Geotechnical Engineering I
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Lecture-08
Particulate nature of the soils

In the previous lecture I have been talking about the constituents of soils and we described different phases which are present in the system soil system. And I have been discussing a bit about the particulate nature of the soils and this is the I gave an analogy that soils we have both ways they act like fluids, they act like solids. And this is where the subject becomes very interesting because this something in between the fluid mechanics and the solid mechanics.

In context of this I was defining what the particulate system is all about and just to reiterate the particulate system is a system of the material which is consisting of particles, sometimes we call them as grains also.

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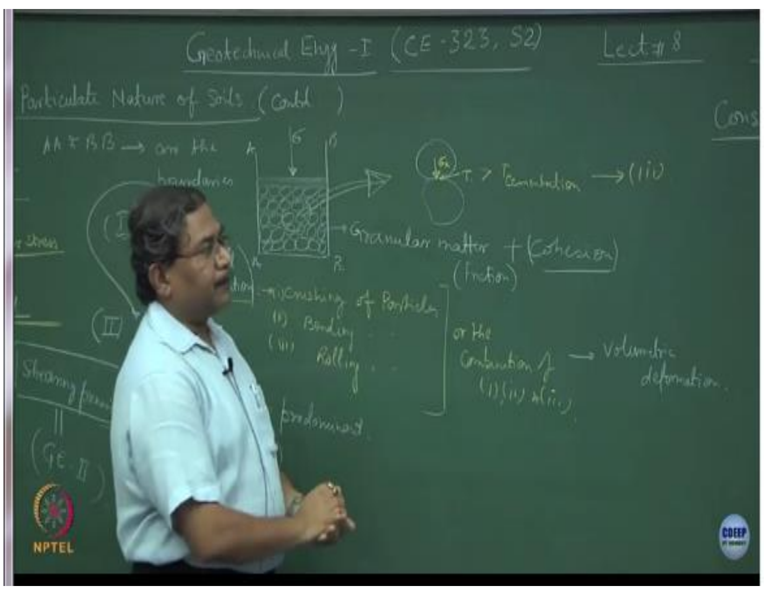

So I have been talking about a situation where you have a control volume and this control volume is confined in such a manner that the boundaries are rigid. So AA and BB are the boundaries and these boundaries are confining the material for the sake of simplicity I am assuming granular material and I had talked about the micro mechanics of the system there is the piston and through which I am applying the normal stress sigma.

So, this part we have already discuss that if these boundaries are rigid there is not going to be any lateral deformation and we had also talked about the mechanisms of deformation that is the crushing of particles. The second mechanism which I discuss in detail was the bending and the third one is the rolling alright and this is our assumption was that if the soil which is particulate in nature is confined within the rigid boundary system is compressed.

Then the deformation is going to be guided by these 3 mechanisms or the combination of these 3 alright. I had also introduce here the concept of stress and strain that if I magnify this system this is how it would look like you have a grain which is in touch with another grain. And because of the normal stress which you are applying over here there will be a normal component of the stress sigma x let us say or whatever this is different than sigma.

So let it be sigma x and there will be a shear stress, the moment shear stress gets bigger than the tau of the binding or what we call as the let us say the cementation that is the particle the cementation which is surrounding the particles you know, we talked about this which gives the cohesion of the material. So the moment tau is greater than tau cementation there is a rolling over which is occurring the mechanism 3 takes over.

But this going to be very minor because the boundaries are rigid, so truly speaking in most of the situation that we were discussing the last lecture the chances of AA and AB being rigid are extremely less unless you are working in a casing system. Let us say I give you an example of (()) (05:32) where you fill up the cylindrical portion with sands and then let the foundation of the bridges set over there.

The second mechanism would be when the boundaries are flexible and this is where exactly I was in the previous lecture. Now the chances are that the boundaries which are confining the soil mass would be flexible, now in this case sorry one more thing you should add to this is that this is what is going to cause the volumetric deformation alright. However when the system is flexible the mechanism 3 becomes more prominent predominant you may say alright.

So it is so happens stop writing and just see my hands the way I will be using my hands to depict what is happening when you are applying normal stress on the system and the boundaries are flexible is just like balloon you know, you keep on pumping in air and what happens the balloons you know it keeps on expanding. So what is going to happen is AA and AB are going to get deflected much more and because of that there would be a flow of material in the lateral direction alright.

So this is what is known as the flow until now you have used the flow of the material in case of fluid mechanics only where the fluids flow. Now these are first time we are trying to use this term for a granular material which is soils, so granular materials also flow freely. This concept I will be using in the second course, when we talk about the shear strength of the materials fine. So this is what is going to be flow process.

The applications of this concept would be when you are designing warehouses particularly when you are filling this hands you know for creating the packs of different types where you allow material to just flow in and then you compact it . This is the good example of you know silos which are normally designed for keeping the grains any type of grain let it be wheat, rice, sugar, whatever. So these concepts are used when we design the silos alright.

So here the material is flowing, in this case the shear strength is going to be predominant. So this becomes a shearing process check out on net when shearing process occurs in natural systems like active faults.

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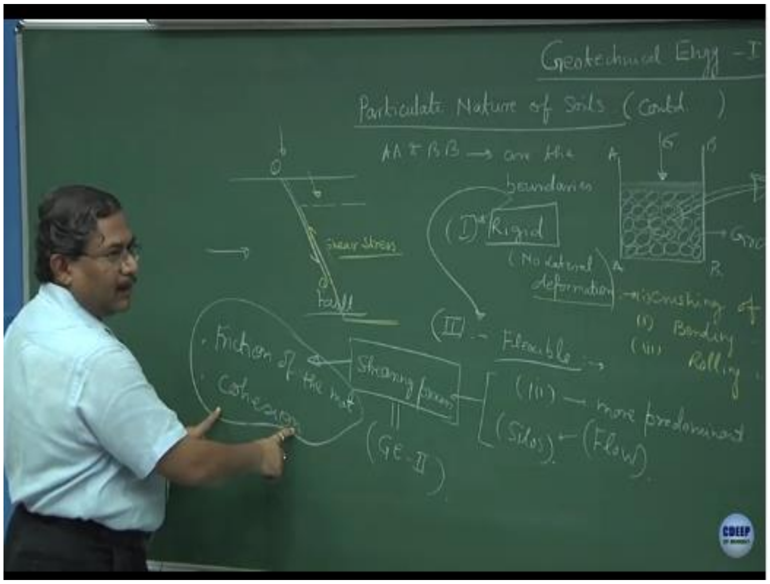

A good example would be I am sure and enjoying geology course you must have studied there is a ground like this and there is an active fault over here. I am sure you must be aware that the Bombay is sitting on 3 active faults and that was the main challenge and designing the (()) (09:07) ceiling. So read the history of what these faults too, now suppose if I load the system from the top and this fault opens up this is the geological process and because of the tsunami is come because of this earthquakes may come and whatever.

So what is going to happen is that this portion of the soil or the rock is going to shift downwards clear and this is how the movement is going to take place. So there is a relative movement along the surface which is let us say I would define as 11 this is part clear. So the moment you loaded from the top and if there is the active fault the whole thing may slide down. In the process on this surface the shear stress develops beautiful application of the engineering mechanics which you have done until now.

You must wondering where we are going to use the concepts of the engineering mechanics this is one of the applications of you know where mostly the guys who are in petroleum geophysics would be very eager to understand what type of stress are going to act, what are the lateral stresses and under what circumstances this type of conditions are going to occur alright. So for the time being I am not going to go into the details of this because this is a topic which I will be covering in geotechnical engineering II.

I will be dedicating rough time on this, so coming back to the point when soils are confined depending upon the boundary conditions, it says simple explanation of a mechanism, where we deal with the rigid and the flexible systems, a rigid system yields the deformation of the soils provided 1, 2, 3 or the combination of these 3 occurring or it could be because of the flow process and which is a beautiful example of shearing process.

Now, if I want to complicate this system and if I say that rather than having this as a granular material suppose this material also has cohesion alright. So the first question is how do you differentiate between granular material which is giving you friction component of the strength and the cohesion component of the strength this again we will be discussing in the second course alright this is beyond because first you have to understand the material itself.

So in this course, geotechnical engineering 1 our understanding or maybe the more emphasis to understand the material rather than going into the shear strength characteristics. Now one interesting thing which I can derive from this whole discussion is the constitutive law.

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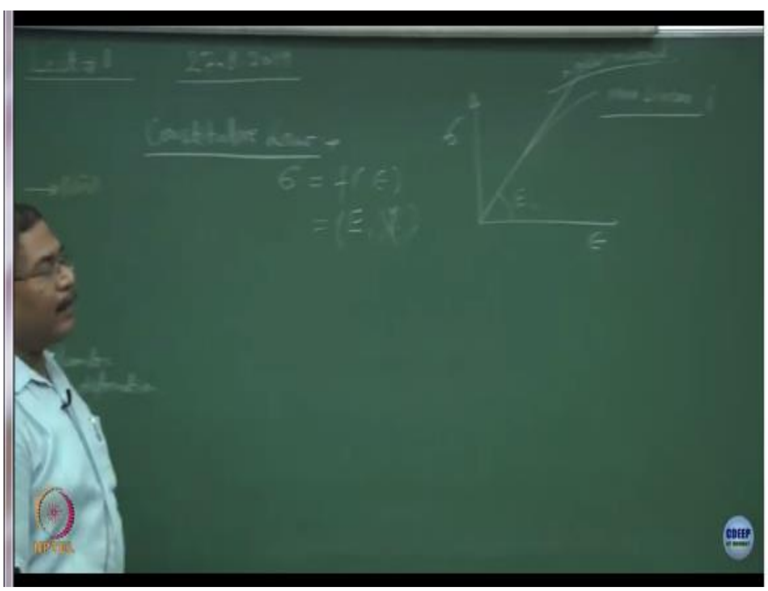

So, many of you would be working on the application of constitutive laws in mechanics particularly in geomechanics or whatever truly speaking constitutive law is a relationship between a stress and strain. You have studied this earlier also in 10, +2 physics is it not? you know how this stress and strain vary and then coefficient of this function is normally defined as elastic modulus. Sometimes we define this as young's modulus or whatever depends upon the material alright.

Now in this case when we are dealing with the granular material this function is going to be a nonlinear function. Now this is what is known as material non linearity, so those of you who might be studying FEM finite element methods and all would be using these concepts quite a lot. So the material is nonlinear why because of all this is not a linear material, a linear material would have been something like this. This is a linear material as far as the stress strain properties are concerned ok.

So by virtue of all these particulate system the material behaves as nonlinear and hence it becomes very difficult to determine the stress strain relationship though there are several test which will be talking about again in the realm of shear strain theory alright, any questions here. The slope of this line could be the elastic modulus, we normally do not use the term y as the yield modulus over here it is ok any question sir you told the flexible part has the predominant of rolling of the particles.

But how we call them as a flexible if it is rolling, no boundaries are flexible. Imagine, you know you go to the villages, what people do is they will be taking a container and they pour some material like wheat or whatever and they use a what do you call this in is a wooden tamp normally I do not know what is the local name and what do they do they just keep on tamping it so densify it is this correct.

So imagine if the boundaries if this was the container made up of rubber or plastic thin plastic what would have happened. So the moment to tamp it from the top it would deflect in the lateral direction clear. So this is what the mechanism is, so when the boundaries are flexible, the material is more free or prone to flow outside it is okay and the processes because of the rolling.

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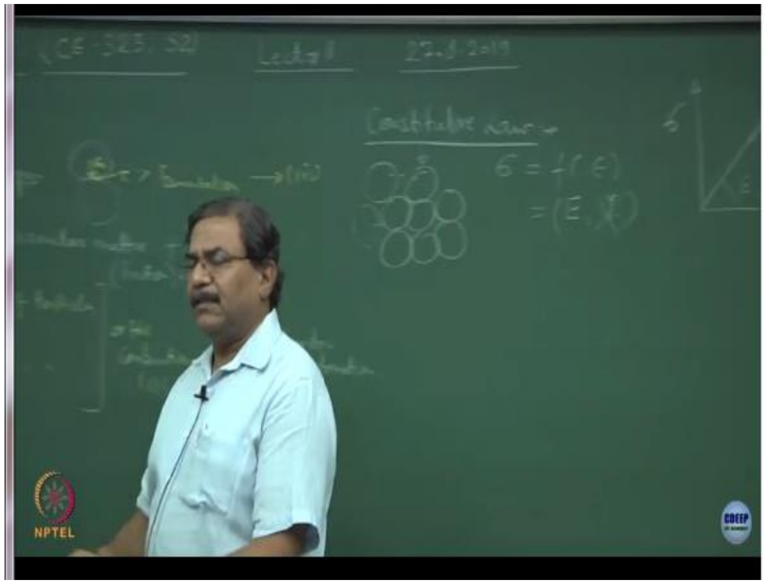

So if you remember the basic model which I had drawn last time, you know you have a set of particles and suppose if I press it from top what is going to happen. The chances are that this particle will slit over and it will acquire a new position like this, what will happen to this, this will also slit over it will acquire a new position like this. We will discuss this things in details is this ok conceptually, are you able to visualize.

So everything is being restrained by the boundaries**.** Sir what is the difference between cohesion and fiction. These are the two components of the shear strength, so shear strength can be mobilized either by ways of friction of the material or because of the cohesion material would behave either in a cohesive manner, uniform material clays they are mostly cohesive.

So you press them, the shear strength is because of the cohesion, then our material sands alright you press them the shear strength is predominantly because of the friction do not bother we will discuss this later clear.

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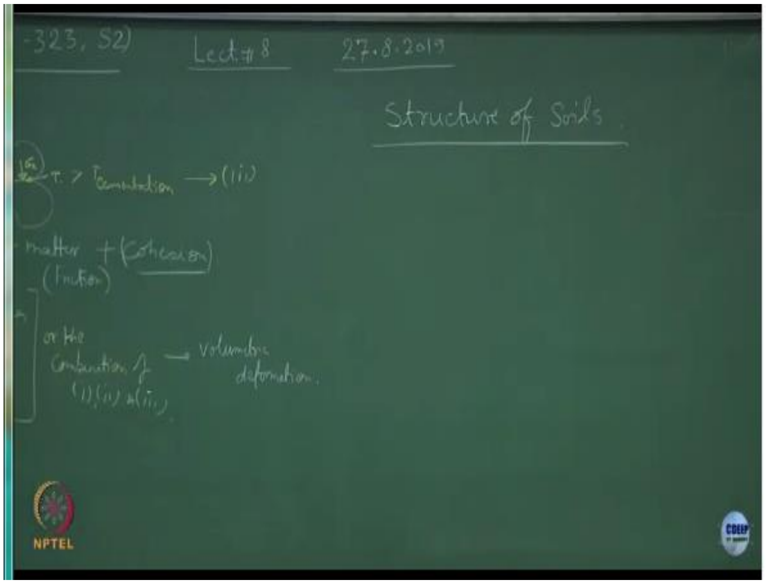

And I am not going to draw this most of figures which are normally used to describe the structure of soils or the grain structure sometimes this is also called as.

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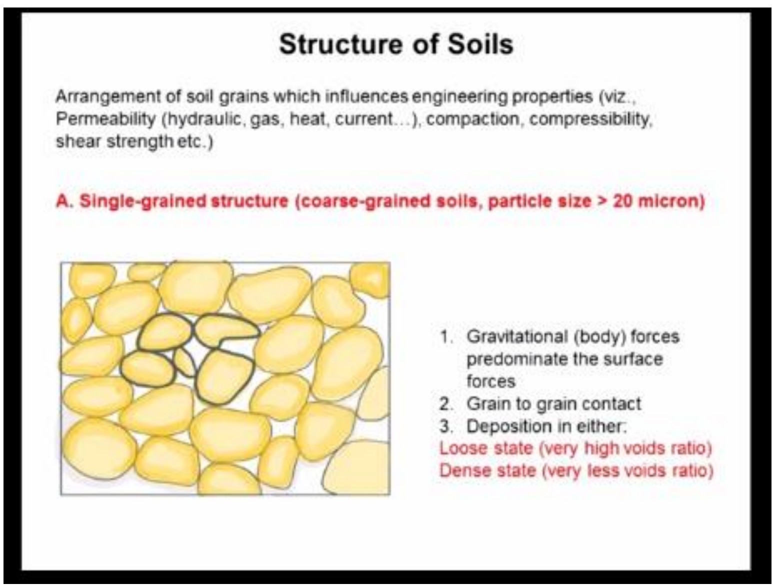

So this is also described as the grain structure soil being a particulate material all the properties of the material are dictated by the way it is formed, deposited, clear and that is what is known as structure. So what I suggest is that you please refer to a book particularly (( )) (17:39) I said try to follow what I am projecting here. I will try to explain you as much as I can but you have to ultimately put it in your memory because this is what is going to be fundamental aspect of the soils which will be using quite a lot.

So when we talk about the structures of the soil this is also known as grain structure alright basically what it defines is the arrangement of the soil grains, whether in takes place, there is a transportation agency and then ultimately these grains of the soils which have become very fine, they come and settle down somewhere. Now what happens is why this is very important to study is because grain structure is controlling all the Engineering properties of the soils alright.

This will control each and everything, so this has a strong bearing on most of the mechanisms any process which occurs in the soil mass and soil mass is nothing but consisting of millions of discrete particles which are particulate materials alright. So what happens is the structure of the soil is going to control the strength, permeability, any type of permeability, hydraulic conductivity, hydraulic means water, fluid conductivity, gases, crude oil alright different type of contaminants, compaction, compressibility, shear strength, consolidation everything.

So henceforth what I will be doing is, it is just like understanding somebody from the very early childhood. So once you understand this boy or girl is like this, you can handle this person carefully and you understand maybe 85% of what this person is going to behave like alright. So that is why this is important, now it so happens the first type of a structure which we normally talk about is single grain structure.

We call it as single grain, body forces are predominant individual particle has weight and hence the stacking is going to be something like this. So what I have shown over here is a single grained structure, each grain is so important that it contributes. If I take out a grain clear or if it out several greens maybe after 3, 4 years when you become an expert in soil mechanics, you will try to model a tunneling process over here.

So tunneling is nothing but removing the soil mass slowly and slowly and creating a tunnel clear. So we can model these type of concepts by removing the elements the way we want, so this is a typical single grain structure. We also call this as coarse grain materials, the another variety of the soils which will be dealing with would be fine grain materials normally the particle size are more than 20 microns, what are the properties of this material, the gravity predominates, we also call them as body forces alright.

So when the settlement process takes place the settlement of the particles to form a deposit is because of the gravity. There are no other body forces which are acting on the no surface force not body force surface forces which are not going to act on this. So the body forces predominate over the surface forces grain to grain contact is very important. So what is that you are talking about you know, 2 grains, just do a simple example, you take few grains of the sand and just rub them sound comes clear and you feel that there is lot of friction which is getting mobilized.

So this is the mobilization of the frictional strength alright when you take a clay you do the same thing it might stick in your hands clear. So that is cohesive strength, so this is grain to grain contact continuum mechanics read about continuum mechanics. Now these type of depositions are either in very loose state or in very dense state. So today we are going to discuss about how to quantify that dense state and the loose state of the material.

When we say loose state, it is say very high wide ratio both are correct, whide's ratio also the correct wide ratio is also correct, so do not get confused by the term . New state is the one where the wide ratio the extremely high, dense state is the one where the wide ratios are less clear. I gave you some example how deltas were form, so next time or maybe dig out the movies from the National Geographic and try to see how the delta formation takes place.

The beautiful example of delta formation the mechanism which controls the entire deposition of the sands would be grain to grain structure is it not a body forces are creating a sort of a assembly of the single grain particle. So when you have salt water, freshwater bringing lot of sediments the density contrast, the suspended particles cannot be or the density control they just deposit over there and that is what is happening over here alright.

By virtue of this structure, either the permeability will be very high or the permeability would be very low depends upon the wide ratio. So a dense system will provide lot of hindrance to conveyance of a fluid, so by virtue of this a dense state of the material whether wide ratios are extremely low hydraulic conductivity or for that matter any connectivity is going to be less write down these concepts because these concepts are absolutely important and unless you have understood this, there is no point in studying the subject fine.

On the other hand, when the system is quite, you know loose the wide ratios are going to be very high, the porosity is going to be extremely high and the system becomes highly conducting. I am talking about only gas conductivity and hydraulic conductivity, heat, current, electromagnetism are different processes. Let us not confuse over there, quick example of this type of structure would be the filters which you create in the swimming pools, most of the filters are created by using granular material.

So there you wanted to filter the water, so most of the filters which are used in Engineering practices are made up of sand beds, single particle clear.

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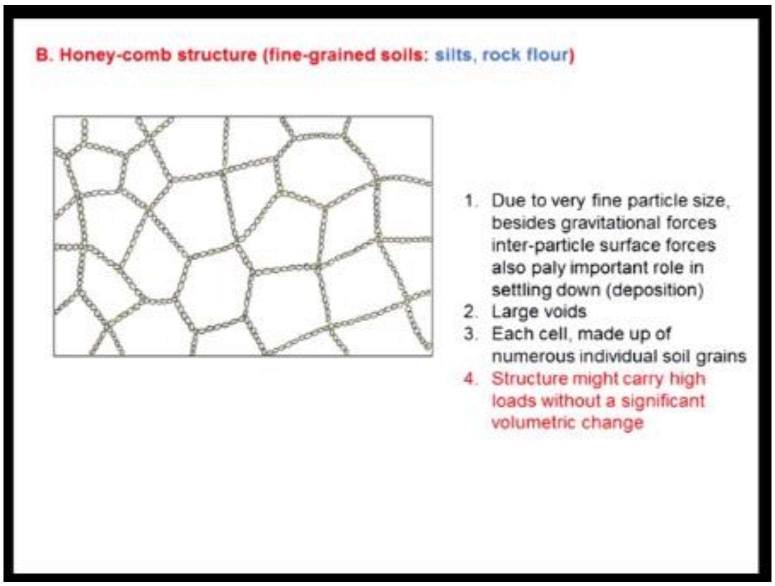

The second type of the structure is what is known as honey-comb structure, we do not call it a honey-comb honey-comb alright. So honey-comb structure an honeycomb structure is normally occurring in fine grain materials, so by definition, fine grain material would be less than 20 microns fine and this would be in silts. And mostly the type of rock does rock flows, how it looks like, this is how it looks like, there is the chain of the particles of the grains, which is assemble like this.

So what happens is due to very fine particle size besides gravitational forces, the surface forces also come in picture and I will show you in today's lecture, what is meant by the surface forces, these are mostly the charges which are acting on the particles. So find out the particle the surface charges are going to be more, so apart from the body forces, the surface forces are also playing an important role they have very large voice alright.

Now each of these cells is made up of numerous grains, numerous particles alright that is the beauty of the system. So several individual grains they come closer to each other and they form a sort of a cell, so this is a cell alright. Now this is what is the honey-comb structure is these type of structures are very good as far as the load bearing is concerned. We were talking about the foundations in the very first lecture clear.

So if I do investigation if I take out samples put the sample beneath the microscope and if I see it the way I showed you last time and if I can establish that this honey-comb structure I should not be very bothered because this type of a structure acts as a reinforcement. So the load bearing is very good and hence the volumetric deformations are not going to be much alright okay.

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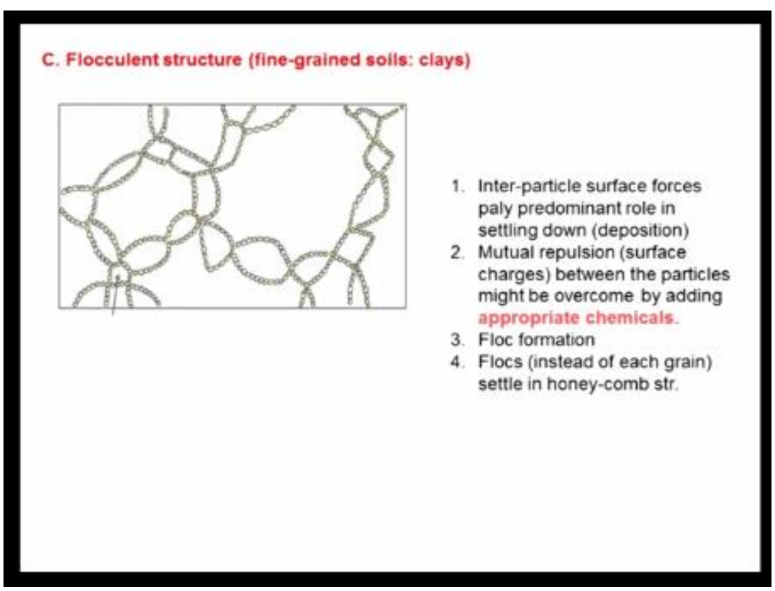

So coming to the another type of structure this what is known as the flocculent structure flocs, I am sure you must have come across flocs mostly the fine grain soils clays alright and clays are of the size 2 microns, typically 2 microns. So this structure would have inter particle surface forces which play a very predominant role as far as the deposition is concerned, the mutual depression is very, very strong.

However this type of repulsion can be nullified if I inject some chemical into it and that is the genesis of stabilization of the soils which we were discussing in the previous lecture. So stabilization of the soils can be done by injecting some chemicals, which would nullify the charge alright floc formation is important thing and these flocs they act as independent grain. So flocs are nothing but in agglomeration of particles which are clay sized, mostly bound together by the electromagnetic forces which are acting between the particles and they create a honey-comb structure.

These type of structures have high permeability very high permeability you can just draw maybe one element I think that would help you 1 unit you can just draw quickly and rest is all a chain of the things. So here when I say flocs, so this is one floc, this floc, because of the electromagnetic forces which are acting on the surface of the particle gets form there is lot of hollow space inside. A person like in a good researcher would utilize this hollow space to inject something into it more fruitful and make the system very juicy.

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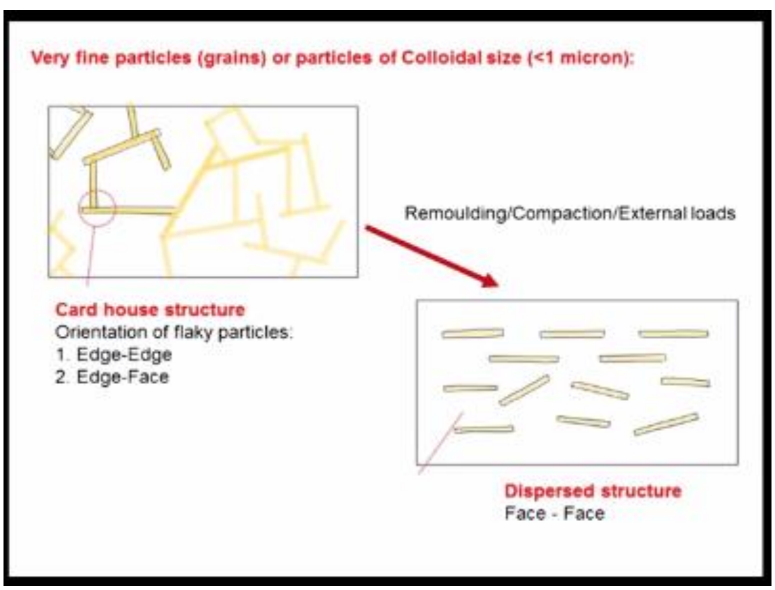

The next one is the one of the ways of defining the very fine particles you know and the colloids. Colloids are less than 1 micron and these are the ones which offer most of the significant properties to the science. There are two types of structures normally we talk about this I think I discuss in the last lecture also, the first one is known as a card house structure. Look at the orientation which I discuss last time this is a platelet of the clay or the grain of the clay edge is meeting the face of the grain.

So this could be either edge to edge or edge to face, edge to edge I think I have not shown a very yeah this would do I mean this is edge to edge you must say this combination alright this is edge to edge. This is a beautiful example of how the face to edge is getting you know created in the settling process. So anyway, so this part is clear card house structure now what I wanted to show you is that card house structure if you compact the soil or if you apply some load on it, it gets converted to disperse structure.

So the first animation should have been the dispersed structure, so when you start from here and you compact the material, it becomes dispersed, more orderly face to face. In geomechanics these 2 are going to have a lot of significance and henceforth, I will be utilizing these mechanisms to define how the properties of the soil must change, quick answer to your question would be permeability is dependent upon the porosity.

Porosity is a fundamental property of the grains of the soils, so if I take out this sample and of the soil and if I want to see what is the porous space that quantification is porosity, we will do it today clear. And hydraulic conductivity is a mechanism, how easily water can pass through a matrix of soil mass.

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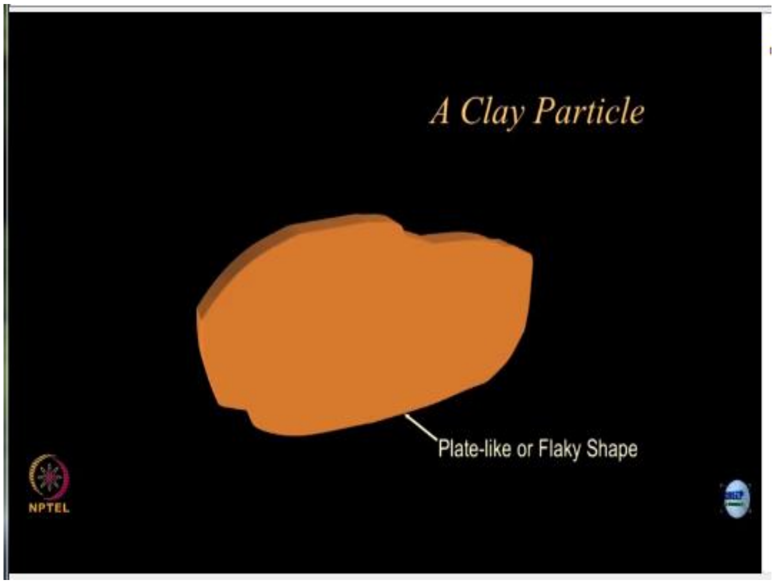

This is what I wanted to show you, if I take out 1 plate or 1 grain of the clay this is how it looks like, so we call this as a plate like or a flaky shaped, look at the charges which come on this.

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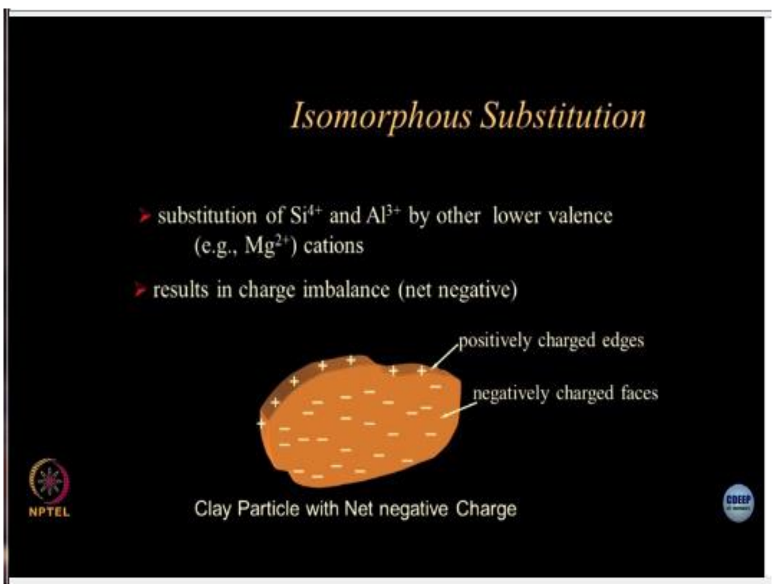

So, the plate face is negatively charged with a very fine particle, so the fundamental property of the fundamental charges negative charge and it gets spread on the surface. On the edges you have positive charge, where bacteria will come and sit on this clay platelet quick where bacteria will come and form a bond mostly bacteria is negatively charged alright. So the chances are that they will be holding the clay platelets from the edges.

So there is something known as isomorphous substitution read about this much more is going to be useful for you. So when I have a magnet like this in soils, the fine grain material which is clay, silica and alumina if you remember we have talked about all these things in the mineralogy part you know, they get substituted by magnesium, calcium, lower valence sands and that is what is known as isomorphous substitution.

This concept can be utilize for creating calcium Sandoz, I did a consulting long back for making calcium sandoz tablets. But the concept is same, I would like to park different type of ions on a surface and surface for me the substrate the technical word in today's language is substrate and on substrate something comes and gets pumped adsorbed. Because of this what happens if the system becomes unstable and the dynamic starts alright.

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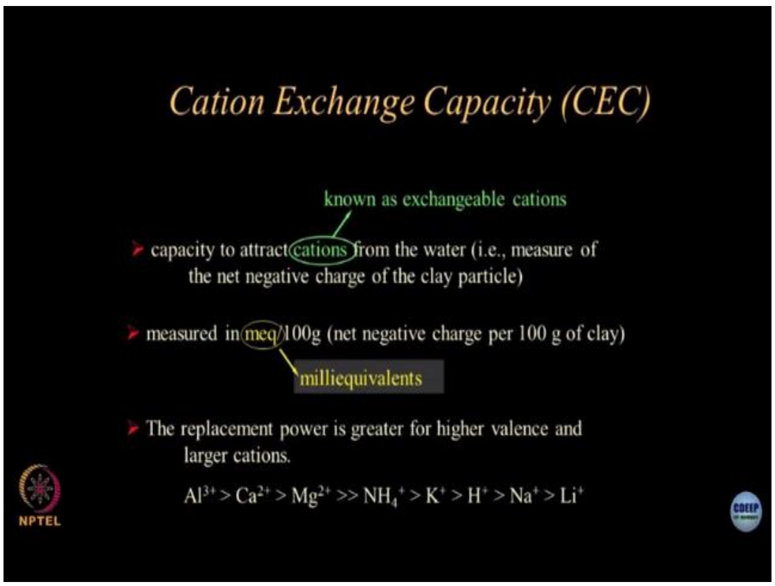

Now the dynamics is nothing but cation exchange capacity which makes the place highly reactive. By definition, the cation exchange capacity of the clay particles is the capacity of these particles to exchange cations with the environment. So suppose if calcium is present and sodium is available in the solution form, what will happen because of isomorphous substitution the sodium comes tries to this locate calcium which it cannot do.

Imagine a car cannot dislocate a truck which is parked in the parking space, so these concepts are the order of the day those who are into R and D related to geo mechanics and different subjects they use these concepts quite a lot, creating different type of filters, liquid phase, gaseous phase and so on. The unit of cation exchange capacity is milliequivalents per 100 grams and this is how the replacement series is.

Alumina has a tendency to replace calcium look at the valance is 3 rest are 2 and 1 calcium, magnesium, ammonium ions potassium, H ions, sodium ions and so on. So depends upon what is that you are trying to do, where you are using these minerals, you can use them at third year level . Normally it is not expected that you should be knowing all these things, but as I am teaching to the masses and people who are interested in doing advance courses on geo environmental engineering and process engineering, particularly chemical engineering related processes for them this is definitely a must.

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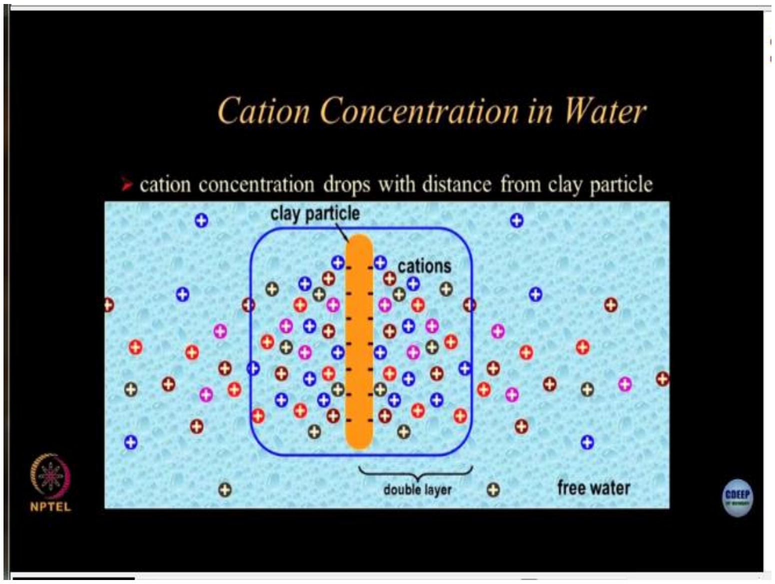

Now try to understand what is the concepts of cation concentration in water, so if you take clay particles and these clay particles when they are submerged in water there is something known as the gradient of the cation concentration you have studied this in physics somewhere, can you relate it f is inversely proportional to r square at subatomic level you have studied the concept of energy wells, is it not, so these are the examples.

I hope you can realize that at the interface of the clay particle, there is lot of concentration of cations and this box which I have shown, is known as a double layer. Geo mechanics cannot be studied unless you understand the concept of the double layer, double layer is the one which is the layer of cation surrounding the clay particles. When the clay particles are kept in water, it is so happens that apparently the size of the clay particle becomes 5, 10, 20 times it is just like grapes, you know you put them in water overnight and what happens next day morning they soil.

So this is what the concepts are lot of R and D is being done in this context to understand how the clay particles behave, what is the electromagnetic forces and how the dynamics of the particles takes place when they come in different type of solutions. And if I change the concentration of the cations or if I use different type of cations, what is going to happen to the equilibrium alright, beyond this boundary is all free water.

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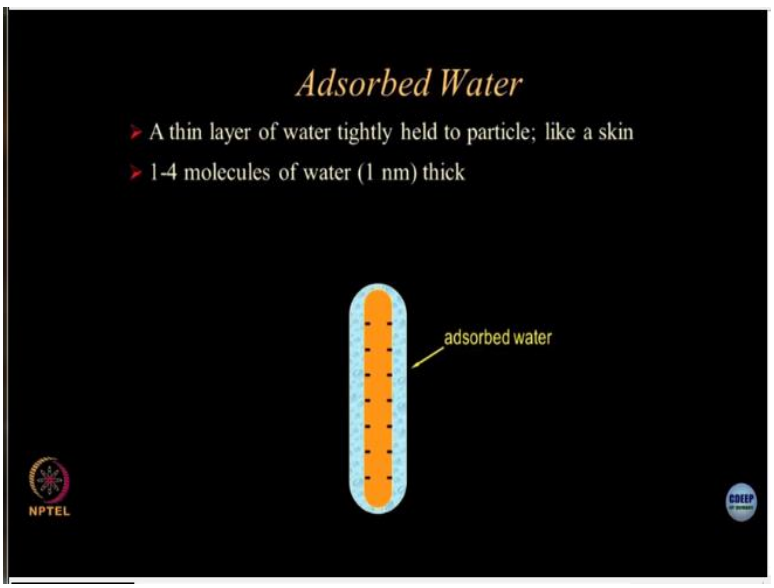

So adsorb water is the one which is surrounding the particle of the clay and this adsorption is because of the water being a dipole, clear. So you imagine as if on the clay particles you have different dipoles coming together and the positive and negative getting connected with each other and this is how the adsorb water gets formed, it looks like a capsule. Sometimes adsorb water is also known as hygroscopic moisture that means you take the clays and put it in your laboratory or in your room and Bombay city being very, very humid right now.

Because of the rains, when you come back you will find that either it has melted it has adsorb so much water or it has become wet. So this is what is known as adsorb water layer and I am sure you must be knowing the role of silica gel. So, what silica gel does, in your electronic items you normally keep a sachet of silica gel, so what it does, silica has a higher tendency to attract moisture and the vapors.

So you can safeguard your equipments because the surface area and the cation exchange capacity is going to be much more as compared to other minerals.

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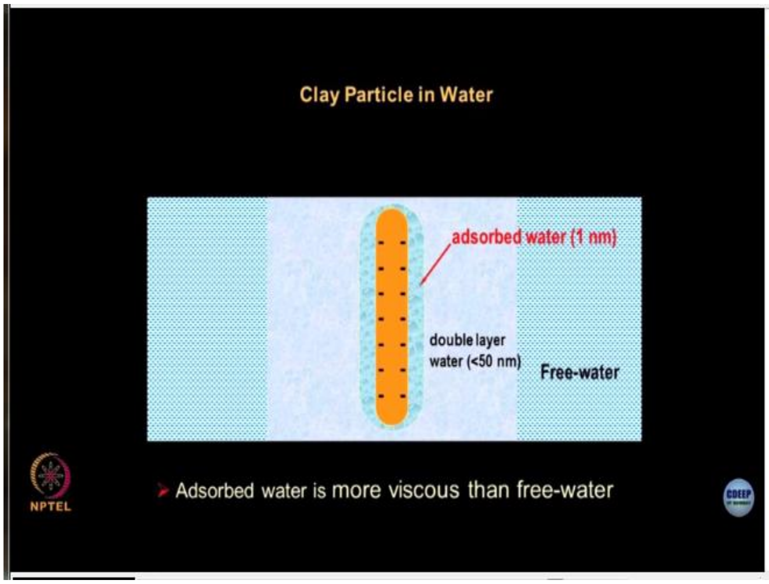

Now, this concept is useful for those who might end up in advanced R and D and otherwise also you should understand this is the clay particle this is adsorb water layer approximately 1 nanometer of size. This thing is surrounded by a double layer of water and double layer is the one which has lot of cations which are present in the system and a whole unit is surrounded by free water, sometime back you were asking this question about the porosity and permeability.

When we will go into the micro details of permeability we will discuss all these concepts again and we will discuss why clays are less permeable as compared to sands. By virtue of the mineralogy the clay particles have a tendency to create a adsorb layer of water and 2 particles when the absorb layer gets developed, now the pore space becomes so less that no fluid can migrate through it, however this thing cannot happen in sands.

Because sands are surface dormant they are not surface active they are no charges on there, clear. So whatever we have been discussing about right now is all for very fine particles like clays. So adsorb water layer thickness like what is the scale of thickness of adsorb water layer and double diffuse layer, if there is some general, good question. Normally double layers as I have written have less than 50 nanometers is very, very empirical.

So do not go by these figures it will depend upon the concentration of cations their valency clear number 1. So I may modulate these layers by increasing the concentration of the cations and the type of cations which I am going to use fine. So a quick answer in third year classroom would be these are tentative numbers and they may change just to give you a comparison about the different clay minerals.

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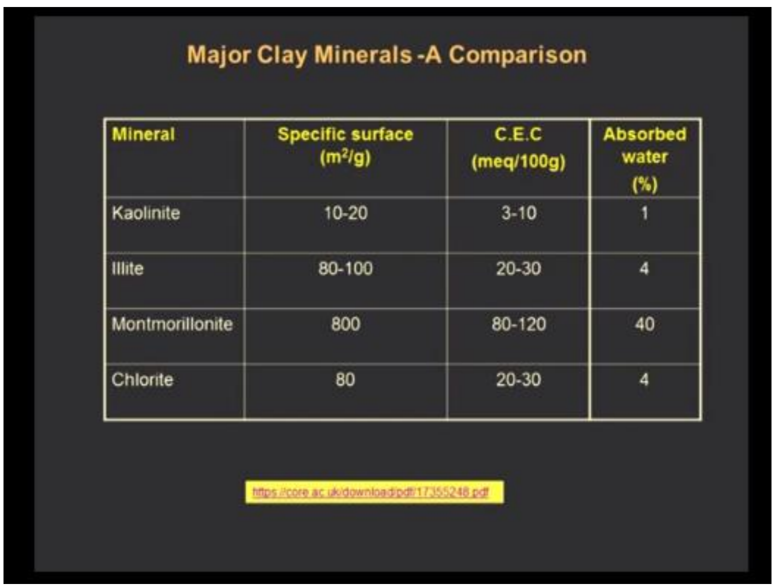
Major Clay Minerals -A Comparison

Mineral	Specific surface (m^2/g)	C.E.C (meq/100g)	Absorbed water (%)
Kaolinite	10-20	3-10	1
Illite	80-100	20-30	4
Montmorillonite	800	80-120	40
Chlorite	80	20-30	4

https://core.ac.uk/download/pdf/17355248.pdf

I have used Kaolinite, Illite, montmorillonite and Chlorite and if you look at the surface area which is normally defined in metre square per gram cation exchange capacity and adsorb water of the minerals, you can make out that why some minerals are so active and why some minerals are so dormant. Sands do not come in the picture anywhere because their surface area is extremely low it would be about 10, 20 metres per gram.

You will realize that specific surface area is the one which guides C.E.C. So if C is surface area is more cation exchange capacity is going to be more, adsorb water maybe more or not do not try to remember these numbers. This is just to give you a feel of how the minerals look like, Montmorillonite if you see the surface area the extremely high 800 meter square per gram. The other day I asked a question, what is the size of a football field if you remember.

Cation exchange capacity is very high, water absorption is also very high is the obvious choice for people from different profession to use this mineral that they want. Whenever you get time, please click on this link which I have provided to read more about, you know how minerals behave is a beautiful paper on clay mineralogy.

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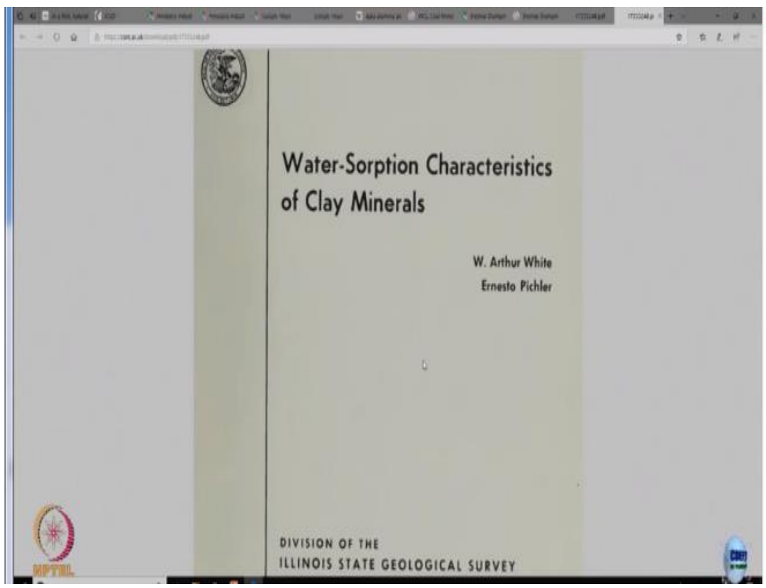

Water sorption characteristics of clay minerals but do not read it at third year level alright, so maybe keep these things pending. If the A minerals have similar charges, then why do they have cohesive forces, why do they have some cohesive nature of. Simple example is you remember you were talking about this thing, clay particle is negatively charged, calcium ion comes from the environment.

Bacteria produces calcite, that calcium gets pulp on the surface of the clay particles clear, 2 particles get bridged by a calcium ion clear carbonate gets form, carbonate deposition 2 particles form a megalith, megalith means they get a stitched together, they get glue together and hence cohesion becomes a way to demonstrate the sheer strength. So if you want to shear these 2 particles is difficult.

I say 2 piece of papers clear and put a small drop of glue and press it a bit and now try to tear it or share it is difficult. The same thing is happening over here is this is ok you got the answer.