Unsaturated Soil Mechanics
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Week - 12
Lecture – 34
Estimation of Swelling Pressure in the Laboratory and Behaviour of Collapsible Soil

Hello everyone. Today, we will discuss a new topic Collapse or Collapsible Soils, which is related to Unsaturation of Soils and some soils they exhibit collapse due to saturation. Say, today we will discuss about that before discussing the collapsible soils and collapse behaviour of some soils; let us discuss what we have discussed in the previous lecture.

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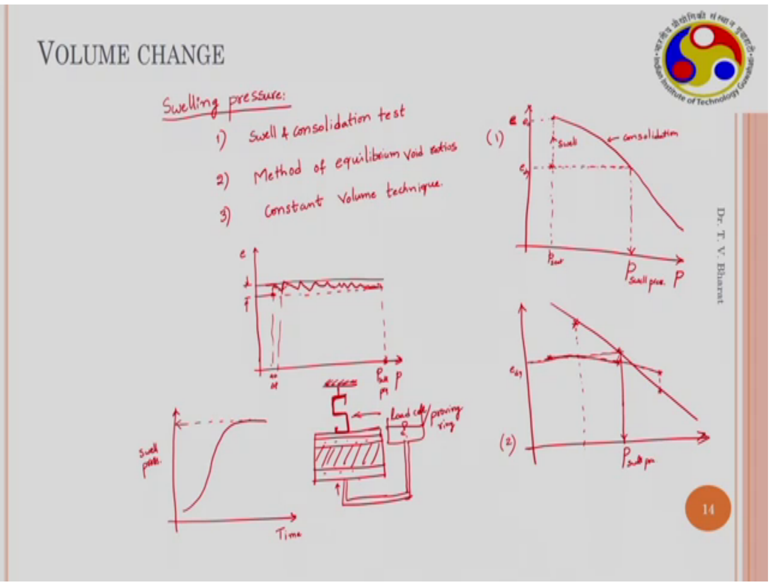

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Swelling pressure:
1) Swell & consolidation test
2) Method of equilibrium void ratios
3) Constant volume technique.

In our previous lecture we have gone through the swelling mechanism or behaviour of some expansive of soils. The swell potential which is exhibited by some expansive soils as due to wetting the underlying mechanisms we have dealt. And, also we have discussed measurement of swelling pressure of soils due to wetting and during when the volume changes are restricted.

So, swelling potential is observed when the volume changes are allowed and swelling pressure is measured or swelling pressure is exerted by the soils, when the volume change is restricted. Let me briefly mention what are the different techniques we have used for estimation of swelling pressure in the laboratory.

So, the swelling pressure can be estimated using a conventional consolidation test, which is swell and consolidation test, under swell and consolidation test we have seen that when you plot the ep curve the void ratio and pressure curve are load. The under the compression initially the soil is at compacted state or any other state, but at dry state which has a void ratio of this much under a seating load or seating pressure. And this is a void ratio at dry state and when the soil is saturated.

So, it swells and the final void ratio at equilibrium is e naught and when this is consolidated this shows this behaviour. So, if you extend a straight line horizontal line from the initial dry state, then corresponding pressure is called soil pressure, because soil pressure is the pressure exhibited by soils when the volume changes restricted or volume changes 0. So, when the volume changes 0. So, it should be same volume or same void ratio then it is e dry then correspondings pressure is called swell pressure. So, this is swell under consolidation this is swelling and this is consolidation swell and consolidation test. And, the second method is method of equilibrium void ratios.

So, in this technique series of tests are conducted on duplicate samples, at different loadings. For example, this is a initial void ratio initial stated dry and when the soil is compressed in the initial state itself. The compression line is this and it any given particular point under any given particular load is this is wetted or saturated. Then, it exhibits some swelling behavior. And, as the load increases this is sample 1 and another sample at different void ratio if it is wetted the exhibited pressure would be smaller. And, at any given higher than this particular load, this may be smaller than that which exhibits a collapse.

So, when you draw a straight line connecting all these points, and when you extend this a horizontal line from the initial void ratio, wherever this cuts that is a swelling pressure. This is a second method and in the third method a constant volume technique, which is popularly used. The constant volume technique from the initial state, the soil is wetted and it tries to swell you load it. So, you increase this much of load in a small load increment is done. And so, it tries to compress again it will try to expand or it will try to increase it is volume then you apply another load.

So, essentially this will be like this, when you extend a horizontal line from the initial void ratio this is the how curve is. And, it is stop’s increasing it is volume when the maximum applied pressure on the soil is equal to the swell pressure. So, it is observed that it is the strain that is a load in the system would influence the estimated swelling pressure. If the strain is smaller the estimated swelling pressure is higher.

So, essentially the lost in the energy is minimal. So, it would estimate correct value of swelling pressure. So, recent days the test is conducted on odometer sample or any other sample. So, you have a porous stone, porous plate at the top and bottom and you have the soil sample. Now, you have a top plate on top of it a load cell is attached. Like this and either load cell or directly you can attach a proving ring.

And, when this is connected to a reservoir, when the water is allowed to enter into the soil sample then the salt raised to swell, but this the load cell which is connected to the load frame would not allow any volume change to take place, but this load cell are proving ring will allow to record, what is the reaction that is exhibited exerted by the soil.

So, from this you can estimate what is the swelling pressure that is exerted by the soil mass and that would be more accurate. So, these raise the swell pressure versus time; time is plotted. So, the swell pressure will increase with time and reaches an equilibrium value maximum values that is at equilibrium. So, this is corresponding to the fully saturated state.

So, this is often estimated these days. Further the suction controlled swelling pressure data and under why varying mean stress how the volume changes under as suction control environment. These tests are conducted to determine the constitutive surfaces, in load suction and degree of saturation or water content.

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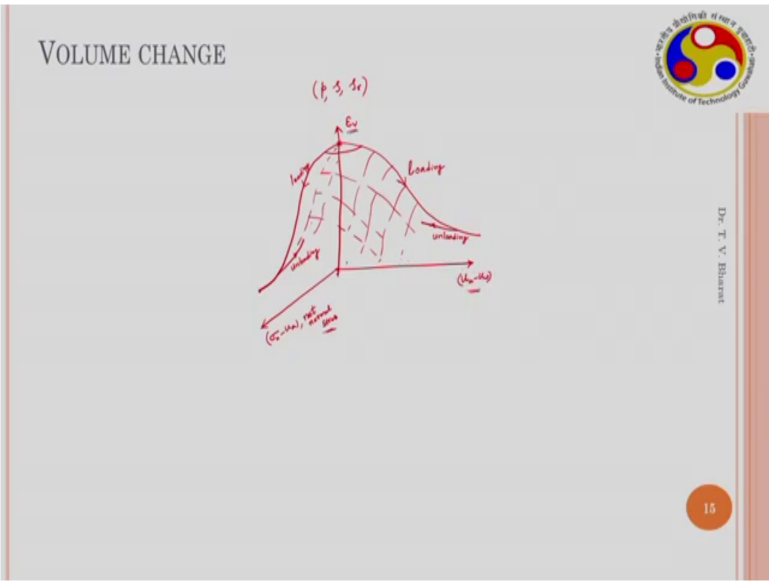

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In the surface is plotted that is often done in these days. So, that could be plotted in this manner this is strain axis or it could be void ratio also or volumetric water content. And, you have matrix suction u a minus u w on x axis and this is another axis epsilon y. And you have another axis, that is sigma n minus u a this is net normal stress minus air pressure net normal stress. The net normal stress versus strain plot you know as the net normal stress increases the strain value decreases, this shows this kind of a behaviour and this is a typical consolidation plot. So, as the loading increases the strain value decreases.

So, if you unload the sample at any given point this is unloading plot. And, this is loading. Similarly, initially the soil condition is this at fully saturated state and when you load it so, the volume of the sample decreases and the strain value decreases with increase in the load. But here at the same condition whatever we have considered earlier.

So, if you increase a suction without any mean stress, then you observe that this also exhibits similar behaviour this is also called loading. This loading is a suction loading. So, when you increase the suction the water content decreases.

So, the volume of the soil decreases, if it is an expansive soil. So, this is a loading curve, and if you wet at any given point. So, these exhibit this behaviour, this is unloading. So, this kind of a surface you obtain this is a surface you get for different combinations, to obtain the surfaces the test under controlled suction are conducted. And, we should be able to vary the mean stress net normal stress and u a minus u w should be controlled to and the we should be able to measure the volume, then we can obtain this kind of a surface, we can build this kind of a surface and which would help in, understanding, the soil behaviour at any given point especially the expansive soils. The volume change behaviour of soils can be estimated under suction and net normal stress environment.

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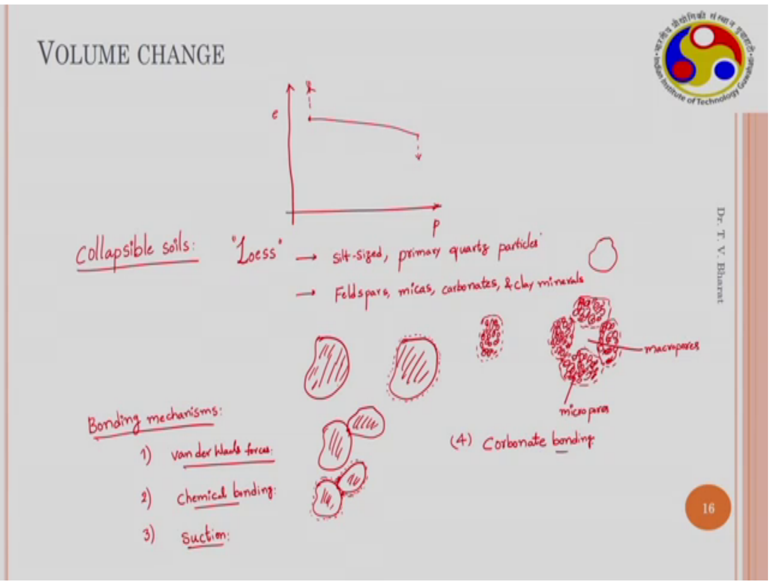

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Collapsible soils: 'Loess' → silt-sized, primary quartz particles
→ Feldspars, micas, carbonates, & clay minerals

Bonding mechanisms:
1) van der Waals forces
2) Chemical bonding
3) Suction
(4) Carbonate bonding

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Coming to the earlier observation that when soil is loaded this is void ratio and this is stress. So, this is compression line when the soil is wetted under particular normal load. Soil may exhibit swelling and at very high loads soil may exhibit decrease in volume or collapse as I mentioned earlier. So, this is the case with expansive soils exhibit swelling under loading less than swelling pressure and under loading greater than swelling pressure if we wet the expansive soil, it will exhibit decrease in volume. Generally this is called collapse.

However there are some soils that exhibit collapsible behaviour. So, the characteristics of the collapse come from the physico chemical nature or some mechanical force that exist within the soil structure, the characteristics of this collapsible soils will study now. Soil called 'Loess'. Loess is a widespread howling deposit which is considered as collapsible soil. Loess is found in many countries such as North and South America or Russia, Europe and Central Asia, China and many other parts of the world.

So, the loess soils are deposited by wind, wind deposited soils and interesting part is that they consist of silt sized primary quartz particle; primary quartz particles, from the cold weathering process they are formed. And glacial grinding process they have they came into existence. It mainly consist of regular shaped silt sized this quartz particles and some clay content also exists within this loess soil.

So, this silt sized particles are deposited, deposited in fluvial transportation due to retreat of continental eyes or glaciers. And, the so, some silt particles. They have they would deposited along the flood plains of rivers, there is a fluvial transportation and due to retreat of continental glaciers. So, the silt is sorted by fluvial action and is re deposited by wind action.

So, further feldspars micas and carbonates and clay minerals are also present along with the primary quartz particles. So, they form open structures. So, this is how they form if this is 1 silt sized quartz particle. And, these are the clay particles, which are surrounded or accumulated around silt particle, and this is the conglomeration of or aggregate of several of these silt particles, which I represented with dotted lines. So, this is one aggregate.

So, such several aggregates would form as open structure like this. So, these dotted lines indicate an aggregate like this. So, these are individual aggregates. These are called micro pores and this is called macro pore. Generally these kind of soils will have duel porosity on micro pore and micro pore.

So, the increase in the load on the soil will only decrease the macro pore volume. So, the micro pore volume nearly remains constant. So, here individual particles are or individual aggregates are attached by several forces that we will discuss now. So, there are several bonding mechanisms one is van der Waal forces; these are the van der Waal forces are between quartz particles making the fabric structure.

So, 2 individual quartz particles this is one quartz particle and this is quartz particle they get attached due to van der Waal forces. The second there is a there could be chemical bonding. So, the ionic variability of surfaces of the quartz particles facilitate attraction of charged clay platelets this is a chemical bonding. So, when the charged particles so, when there is ionic variability on the clay silt particle, and clay platelets clay particles are attracted this is another particle and clay particles are surrounded.

So, now when there is some moisture that is available general atmospheric conditions clay platelets, absorb, moisture and then retains retain some moisture which is called hydroscopic moisture content. So, that when the hydroscopic moisture content exist there is a clay bridge that form between these 2 particles. In the third force could be suction or negative pore water pressure. As the water content is only very small the amount of water that is presented the natural atmosphere is very small compared to the total volume of force that are exist.

So, there is a negative pore water pressure that exist and suction values are very high in this particular soils and there could be carbonate bonding. So, this carbonate bonding is between different quartz particles and other soil bondings like gypsum etcetera also may present.

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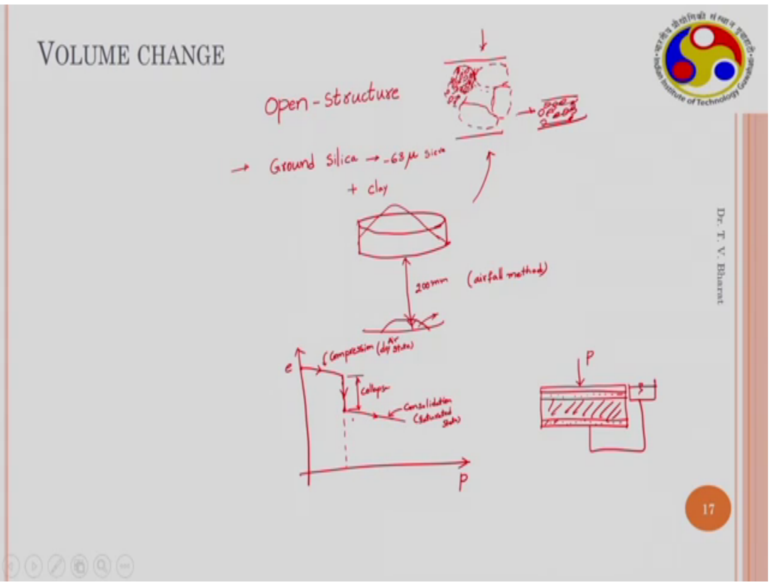

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The loess soil can also be artificially made, because the essential form of structure that is open structure, that exist in the soil. So, open structure is as I showed so, this is individual aggregate, and this is another aggregate, and this is another aggregate, and this is another aggregate.

So, individual aggregates will have several of these quartz particles, that exist with different bonds and there is another bond between the quartz particles here and then the next aggregate. So, under application of the load, the macro volume would not collapse only the small amount of macro volume make decrease, because the bond between different aggregates is very strong and the applied load will not cause any damage to the macro pore volume or damage to the open structure of the loess soil.

So, now as the forces are known because there are silt size particles and clay particles, different combinations cause open structure the loess soil can be made artificial in the laboratory. So, this is attempted by several searchers by considering ground silica, which is a passing through 7 4 microns c o or 63 microns c o, and which is mixed with different proportions of clay in oven dried state and, this is deposited. The way the loess soil deposit due to wind action, the soil is kept in a (Refer Time: 22:43) and deposited onto a surface, by maintaining a gap of 200 mm by what is called a air fall method. And, the soil is deposited here. And, this soil which is now spread small moisture so, that to artificially facilitate clay bridges between the silt particles and this is how naturally it exists.

So, this after spraying some moisture and the structure of the loess soil may become open structure like this and then studied using collapse build test. In odometer it can be studied where in the odometer under 2 porous stones, the soil is initially compacted at particular density and then load plate is attached on top of it the loading is applied, then this is connect it to reservoir and the moisture is allowed to enter.

Now, e p plots can be plotted. So, here so, this is the initial condition of the soil. So, now, when it is compressed to one particular loading so, this is a loading level. Then here when the soil is wetted soil collapses. So, this is the collapse potential are the collapse, now if you consolidate. So, this is how it shows. This is consolidation, this is compression, because this is air dry state and this is completely saturated state. So, under particular load, it is observed that soil will collapse, the volume will decrease.

So, expansive soil under this particular loading when you saturated the volume will increase or void ratio will increase, but this collapsible soils will decrease its volume. So, essential because as soon as the soil is saturated. So, there is a initially the clay bridges that exist between the silica particles would start breaking because the suction is absent now. So, suction is essentially goes to 0. So, the now the bridging formation is gone. So, this whole structure will collapse.

So, now, the aggregates will collapse and all the silt particles with crumble into aggregates like this upon saturation. So, initially you have micro pore volume and micro pore volume after saturation there is 2 different pores would not exist.

So, because of the loss of suction within the soil structure with supported the open structure until it got wet. So, that is collapse and under different particular loadings also this can be studied.

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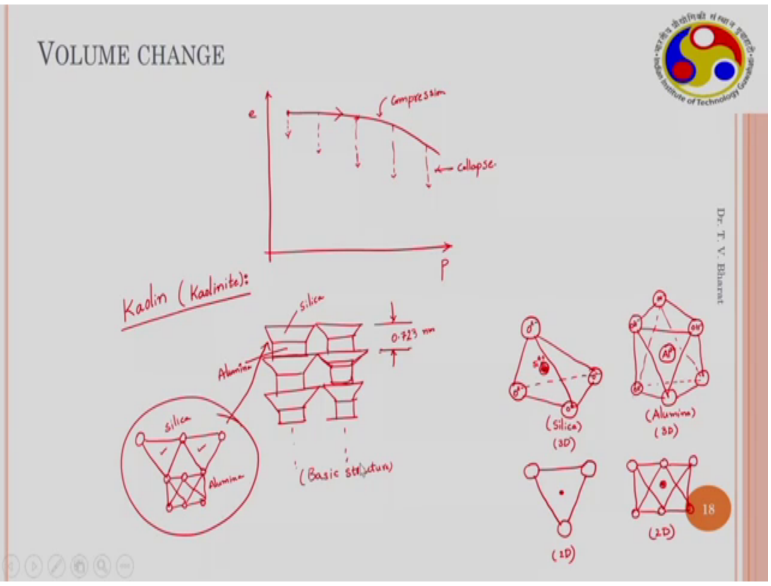

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So, the soil is initially somewhere here. So, if this is compressed this is how the volume decreases. So, this is compression. So, when it is wetted it exhibits minimals collapse and as the load increases the collapse will increase something like this. So, this is collapse under different loading.

So, this is very well studied. Essentially, if the building is constructed on such kind of a soils collapsible soils will dry state, whatever the loading you apply the change in the volume is negligible it does not exhibit much volume change. Therefore, we consider that this is safe, but; however, under the same loading when there is a sudden incretion of water into the soils due to floods or may be due to intense rainfall. Than a sudden collapse of the soil structure causes a macroscopic collapse behaviour or volume decrease behaviour we observe and entire building can sink in to the ground.

On the other hand if the building is constructed on expansive soil if the building pressure the exerted pressure from the building load is lower than the swelling pressure of the underneath expansive soil, then the saturation or wetting of the underneath expansive soil causes increase in the swell potential. The entire building can get uplifted due to the swelling nature of the underneath soil. So, there are other clays such as Kaolin, which contains a kaolinite mineral. So, which is rich in kaolinite mineral the kaolin clays also found to be exhibiting collapse behavior. This is observed very recently, because the kaolinite mineral has silica and alumina units attached in this manner; several units are attached in this manner.

So, the basal spacing this distance is 7.723 nanometers. So, this is silica sheet, this is alumina sheet, which are attached in this manner. And each basic unit is attached to other basic unit in a strong bond. So, this is basic structure of the kaolinite in a 3 dimensional manner, if you visualize the silica contains 4 oxygen atoms. So, in between you have a silicon O 2 minus these are oxin atoms this is basic silica, in a 3D views this is silica. This is 2 D and this is 3 D. And, similarly alumina you have 6 O H minus are available these are O H minus hydroxilayance.

So, in between you have alumina A l 3 plus this is O H minus. So, this whole thing is called alumina, you have aluminium here and you have silicon here. So, this is alumina in 3 D view. So, in 2 D view this can be visualized as 6 hydroxyl ions and in between you have alumina so, in 2 D view. If, these 2 are combined in 2 D view the silica and alumina are combined. So, that can be represented as these are 2 silica and this is alumina sheet this is how they got attached.

So, this is one silica another silica and this is alumina and this is one silica another silica. So, this is the whole unit so, this is a 2 silica and one alumina this whole is represented in this manner. So, these number of sheets basic units are attached and it is forms the kaolinite mineral.

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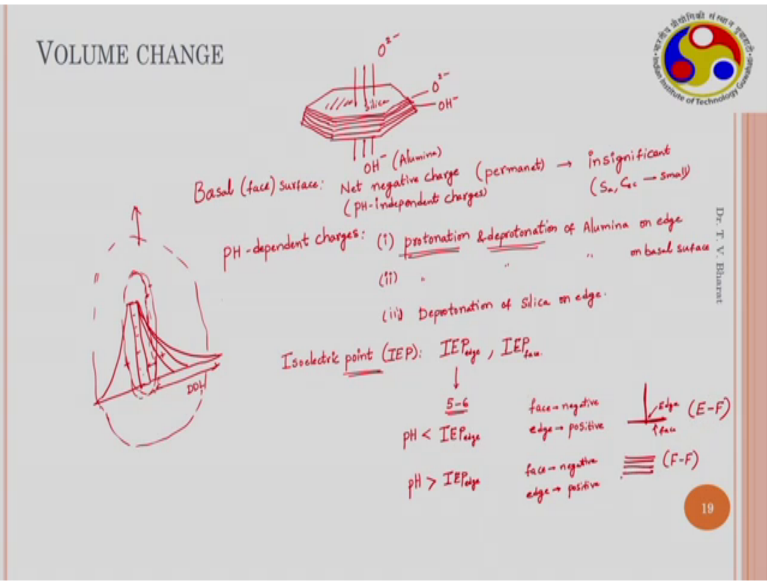

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Basal (face) surface: Net negative charge (permanet) → insignificant (S_a, C_e → small)
(pH-independent charges)

pH-dependent charges: (i) protonation & deprotonation of Alumina on edge
(ii) " " " on basal surface
(iii) Deprotonation of Silica on edge.

Isoelectric point (IEP): IEP_{edge}, IEP_{face}
↓
5-6
$pH < IEP_{edge}$ face → negative edge → positive (E-F)
$pH > IEP_{edge}$ face → negative edge → positive (F-F)

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So, kaolinite mental when it is represented the sheets attached this is a one particular sheet of silica and alumina. And, you can consider number of sheets those are attached in this manner. This is a basal plane or surface, we have termination sides here O 2 minus 1 silica face, on the other face you have alumina face here you have termination sides as minus. Similarly, at the edges you have both O 2 minus and O H minus.

So, on alumina face you have O H minus as termination sides and on silica face you have O 2 minus termination sides. And, because of this termination sides and they acquire charges under some particular PH environment. And, this causes changes in the structure of the clay soil and which causes collapse under wetting, the will this will be explained now. And, if loess soil collapse nature is due to some mechanical loading is due to wetting phenomena under loading, which is a similar to some mechanical behaviour, but here the collapse behaviour of kaolinite is purely due to physicochemical in nature.

So, physicochemical because the changes in the charges on the clay surface and the edges result in different associations of particles like edge to face, face to face etcetera, which is (Refer Time: 36:14) collapse of the soil. Let us try to understand this by understanding, what are different charges that exist in the soil. So, on basal surface of silica basal plane or surface of that is face that is this surface, always contains net negative charge.

So, this is acquired due to isomorphous substitution, which is permanent charge to the clay platelets, but this is insignificant because specific surface area solo this is in significant value in terms of magnitude, the because surface area and cation exchange capacities are very low in small. However, hand the clay acquires PH-dependent charges. So, this is a PH independent charges. So, this is due to react to termination sides on the surfaces and alumina basal surface. Alumina face and edges cause these reactive surfaces or reactive alumina face and reactivate edges cause PH dependent charges.

So, this PH dependent charges come from protonation and deprotonation of alumina sheet, protonation and deprotonation of alumina on edge and protonation and deprotonation of alumina on basal plane, basal surface and deprotonation of silica sheet on edge. So, essentially the protonation is the absorption of H plus ions on to the surface when the PH of the environment is very low, there is a abundance of H plus ions.

So, H plus ions will be absorb on to the surface, then it acquires positive charge. So, deprotonation means it releases H plus ions from the surface, when abundant O H minus ions are available in the solution. So; that means, with very high P H values. So, the deprotonation occurs due to release of H plus ions from the surface. So, protonation that is H plus acquiring H plus ions are release in H plus ions causes different charges to the surface and edge. So, the PH at which the surface charges are changed and PH at which the edge charges are changed are too different, that makes it to too complex to understand how this charges would change.

So, this is commonly understood using Iso Electric Point called I E P. So, generally this is defined as the PH value at which the clay particles isoprotic mobility or data potential is 0. So, if you consider the clay platelet to be like this, which has a negative charge on the surface this is a diffuse double layer around it. So, due to changes in the PH environment surrounding this clay part platelet. So, the diffuse double layer thickness would vary change. So, when the charge negative itself gets 0. So, the charge on a surface is close to 0.

So, the zeta potential which is this is less than the actual diffuse double layer thickness if this is the diffuse double layer thickness the zeta potential is considered to be very small somewhere here. So, data potential is considered to be where isoprotic mobility, when the particle is moving there is a shear resistance or shear force that exists on the surface.

And, because of which whatever the charge that exists on the around the particle there is some film due to diffuse double layer there is a this much film would exist surrounded, but in the particle is an motion due to some electric current. So, due the shear force the thickness of film that exist surround clay platelet would diminish or reduce and the charge on this particular the charge on this particular film under motion is called 0 potential.

Essential isoelectric point would indicate where the charges are essentially 0 at the particular pH. So, the IEP of edge is different and IEP of face are different. So, generally IEP of edge is between 5 to 6 and IEP faces are much higher generally IEP of edges 5 to 6. So, when the pH value of the solution is less than IEP of edge. So, generally the clay surfaces due to isomorphs substitution the silica surface will have net negative charge, face has negative charge and it just carry positive charges.

So, because the PH value is less than the IEP of edge because the pH is low so, it adsorbs H plus ions on to the surface and which results in which results in positive charge on the edge. So, due to negative value on the face and positive value on the edge so, it has edge to face flocculation. So, this is edge and this is face. So, this kind of a structure forms when the pH value is less than IEP of edge, when the pH value is greater than IEP of edge where face is negative and edge is positive.

So, which results all are negative so, therefore, it results into dispersed structure like this so face to face arrangement. So, this is called face to face arrangement and this is called edge to face arrangement. So, the clay platelet us would get arranged into either edge to face or face to face arrangement depending on the PH of the environment.

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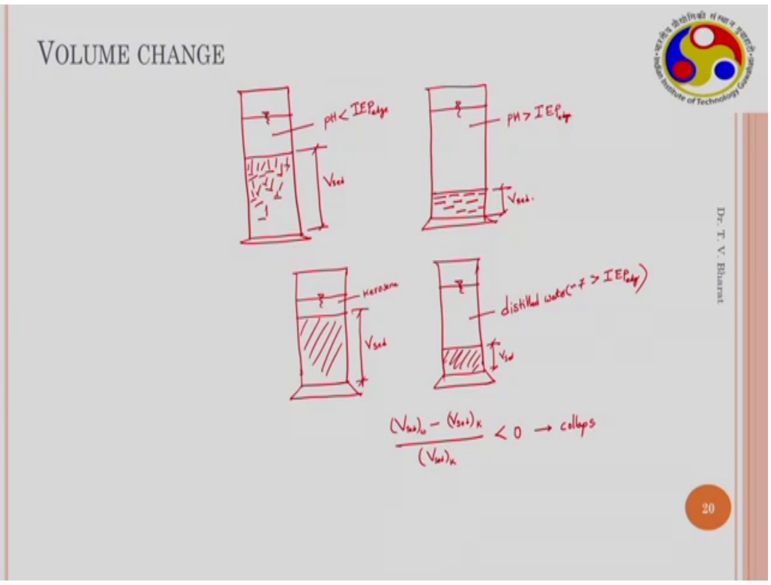

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$$\frac{(V_{sed})_w - (V_{sed})_K}{(V_{sed})_K} < 0 \rightarrow \text{collaps}$$

So, therefore, if I consider the volumetric flask, where if I pour clay sediment, they assume this kind of a structure edge to face and the volume of the sediment would be highest. This is volume of the sediment this is when pH of the solution is less than IEP of edge, the same volumetric flask same clay is pore, but the PH environment is such that PH is higher than IEP of edge, it results in very low volume.

So, because particles are dispersed in nature this is the segment volume. So, that is the reason why when the kaolinite is mixed with kerosene the segment volume is higher compared to pure distilled water that will have pH of around 7. So, which is greater than IEP of edge, so, particles will be in dispersed. So, therefore, the volume will be much lower than compared to kerosene.

So, therefore, the swell potential when this calculated as volume of sediment in water minus volume of sediment in kerosene divided by volume of sediment in kerosene which is the negative value less than 0. So, the negative value indicates the behaviour.

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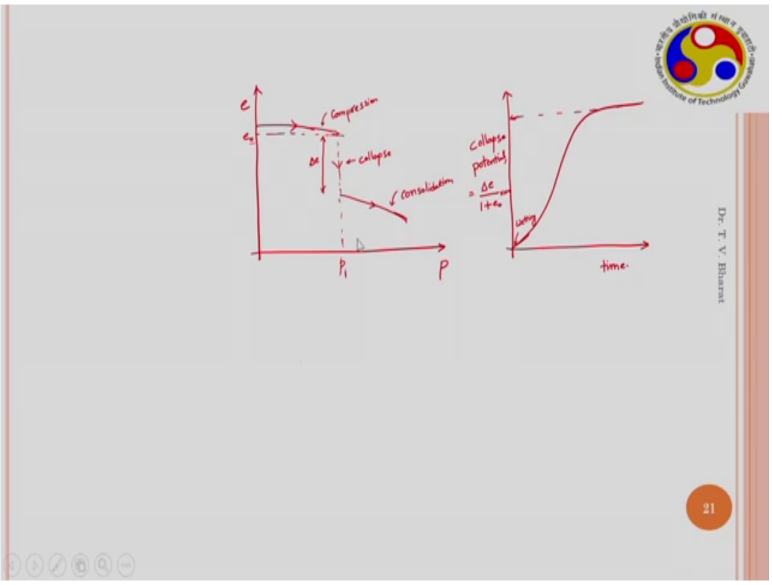

So, when this kaolinite is tested in the odometer, the collapse tests can be conducted where the void ratio and P load or stress main stress can be plotted, when the soil is compacted at one particular compaction density. And, when which is loaded which exhibit this behaviour when this is wetted this suddenly collapses and when you consolidate this curve goes like this.

So, this is compression and this is consolidation and this is collapse. It is plotted as collapse potential versus time, it starts from origin. So, the collapse potential increases with time and reaches in equilibrium value after certain time. So, this collapse potential is nothing, but change in void ratio divided by 1 plus initial void ratio; that means, this is the u naught and this is delta e. This delta e by 1 plus c naught is a collapse potential this collapse potential will increase with time as soon as this is a point where it wetted or inundated.

So, it changes with inundation pressure again, this is one particular inundation pressure, but with change in the inundation pressure this collapse potential also vary. So, the kaolinite clay also exhibits collapse behaviour similar loess soil, but in the loess soil because there are several different particles like silica, there is silt sized quartz particles and clay particles surrounded by them. And, which forms bridges around different silica particles which causes open structure.

And, this gets collapse to as soon as this is wetted or saturated. In case of kaolinite there is open structure because of the different charges on the face and edge and this causes open structure formation in completely air dried state. As soon as this is saturated with pH solution higher than IEP of edge, then the charges on all the surfaces and edges will be same which causes collapse of the soil. So, the collapse nature of kaolinite soil is purely physicochemical.

Thank you.