Soil Mechanics
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Lecture - 4

In the previous lecture we have studied about soil aggregate relationships and clay minerals. In this lecture, we will understand about the particle forces and their behavior and clay water interaction. If you review the previous lecture, we have also studied about grain shape. And we said that for coarser fraction of soils different shapes of the grains are possible like Angular, Sub-angular, Sub-rounded, Rounded and Well-rounded. As we see here for the coarser fraction of soils Angular, Sub-angular, Sub-rounded, Rounded and Well-rounded shapes are possible because of the different degrees of weathering. In case of fine fraction of soils, we said that in majority of the particles the shape is platelet particles or needle shaped particles or half open tube particles. So, distinctive varieties in the shapes can be noted and we also studied about different types of minerals particularly clay minerals like Kaolinite, Illite and Montmorillonite. We have seen the structures of these minerals and also the sizes of these Kaolinite, Illite and Montmorillonite crystals.

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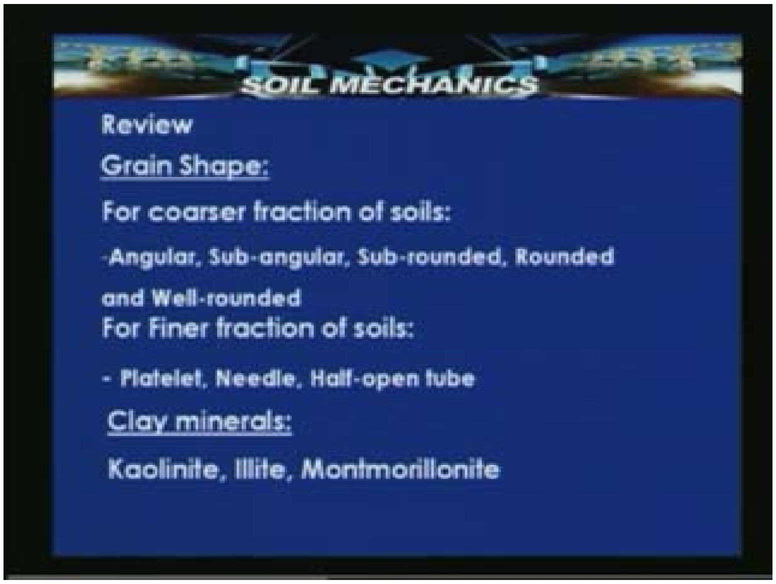

SOIL MECHANICS

Review

Grain Shape:

For coarser fraction of soils:

-Angular, Sub-angular, Sub-rounded, Rounded and Well-rounded

For Finer fraction of soils:

- Platelet, Needle, Half-open tube

Clay minerals:

Kaolinite, Illite, Montmorillonite

In this slide we will try to see the occurrence of the clay minerals in soils. Clay minerals are not stable and static entities in soils. As we discussed the soils are subjected to continuous weathering. So this weathering gradually changes them by dissolving some minerals and reprecipitating others. Intensity of weathering increases with increasing temperature and is higher in moist than in dry soils. That is moist soils have high degree of weathering than dry soils. Since clay minerals are the products of chemical weathering of rocks, both the climate and parent rock influence the type of the minerals found. We have discussed already in the origin of the soils that the clay minerals are the main products of the chemical weathering of rocks which are obtained by the disintegration of the rocks and their transportation with different agencies like wind, water and air. The clay minerals are the products of chemical weathering of rocks, both climate and parent rock influence the type of the minerals found.

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SOIL MECHANICS

Occurrence of clay minerals in soils

- Clay minerals are not stable, static entities in soils. Weathering gradually changes them by dissolving some minerals and reprecipitating others. Intensity of weathering increases with increasing temperature, and is higher in moist than in dry soils.
- Since Clay minerals are the products of chemical weathering of rocks, both the climate and parent rock, influence the type of minerals found.

Now let us summarize this occurrence of the different clay minerals whatever we have studied in soils. This table shows clay mineral group versus occurrence.

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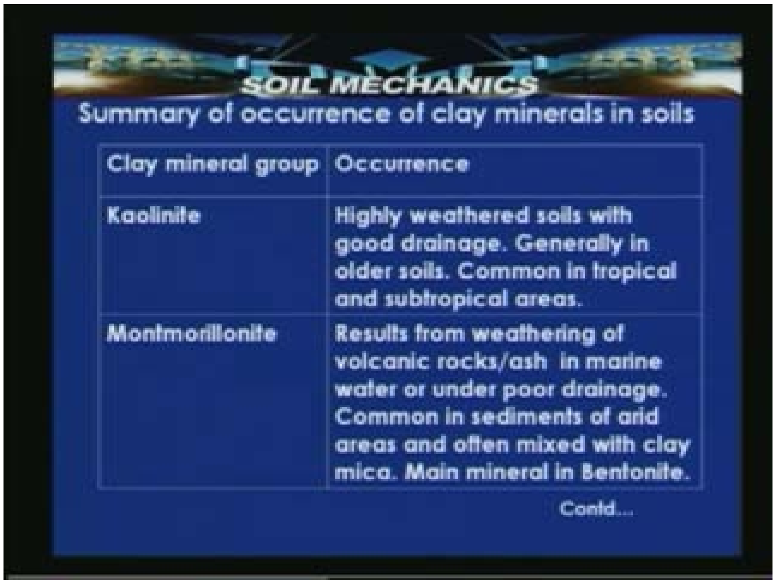

SOIL MECHANICS

Summary of occurrence of clay minerals in soils

Clay mineral group	Occurrence
Kaolinite	Highly weathered soils with good drainage. Generally in older soils. Common in tropical and subtropical areas.
Montmorillonite	Results from weathering of volcanic rocks/ash in marine water or under poor drainage. Common in sediments of arid areas and often mixed with clay mica. Main mineral in Bentonite.

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This table shows clay mineral group and their occurrence in soils. Let us first consider Kaolinite. Kaolinite generally occurs in highly weathered soils with good drainage. So when there is a good drainage under highly weathered soils then these Kaolinite soils are going to be prevalent. Generally these minerals occur in older soils. That is old deposits common in tropical and subtropical areas. So Kaolinites are common in tropical and subtropical areas. Then come to the other mineral Montmorillonite. This mineral results from the weathering of volcanic rocks or ash in marine water or under poor drainage. It is common in sediments of arid areas and often mixed with clay mica and there is a predominant mineral in Bentonite.

Now let us look at the other minerals like clay mica which is nothing but Illite mineral. It will be there in soils derived from the weathering of sedimentary rocks in arid regions. So if there are soils which are derived from the weathering of sedimentary rocks in arid regions then this clay mica mineral can be prevalent. It is a dominant mineral in slate and shale. Other mineral chlorite occurs in the areas of metamorphic rock. It is common in marine sediments and sedimentary rocks but not normally present in dominant proportions. So the major minerals which are present in a dominant way are Kaolinite, Montmorillonite and Illite. So these Kaolinite, Montmorillonite and Illite dominate in soils.

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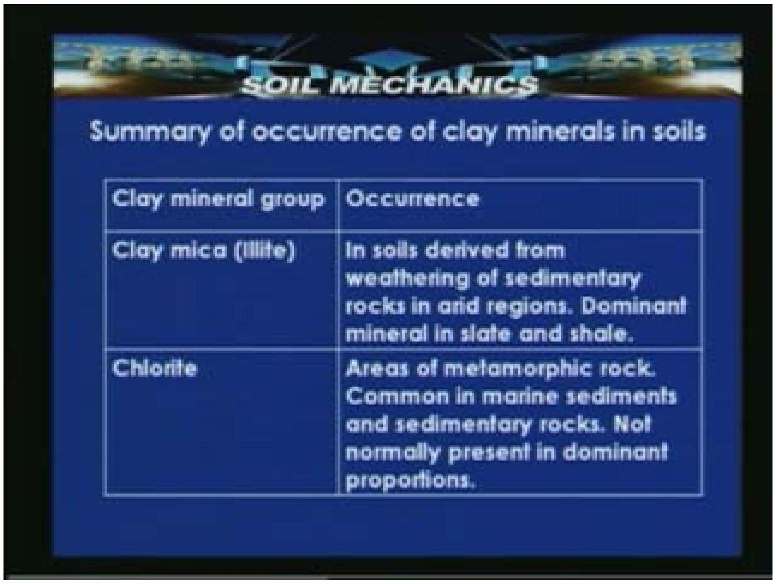

SOIL MECHANICS

Summary of occurrence of clay minerals in soils

Clay mineral group	Occurrence
Clay mica (Illite)	In soils derived from weathering of sedimentary rocks in arid regions. Dominant mineral in slate and shale.
Chlorite	Areas of metamorphic rock. Common in marine sediments and sedimentary rocks. Not normally present in dominant proportions.

How do identify these minerals? That is the question which will come whenever we get these minerals which are in soils we are required to identify these minerals. Let us try to look into the different methods which are available to identify these minerals. First of all no one method is satisfactory for identification because one reason is interference of minerals in a mixture, and the range of composition and crystal structure of clays from different sources. So, what we say is it is very difficult to determine or identify the minerals satisfactorily; the reasons are interference of minerals in a mixture or range of composition and crystal structure of clays from different sources. There are three methods to identify the clay minerals. One is X-ray diffraction that is XRD method, the other one is differential thermal analysis DTA method and third one is Casagrandes plasticity chart.

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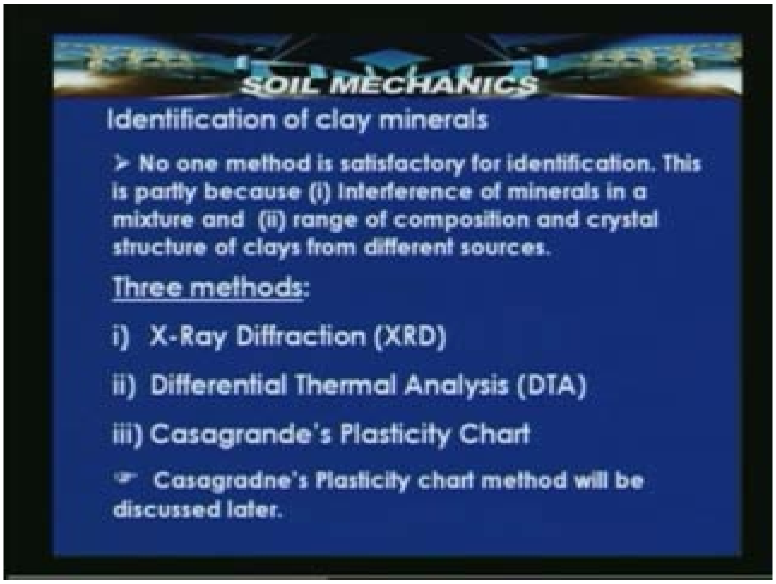

SOIL MECHANICS

Identification of clay minerals

- No one method is satisfactory for identification. This is partly because (i) Interference of minerals in a mixture and (ii) range of composition and crystal structure of clays from different sources.

Three methods:

i) X-Ray Diffraction (XRD)

ii) Differential Thermal Analysis (DTA)

iii) Casagrande's Plasticity Chart

☞ Casagradne's Plasticity chart method will be discussed later.

So the third method the Casagrande’s plasticity chart we will discuss later but now in this lecture let us look into the first two methods like X-Ray Diffraction method and DTA method. The XRD method is a most widely used method of identification of clay minerals is from an X-Ray Diffraction pattern of a powdered sample of the clay size fractions of a soil. This method is widely used and this is based on the principle that minerals with regular or repeating patterns of crystal structure diffract X-rays. Minerals can usually be identified from the typical diffraction lines. XRD method is most widely used method of our identification of clay minerals from the X-Ray Diffraction pattern of a powdered sample of the clay size fractions of a soil. It works on the principle that minerals with regular or repeating patterns of crystal structure diffract X-rays.

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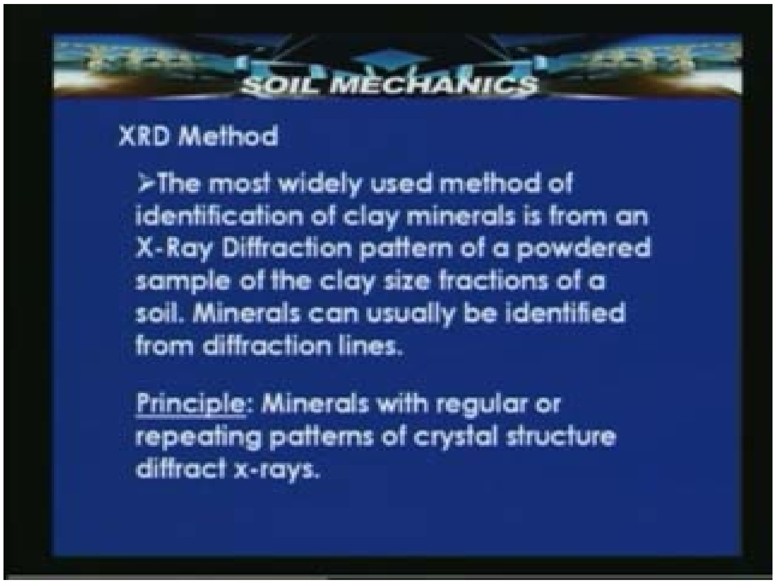

SOIL MECHANICS

XRD Method

- The most widely used method of identification of clay minerals is from an X-Ray Diffraction pattern of a powdered sample of the clay size fractions of a soil. Minerals can usually be identified from diffraction lines.

Principle: Minerals with regular or repeating patterns of crystal structure diffract x-rays.

So, a schematic diagram of the X-Ray Diffraction unit for the crystal identification is shown here.

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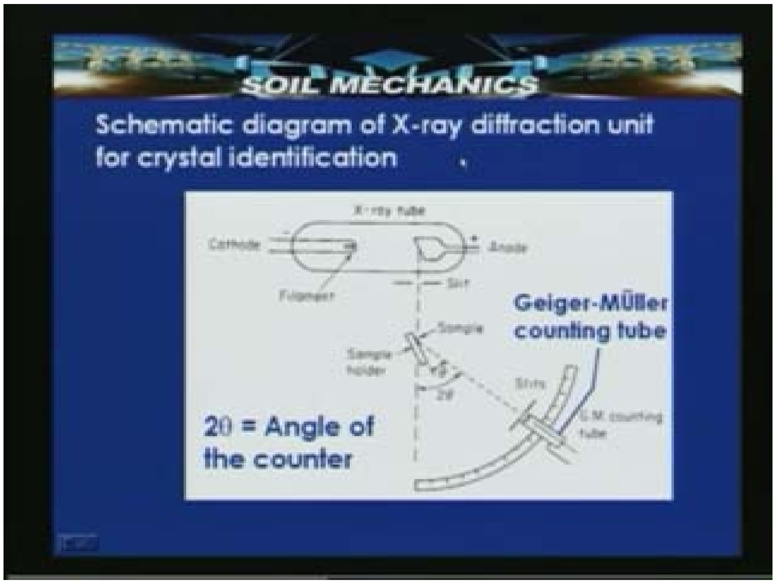

SOIL MECHANICS

Schematic diagram of X-ray diffraction unit for crystal identification

Here is shown an X-ray tube, here is the sample holder and this one is the Geiger-Muller counting tube. Here the sample holder rotates about this particular point. So when the sample holder rotates theta, the Geiger Muller counting tube reads it as 2 theta. So, as shown in this sample, whenever X-ray reflects with high intensity, the Geiger Muller counting tube records that particular intensity and particular angle of the counter. So this method is useful for finding out the intensity of the reflection with angle theta.

Here in this slide the typical XRD pattern of Kaolinite, Montmorillonite and Illite can be seen. So here on the x axis the degrees 2 theta that is nothing but the angle of the counter tube is plotted and on the y axis intensities of reflection is shown. In this slide this particular bottom most curve is for a Kaolinite mineral, the middle one is for Montmorillonite mineral and Illite shows the top most curve. Distance to diffraction pattern of Kaolinite powder can be seen. This is the distance of the 2-diffracting planes with peak resulting at 7.3 Angstroms is the distance between the 2-diffractive planes, the next peak which is the 2nd order reflection and the other peak is at the lower order reflection from other plane that is 2.57.

Illite can be recognized with the distinctive pattern of diffraction with 10 Angstroms as the distance between the diffractive planes and higher degrees of reflections. Similarly the Montmorillonite also can be seen with higher order of diffraction and then higher degree of reflections. So, different minerals with different crystalline structures will have different X-Ray Diffraction patterns. And in fact these different patterns help us to identify different minerals. This is based on the X-Ray Diffraction method to identify Kaolinite, Montmorillonite and Illite minerals.

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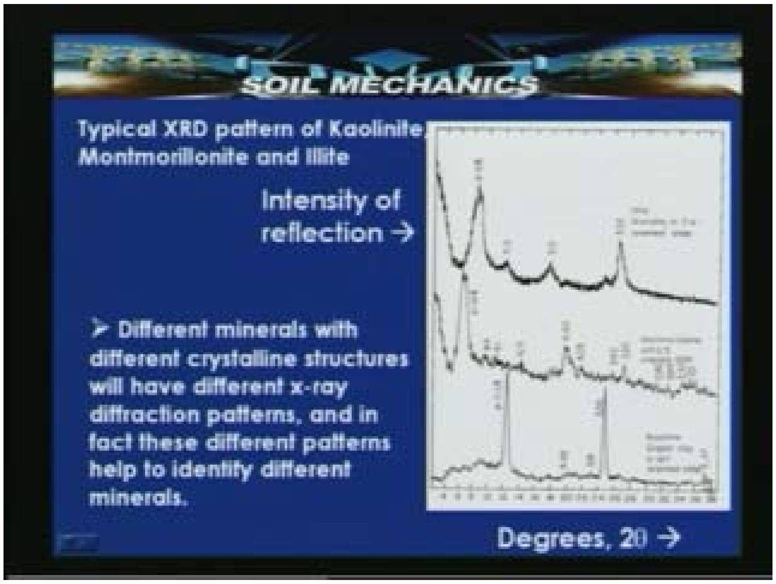

SOIL MECHANICS

Typical XRD pattern of Kaolinite Montmorillonite and Illite

Intensity of reflection →

- Different minerals with different crystalline structures will have different x-ray diffraction patterns, and in fact these different patterns help to identify different minerals.

Degrees, 2θ →

Having seen about XRD method, we are required to know about the demerits. First one is, this method is not suitable for soils with mixtures of clay minerals, organic matter and non-clay mineral constituents. If the soil has got a mixture of different minerals, it is very difficult to identify these minerals through XRD method. If the soil has got organic matter or non-clay mineral constituents then it is very difficult to identify or distinguish from the XRD method. There is an inability to specify the proportion of the each mineral in a mixture in this method. XRD method will not give the percentage of Kaolinite in a given soil or the percentage of Montmorillonite or Illite in a given soil. So, it has got two distinctive demerits. One is that with mixtures of clay minerals it is very difficult to identify and the second one is the inability to specify the proportion of each mineral in a mixture.

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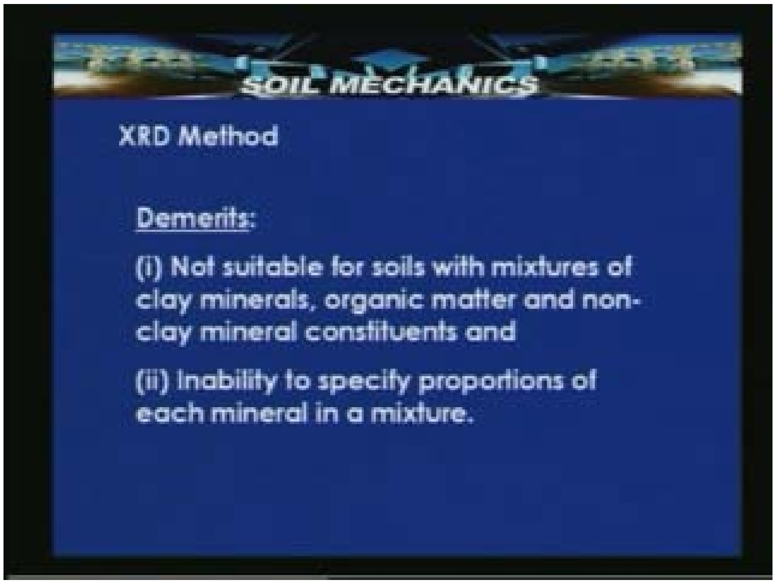

SOIL MECHANICS

XRD Method

Demerits:

(i) Not suitable for soils with mixtures of clay minerals, organic matter and non-clay mineral constituents and

(ii) Inability to specify proportions of each mineral in a mixture.

Now, let us look at differential thermal analysis method or DTA method. Differential thermal analysis method determines the temperature at which the changes occur in a mineral when it is heated continuously to higher temperature. The intensity of change is proportional to the amount of the mineral present. Clays lose water or go through a phase change at specific temperatures. They can be exothermic or endothermic. Clays can take water or give water, so they lose water or go through the phase changes at specific temperatures. The temperatures at which these reactions or these changes occur are characteristic of the mineral and can therefore be used for identification. So the differential thermal analysis determines the temperature at which the changes occur in a mineral when it is heated continuously to a higher temperature. The intensity of change is proportional to the amount of the mineral present. The temperatures at which these reactions occur or characteristics of the mineral and can therefore be used for identification.

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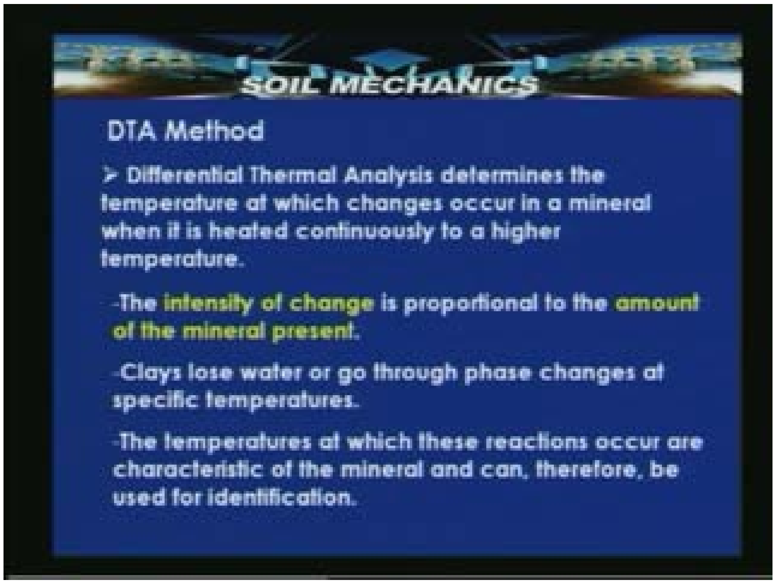

SOIL MECHANICS

DTA Method

> Differential Thermal Analysis determines the temperature at which changes occur in a mineral when it is heated continuously to a higher temperature.

-The intensity of change is proportional to the amount of the mineral present.

-Clays lose water or go through phase changes at specific temperatures.

-The temperatures at which these reactions occur are characteristic of the mineral and can, therefore, be used for identification.

In this slide the DTA apparatus with associated recording and control mechanisms are shown. Here is a furnace in which the specimen sample is kept and inert material which is nothing but a control material connected to the thermocouples is shown. For the DTA measurement a sample of clay and a sample of inert material are slowly heated in the furnace. So in the DTA method what it is done is that a sample of the clay specimen and a sample of the inert material are slowly heated in a furnace to higher degrees of temperature.

Generally calcined aluminium oxide or ceramic are used as a reference material or as an inert material. So as a reference material or a control material, ceramic or calcined aluminium oxide is used. When a temperature is reached at which the clay loses water by vaporization, the sample temperature will drop below that of inert material. So, different types of minerals experience changes at particular temperatures. Based on these observations one can find out the type of minerals based on the known minerals at known temperature changes.

The DTA apparatus involves placement of the sample along with inert material and heating to several degrees of temperature. As an inert material either ceramic or calcium aluminium oxide is used. When a temperature is reached at which the clay loses water by vaporization the sample temperature will drop below that of the inert material. So these particular changes are noted at specific temperatures and they are used as muster examples for identifying the mineral.

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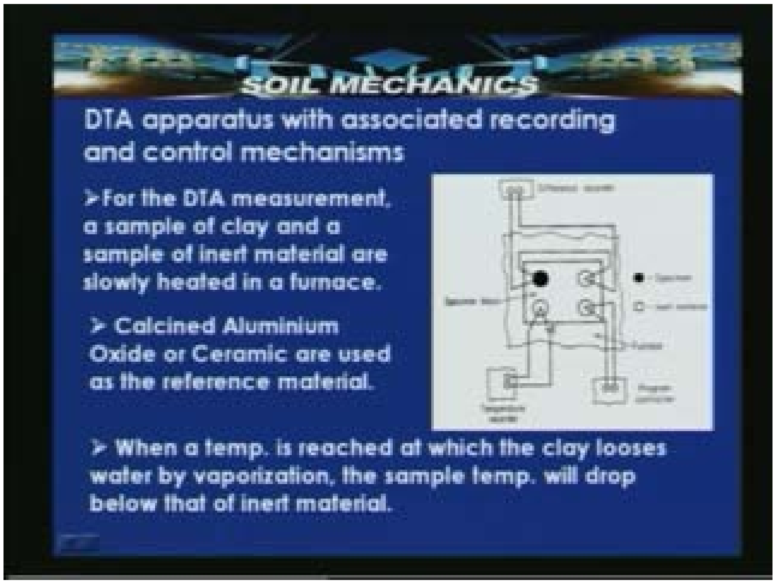

SOIL MECHANICS

DTA apparatus with associated recording and control mechanisms

- For the DTA measurement, a sample of clay and a sample of inert material are slowly heated in a furnace.
- Calcined Aluminium Oxide or Ceramic are used as the reference material.
- When a temp. is reached at which the clay looses water by vaporization, the sample temp. will drop below that of inert material.

So having seen the occurrence of minerals and soils let us try to look into the different types of grain sizes. As we said while introducing the origin of soils, the soils will be subjected to different degrees of weathering and they will be transported with different agencies like wind, water, air or due to glacial action. This table shows soil type and diameter range. Cobbles and boulders can have diameter d or a particle size greater than 75 mm. Gravels range between 4.75 and 75 mm that is fine gravels and coarse gravels. Sands have greater than 0.075 mm to 4.75 mm, all the soils which are falling in this region are termed as sands. Silts lie between 2 micron, the soils falling in the region between 0.002 mm and 0.075 mm is termed as silts and clay is less than 0.02 mm or 2 microns.

Most of the coarser particles are approximately equidimensional and most of those in clay size are far from equidimensional. We also discussed that they are plate shaped particles and we have also seen the photo micrographs of these different particles. In this slide what we have seen is the soils with different sizes and as we go down from boulders to gravels to sands to silts and clays the particle size decreases, that is required to be noted.

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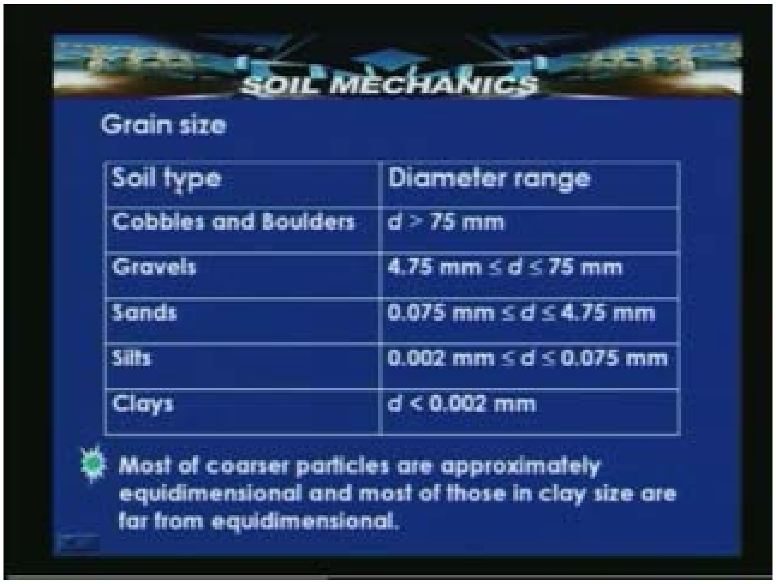

SOIL MECHANICS

Grain size

Soil type	Diameter range
Cobbles and Boulders	$d > 75$ mm
Gravels	4.75 mm $\leq d \leq$ 75 mm
Sands	0.075 mm $\leq d \leq$ 4.75 mm
Silts	0.002 mm $\leq d \leq$ 0.075 mm
Clays	$d < 0.002$ mm

- Most of coarser particles are approximately equidimensional and most of those in clay size are far from equidimensional.

Now having seen the different ranges of particle sizes, I would like to introduce here one term called specific surface area. This particular term specific surface area is also abbreviated like SSA. The smaller a particle size, the larger is its specific surface. Let us assume the soil with an equivalent shape of a particle as a cube in a total volume of 1 cm cube. So assume that the soil is idealized like a cube of side of dimensions d. This is only an idealization, the soil is idealized like a cube of size d.

Let us see in this table, here the length of the cube side, total surface area and surface area per volume is 1 cm cubed and that is the volume. If you look into it, if I have got a cube of side 1 cm then the total surface area of all phases works out to be 6d square that is nothing but 6 cm square. And surface area per volume is nothing but 6d square by d cubed works out to be 6.

Suppose if I take particle size equivalent to 1 micrometer or 10 to the power minus 4 cm the total surface area works out to be 6 into 10 power 4, the increase in the specific surface area can be noted 10,000 times there is an increase in the surface area and surface area per unit volume is also 6 into 10 power 4. Then 1 nanometer or 10 power minus 7 cm works out to be as total surface area as 6 into 10 power seven and surface area per volume is around 6 into 10 power seven. So what we have seen is that the smaller a particle size or the smaller a cube size, the larger is its specific area and specific area per volume.

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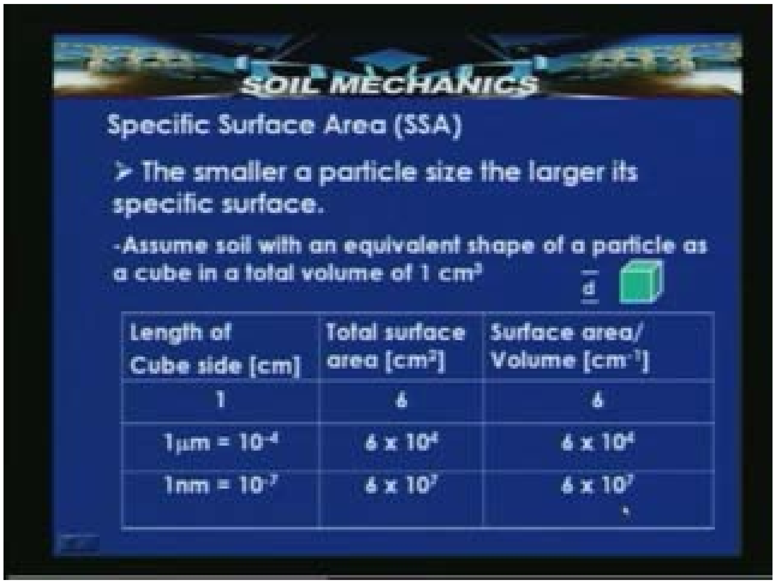

SOIL MECHANICS

Specific Surface Area (SSA)

- The smaller a particle size the larger its specific surface.

-Assume soil with an equivalent shape of a particle as a cube in a total volume of 1 cm^3

Length of Cube side [cm]	Total surface area [cm^2]	Surface area/ Volume [cm^{-1}]
1	6	6
1μm = 10^{-4}	6 x 10^4	6 x 10^4
1nm = 10^{-7}	6 x 10^7	6 x 10^7

With that example let us look here; we can see that the surface area goes up directly as the particle size goes down, so number of particles in a given volume also increased. Specific surface area is a parameter which is defined as the total surface of the individual grains per dry mass of the grains. Specific surface area can be given with the definition, if you see here specific surface area is equal to surface area by (volume into mass density) which is nothing but the dry mass of the grains. That can be written as 6d square by d cubed rho, expressing the surface area, d cube is the volume and rho is the mass density of soil. By simplifying we will get 6 by drho where the units of the specific surface area works out to be m square by g or cm square by g. Specific surface area is inversely proportional to the particle size. If the particle size is larger then there is a less specific surface area and if the particle size is finer it means that for the soil with clay particles is supposed to be of higher specific surface area. So, Specific surface area is inversely proportional to the particle size.

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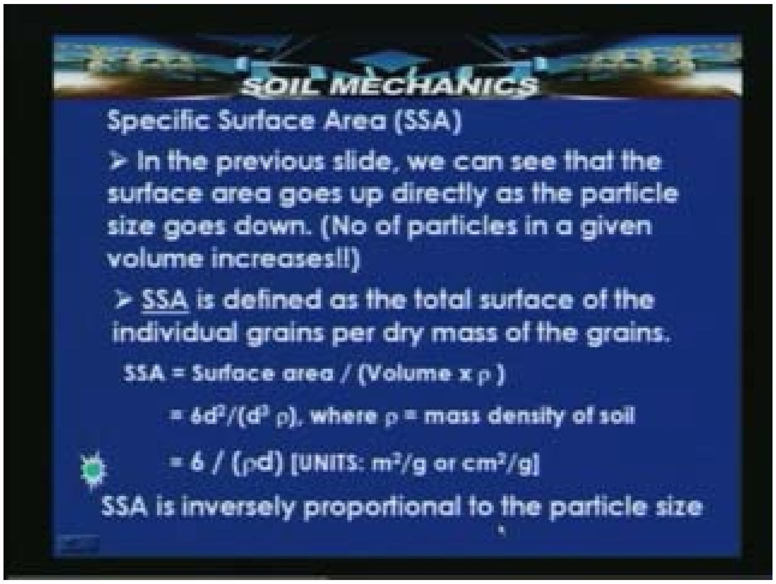

SOIL MECHANICS

Specific Surface Area (SSA)

- In the previous slide, we can see that the surface area goes up directly as the particle size goes down. (No of particles in a given volume increases!!)
- SSA is defined as the total surface of the individual grains per dry mass of the grains.

SSA = Surface area / (Volume x ρ)

= $6d^2/(d^3 \rho)$, where ρ = mass density of soil

= $6 / (\rho d)$ [UNITS: m^2/g or cm^2/g]

SSA is inversely proportional to the particle size

According to Lambe and Whitman (1969) we can give the specific surface areas of different minerals in the soil. Quartzite is the mineral which is predominantly there in sandy type soils. The specific surface area here is mentioned around 0.03 m square by g and water adsorbed on to the mineral is equal to 1.5 into10 to the power minus 4 percent. We will understand about this term adsorbed in the due course of this lecture.

For the mineral Kaolinite the specific surface area is 10 m square by g and water adsorbed is 0.5. Illite is 100 and water adsorbed is 5. Montmorillonite is 1000 and water adsorbed is 50 percent. The sample calculation is given for the calculation of percentage water adsorbed onto the soil. For Kaolinite water content is given as specific surface area into thickness of layer of water into mass density of water. Here in this case 10 m square by g (the specific surface area of kaolinite) into (thickness of layer of water) 10 power minus 10 m into 10 power 6 g by m cube (the mass density of water) which works out to be 5 into10 power minus 3 or 0.5 percent. As you have seen here, for kaolinite, Illite and Montmorillonite the specific surface area increases. Specific surface area of Montmorillonite is 100 times the specific surface area of kaolinite. And we can also see that as the specific surface area increases then the percentage water adsorption also increases.

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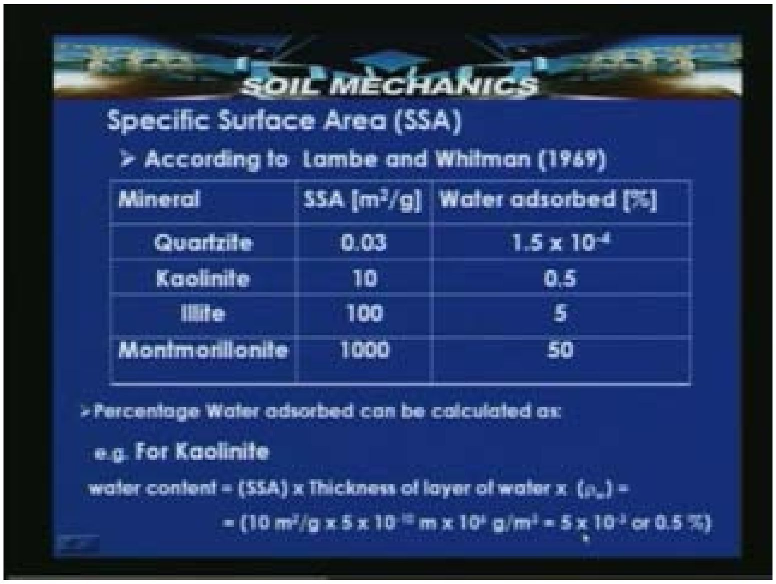

SOIL MECHANICS

Specific Surface Area (SSA)

- According to Lambe and Whitman (1969)

Mineral	SSA [m^2/g]	Water adsorbed [%]
Quartzite	0.03	1.5×10^{-4}
Kaolinite	10	0.5
Illite	100	5
Montmorillonite	1000	50

- Percentage Water adsorbed can be calculated as:

e.g. For Kaolinite

water content = (SSA) x Thickness of layer of water x (ρ_w) =

$= (10\ m^2/g \times 5 \times 10^{-10}\ m \times 10^6\ g/m^3 = 5 \times 10^{-3}$ or 0.5 %)

So water adsorption is a function of specific surface area and specific surface area is a function of particle size that is what we have discussed. The percentage of water adsorption onto the particular clay mineral is a function of specific surface area and a specific surface area is a function of a particle size. We also said that specific surface area of Montmorillonite is 100 times that of kaolinite. This can be visualized when one realizes that 6g of Montmorillonite has approximately the same surface area as an entire football field. A specific surface area of 25m square by g has also been suggested as the lower limit of the colloidal range that is less than 2 micron size.

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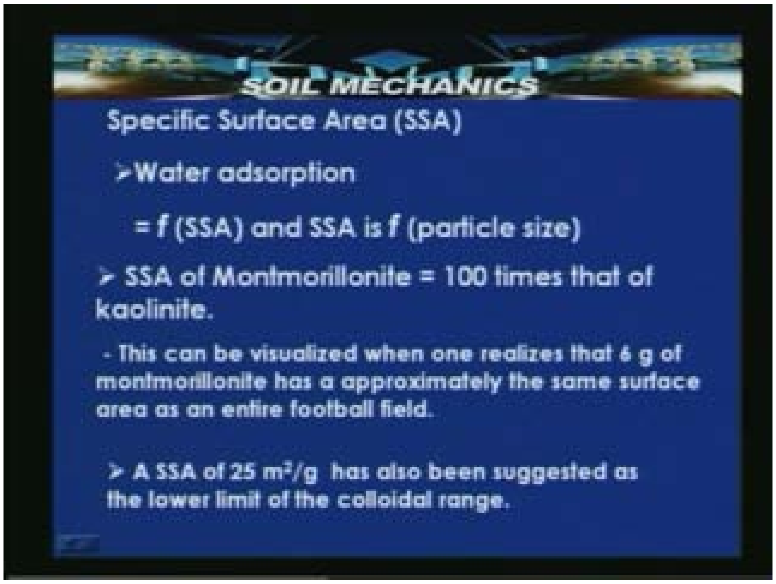

SOIL MECHANICS

Specific Surface Area (SSA)

- Water adsorption

  = f (SSA) and SSA is f (particle size)

- SSA of Montmorillonite = 100 times that of kaolinite.

  - This can be visualized when one realizes that 6 g of montmorillonite has a approximately the same surface area as an entire football field.

- A SSA of 25 m^2/g has also been suggested as the lower limit of the colloidal range.

If you see, the interrelation between the grain size and specific surface area is as follows. As the grain sizes decrease, the specific surface of the soil which is simply the total surface area of the individual grains per dry mass of the grains increases exponentially.

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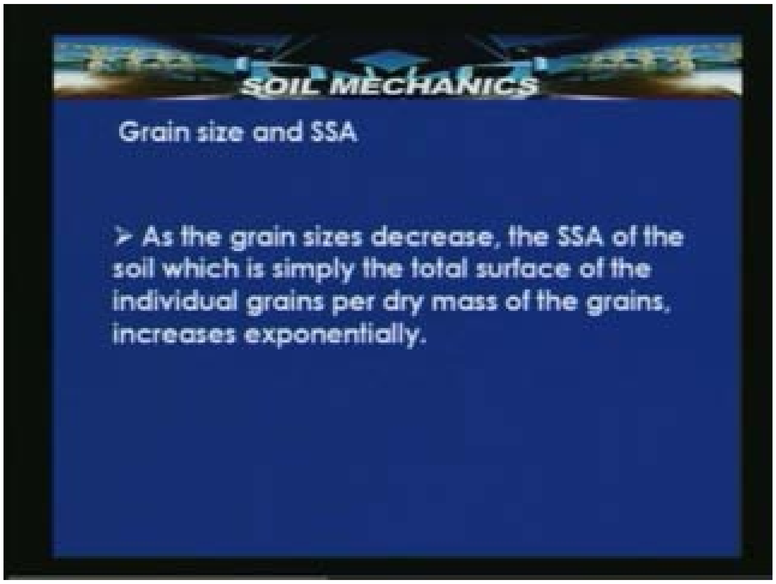

SOIL MECHANICS

Grain size and SSA

- As the grain sizes decrease, the SSA of the soil which is simply the total surface of the individual grains per dry mass of the grains, increases exponentially.

Here in this picture, this is the photomicrograph of quartzite mineral, this is a photomicrograph of Kaolinite mineral and this is the photomicrograph of Montmorillonite mineral. As we go from left to right here the particle size decreases, as you go from bottom to top, the specific surface area increases. So with an increase in specific surface area and decrease in particle size different types of behavior can be noted. These photomicrographs we have seen in the previous lecture, but these slides are again shown to show the influence of increase in specific surface area with a decrease in particle size and changing in the mineral.

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SOIL MECHANICS

Increase in SSA

Decrease in Particle Size

Having seen and having learnt about specific surface area let us see again a comparison of the size, shape and specific surface area of the several clay particles. If you see here we have discussed that Montmorillonite has got the finest tiny particle size followed by clay mica which is nothing but Illite then chlorite and kaolinite. As we come down from top to bottom the particle size increases and specific surface area decreases.

For Montmorillonite it was shown like 800 m square by g, for clay mica it was shown as 80, chlorite is around 80 and Kaolinite has 15 m square by g. Clay particles are plate shaped because the layer lattice structure results in strong bonding along two axes but weak bonding between the layers. The variation in SSA that is nothing but specific surface area is attributed to different thickness of plate shaped particles.

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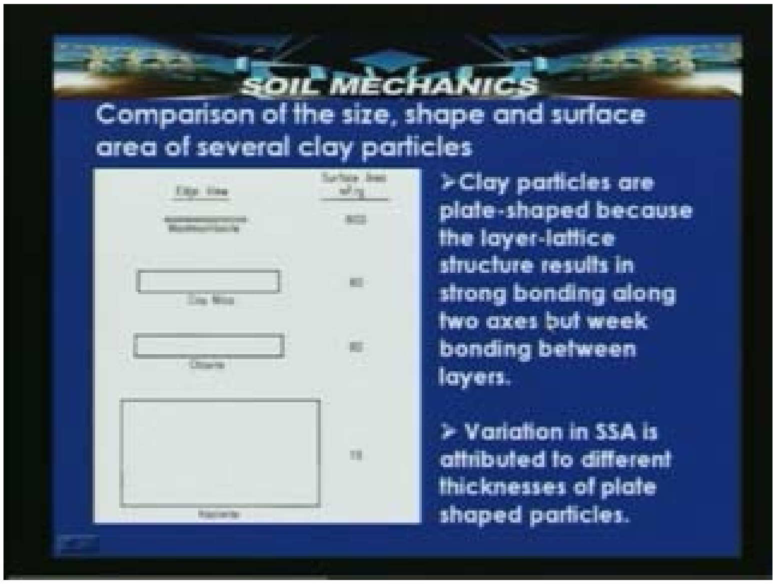

SOIL MECHANICS

Comparison of the size, shape and surface area of several clay particles

- Clay particles are plate-shaped because the layer-lattice structure results in strong bonding along two axes but week bonding between layers.
- Variation in SSA is attributed to different thicknesses of plate shaped particles.

We have introduced the grain shape, grain size and type of the mineral. Now it is time for us to understand about clay water interaction. Water though neutral, has its oxygen and hydrogen atoms spaced in such a manner that the center of gravity of the positive and negative electrical charges do not coincide and hence water molecules are dipolar. We knew that water molecules are dipolar because of this eccentricity in arrangement of the central gravity of the positive and negative electrical charges. So molecules of water can be treated as a bar magnet with positive and negative charges at opposite ends that is what it has been shown.

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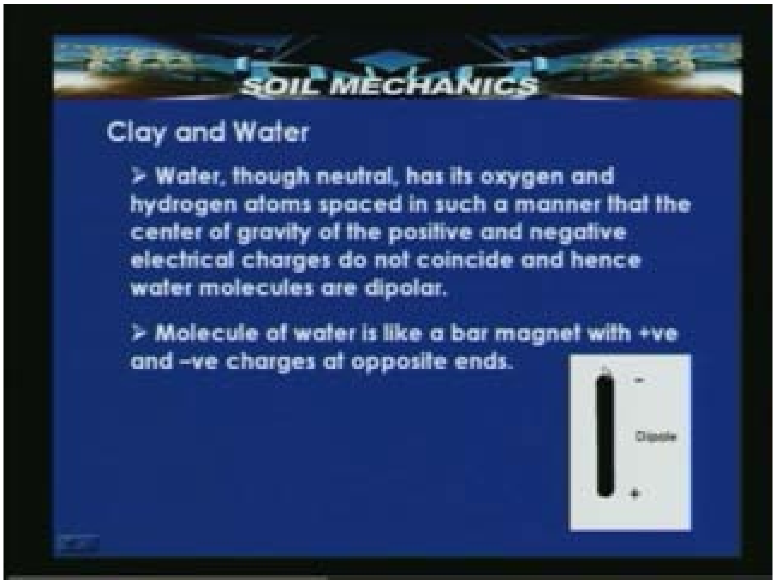

SOIL MECHANICS

Clay and Water

- Water, though neutral, has its oxygen and hydrogen atoms spaced in such a manner that the center of gravity of the positive and negative electrical charges do not coincide and hence water molecules are dipolar.
- Molecule of water is like a bar magnet with +ve and –ve charges at opposite ends.

In this slide, under a) model of water molecule is shown, this is the hydrogen and this is the oxygen. Here the relative location of atoms in the water molecule are shown that is 0.97 Angstroms and between two hydrogen atoms it is 1.4 Angstroms. This angle is around 105 degrees and between hydrogen and oxygen it is 0.97 Angstroms and third under c) polar representation of the water molecule that is dipole action like a magnet with positive and negative end.

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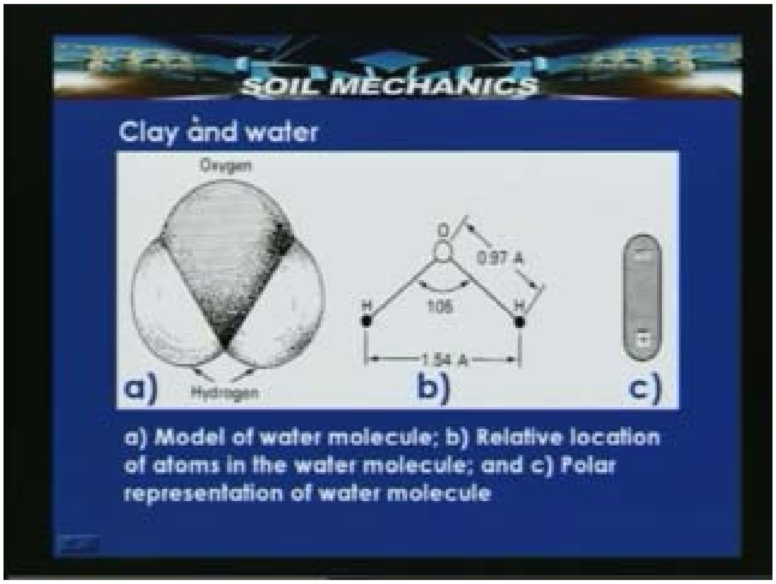

Clay and water

a) Model of water molecule; b) Relative location of atoms in the water molecule; and c) Polar representation of water molecule

If you look into these clay particles, we said that the clay particles are plate shaped particles. So we can idealize and indicate like a thin plate like this. Clay particles always carry a net negative charge on the surface except at the edges. The reasons for this charge accumulation can be attributed to Isomorphous substitution, Breakage of particles and dissociation of hydroxyl radicals. The large clay particle can break and form small particles and dissociation of the hydroxyl radicals.

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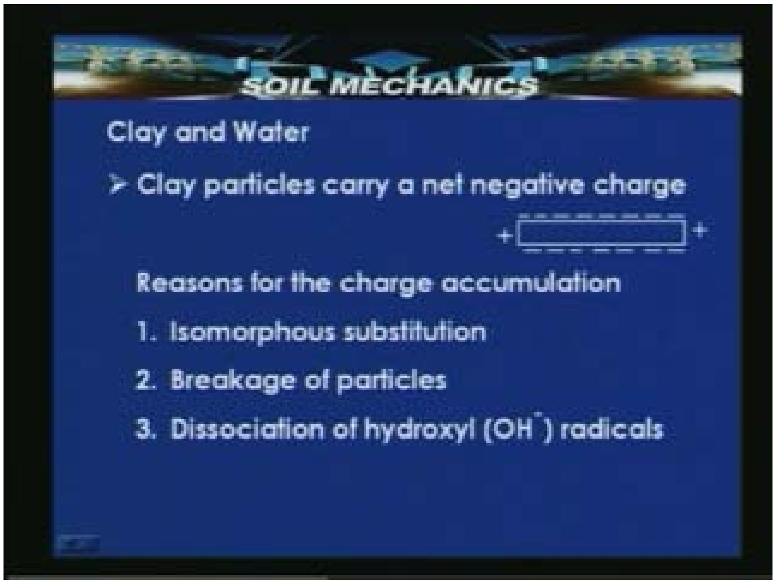

SOIL MECHANICS

Clay and Water

- Clay particles carry a net negative charge

Reasons for the charge accumulation

1. Isomorphous substitution
2. Breakage of particles
3. Dissociation of hydroxyl (OH^-) radicals

Isomorphous substitution is the replacement of the cation in the mineral structure by another cation of the lower valence but of the same physical size. With this it may lead to different clay minerals with different physical properties. For example, replacement of silicon ion in a tetrahedral unit by aluminium ion, this could happen when aluminium ions are more readily available in water. In this slide we have defined that Isomorphous substitution is one of the reasons for the accumulation of the charge on the clay surface.

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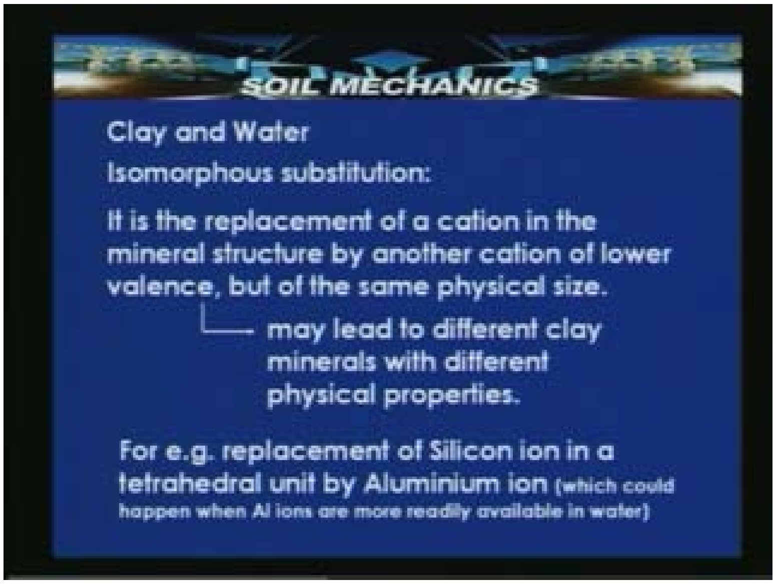

SOIL MECHANICS

Clay and Water

Isomorphous substitution:

It is the replacement of a cation in the mineral structure by another cation of lower valence, but of the same physical size.

└── may lead to different clay minerals with different physical properties.

For e.g. replacement of Silicon ion in a tetrahedral unit by Aluminium ion (which could happen when Al ions are more readily available in water)

Here the negatively charged clay particle surface is shown that is the solid clay particle surface. These serrations are shown indicating the broken edges where the clay particle can carry partly the positive charges here. You can see the positive charges here and some negative charges here. The entire surface both top and bottom is charged with negative surface. These are the positively charged cations prevalent in the pore water. These are the polar water molecules formed due to the dipolar action of the water molecule. The net negative charges on the clay surface can be seen here. This is the environment surrounding the clay particle where you have cations present in the pore water, positively charged cations and polar water molecules surrounding both sides of the particles.

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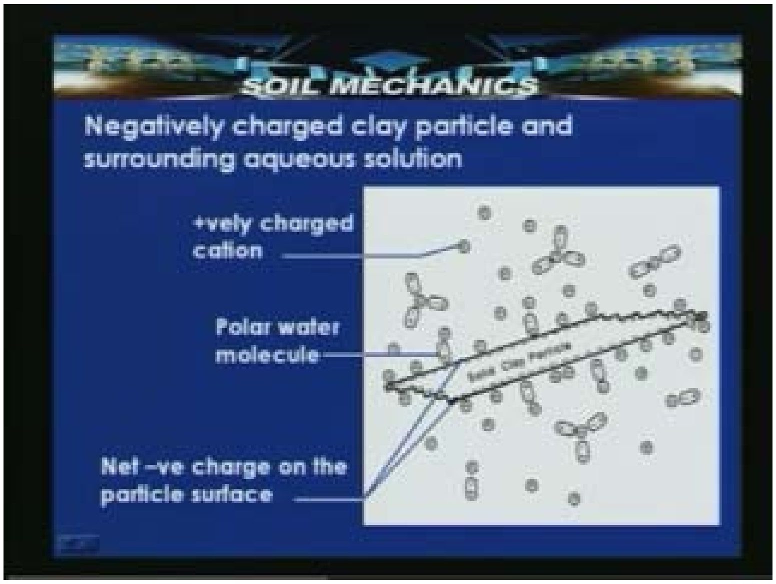

SOIL MECHANICS

Negatively charged clay particle and surrounding aqueous solution

+vely charged cation

Polar water molecule

Net –ve charge on the particle surface

Generally there are three mechanisms where clay and water can interact. General mechanisms of clay and water interaction are as follows: the mechanism a) is defined as the attraction between negatively charged surface of the clay where this is the negatively charged clay particle surface and this is the clay particle surface. Then the mechanism is the attraction between the negatively charged faces of clay and positive ends of dipoles.

The other possibility is attraction between the cations in the water that is these are the cations in the water and negatively charged ends of dipoles. So with that also there is a possibility of attraction. Third method is the sharing of hydrogen atoms in water molecules by hydrogen bonding. That is, the oxygen atoms on the clay surface are shared by the hydrogen atoms in the water molecule. With these three possibilities there is definitely a way the clay and water is attracted and adhere together.

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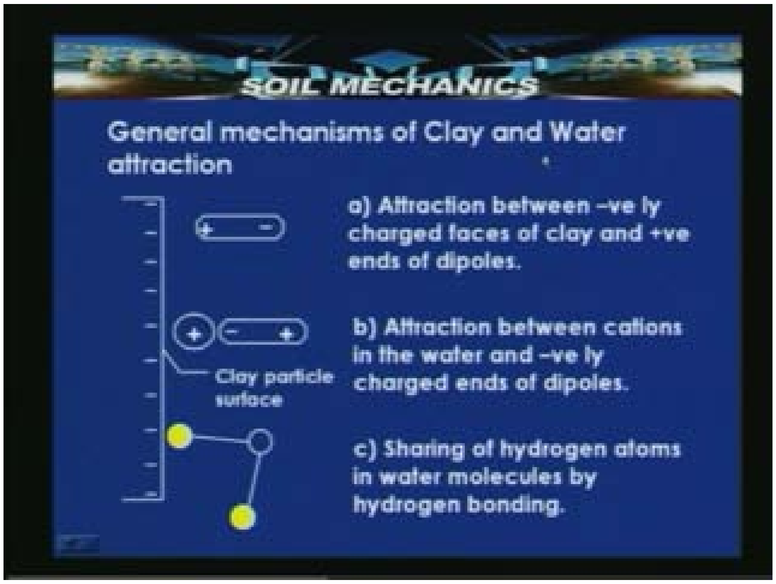

SOIL MECHANICS

General mechanisms of Clay and Water attraction

a) Attraction between –ve ly charged faces of clay and +ve ends of dipoles.

b) Attraction between cations in the water and –ve ly charged ends of dipoles.

c) Sharing of hydrogen atoms in water molecules by hydrogen bonding.

Surface the entire clay particle is negatively charged and the edges are positively charged. Here you can see the negatively charged end of a dipole is attracted towards the positively charged end of clay particle. Whereas here these dipoles are attached to the negatively charged surface and cations present in the pore water are also attached to the negatively charged surface. The hydrogen atoms in water molecules are attached to clay particle surface. So these are the limits of the diffused double layer we call where there is a zone in which the water is held very tightly to the clay particle. The negative charge is to be neutralized by the opposite charge leading to the formation of adsorbed water layer and double layer.

We will understand and we will try to define the adsorbed water layer and double layer in due course of this lecture. If you note here, we call water in this zone is adsorbed water. Water is attracted and bounded to the clay particle with strong bonding. The clay particle has got surplus negative charge. So what it does is that, it tries this negative charge to be neutralized by attracting the opposite charge leading to the formation of the adsorbed water layer and double layer.

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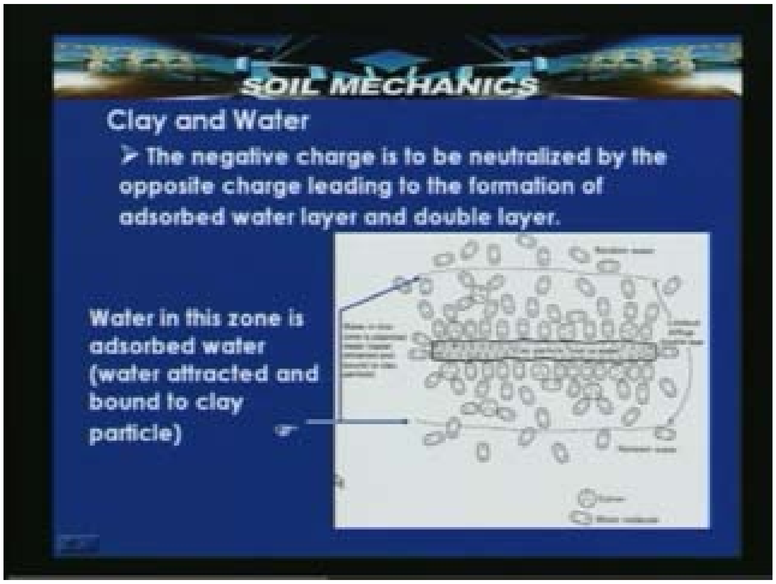

SOIL MECHANICS

Clay and Water

- The negative charge is to be neutralized by the opposite charge leading to the formation of adsorbed water layer and double layer.

Water in this zone is adsorbed water (water attracted and bound to clay particle)

What is this adsorbed water and what is its difference between absorbed water? Adsorbed water is held on the surface of the particle by powerful forces of electrical attraction and virtually in a solid state. This layer is of very small thickness ranging up to 10 Angstroms.

If you look at this particular picture here, you can see a clay particle, negatively charged surface here, a positive end of a dipole and negative end of a dipole. This positive end of a dipole is attached to the negatively charged clay surface. This zone where water is held tightly to the particle is called adsorber. These dipoles or cations in the pore water are highly oriented and forms something like highly viscous water attached to the solid grain of clay. The layer next to that which follows is viscous water with a decrease in the viscosity which is something like very close to the particle there will be higher electric potential so there will be very high viscosity and you assume that while traveling away from the clay particle the degree of viscosity decreases. If you come out of this double layer you will see the free water which is nothing but the water which is adsorbed in the atmosphere.

Adsorbed water is either supplied or due to the hygroscopic action of the mineral it keeps water in it. This adsorbed water cannot be removed by oven drying at 105 to 110 degree C and may therefore be considered to be the part of the solid soil grain. That is the reason why, while determining water content we said that we maintain the oven around 105 to 110 degree C because we do not want to disturb or we do not want to distort the structure of the soil. In view of that if the soil is not having any organic portion we maintain temperature around 105 to 110 degree C. And if the soil has got an organic portion then the temperature of the oven is required to maintain at 60 degree C to determine the water content. In order to remove adsorbed water the soil is required to be heated more than 200 degree C. Adsorbed water is a layer of water which is surrounded very tightly to the clay particle by powerful forces of electrical attraction and virtual in a solid state. This layer is of very small thickness which is equivalent to around 10 Angstroms. This cannot be removed by oven drying at temperatures around the order of around 105 to 110 degree C and may therefore be considered to be a part of the solid soil grain.

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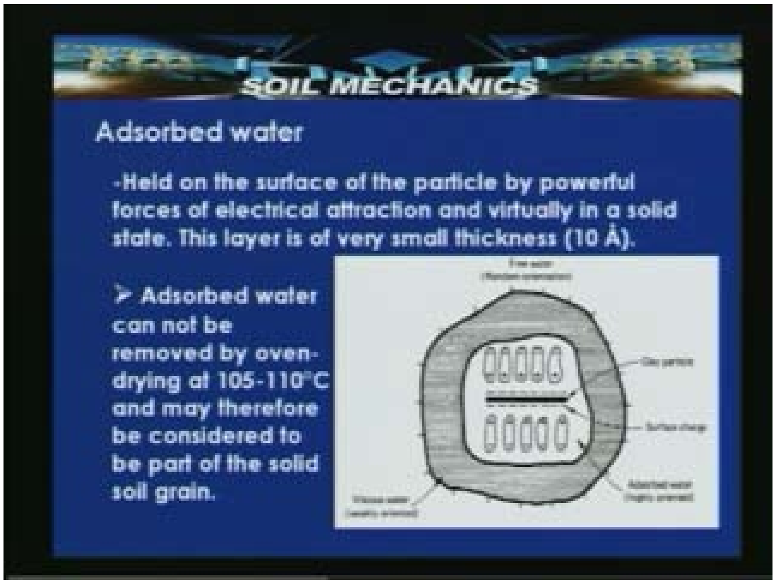

SOIL MECHANICS

Adsorbed water

-Held on the surface of the particle by powerful forces of electrical attraction and virtually in a solid state. This layer is of very small thickness (10 Å).

➢ Adsorbed water can not be removed by oven-drying at 105-110°C and may therefore be considered to be part of the solid soil grain.

If you see here in this picture the clay particle surface is shown and a net negative charge on the clay surface and highly oriented cations are shown and the zone of the diffuse layer is shown. So this particular rigid layer and diffuse layer put together is called electric double layer. Electric double layer is the layer where the field intensity or electrical potential is very high and very close to the edge of the clay surface. This can be their replica on the other side of the clay particle.

Here one side of the clay particle surface is shown and here it is maximum near the edge of the clay particle. As you travel towards right from the distance of the clay particle there is a decrease in the electric potential or field intensity and it further drops down when the field intensity is equivalent to that of the free water. This particular zone is called rigid layer and this zone is called a diffuse layer. In total these two layers put together is called the electric double layer. These cations distribute themselves around the negatively charged surface they are highly oriented and with the greatest density near the surface and a decreasing density with increasing distance from the surface. That is what we have seen here, the density will be very very high here. As you go down it gets scattered and the density decreases.

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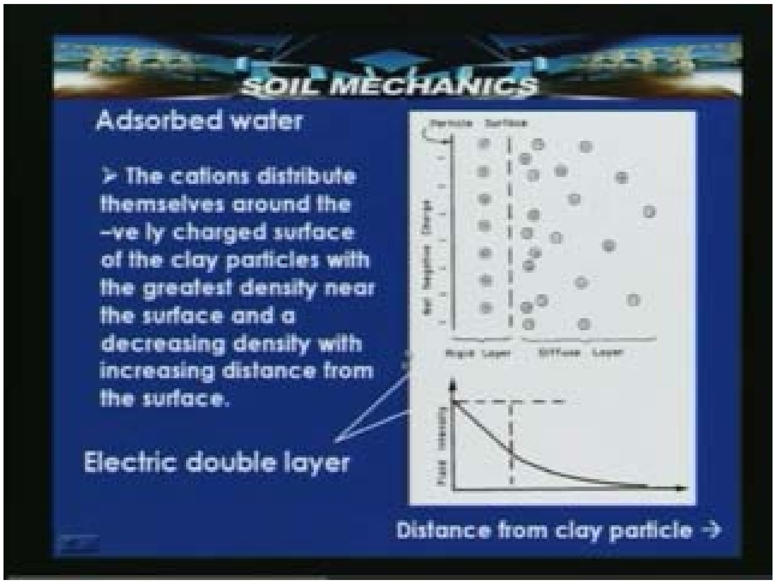

SOIL MECHANICS

Adsorbed water

- ➢ The cations distribute themselves around the –ve ly charged surface of the clay particles with the greatest density near the surface and a decreasing density with increasing distance from the surface.

Electric double layer

Distance from clay particle →

We also said that in the zone nearer to the clay surface or clay particle surface the viscosity is very very high. The water adhered to the clay particle surface is strongly added and it resembles something like solid soil grain so the viscosity versus distance from the particle is shown in this slide where you see 10 Angstroms to 100 Angstroms adsorbed water and the double layer extend up to 400 Angstroms. All put together, the total thickness of electrical double layer works out to be around 500 Angstroms or so. This is the viscosity for free water. So in this diagram the variation of viscosity with the distance of a particle is shown.

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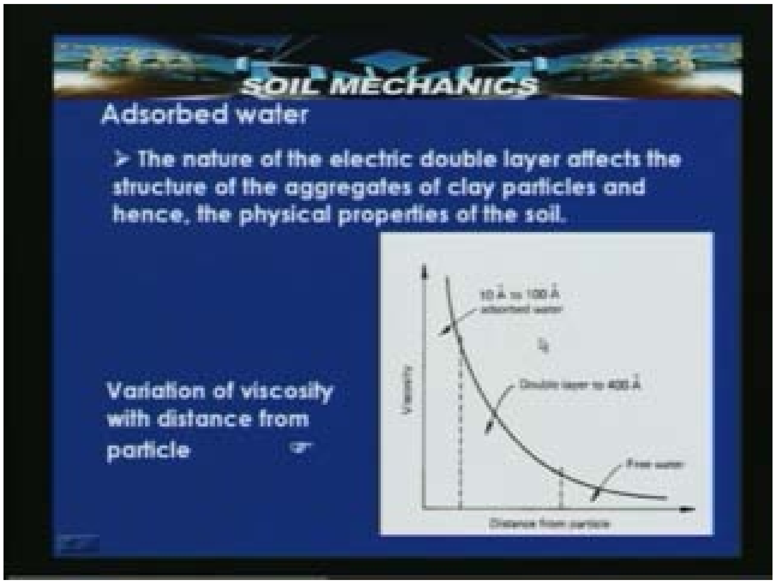

SOIL MECHANICS

Adsorbed water

- ➢ The nature of the electric double layer affects the structure of the aggregates of clay particles and hence, the physical properties of the soil.

Variation of viscosity with distance from particle

The nature of the electrical double layer affects the structure of the aggregate of clay particles and hence the physical properties of the soil. So this adsorbed water can influence or affect the physical properties of the soil. In this slide a typical Kaolinite particle with size is 10,000 Angstroms to 1000 Angstroms thickness. The thickness of the kaolinite crystal is shown as 1000 Angstroms and the length of the plate particle is around 10,000 Angstroms along with the adsorbed layer and double layer water is shown here. So the adsorbed water layer is adhered to the Kaolinite crystal is shown here which is of thickness equivalent to 10 Angstroms and double layer water is shown here with the thickness ranging up to 400 Angstroms. This is a typical Kaolinite crystal along with adsorbed water layer and double layer water.

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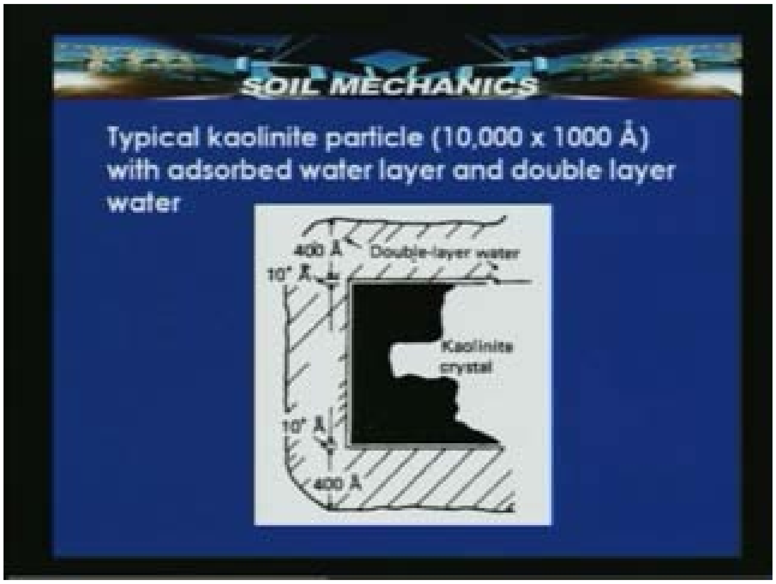

SOIL MECHANICS

Typical kaolinite particle (10,000 x 1000 Å) with adsorbed water layer and double layer water

In this picture as we have seen the Montmorillonite particle is a tiny particle with 1000 Angstroms in length and 10 Angstroms in thickness. So the adsorbed water layer can extend up to 10 Angstroms like Kaolinite crystal and double layer water can extend up to 200 Angstroms that is between particles. In between we have seen the structure of the Montmorillonite particle; it can keep water up to 400 Angstroms within the particle. As this mineral has got large affinity for water it is prone for high shrink well characteristics.

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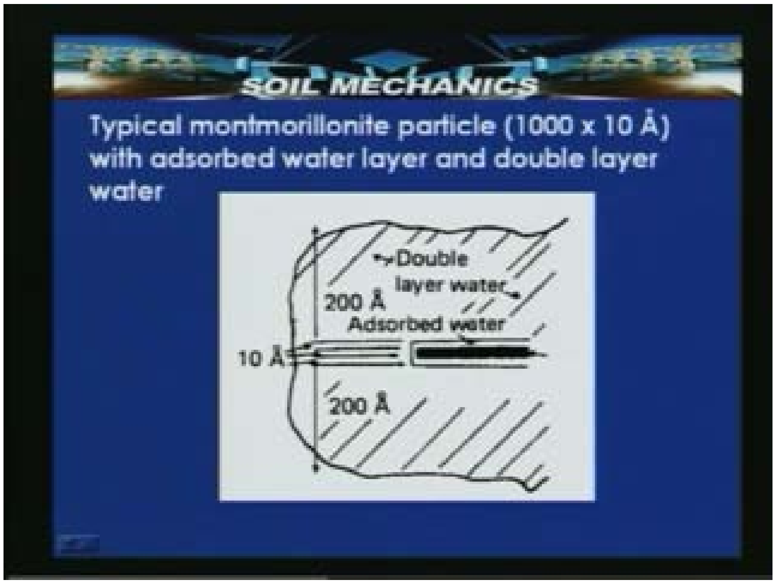

SOIL MECHANICS

Typical montmorillonite particle (1000 x 10 Å) with adsorbed water layer and double layer water

So, having seen specific surface area and adsorbed water let us try to define one more important terminology called cation exchange capacity of a soil, it is indicated like CEC. The ability of a clay particle to adsorb ions on its surface or edges is called CEC. The ability of a clay surface or a clay particle to adsorb ions on its surface or edges is called cation exchange capacity of a given surface. CEC measured in milliequivalents per 100g of dry soil particles is a measure of net negative charge on the soil particles resulting from the Isomorphous substitution and broken bonds at the boundaries. Cation exchange capacity is a function of mineral structure of the clay and the size of the particle. We will see how this relation goes.

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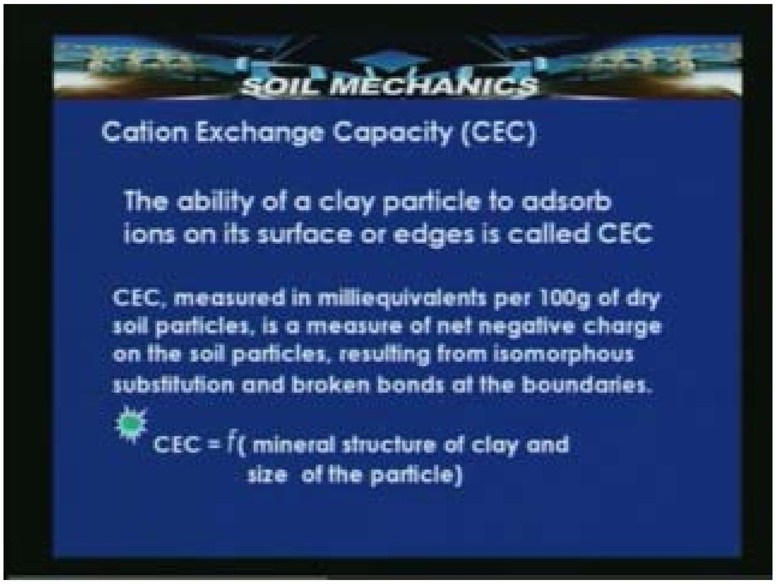

SOIL MECHANICS

Cation Exchange Capacity (CEC)

The ability of a clay particle to adsorb ions on its surface or edges is called CEC

CEC, measured in milliequivalents per 100g of dry soil particles, is a measure of net negative charge on the soil particles, resulting from isomorphous substitution and broken bonds at the boundaries.

CEC = f(mineral structure of clay and size of the particle)

In this table the mineral type and typical value of CEC in units of milliequivalent per 100g of dry soil is shown. Quartzite possesses very small CEC value. Due to fine particles and broken bonds there will be some charge, they have got some affinity but the ability is very very small. That is why the cation exchange capacity of Quartzite mineral which is prevalent in the sands is very small, this is due to fine particles and broken bonds.

For Kaolinite this cation exchange capacity ranges from 3 to 8. For Illite it ranges from 40 to 50 and Montmorillonite is around 80 to 100. The cation exchange capacity of the Montmorillonite is ten times the cation exchange capacity of the Kaolinite. This indicates that the smaller amount of Montmorillonite is required than kaolinite to impart properties of the clay to the mixed grain soil. That means when it happens to mix Montmorillonite basis soil to the other types of the grain soil to impart the properties of the clay only less amount Montmorillonite is required than the soil with the Kaolinite mineral. So the cation exchange capacity of Montmorillonite is ten times the cation exchange capacity of Kaolinite.

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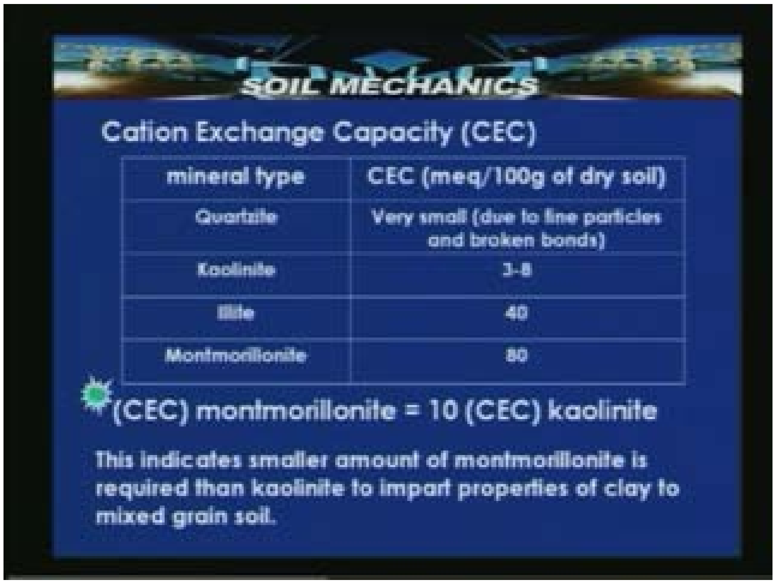

SOIL MECHANICS

Cation Exchange Capacity (CEC)

mineral type	CEC (meq/100g of dry soil)
Quartzite	Very small (due to fine particles and broken bonds)
Kaolinite	3-8
Illite	40
Montmorillonite	80

(CEC) montmorillonite = 10 (CEC) kaolinite

This indicates smaller amount of montmorillonite is required than kaolinite to impart properties of clay to mixed grain soil.

Cation exchange, generally there are exchangeable cations on the negatively charged surface of the clay. Exchangeable cations are positively charged ions from salts in the pore water which are attracted to the surface of the clay particles to balance the negative charge that is why they are called exchangeable cations. The cations can be arranged in a series of terms of their affinity for attraction as follows: Aluminium power 3 plus is greater than Ca power 2 plus greater than Mg power 2 plus greater than NH_4 plus greater than K plus greater than H plus greater than Na plus greater than lithium plus. This indicates that for example aluminium power 3 plus ion can replace calcium 2 plus ion and calcium 2 plus ion can replace sodium ions. This process is called cation exchange. When higher valence cation comes then it gets replaced by the lower valence cation. That means the soil exposed to pore water having cation with higher valence will change to lower valence by losing the soil with cation with lower valence. That is the higher valence cation replaces the lower valence cation which is adhered to the negatively charged clay surface. So this process is called a cation exchange.

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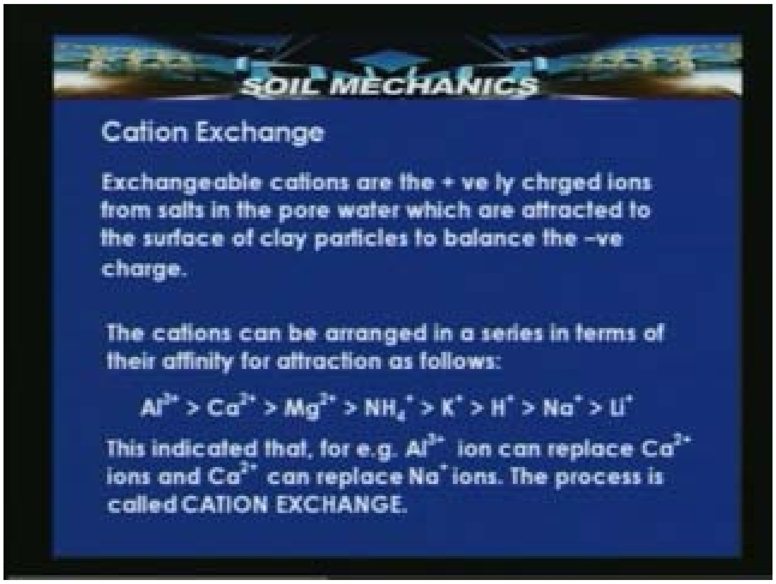

Cation Exchange

Exchangeable cations are the + ve ly chrged ions from salts in the pore water which are attracted to the surface of clay particles to balance the –ve charge.

The cations can be arranged in a series in terms of their affinity for attraction as follows:

$$Al^{3+} > Ca^{2+} > Mg^{2+} > NH_4^{+} > K^{+} > H^{+} > Na^{+} > Li^{+}$$

This indicated that, for e.g. Al^{3+} ion can replace Ca^{2+} ions and Ca^{2+} can replace Na^{+} ions. The process is called CATION EXCHANGE.

The practical example of this cation exchange is the stabilizing black cotton soil which is known as lime stimulation. Let us assume that the stabilization of the sodium based clay soil using the lime and also let us assume that the clay has got Montmorillonite based mineral predominantly with sodium. Suppose if it gets exposed to lime that is calcium chloride after undergoing the reaction, calcium based clay and sodium chloride will be formed. In this process we can see the practical relevance of the example of the cation exchange.

In this example what happened is, here the calcium 2 plus ions replaces the sodium ions and in the process reduces the sodium Montmorillonite and because of it the adsorbed water layer would become thinner and undergoes a structural distortion. So here what happened is that with the replacement the adsorbed water layer thickness decreases and with that the adsorbed water layer becomes thin and in the process the swelling of this soil is limited.

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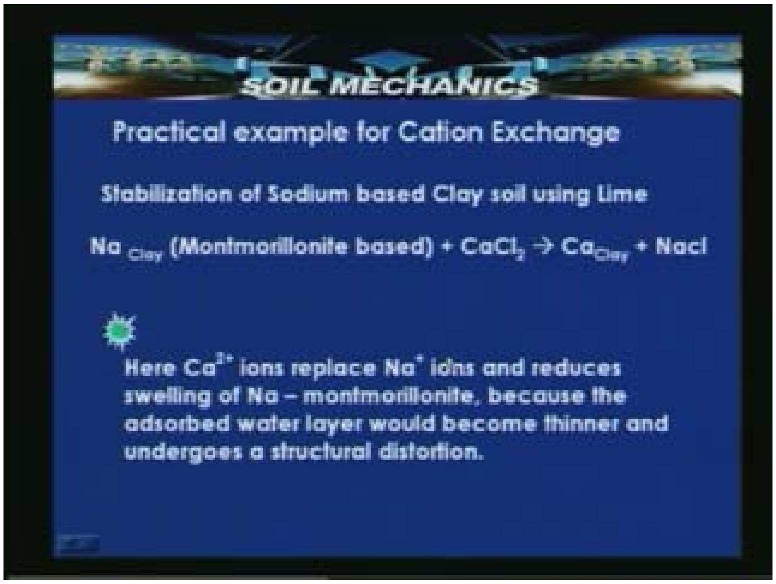

SOIL MECHANICS

Practical example for Cation Exchange

Stabilization of Sodium based Clay soil using Lime

Na_{Clay} (Montmorillonite based) + $CaCl_2 \rightarrow Ca_{Clay}$ + Nacl

Here Ca^{2+} ions replace Na^{+} ions and reduces swelling of Na – montmorillonite, because the adsorbed water layer would become thinner and undergoes a structural distortion.

In this lecture if you summarize we have seen about occurrence of the clay minerals in soils and methods for their identification and we studied about specific surface area. We noted that the specific surface area is inversely proportional to the particle size. We also discussed about the interaction between clay and water. That is, we defined adsorbed water and cation exchange capacity and we tried to interlink with different clay minerals to understand the terminologies.

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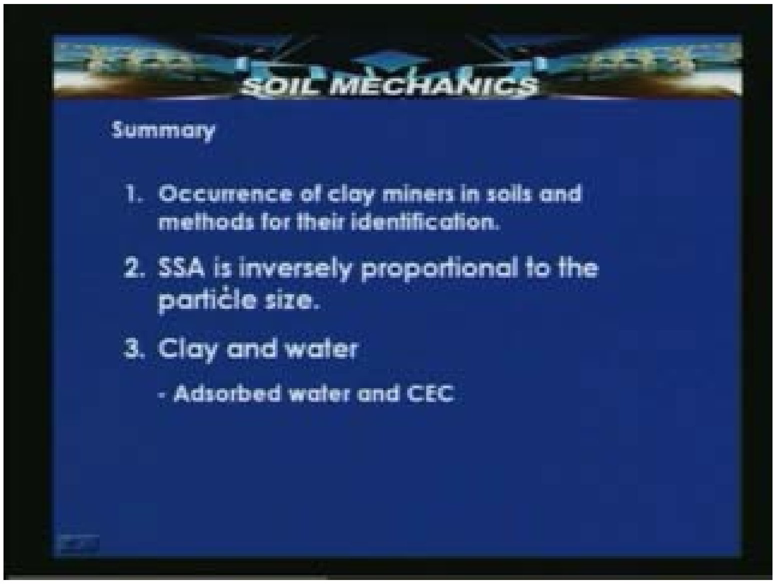

SOIL MECHANICS

Summary

1. Occurrence of clay miners in soils and methods for their identification.
2. SSA is inversely proportional to the particle size.
3. Clay and water
   - Adsorbed water and CEC