Expansive Soil
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Lecture 09
Swelling of Expansive Soil

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Hello everyone, welcome to the course Expansive Soil. This will be the 8th lecture and it will be in module 4. We will be learning about the swelling behaviour of the expansive soil. Today topic, we will be focusing on how the soil swells or the swelling mechanism of an expansive soil. In the last class, we discussed about different kinds of attractive forces and repulsive forces and how do they exist in a clay-water system. In this class, we will learn how this attractive and repulsive forces helps in the swelling behaviour of the soil.

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When you talk about the swelling of expansive soil, generally the swelling takes place in two stages. The one is known as inner crystalline swelling, the second one is known as osmotic swelling. So, we will discuss about these stages of swelling one by one.

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The first one is inner crystalline swelling. So, inner crystalline swelling a less amount of swelling of expansive soil takes place. This swelling process takes place in generally three to four steps. In the first stage, you can see, this is a dry Montmorillonite or an expansive clay mineral, you can see this is a first layer of the soil mineral and in between they have a cation.

So, these cations can be like sodium, potassium, magnesium and calcium. Mostly they are in dehydrated or dry state. In the first stage, the separation between this layer is 9.6 angstrom. And in the first stage, the water content is very less. Now, due to this hydration energy of this cations, they will try to absorb moisture.

So, in the second stage, they will absorb a layer of water molecules and as a result of which the separation between these two plates will increase to 12.3 angstrom. Here, we can see a, layer of water molecules is being absorbed by these cations. And due to this absorbed of water molecules the water content can increase from 1 percent to 6.2 percent.

Whereas, the distance got increased from 9.6 angstrom to 12.3 angstrom. In the third stage of this swelling, another layer of water molecule got absorbed by these cations and as a result of this again the inter layer distance increased from 12.3 angstrom to 15.2 angstrom. And due to this increase in the water layer, the water content was increased from 6.2 percent in the second stage to 16.5 percent in the third stage.

After this third stage, there will be the fourth stage. In the fourth stage up to four layer of water molecules get absorbed by this cation. And as a result of which again the separation between these plates got increased a value higher than 15.2 angstrom and generally it can go up to 20 angstrom. And here the water content increase up to 25 percent. So, this is the fourth stage of the inner crystalline swelling.

And at this stage the inner crystalline swelling ceases and because of this inner crystalline swelling, generally the inter layer distance increase up to 10 angstrom. So, here we can see, these are the different four stages of all this inner crystalline swelling and due to which the water content got increased from 1 to 25 percent. Now, in order to prevent this inner crystalline swelling to take place, we need a large amount of pressure.

If you look into this, to prevent from absorbing one layer of the water molecules, you need 400 N/mm^2 of pressure. So, this is known as the swelling pressure. So, swelling pressure can be defined as the amount of pressure which we will be required to prevent the soil from swelling. Similarly, for the second stage of swelling, you need 100 N/mm^2 of pressure to prevent the soil from absorbing the second water layer.

And similarly for the third and fourth layer you need 27 N/mm^2 of pressure. So, these are the swelling pressure for different stages of this swelling. We can see with increase in the layer of the water molecules, the swelling pressure keep on decreasing. Generally, in inner crystalline swelling a less amount of swelling takes place in comparison to the other stage of swelling that is known as osmotic swelling. And depending on the type of cations, generally this amount of swelling is bit different.

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Here, we can see this inner crystalline swelling, these are the clay plates, and in between them, there is an exchangeable cation, it is in dry stage. In the first layer of water molecules, you can see these are the first layer of the water molecules are being absorbed by these

cations as a result of which the plate separation is increased. This is the fourth layer you can see.

The cations are fully hydrated in this stage, which is result in the repulsive force and expand in the clay plates which results in the swelling of the soil. Since the inner crystalline swelling has a very high value of swelling pressure, generally this is being ignored for any engineering application.

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The next stage of swelling is the osmotic swelling. In this osmotic swelling, a large amount of swelling takes place. The osmotic swelling takes place because the process of osmosis. Here, we can see these other two clay plates negatively charged and in between there are cations and also there will be some water present over here that can be some absorbed water. So, we have a cation concentration C1 which will be inside this part.

And outside of this clay system clay-water system, we have another concentration *C2*. Generally, this *C1* is very high in comparison to *C2*. As a result of this concentration gradient, the water from outer system will enter into the inner system, as a result of which more water enters the separation between the two plates will increase and also some of the cations will also move out to equilibrate the concentration.

As the water moves in, the plate separation which was *2d* earlier becomes *2d'* where *2d'* is very high in comparison to *2d* and there is a large amount of swelling takes place. So generally, for this stage of swelling, the swelling pressure is less than 2 N/mm^2. And a large amount of swelling takes place in osmotic swelling in comparison to the inner crystalline swelling.

If we see the water molecule over here, you can see this is a clay plate and as you move away from the clay plates, the cation concentration keep on decreasing. And here the water can be divided into two ways one is double layer water and other is a free water. So, the free water has the properties of like normal water, whereas, the double layer water bounded by some attractive and repulsive forces.

If we draw the electrical potential versus distance, the electrical potential next to the clay plate will be significantly higher. And as we move away from the clay plates, the electrical

potential will keep on decreasing. And at a point far away from the plate distance the electrical potential will be almost 0, that point is known as the reference point.

Now this osmotic swelling depends on many other things like concentration of the ions, the valency of the ions, the dielectric constant, the pH. And since those controls the osmotic swelling, those also controls the total swelling of an expansive soil. And as I told you, the amount of osmotic swelling is significantly higher in comparison to inner crystalline swelling, any change in osmotic swelling will also influence the total swelling of an expansive soil.

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So here we will see how this swelling of expansive soil takes place. Here I am taking the example of Montmorillonite mineral. This is an exchangeable cation and this can be a sodium, potassium, magnesium, like this one, and this is in the dry state or little amount of water is there and outside we have pure water. Now, if we compare the concentration here is $C1$ and concentration here is $C2$.

The concentration of $C1$ is significantly higher in comparison to $C2$. Now, because of this concentration gradient, there will be a flow of water into this system. So, here we can see, the water molecules will enter into the system and when a large amount of water will enter the plate separation will increase and this will take place and until there is an equilibrium between $C2$ and $C1$. As a result of this plate separation the swelling of the soil takes place.

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So, the reverse thing takes place where do we put in expansive soil into a high salt concentration. Say example, this is an expanded soil or swollen soil which has been already expanded because of the absorption of the water by this exchangeable cation. Now, we will put this one into a high concentration salt solution. So, now, this is $C1$ and $C2$.

Now, the case will be reversed that means, the $C2$ is higher than $C1$. So, as a result of which the water molecules will move in the opposite direction, we can see over here. So, water will move away from the clay plates and it will go to the outer solution. This movement will take place until and unless there is an equilibrium between the concentration $C1$ and $C2$.

And as the water molecules move away, the plate will come to a closer spacing and we say that one is a shrinkage of the soil or shrinkage of expansive soil. And because of this reverse mechanism, the volume of the soil will be decreased.

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There are two kinds of water, one is free water and another is a diffuse double layer of water. Apart from these two layers of water there is another layer of water which is known as absorbed water. This absorbed water is strongly attached by the negative charge of the clay plates. And similarly, it is attached with the clay plates because of the hydrogen bonding between the clay plates and the water molecules.

Here we can see, the clay plates are negatively charged. Now, we know that water molecule is a bipolar. So, this is the positive end and the negative end, this is the positive end, negative end. Similarly, the other end of this water molecule will also be attached to here and like this. But this force of attraction will keep on decreasing as we move away from the plate.

That means this layer of water molecules will be held very tightly in comparison to this layer. And consequently, this layer will be held very tightly in comparison to third layer. So, when we move away the force of attraction will keep on decreasing. So, this takes place for few layers of the water molecules and as these are very strongly absorbed, this is known as absorbed water.

Now, this absorbed water has a different properties in comparison to the free water or diffused double layer water. Here, if we compare the density of the water, generally it has a very high density next to the clay plates and the density will keep on decreasing when we go with one to fourth layer of the water molecules.

So, for the first layer of the water molecules the density is around 1.4 g/cc, whereas for the fourth layer, it becomes 0.7 g/cc and then again it starts to increase and it becomes 1 g/cc for free water. Then comes the viscosity. The viscosity of this absorbed water is significantly higher in comparison to the free water.

And if we compare with the first layer of the water molecules generally this is around 100 times more in comparison to the free water. Similarly, the dielectric constant. The dielectric constant of the absorbed water is very less in comparison to free water. So here we can see the dielectric constant is in between 2 to 50 and it is around 1/10th of the free water, very

next to the clay plates. For a reference, the dielectric constant of free water is 80. Here we can see, the absorbed water has a very less value of dielectric constant in comparison to the free water.

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After the absorbed water, there will be the diffuse double layer water. So, here you can see, this is a clay surface, which is negatively charged. This is a cation. Now, this negatively charged clay plate will try to attract this cation towards this direction. At the same time due to the concentration gradient this cation will try to move away from the clay plates. This is quite similar to our atmosphere.

Our atmosphere is attracted by the gravitational force of the earth. So, if we compare this is our earth's surface and if this is the atmosphere, the atmosphere or the gas molecules present in the atmosphere will be attracted towards the earth's surface because of the force of gravitation. Now, this gas molecules will try to diffuse away towards the outer atmosphere, because of the diffusion.

Now, there will be a combined force which will be attractive and which will be repulsive. And because of these two forces, they will be distributed in such a way that their concentration will keep on decreasing as we move away from the earth's surface. Similar thing happens over here. This cation will be attracted towards the clay surface because of this negative charge.

And also, it will try to move away from the clay plates because of the diffusion. Due to this attractive and repulsive force this will be distributed in a diffuse double layer, where their concentration it is keep on decreasing when we move away from the clay plates. So, here we have larger amount of cations, and as we move away from the clay surface, the amount of cations will keep on decreasing. So, this layer is known as diffuse double layer.

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Here, we can see, a clay plates and it is negative charges we know. So, these are, this red-red buttons are the cations, the yellow one the anions. This is the distribution of these cations and anions in a diffuse double layer. Here we can see, it edge view of the clay surface in negative charge next to the clay surface there will be large amount of cations.

And as we move away from this plate, the cation concentration will keep on decreasing. But at the same time, if we look into the concentration of the anion, the concentration of the anion will be very less next to the clay surface because the negative charge of the clay surface that will repel this anion. But as we move away from the clay plates, the anion concentration will keep on increasing.

And after a certain distance, that is known as the reference point, the anion concentration and the cation concentration will be almost identical. Here in the dry state, the negative charge of this clay plates will be balanced by these cations, which are known as exchangeable cations. And the examples are calcium, magnesium, sodium and potassium. Generally, these are the exchangeable cations present over here.

And when we add water to this clay plates, this cations and anions float around the clay particles and this configuration where the cations and anions are floated together is known as a diffuse double layer. The cation concentration decreases with the distance from the surface of the particles whereas the anions concentration will increase with the increase in the distance from the clay plates.

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Depending on what kind of cations we have, the distribution of the cations will also be different. Say for example, if we take a monovalent cation, we will get a distribution like this one, where the cation concentration will be keep on decreasing with distance. At the same time, if we take a divalent cation, the distribution of the cation will be followed this curve.

Similarly, the trivalent cation will follow this curve. If we compare this three, so we can see the trivalent cations, generally, we have a large amount of trivalent cations next to the clay plates and as we move away, it will decrease quite rapidly in comparison to divalent and monovalent cation. Similarly, divalent cation will also decrease rapidly in comparison to the monovalent cations.

This is because of this their higher forces of attraction between the cations and the negative charge. Since the trivalent cation has three charges it strongly attracted, where is the divalent cation has +2 charges so, it will be less strongly attracted towards in comparison to trivalent cations and monovalent will be less strongly attracted in comparison to divalent and trivalent cations.

If we consider the distribution of the cations and anions, we can see, how they are distributed here. In this plot, we can see this is ion concentration plotted in Y-axis and distance from the particles is plotted on X-axis. The cation concentration is significantly higher next to the clay plates because the clay plates is negatively charged.

And due to this negative charge, the cations are very strongly attached here, but as we move away, the cation concentration will keep on decreasing. If we compare with the anion concentration, some of the anions will be present here and their concentration will keep on increasing as we move away from the clay plates.

But as we move away to a far distance, the anion concentration and cation concentration will come to an equilibrium and they will be almost identical. So, this point is known as reference point as I told earlier.

Now, if we calculate the total surface area, say for example, total surface area BAD, so, that will represent the excess of this counter ions, excess of this positive ions, which are present in this diffuse double layer. Similarly, if we calculate the area BCD, so that will tell us about the total deficiency of the ions of the same size and the total area ACD will tell you about the net diffuse layer charge or the surface charge of the clay surface.

So, from this plot we can determine what will be the total excess of this counter ions, what will be the total deficiency of the ions of the same sign and what will be the net diffuse layer charge or surface charge of the clay surface or clay water system from this distribution of the ions with distance plot.

Then the question arises how these cations or anions are distributed themselves in a double layer. To calculate the distribution of the anions and cations in a double layer, there are certain theories which are available. The most widely used theory is Gouy-Chapman's theory of diffuse double layer, this was first given by 1910 by Gouy and then it was modified by

Chapman in 1913, and combined together this is known as Gouy-Chapman's theory of diffuse double layer.

This theory explains the effect of the various parameters of the medium on thickness of the diffuse double layer. This theory was developed considering two well known equations, one is a Poisson's equations, which tells us about the variation of the electrical potential with respect to distance. And the second equations which is Boltzmann equations which describes the relationship between the ion distributions and the electrical potential. So, these two equations are used to derive the Gouy-Chapman's theory of diffuse double layer.

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Before the derivation of this layer certain assumptions were made. So, these are the four assumptions which were made to derive this diffuse double layer theory. The first one is ions in the double layer are point charges and there are no interaction between them. The second one is the charge on the particles surface is uniformly distributed.

The third one is the particle surface is a plate that is large relative to the thickness of the diffuse double layer. Then the fourth one is the permittivity of the medium next to the particle surface is independent of its position. So, these are the four assumptions which were made in deriving the diffuse double layer thickness by Gouy-Chapman's.

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So, we will go to those equations how it has been derived. So, first the Boltzmann equations, which tells us about the distribution of the ions. Here, if the concentration of the ions of type i is n_i in a force field of equilibrium, then the equation, then using the Boltzmann equation;

$$n_i = n_{i0} \exp\frac{\left(E_{i0} - E_i\right)}{kT} \qquad (1)$$

This subscript '0', that means, the reference state. If you could recall, I stated the reference point where the concentration of the anion and cation was same. So, that is the reference state or reference point which is a large distance from the surface. E is the potential energy, T is the temperature in Kelvin, K is Boltzmann's constant which is a value of 1.38×10^{-23} J/K.

Then the potential energy of an ion in an electric field can be derived using this equation;

$$E_i = v_i e \psi$$

Where, v_i = Ionic valency, i can be like v_1, v_2, like monovalent divalent, trivalent,

e = Electronics charge =1.602x10^{-19} C and

ψ = Electrical potential

Now, we know that the electrical potential decreases with increase in the distance from the charge surface.

So, earlier we have derived this one or we have seen how these electrical potential changes with the distance. So, next to the clay plate the value is significantly high, but as we move away, it will keep on decreasing at a reference set it becomes 0. So, electrical potential decreases with the increase in the distance from the charge surface.

The potential at the surface is designated by ψ_0.

Electrical surface potential at the reference state, E_{i0} = 0, because the electrical potential, ψ, will be 0 at the reference state. Since, ψ = 0, E_{i0} will be equals to 0. So, therefore;

$$E_{i0} - E_i = 0 - E_i = - E_i = -v_i e \psi$$

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So, the finally the Boltzmann's equation will be equals to;

$$n_i = n_{io} \exp\left(\frac{-v_i e \psi}{kT} \right) \qquad\qquad (2)$$

Now, let us draw the distribution of the anion and cations with distance. So, this is whatever we have already studied. If we compare the cation distribution this is clay plates, this is a clay plates negatively charged and this is a reference state or reference point.

Next to the clay plate, the number of cations are very large or the cation concentration is very high. As we move away from the clay plate its concentration will keep on decreasing. And at a reference state it becomes equals to n_{i0}. For cations, the vi becomes positive. Because say for example, if you take sodium, so v_i will be equals to 1, for calcium it will be 2 and the electrical potential is negative, which is for all the cations.

So, this term $-v_i.\psi$ will be a positive one because the $- ((+ve) \times (-ve)) = +ve$

Similarly, if you look into the anion concentration anion distribution, in fact, the anion concentration next to the clay plate will be very small and it will keep on increasing and it will reach to the same value of the cation concentration at the reference state O.

Here the v_i will be -ve because the of anion, ψ will be -ve because the electrical potential is negative. So, the product of $-(v_i.e.\psi)$ will be a negative one. So, here we can see the positive and negative signs are used for the cations and anions, respectively.

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We know that Poisson's equations equals to;

$$\frac{d^2\psi}{dx^2} = -\frac{\rho}{\varepsilon} \tag{3}$$

So, this is known as Poisson equation. So, let the equation becomes is equation number 3. Where, x = Distance from the surface which is expressed in meter, ρ = Charge density which is in C/m^3, ε = Permittivity of the medium, that is C^2 J^{-1}m^{-1}.

And when we calculate the charge density for a cation and anion environment, so that will be equals to;

$$\rho = e \sum v_i n_i = e\left(v^+ n^+ + v^- n^-\right)$$

So, where n_i is ion per unit volume, v$^+$ is a valence of the cations, v$^-$ is a valence of the anion.

Now, using the n_i from equation 2. Now, we will replace this n_i value in this equation. So, if we replace n_i value and take from this equation 2, this equation becomes equals to;

$$\rho = e \sum v_i n_{i0} \exp\left(\frac{-v_i e\psi}{kT}\right)$$

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Now, the substituting the value of rho in equation 3, the equation 3 will become equals to;

$$\frac{d^2\psi}{dx^2} = -\frac{e \sum v_i n_{i0} \exp\left(\dfrac{-v_i e\psi}{kT}\right)}{\varepsilon}$$

This is the differential equation for the electrical double layer adjacent to a planner surface. Now, the solution of this equation will helps in determining the electrical potential and the ion concentration as a function of distance from the plate surface.

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By solving this equation, we can get the diffuse double layer equation. Let how to solve exist, I will give you an example. Assuming a simple case of single type of ion, which are cations and anions of equal valency.

So, we will take two ions, v^+ plus and v^-. Say for example, sodium, Na^+, this is an example I am giving, this is Cl^-, both valence is +1 and -1.

That means, the valency is 1 negative and positive. And at reference state, the concentration will become identical. So,

$$n_o^+ = n_o^- = n_0$$

This is the concentration of this anion and cation at the reference state.

$$v^+ = -v^- = v$$

We know that,

$$n^+ = n_o \exp\left(\frac{-ve\psi}{kT}\right) \quad \text{and} \quad n^- = n_o \exp\left(\frac{ve\psi}{kT}\right)$$

Since, this is a positive one this is we get and negative of negative will becomes positive here. So, therefore, the negative sign is here that is positive sign over here.

$$\rho = e\sum v_i n_i = e\left(v^+ n^+ + v^- n^-\right)$$

Now, we will replace this n^+ plus by this equation and n^- by this equation. By replacing those values, we will get the equation;

$$\rho = e\sum v_i n_i = e\left(v^+ n^+ + v^- n^-\right)$$

$$= \left[evn_o \exp\left(\frac{-ve\psi}{kT}\right) + e(-v)n_0 \exp\left(\frac{-(-v)e\psi}{kT}\right)\right]$$

$$= \left[evn_o \exp\left(\frac{-ve\psi}{kT}\right) - evn_0 \exp\left(\frac{ve\psi}{kT}\right)\right] = -2evn_0.\frac{1}{2}\left[\exp\left(\frac{ve\psi}{kT}\right) - \exp\left(\frac{-ve\psi}{kT}\right)\right]$$

$$= -2evn_0.\sinh\left(\frac{ve\psi}{kT}\right)$$

Now replacing the value of rho in equation 3, we will get,

$$\frac{d^2\psi}{dx^2} = \frac{2n_o ve}{\varepsilon}\sinh\frac{ve\psi}{kT}$$

This is the diffused double layer equation for a single layer.

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When we solve this, we will get few dimensionless constant in the name of potential function and distance function.

The potential function will be;

$$y = \frac{ve\psi}{kT}$$

$$z = \frac{ve\psi_0}{kT}$$

So, these are the two potential function.

The distance function,

$$\xi = K.x$$

And,

$$\frac{1}{K} = \sqrt{\frac{\varepsilon kT}{2n_0 e^2 v^2}} = \sqrt{\frac{\varepsilon_0 DkT}{2n_0 e^2 v^2}}$$

So, this equation will help us to find out the diffuse double layer thickness. This equation will tell us about the thickness of the diffuse double layer and the parameters on which the diffuse

double layer thickness depends. This is all about a single diffuse double layer, but hardly there is a single diffuse double layer.

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In clay-water system, there will be Interacting Double Layers. So, here you can see this is a single double layer, this is a single double layer. But in a clay water system where the two double layers, two single double layers interact, we will get interacting double layers. Here, we can see this is the plot between the electrical potential and distance, the plot between the number of ions and distance, this is the electrical potential, this is a variation of the electrical potential.

As we move away from the plate it will decrease and then it will reach to a mid-plane potential,

$$y = \frac{ve\psi}{kT} = u$$

It will start to increase like this one. Similarly, if you compare with the cation concentration it will keep on decreasing as you move away from the plate and it will reach to a value over here and then again it will try to increase. This is anion concentration. It will decrease and it again it will remain same. So, this is the interacting double layer which we will get by combining two single double layers.

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Although this Gouy-Chapman's theory or diffuse double layer theory is quite widely used in deriving the diffuse double layer thickness, it has certain limitations. First of all, it has been assumed that the ions are point charges that means the size of the ions are not considered. Then the water structure and electrical properties of the water molecules are ignored.

Then the dielectric constant of the free and absorbed water were assumed same. I had already discussed how the dielectric constant of the free and absorbed water are significantly different, but in this diffuse double layer theory they were assumed to be same. Next is the, clay particle charges are assumed to be uniformly distributed throughout the clay plates.

But in actually there are some localization exists. So, that means, it is not uniformly distributed throughout the clay surface. The fifth point is, the hydration of the ion particles

are ignored. So, these are the few limitations of the diffuse doubler derived by Gouy-Chapman's.

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So, in order to overcome these limitations, few more theory has been developed, first one is a stern model of diffuse double layer. It was first given by Stern in 1924. In stern layer, they have considered a counter cations, which are present very close to the plate. The center of the positive charge of the cation can come very close to the surface of the particles and adsorbed on the stern layer.

The distance of this closest approach to the charge surface is depend on the size of this ion. If you change the size of the ion, the distance to the closest approach also changes. Now, if we look into this, we have this, is the electrical distribution of the electrical potential with distance, then we will get a distribution like this one, where the electrical potential first linearly changes from ψ_0 to ψ_δ then it decreases like a diffuse double layer.

So, this ψ_δ is known as the stern potential and ψ_0 is known as surface potential. These counter ions are separated from the clay surface by a distance δ. And this δ is known as the Stern layer. This can also be explained in terms of a molecular condenser layer, which will be formed because of the strongly absorbed cation next to the clay surface.

These are the known as the counter ions, which are very strongly adsorbed to the clay surface and form the stern layer. Now, when we add some solution to it, the diffuse double layer will decrease and some counter ions will move from double layer to the Stern layer and thereby decreasing the Stern potential σ_D.

If we calculate the net charge, then if σ_S is the net counter ion charge of the Stern layer, and σ_D is the net counter ion charge of the diffuse double layer, the summation of this two will give you the total charge of the diffuse double layer or the clay surface. So, this is the stern layer which was given by Stern in 1924. The Stern layer has generally a low dielectric constant in comparison to the free water.

And also, before deriving this theory, the Stern considered that unlikely the Gouy model the distance of the closest approach of the counter ion to the charge surface is limited by these ions. And these counter ions or the cations do not take part in the formation of diffuse double layer. And beyond this stern layer, the next layer is the diffuse double layer. And we need to

remember that with a decrease in the hydrated ions of this stern layer, the number of adsorbed ions increases on the Stern layer.

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Now, next is the Grahame Model of diffuse double layer. In Grahame Model of double layer, Grahame consider the two planes one is known as Outer Helmholtz plane and another one is known as Inner Helmholtz plane. The Grahame made a distinction between the plane passing through the centers of the counter ions of the closest approach to the surface and the limit of the diffuse double layer or the position of the closest approach of the co-ions that is your OHP.

So, he assumed, two planes one is Inner Helmholtz plane, this is a plane of the center of the chemisorbed anions. So, these are some of the anions which are specifically adsorbed on the clay surface, these anions overcome the electrostatic repulsion due to the influence of the strong specific adsorption and enter into the Stern layer across the outer and crossing the Outer Helmholtz plane.

This Inner Helmholtz plane refers to the plane which is passes through the center of this specifically adsorbed anions and this plane is known as the Inner Helmholtz plane. And generally, its thickness is around 1.5 angstrom. The Outer Helmholtz plane is located at a cationic radius which will be equal to the radius of this cation plus a molecular layer of water. The distance between the solid surface to the OHP is called his Stern layer and is equals to 6 angstrom.

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So, if we plot the variation between the electrical potential and the distance, this is the surface potential and next to the IHP it will decrease significantly, linearly also. This is electrical potential edge IHP and then this will be electrical potential edge OHP and that will be equals to sigma D, that is your Stern potential.

And this thickness is known as the Stern layer. And next to this OHP, this is the diffuse double layer. So, basically in Grahame Model, he proposed the IHP and OHP considering the chemisorbed of some specifically absorbed anions.

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Next will be the Zeta potential. We know that the clay surface adsorbs some cations like if this is a clay surface these are some cations which are very strongly adsorbed over here and then comes the water molecules, these are the few layers of the water molecules which are very strongly attached. So, if we draw this, this is clay surface, this layer is known as Stern potential.

Now, what happens, these water molecules are very strongly attached. Next to this layer is diffused double layer. So, generally this will be attracted in this direction diffuse double layer water will move in this direction. So, there will be a separation between immobile and mobile water surface. So, this is also known as a slip plane.

So, due to the opposite effect of drag of water molecules and electrostatically pull by moving the particles towards the clay surface, the diffuse double layer will be sheared at a certain point or that is a slip plane, that plane is known as shear plane and the potential at this shear plane will be known as zeta potential.

Generally, this plane distinguished between the mobile fluid from immobile fluid. The magnitude of the Zeta potential indicates the degree of electrostatic repulsion between the particles in a clay suspension. If the Zeta potential is more, that means, more amount of repulsion is there and the particles will be in suspended state. If we add some salt solution to it, then the Zeta potential will decrease.

That means, the repulsion between the particles will decrease and the particle will coagulate or flocculate. So, therefore, the Zeta potential indicates the stability of a colloidal system. Higher is the Zeta potential higher will be the dispersion, lower is the Zeta potential lower will be the dispersion and higher will be the flocculation.

So, when we add some salt concentration to it, some of the counter ions move towards a Stern layer which results in a decrease in the Zeta potential and that leads to the flocculation of the water molecules.

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These are the few points which I discussed in today's class.

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So, with this I would like to end today's class. These are the few of the references which are used for preparing this class. In the next lecture, we will be learning about what are the different factors which controls the diffusible layer thickness and how they changes the engineering behaviour of expansive soil. With this I would like to conclude today's lecture. Thank you very much for your attention. Thanks.