry state may not be like this, dry state clay platelets, may be arranged in this particular manner. So, generally they have 2 pores, this is called micro pore and this is called macro pore. So, when this clay platelet is wetted so, then at fully saturated state, the clay platelets turn to be in this manner. So, this is flocculated are edge to face flocculation and this is face to face dispersion. So, the particle arrangement also changes with addition of water. And because of the macro pore that is situated, this because of this initially, some void space may be available as you compare this void space or macro pore volume will get decreased.

So, when it gets decrease more particles are arranged into face to face arrangement and during saturation as the diffuse double layers form for individual clay platelets as diffuse double layers around the clay platelets form sorry, individual clay platelets, they are arranged in this particular manner, because of the repulsion between individual clay platelets. So, when the diffuse double layer forms around this. So, there is a repulsion between this particle and this particle and they get arranged automatically in to face to face arrangement, they are brought into face to face arrangement automatically.

So, this is a reason for the manifestation of swelling in macro scale. In micro scale or nano scale there is a formation of diffuse double layer are film around clay platelets due to the isomorphous, due to negative charge on a surface, that is due to isomorphous substitution. And, it forms film water film around clay platelet, which contains positive charge and when there is a repulsion between these 2 films so, there is a volume increase or the swelling takes place. So, the swelling is a manifestation of formation of diffuse double layers and hydration also place some role. This can be visualized or understood very clearly with simple thought experiment so, which is commonly frequently done test in laboratory, which is called free swell test or equilibrium sediment volume test.

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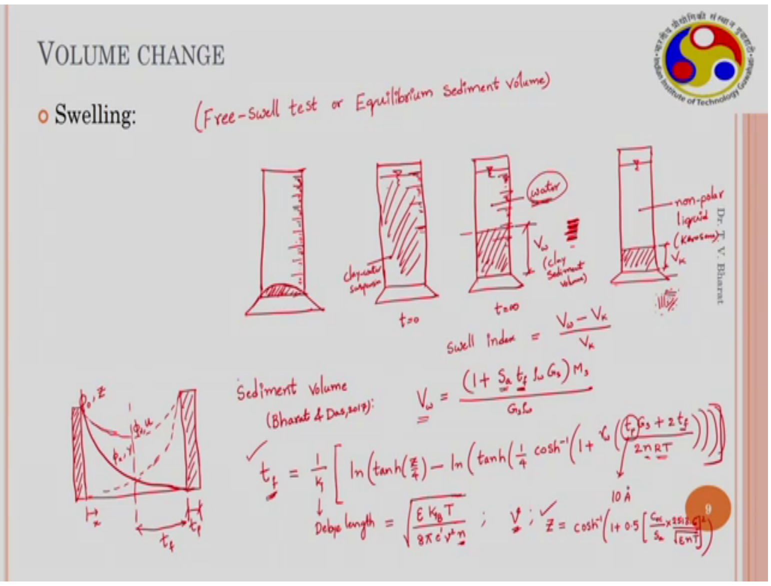

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- Swelling: (Free-Swell test or Equilibrium Sediment Volume)

Swell Index = $\frac{V_w - V_k}{V_k}$

Sediment volume (Bharat & Das, 2017): $V_w = \frac{(1 + S_a t_f \rho_w G_s) M_s}{G_s \rho_w}$

$t_f = \frac{1}{K_1}\left[\ln\left(\tanh\left(\frac{Z}{4}\right)\right) - \ln\left(\tanh\left(\frac{1}{4}\cosh^{-1}\left(1 + \ldots\right)\right)\right)\right]$

Debye length = $\sqrt{\frac{\varepsilon K_B T}{8\pi e^2 v^2 n}}$; $Z = \cosh^{-1}(1 + 0.5[\ldots])$

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So, when you take a beaker, in this particular test we take a beaker, which has graduation scaling, which are scaling on the surface. So, in this you put clay powder then the volume occupied is very very small, may be if you put 2 gram of bentonite or 2 gram of expansive clay into 100 ml beaker and the volume is this much only, but as soon as you add water and thoroughly mix it. So, this you can prepare clay dispersion, you can prepare a clay suspension, clay water suspension, this is at time t equal to 0 as soon as you mix with water, but after certain time. After certain time, you see that this is a clear water level and this is clay sediment.

So, this is a clay sediment volume in water is called clay sediment volume at equilibrium, because the slowly the clay particles will start settling under gravity and they occupy this volume at equilibrium. So, this is time t equal to infinity at equilibrium. So, the volume of the sample at equilibrium in water is this much. So, because each individual clay platelets, when they are dry state, they are very close to each other and they may be the volume occupied by this clay is very small. But, several folds the volume increases because, the increase in the diffuse double layers around the clay platelets with saturation.

So, this can be very clearly understood by conducting another test in non polar liquid. So, another test can be conducted choosing 100 ml solution. This is non polar liquid like kerosene. So, we can use kerosene and conduct a test and the volume occupied by the clay particles, now is only this much. So, volume occupied by segment volume in kerosene. So, here this is distil water and this is kerosene. So, the this is often indicated as swell index, which is equals to volume in water minus volume in kerosene by volume in kerosene. Because, in case of kerosene, this is a non polar liquid, the diffuse double layers around the clay platelets would not form and particles, if there at all arranged they may be arranged in flocculated manner like this and you have pore plate like kerosene around it.

The diffuse double layers would not form. So, the volume occupied by sediment in kerosene is only this much and as when the diffuse double layers form here, the particle arrangement is parallel and there are diffuse double layers around each individual particles. So, this is thickness of individual clay particle after diffuse double layer is considered. So, there arranged in parallel plate and this is the volume that is occupied. So, this is significant volume that is generally occupied.

So recently, we have given the formulation for the sediment volume. So, the sediment volume: sediment volume in water, water can be theoretically obtain from theory by Bharat and Das like using this particular expression, where t f the thickness of the film is equals to 1 by kappa log tan h of z by 4 minus log tan h of 1 by 4 cos h minus 1 plus gamma w times t p G s plus 2 t f by 2 n RT. So, this is the expression. So, here the sediment volume can be directly estimated using if you know the surface area of the clay specific surface area of the clay, which is expressed in meter square per gram and thickness of film that is diffuse double layer thickness of for individual clay particle.

So, if that is known that can be estimated using this equation and rho w density of water that is 1 gram per centimeter cube you can use, G s specific gravity of solids that needs to be estimated and used and this is mass of solids initially 2 gram of soil, if you take this is 2 gram divide by specific gravity into rho w. So, here the thickness of film is equals to 1 over kappa. So, this kappa is called Debye length, which is the which is related to the pore fluid property Debye length is equals to square root of dielectric medium a dielectric property of the fluid. So, in this case it is water therefore, there is 80.4 and Boltzmann constant K b times T temperature in Kelvin 8 pi electron charge and valence square times the concentration here, where and when we are using, what are the concentration will be very less maybe, you can use 10 power minus 4 10 power minus 5 molar.

So, this is the kappa Debye length log tan h, z is the surface potential, which I describe the previously in the previous slide. So, if this is the clay platelet. So, the charge distribution or potential distribution varies in this particular manner around the clay platelet, this is a with distance x at surface, the surface potential is either phi 0 or non dimensional from this is z and this is the variation phi x or y, this is non dimensional form.

So, this is for individual clay platelet. So, if you have 2 platelets, there interacting. So, for individual clay platelet, this also should vary in this particular manner, but due to interaction, there is a some potential that is developed here, which is called mid plane potential phi d or non dimensional form u. So here, the z is surface potential minus log tan h 1 by 4 cos h inverse 1 plus gamma w into t p is a thickness of clay platelet.

So, this is thickness of clay platelet and this is sickness of film, film thickness. So, thickness of clay platelet generally for smectite minerals it varies between 10 angstrom units to 40 angstrom units, we can use an average value of 10 angstrom units and even, it could be could be less than that also, but then we can use of mean particle size of 10 angstrom units and this is not very sensitive even, if you use 40 angstrom units, it does not significantly alter.

So, specific gravity and thickness of film so, this is a implicit equation. So, thickness of film is in terms of thickness of film. So, you need to give some value of thickness of film and then solve this expression and then see whether, this is matching with the right hand side term. So, then that is how this can be converged and 2 n RT, RT this is RT gas constant RT temperature in Kelvin n is a concentration same as this same as this one. So, this particular equation can be used to understand the sediment volume that can be occupied, when there is no mechanical forces, there is only one body force that is considered that is gravity.

So, under the gravity the particles are arranged in this particular manner. So, there is only physicochemical forces electrostatic potentials around the clay platelet due to negative charge on a surface and there is a body force. So, when the body force and surface forces are at equilibrium. So, this equation is valid and particles are assume to be parallel to each other and that assumption is also valid only. So, the only issue could be the valance, what valence should be considered here? You have several exchangeable cations around the clay platelets. So, it could be sodium, calcium, potassium, magnesium sometimes and such different cations could be possible could be available around clay platelet and when the cation exchange capacity is determined for individual cations, what is a amount that is contained also can be determined.

So, from that if you determine, what valence should be used as a question and people often use average valance and are depending on the dominant cations that are present people might use 1, if it is sodium 2, if it is dominant is calcium like that. So, therefore, this particular expression is more valid in case in case of in case of if you use instead of water, if you use sorry, this situation is very valid and it is shown that it exactly predicts the experimental observations provided, if you have humanized clay. So, clay should contain only 1 single dominant cation as an in exchangeable state.

So, then it can provide exact solution, exact prediction of sediment volume. So, if you have multiple ions then instead of water, one particular pore fluid at concentration near 1 molar or 0.1 molar could be used. So, that. So, the influence of other cations will be suppressed and. So, we can use a concentration given concentration and valence, one could be used to predict the sediment volume accurately. So, this provides us the concept of swelling and the maximum selling that takes place under 0 mechanical stresses, it often the swelling also takes place under mechanical loading.

So, when the so, here the z also can be obtained z is a specific surface area, sorry z is the surface potential in non dimensional form that can also be obtained using this particular expression cos h inverse of 1 plus 0.5 times C ec cation exchange capacity divided by specific surface area times 2513.6 by square root of dielectric constant concentration temperature in Kelvin whole square. Using this expression, we can determine the surface potential non dimensional in non dimensional form this is a whatever we have so far seen is the maximum swelling that takes place in clay soil under completely saturated state, but under mechanical loading is often is interest to the geo technical community.

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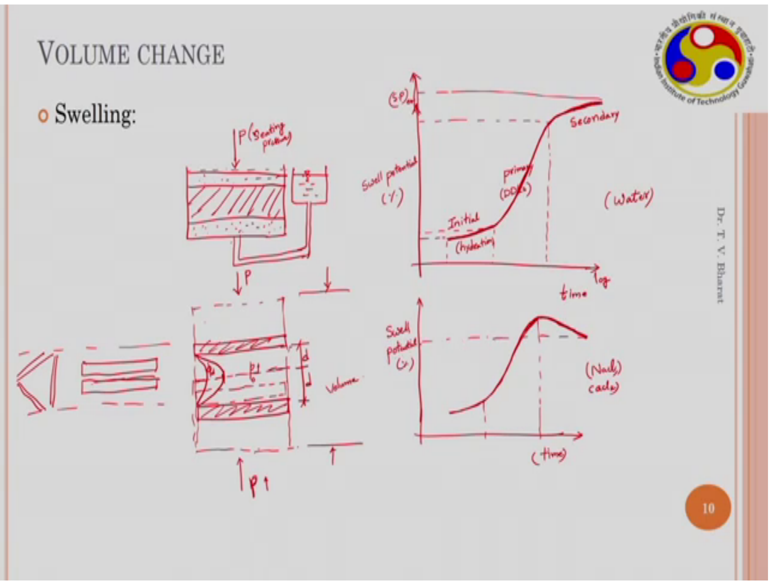

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- Swelling:

The free swell tests are also conduct under slight mechanical loading, where in the consolidation setup, where you have porous stone. So, this is the free diagram, free body diagram and when these are illustration and not all the parts are shown here, you have porous plates and you have a clay sample, which is initially at completely dry state, which is probably compacted at hydroid (Refer Time: 33:22) state. So, then when this is connected to a reservoir. So, saturate the sample. So, this is completely saturated now. So, we have a top plate and then you applying loading on this probably, this is nominal loading I called seating loading or seating pressure, when that seating pressure is applied and when it is started saturating, when you start saturating the soil sample, it start to swell.

The swell behaviour with time is interesting. Swell expressed as percentage versus in log scale the time is plotted, which is seen that which goes through some small swelling initially and then after that there is a sharp increase in the swelling potential. Swell potential probably, this can be written as swell potential, sharp increase and then the increase in the swell potential decreases and reaches in equilibrium value after certain time. So, initially the it has the rate of swell potential is smaller and slowly after reaching certain time, the swell potential rate is very high and again after reaching certain time, the swell potential drops.

So, this is divided into 3 different stages in the first stage, this is called initial swelling and in the second stage, this is called primary swelling in the last stage, it is called secondary swelling. So, the initial swelling is thought to be due to the hydration of interlayer clay minerals and hydration of exchangeable cations and hydration of surfaces clay, clay particles surfaces. So, this is due to hydration. So, therefore, this is a small quantity smaller amount the swelling due to hydration is only small and the primary swelling is due to formation of diffuse double layers.

So, the formation of diffuse double layers is significant swell potential, you observe that is that is why it is called primary swelling and secondary swelling is thought to be due to the distribution of water in the within the clay surface and that causes a slight increase in the swell potential. So, this is this is because, there were few tests that all conducted with instead of water, they have conducted with this is with water, when that similar tests are conducted with different pore fluids like sodium chloride or calcium chloride, it is observed that. So, the you have initial swelling and you have primary swelling and beyond that the secondary swelling decreases.

So, the potential swell potential decreases. So, the volume decreases in this particular manner. So, this is a primary swelling and this is a sorry, this is initial swelling and this is primary swelling, the secondary swelling decreases because here, the diffusion of ions that takes place is believed to be due to the diffusion of ions that are taken place and because of that diffuse double layer thickness will reduce again. So, initially the water is hydrated around the clay platelets and cations surface cations and after that there is diffuse double layer formation and after that as your, adding with NaCl and CaCl 2.

So, here the calcium or sodium as they start diffusing, because of this diffusion the diffuse double layer thickness decreases slightly and then which causes decrease in the swell potential. So, that is because this clay platelet. For example, if this is assume to be like this only individuals clay platelet and these another clay platelet and when the diffuse double layers form under the gravitational pull, they may be arranged in this particular manner. So, this consists of actual volume after full saturation initially, the particles maybe situated in this particular manner under gravity or it could be in this manner.

So, now under the gravity, this is the volume. The clay platelets the clay platelets occupy, but this is the volume after full saturation, these are the diffuse double layers. Now under the particular loading say P. So, this is diffuse double layer potential, this is how the potential varies. So, that is a phi with distance, this is mid plane distance, this is mid plane distance. So, of this is phi d at the at this point. So, this phi d is related to the osmotic pressure osmotic pressure at this particular distance. So, this osmotic pressure P 0, which is generated due to the mid plane potential are physicochemical effect is equal to the applied pressure applied mechanical pressure.

So, always this should be at equilibrium, when this pressure is increased, the pressure is increased osmotic potential will be increased by decreasing the distance between these 2 particles. So, the particles would move into the new location, which move close to each other and this potential increases the phi d increases and P also increases to the same amount as a mechanical pressure. So, these are all at equilibrium every time. So, under that particular load, this is the swell potential, we measure with time and this is at equilibrium. So, this is at equilibrium swell potential and this is also at equilibrium swell potential. So, this is swell potential at equilibrium.

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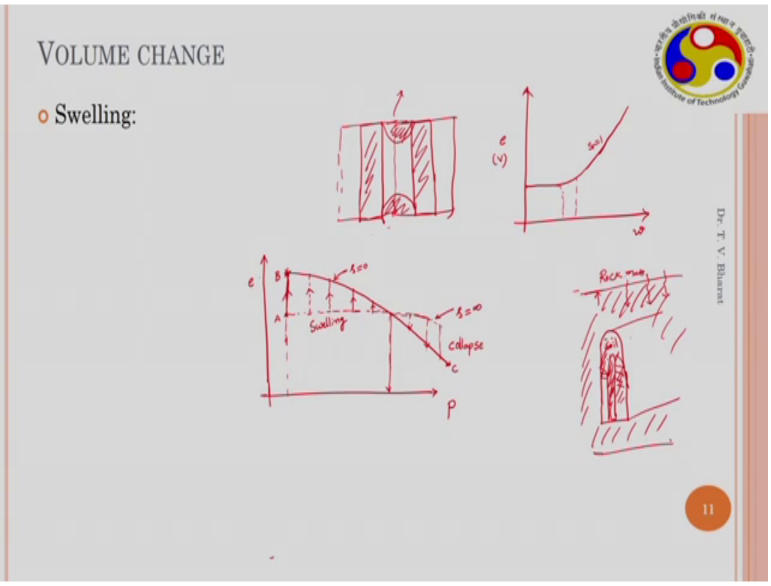

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- Swelling:

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Similarly, when this water leaves around this clay platelet, you have diffuse double layers. So, this is clay platelet and these are another clay platelet, these are diffuse double layers around the platelets, when this is exposed to the atmosphere conditions water starts living, which causes evaporation then particles will come close to each other. So, this causes reduction in the volume of voids or decrease in the void ratio. So, therefore, when we plot void ratio or volume with respect to water content in shrinkage characteristic curve, the volume decreases as the water content decreases because, particles will start coming close to each other after certain time.

These S r equals to 1 and degree of saturation remain same, but end at one particular point the air enters into the system and once air started entering into the system. So, they get emptied, this is air and the water content will start decreasing and volume will try to stop decreasing and after certain time in sufficient water is left then particles will form a bond and then the volume of the sample does not decrease anymore. So, this can be understood using diffuse double layer theory at least qualitatively, if not quantitatively the swelling and shrinkage characteristics. So, this swell and shrink happens cyclically cycle with in cycle in several cycles of swell shrink characteristics often occur in nature due to evaporation and infiltration.

So, this causes increase in the volume of the soil and decrease in the volume of the soil and this particular aspect, under loading is very interesting because, when void ratio. So now, we have seen that when nominal loading is applied on soil and the soil initially, it a dry state when, this soil is completely wetted or completely saturated with water then soil start swelling and the swell potential increases with time and reaches in equilibrium value. However, if the soil is the change in the volume of the soil is restricted by some means then the soil exerts pressure on the surroundings.

So, this pressure is called swelling pressure. So, this can be understood this can be determined in the laboratory for a given particular initial state of the soil and for a given soil, what is the swelling pressure, that exhibit that it exhibits. Now this can be understood using by plotting void ratio versus pressure diagram, this you have seen yesterday that, when the soil initially at dry state, when it is compressed. So, the volume changes marginally. So, this is initial state at point A and which is loaded and small change in the volume that is observed with increase in the loading.

Now, if this same soil at initial condition a under this seating load if this is saturated. So, then you observe that there is a swelling that takes place. So, then it goes to point B and now if this soil is compressed or consolidated. So, if this soil is compressed or consolidated, this follows this pattern. So, this reaches to say point C. So, this is consolidation at suction is equals to 0 and this is compression at suction equals to initial state that is infinity or some value finite value, I did not mean, I do not mean the infinities (Refer Time: 44:58) infinity, but is the large value I mean to say, it is a large value. So, the soil the expansive soil swell between any of this load, when you start wet the sample it will swell, but beyond this particular load, when you wet the sample the volume decreases, which is called collapse. This is called swelling, this is called collapse.

So, the expansive soil also can decrease it is volume, because of the loading conditions. So, therefore, to understand this expansive soil behavior, the loading is important. The initial state of the sample is important, because if the compaction density is different, the initial point a would should either up or down depending on the whether it is compacted at higher density or compacted at lower density then, the swelling pressure also change the swell potential changes and when you do the consolidation that curve changes. So, initial curve also changes. So, therefore, the estimated pressure also changes.

So, therefore, complete swelling characteristic would change. So, it is often very important to measure or determine the swelling pressure, because we have seen earlier that the nuclear waste, which is stored in underground repositories in a canister and which is an a k bar, you know underground repositories stored, when this canister is stored which is compacted with soil the canister is. So, the canister is surrounded by the soil. So, this contains bentonite and surrounded by rock mass. So, therefore, here also which is compacted with bentonite buffer material so, you have bentonite all around.

So, now the nuclear waste is contained here somewhere and now which is surrounded by compacted bentonite and surrounded by rock mass. This rock mass is generally saturated, when the water seeps into the ground seeps into the bentonite compact bentonite, because the volume changes are restricted here, volume cannot expand volume cannot increase. So, it exerts the bentonite exerts pressure on the surroundings. So, this pressure need to be estimated for the understanding the mechanical loading that happens on the repository. So, therefore, often the swelling pressure of the bentonite is very much important.

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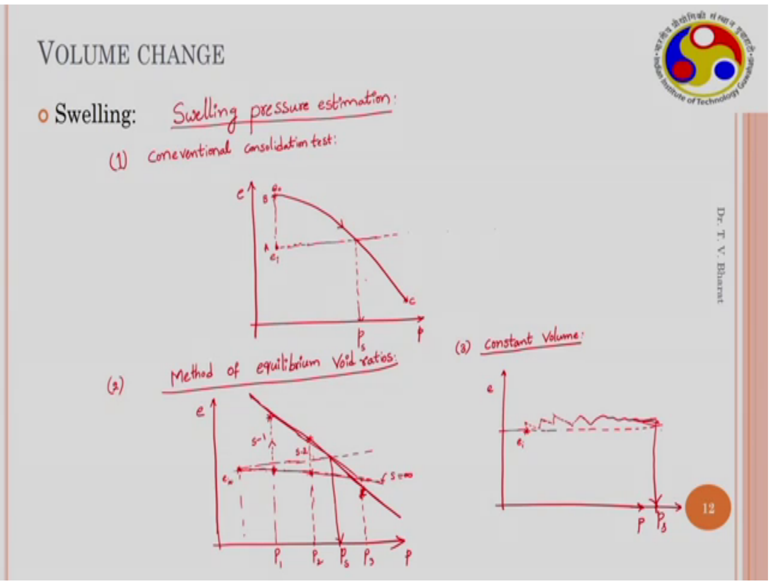

VOLUME CHANGE

- Swelling: Swelling pressure estimation:

(1) Conventional consolidation test:

(2) Method of equilibrium void ratios:

(3) constant volume:

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Swelling pressure estimation can be done in the laboratory using simple test, simple test using odometers. So, there are 3 ways to estimate the swelling pressure, first method is called conventional consolidation test. So, in this particular test, we conduct similar to what I just described, when you conduct a consolidation test on a fully saturated state and the so, this is the void ratio and P. So, initially the soil is soil condition is here, when this is saturated under the same loading, it get saturated and this is a void ratio at equilibrium. Now, if this is consolidated, if this soil is consolidated it follows this path and it reaches somewhere C or something. Now, extending this drawing a line from the initial point A, horizontally and wherever this line intersects the consolidation line, the corresponding pressure is called swelling pressure.

So, this is because the swelling pressure of the soil is pressure that the soil exhibits or exerts on the surroundings, when the volume of the soil is constant. So, initial volume of the soil sample, this is e initial is this one and this is e 0, which is at equilibrium with water. So, when this is consolidated so, how much pressure is required to bring the void ratio to the same value as it has initially is a swelling pressure of the soil. So, this is a one method to obtain the swelling pressure of the soil. So, this is very commonly used technique to obtain the swelling pressure. However, as the in swelling the some energy is some energy spent in swelling and after that, which is compacted again back and generally, this estimates a lower swelling pressure. But this is very simple technique to a estimate the swelling pressure, often you have restriction for example, highly expensive clays the swelling potential will be very high. And generally, we take 2 centimeter by 6 centimeter samples, 6 centimeter diameter and 2 centimeter thickness. So, the mound contains generally, 2 centimeter thick and 6 centimeter diameter, when you compact the sample to say nearly half or less than half, if the swell potential is significantly high.

Then you need to compact the sample to into a very thin sample. So, this makes lot of difficulties in exactly estimating the swelling pressure, swelling potential. So, the distribution is not accurate. So, there is a other method of equilibrium void ratios. So, in this particular technique, we need to conduct several tests. This is void ratio versus load and this is the initial void ratio, a dry state e initial and if this is a line extending, this is extending line horizontally and if this is compressed, the soil is compressed in the dry state itself.

So this is what, we have obtain and if this is now along this line. So, number of test need to be conducted in this particular test at different points, this is a seating load and this is load 1 P 1 under this particular loading, when it is compressed up to this load then, if it is allowed to swell or wet the soil sample and it swells to this particular value. This is sample 1 and similarly another sample is taken and which is compressed to another particular load level. So, this is P 2. So, now, this is allowed to swell by saturating it. So, it exhibits this much of swell. So, this is sample 2. So, another sample maybe somewhere here, maybe somewhere here, this particular loading say, P 3 which is wetted then, it exhibits collapse or compression.

So, when you join these 3 points, when you join these 3 points. So, you get a straight line, this is a straight line and wherever this straight line meets the horizontal point, this is called swell pressure. So, the other method is constant volume technique. So, in this particular method void ratio and load is represented in this manner initially, the soil state is somewhere here. So, this is initial state now, when you inundate the soil this starts increasing, it is volume then, if you apply some load then this moves like this and again it starts swelling. Then apply some more load is very small load, apply some more small load then it will start decreasing, its volume. Again it will start increasing its volume then again, if you apply some more load. So, it will decrease its volume. So, again if you apply some more load likewise it moves like this and then essentially, you are maintaining volume constant near to constant.

So, then after some particular application of the loading, it stops increasing its volume then the corresponding pressure is called swelling pressure P s. So, out of these techniques in the first technique only single sample is sufficient to do the test. And this is swell under loading initially, you make the sample to swell and after that you will loaded consolidate and from this, you determine the swelling pressure. In the second test series of test, need to be conducted from the initial state of soil sample. Initially, if the void ratio is e i then, the soil is compressed in the dry state then, it is allowed to swell.

And, another sample is compressed to another loading and it is allowed to and this is wetted and another sample is again taken and this is brought to this condition by applying this much of load and it is wetted. And, it may exhibit a collapse or volume decrease then by joining all these points, you will get a straight line, wherever this straight line meets the horizontal line from the initial void ratio point. So, that corresponding pressure is called swelling pressure of the soil. So, here number of test need to be conducted in duplicate samples to obtain accurate data.

So, in the third method constant volume technique, one test is sufficient. In the odometer, when the soil is allowed to swell due to saturation, it starts swelling then you apply very small load, small incremental load. Then the volume stops to increase and or under this loading, it tries to come to this equilibrium and again, if it starts to increase, you put another load. So, that is how, you increase the loading on x axis, but volume is remind nearly constant. So, this is a strain, this is a strain that is allowed during the testing. So, if the strain is smallest possible then, you will get accurate swelling pressure data. So, these are different techniques to estimate the swelling pressure in the laboratory. We will see more in the next class.

Thank you.