Soil Mechanics
Prof. B.V.S. Viswanadham
Department of Civil Engineering
Indian Institute of Technology, Bombay
Lecture - 5

In the previous class we have studied about occurrence of the clay minerals in soils and methods of their identification.

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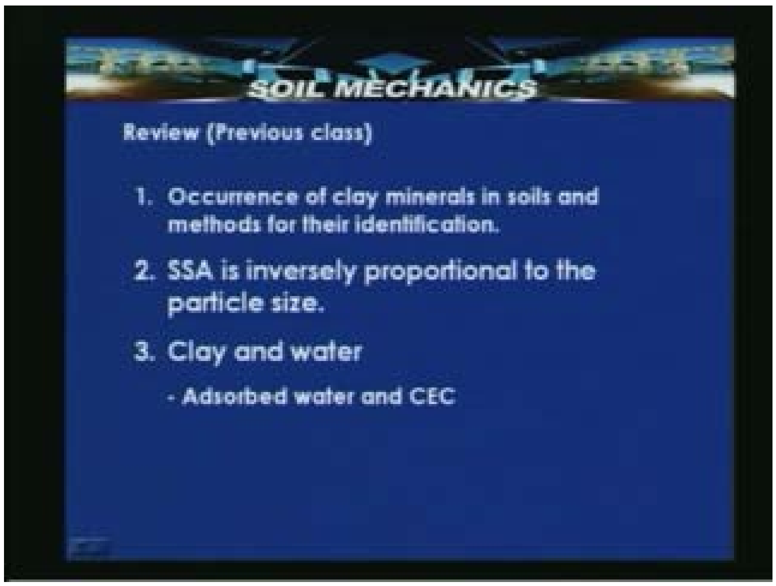

We also studied about an important parameter called specific surface area and we said that the specific surface area is inversely proportional to the particle size.

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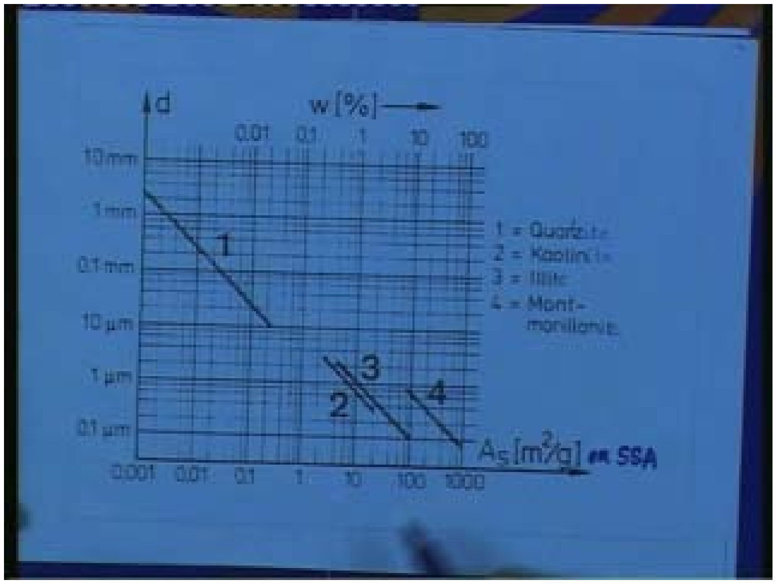

If you look into this chart, this graph shows variation of specific surface area A_s in m square by g or specific surface area with particle size. And on another axis water content is plotted here. We have plotted a graph for different minerals where 1 represents quartzite, 2 represents kaolinite, 3 represents illite and 4 represents Montmorillonite.

We can see here, with an increase in specific surface area there is an increase in water adsorption content. With decrease in particle size an increase in specific surface area can be noted. Different variations for different minerals can be seen here. In addition to this we also saw clay and water interactions, we even defined exhauble water and cationic exchange capacity. We also said that with increase in specific surface area there will be an increase in the cationic exchange capacity. Now, having seen clay and water interactions let us look into the soil structure or soil fabric which is nothing but the arrangement of soil particles relative to each other. So, in this lecture we will be seeing about the arrangements of the soil particles, particularly for coarse-grained soils and fine-grained soils.

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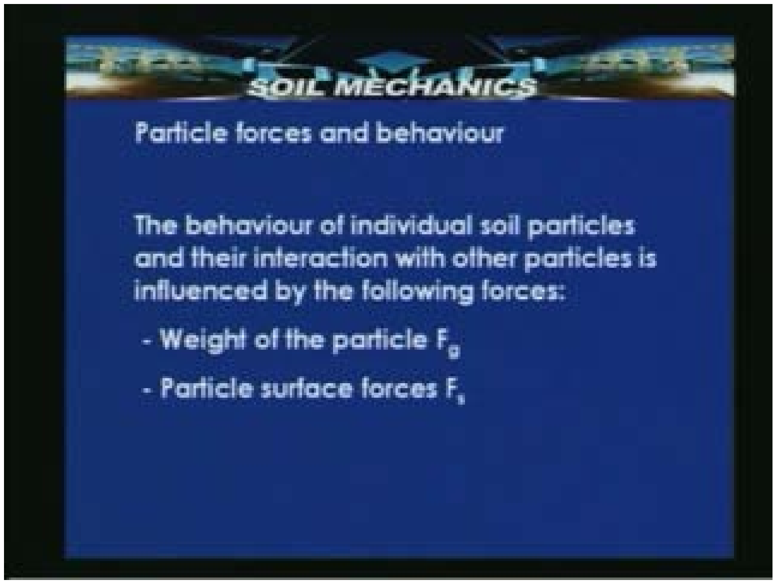

Before looking into this arrangement, let us try to look about the particle forces and their behavior. The behavior of individual soil particles and their interaction with other particles is influenced predominantly by two forces. One is the weight of the particle that is weight force F_g and particle surface forces that is F_s. Now, let us see how they relate with each other and influence in particle arrangement.

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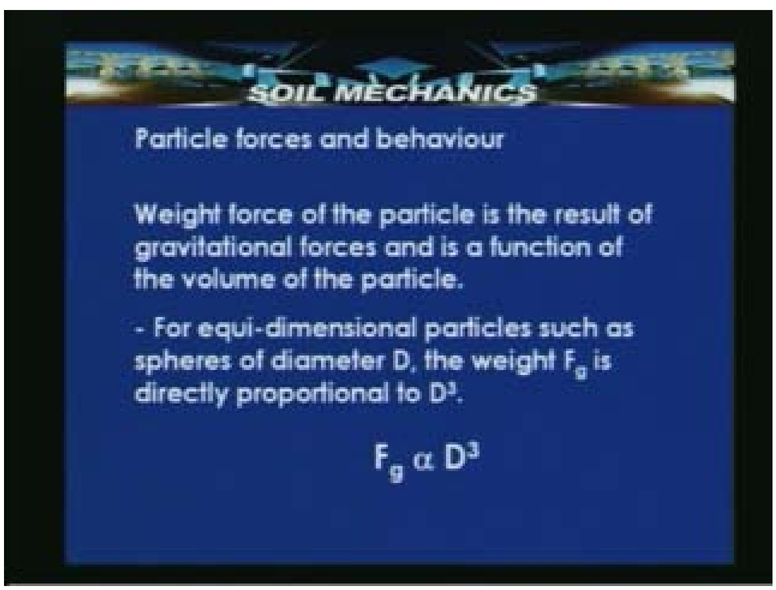

Weight force of the particle is the result of the gravitational forces and is a function of the volume of the particle. For example, for equi-dimensional particles such as spheres of diameter D, suppose if you represent a particle as a sphere of diameter D, the weight F_g is directly proportional to D cube. So, with an increase in particle size the gravity force increases. A clay particle is shown in this slide.

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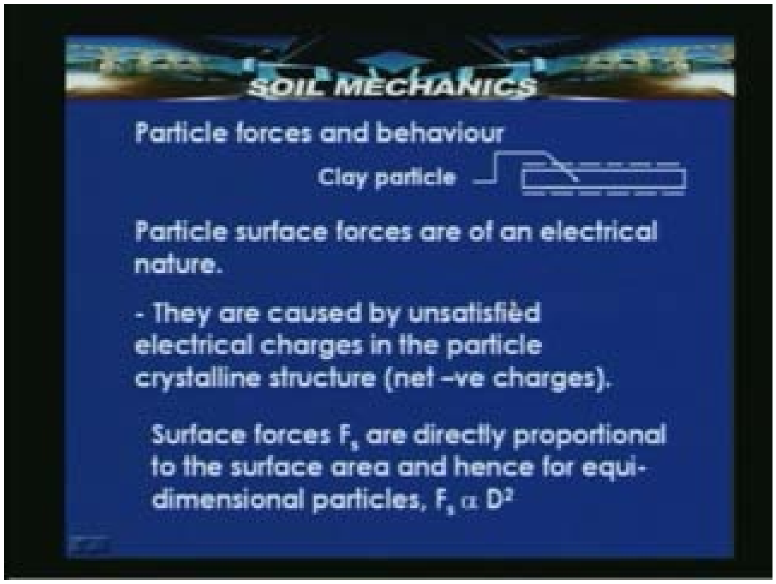

Clay particle is predominantly represented as a platelet shape particle and the surface is shown with negatively charged surface. Particle surface forces are of an electrical nature. They are caused by unsatisfied electrical charges in the particle crystalline structure. That is, there will be always net negative charges on both sides of the surface of the clay particle. So surface forces F_s are directly proportional to the surface area, hence for the equi-dimensional particles F_s is proportional to the square of the particle size. So we said that with a decrease in particle size there will be an increase in the specific surface area, so F_s is proportional to D square. That means for particles with finer size the surface forces are directly proportional to the square of its size.

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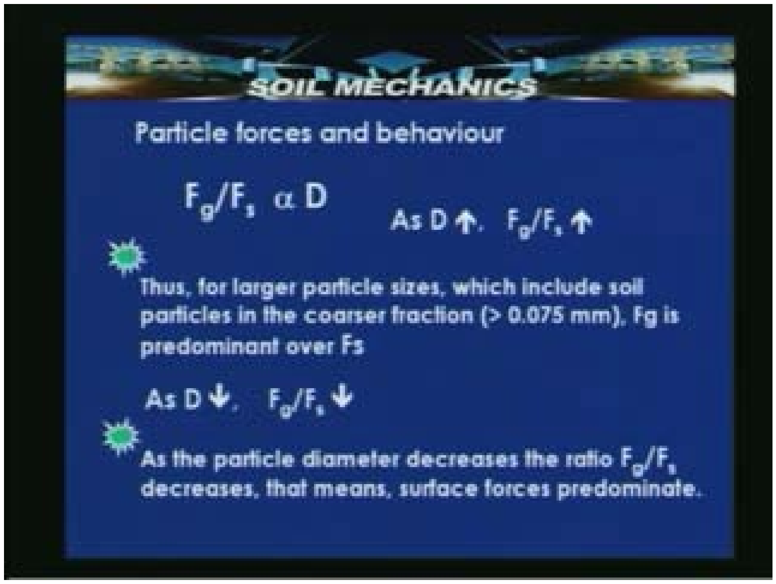

Now if you compare, the variation of F_g by F_s is proportional to D and as the particle size diameter increases the ratio of F_g by F_s increases. Thus for the larger particle sizes which include soil particles in the coarser fraction that is greater than 75 micron or 0.0075mm or 0.075mm F_g is predominant over F_s. Suppose for decreasing particle size diameter, the ratio F_g by F_s decreases which means the surface forces predominate. With an increase in the particle size the ratio F_g by F_s increases. So with an increase in the particle size gravity forces predominant over surface forces. With decrease in the particle size, surface forces predominant over gravity forces. This is an important concept we should keep in mind, before looking into the particle arrangement of the soil particles. Now let us look soil structure or soil fabric, it is also called as soil fabric.

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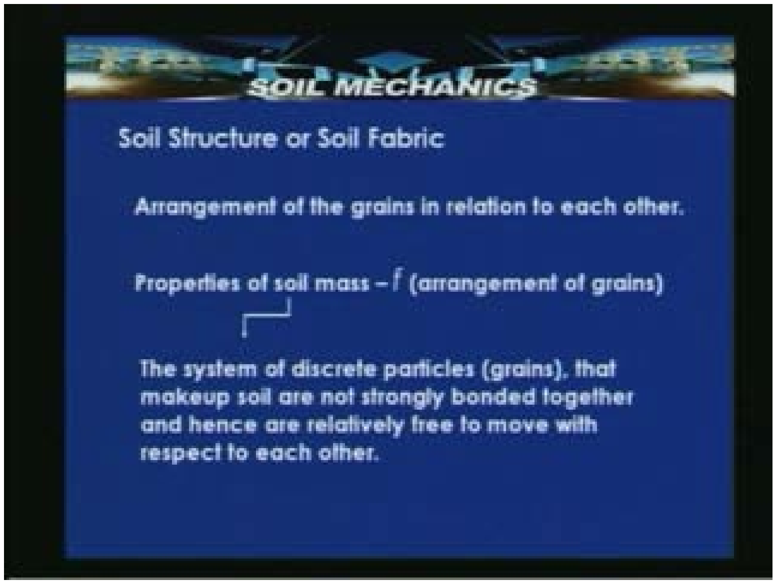

The arrangement of the grains in relation to each other is defined as soil structure or soil fabric. Properties of soil mass are demonstrated here. They are basically the function of the arrangement of grains. The system of the discrete particles or grains, that makeup soil particles are not strongly bonded together and hence are relatively free to move with respect to each other.

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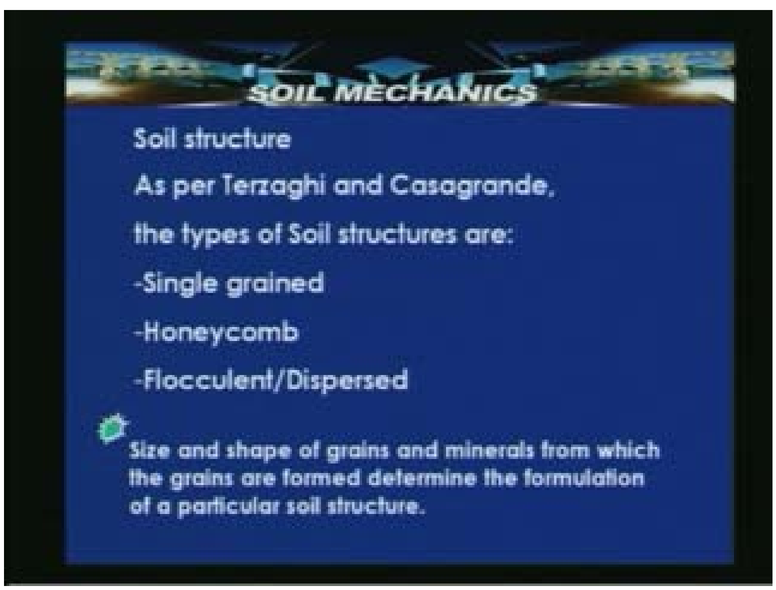

According to Terzaghi and Casagrande, the types of the soil structures basically are classified as follows: Single-grained, Honeycomb, Flocculent and dispersed structures. This covers both coarse-grained and fine-grained soils. Size and shape of the grains and minerals from which the grains are formed determine the formulation of a particular soil structure. Single-grained and Honeycomb are basically for coarse-grained particles. Flocculent and dispersed structures are for fine-grained soils.

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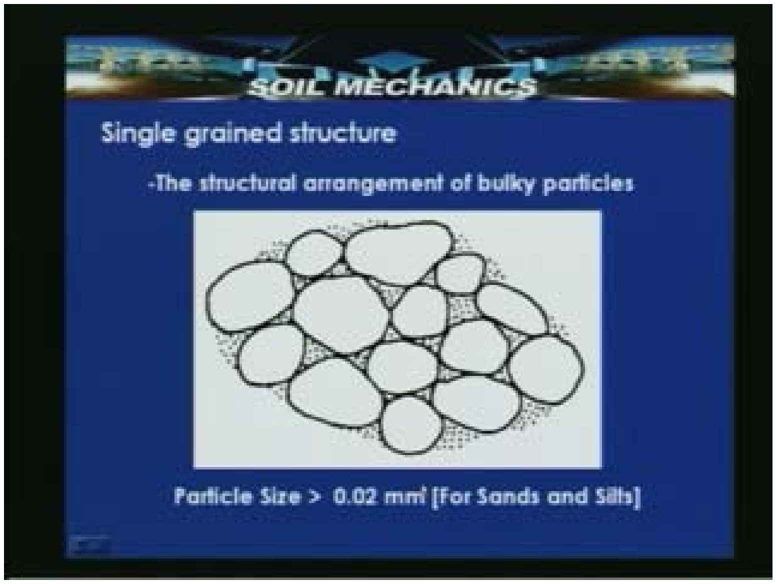

If you look into this slide single-grained structure is shown. The structural arrangement of the bulky particles can be seen here. The particles of different sizes and different shapes can be seen, in contact with each other and the spaces in between these particles can be voids or it can be filled with particles of small size. For sand and silts the particle size is greater than 0.02mm, this type of single-grained structure can be governed

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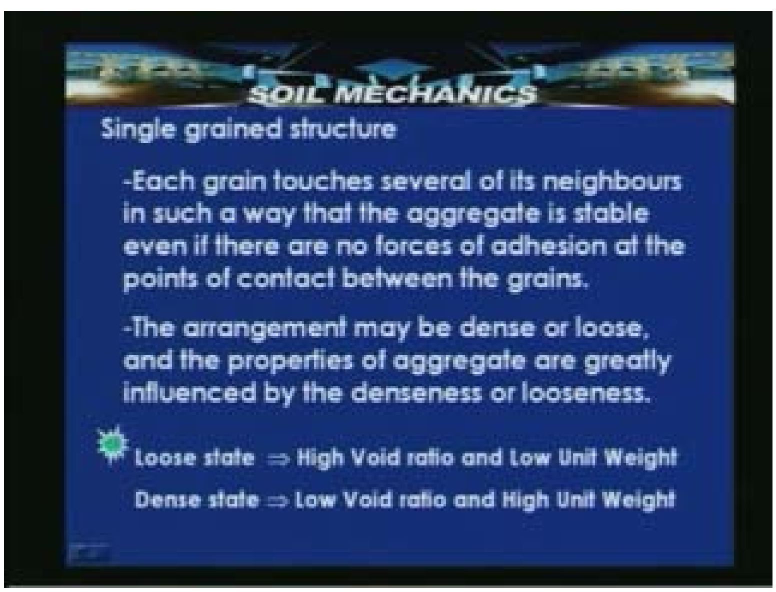

In the single grained structure, as we have seen each grain touches several of its neighbours in such a way that the aggregate is stable even if there are no forces of adhesion. That is no forces of adhesion in the sense no bond or no cohesive at points of contact between the grains. The arrangement may be dense or loose, and the properties of aggregate are greatly influenced by the denseness or looseness. So the particles can be in a form of dense packing fashion or a loose packing fashion. The properties of the aggregate are greatly influenced by the denseness or looseness. For example, if you see a particle packing with a loose state can yield high void ratio and low unit weight, and a particle packing in dense state can yield low void ratio and high unit weight.

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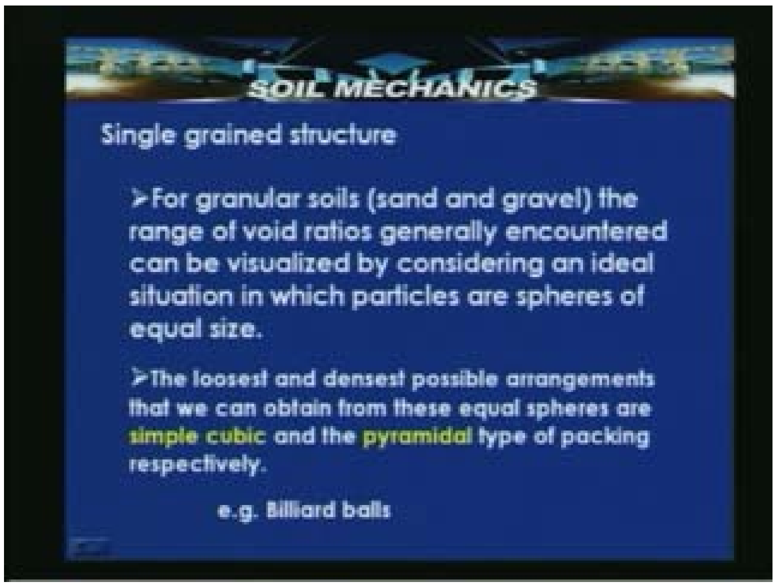

For granular soils that is predominantly for sand and gravel, the range of void ratios are generally encountered can be visualized by considering an ideal situation, in which the particles are spheres of equal size. Though the particles are having different shapes, because of their different patterns of arrangements they are idealized as spheres of equal size. The loosest and densest possible arrangements that we can obtain from these spheres are simple cubic and the pyramidal type of packing respectively. Simple cubic is for loose state and pyramidal type of packing is for dense state. Consider an example billiard balls with particular arrangement like this.

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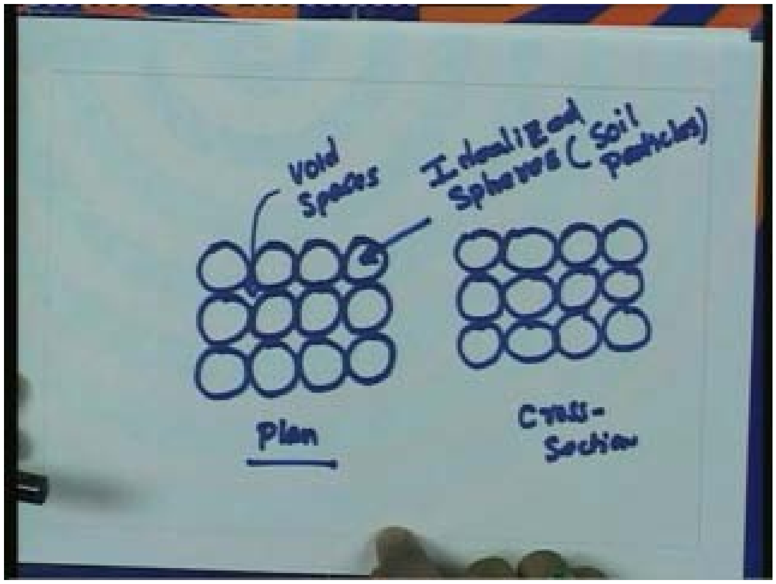

Different spheres of equal diameter D, stacked in a loose fashion and these are idealized spheres representing soil particles. This is in cross section and these are the void spaces. You can see here, with this arrangement large amount of voids can yield maximum void ratio and low unit weight. The other arrangement called as pyramidal arrangement looks like this.

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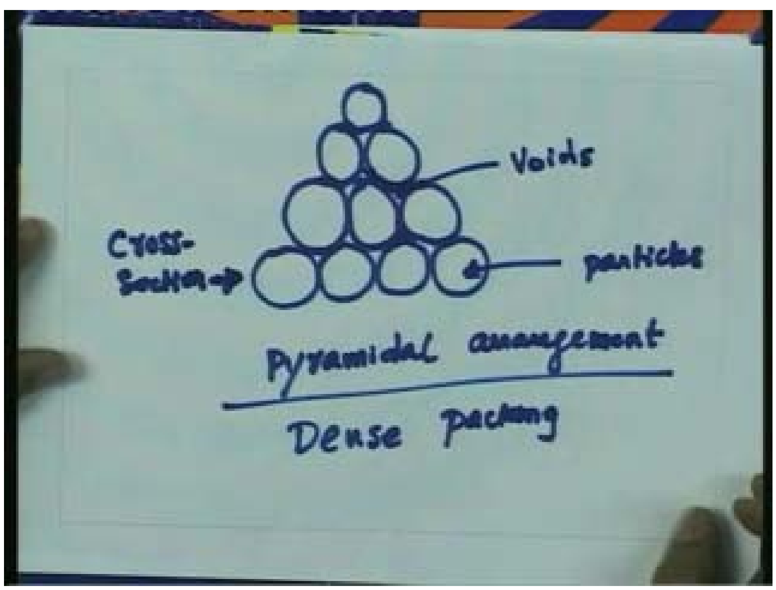

Here we can see the pyramidal arrangement for dense packing. This is the cross section and these are voids. It can be seen, this reduction in voids yields minimum void ratio and high unit weight. So far we have seen two arrangements. The first one is simple cubic arrangement for representing the loose state and pyramidal arrangement is for representing the dense packing state.

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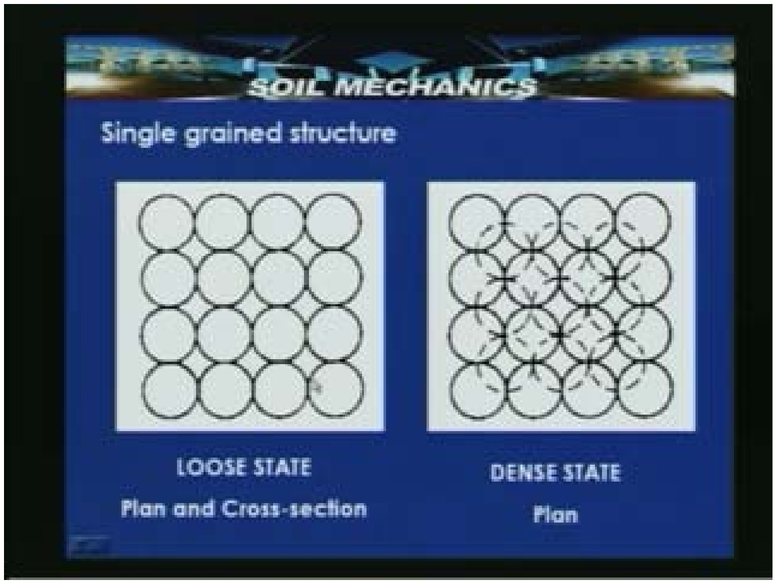

So let us look into this slide, a single-grained structure in the loose state for both plan and cross section is shown. For dense state of single-grained structure in plan is shown here and these are the spheres at the bottom. In the next level, these are the spheres and this sphere will be there at the top most state. So this arrangement represents the dense packing state and this arrangement represents the loose packing state.

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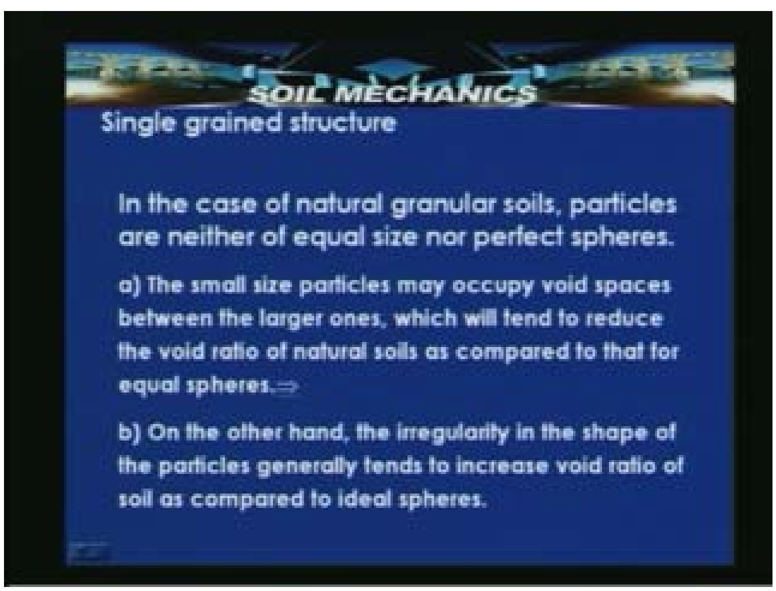

In the case of natural granular soils, particles are neither of equal size nor perfect spheres. But we are idealizing like equal spheres, how far they are correct. This can be seen with this following justification. The small size particles may occupy void spaces between the larger ones, which will tend to reduce the void ratio of natural soils as compared to that for equal spheres.

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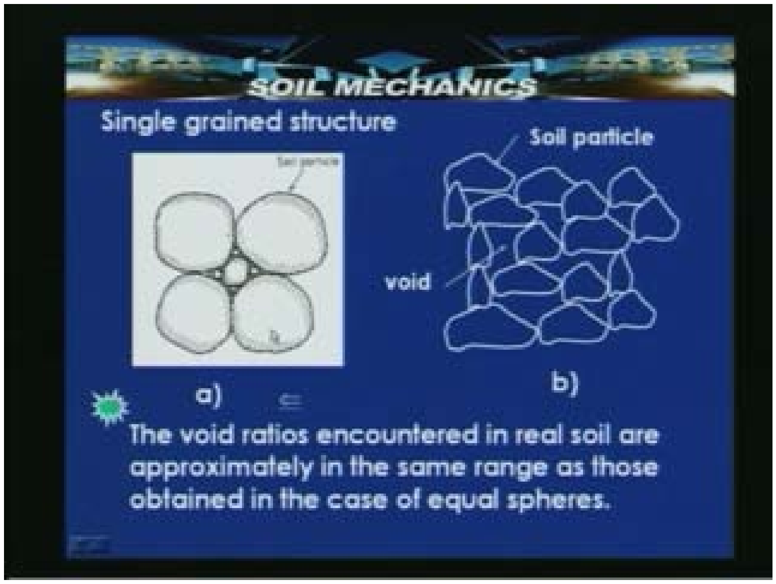

Let us into this aspect here. It can be seen here that between the large soil particles the small particles of different soils gets filled and forms densest possible packing. So this is one extent where the small particles get packed in between the large soil particles. This can yield densest possible packing which may be possible and which can yield minimum void ratio in the natural state.

On the other hand, the irregularity in the shape of the particles generally tends to increase void ratio of the soil as compared to ideal spheres. We also discussed by discussing the shape of the soil grain, we said that the soil particle can have different grain shapes. The irregularity in the shape of the particles generally tends to increase void ratio of the soil as compared to ideal spheres. So this can be looked like this, if you see in this slide with figure b here, these are the large void spaces which are formed because of the irregular particle sizes and particle shapes can yield large void spaces. So the void ratios encountered in real soil are approximately in the same range as those obtained in the case of equal spheres. So, one case represents the densest possible state and the other one represents the loosest possible state.

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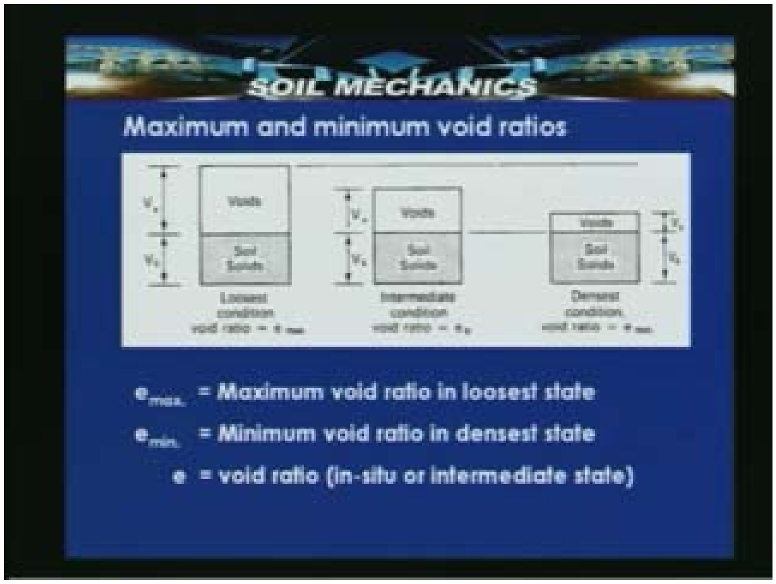

Let us look further into the Deductions from these maximum and minimum void ratios. We said that the densest possible state of packing of soil grains can yield minimum void ratio. The loosest possible state of packing of soil grains can yield maximum void ratio of soil. So, here if you see this first phase diagram, generally this is a two phase diagram represented for dry sand. Let us consider this for dry sand. In the loosest condition the void ratio is equal to e_{max} here. Here the volume of solids and volume of voids are marked. The large amount of volume of voids can be noted here.

In the densest possible packing, like whatever we have discussed in the previous slide with that the densest condition represents void ratio e_{min}, that is minimum void ratio in densest state. Reduction in the volume of voids can be noted and the constant amount of volume of solids can be seen here. The decrease in volume of voids represents the range over which a particular soil can vary, can have maximum and minimum void ratios. For example an intermediate condition to which the soil has been found in natural state or compacted, while placing the soil can have an intermediate void ratio that will be in between maximum void ratio and minimum void ratio.

Here you can see intermediate condition, the void ratio is represented as e or e_0. e is the void ratio which is called insitu void ratio or void ratio in the intermediate state. e_{max} is the maximum void ratio in the loosest state and e_{min} is the minimum void ratio in the densest state. With this an important parameter can be defined, that is called relative density. Before defining relative density, we can also see what is the possible maximum void ratio for the cubic arrangement?

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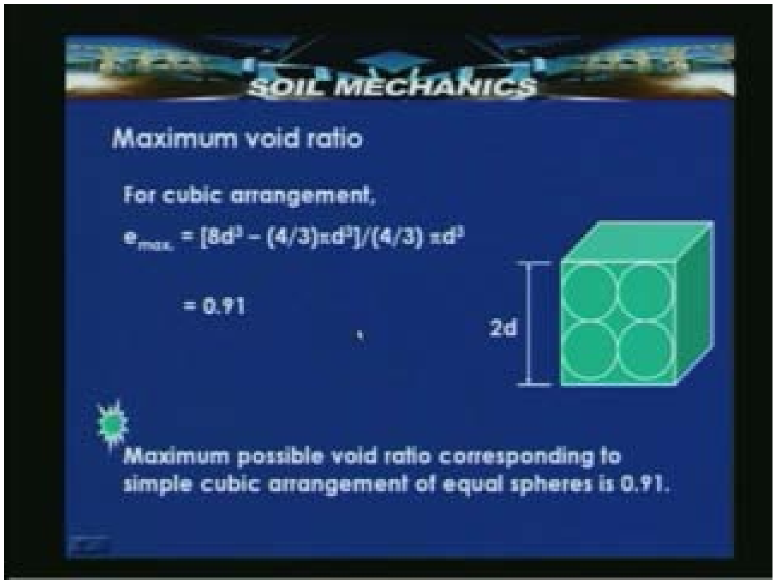

If you consider four particles of soil idealized as spheres of diameter d, where d is the particle size diameter. You assume that maximum void ratio from the cubic arrangement e_{max} is equal to 8d cube that is nothing but the total volume minus the volume of the solids that is nothing but equivalent volume of eight complete spheres. Here 4 by 3 pi d cube is the volume of the solids. So, total volume minus volume of the solids leads to volume of voids towards the ratio of volume of solids 4 by 3 pi d cube. That is the volume of eight spheres in this particular space of cube of size 2d which deduces the maximum possible void ratio is e_{max} is equal to 0.91. Maximum possible void ratio corresponding to simple cubic arrangement of equal spheres is 0.91.

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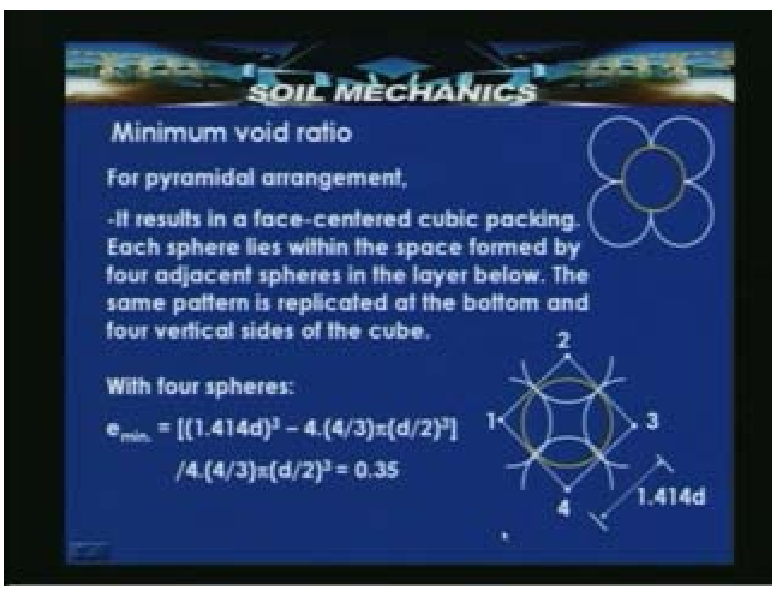

Let us look into the formation for minimum void ratio. For pyramidal arrangement, it results in a face-centered cubic packing. Each spheres lies within the space formed by four adjacent spheres in the layer below. The same pattern is replicated at the bottom and four vertical sides of the cube. You consider here, four spheres and the space in between these four spheres is filled by a sphere on the top.

If you look here with four spheres at the bottom that these are the parts of the four spheres and this yellow one is the sphere at the top. If you represent this as root 2d which is equivalent to 1.414d, in that if you assume that is the total volume minus the spheres which are falling within this space is represents the volume of solids, that will be six spheres and eight octants or four complete spheres. So, by taking four complete spheres volume as the volume of the solids, this is nothing but the volume of voids.

The volume of voids to the volume of solids yields the minimum possible void ratio for the pyramidal arrangement in the case of a densest packing. For the cubic arrangement, the loosest state with the maximum void ratio will be around 0.91 and for pyramidal arrangement with the densest state the minimum void ratio will be around 0.35. So having seen maximum and minimum void ratios, let us now define a parameter called relative density which is indicated as D_r which is widely used for indicating the compactness of the soils, in case of coarse-grained soils.

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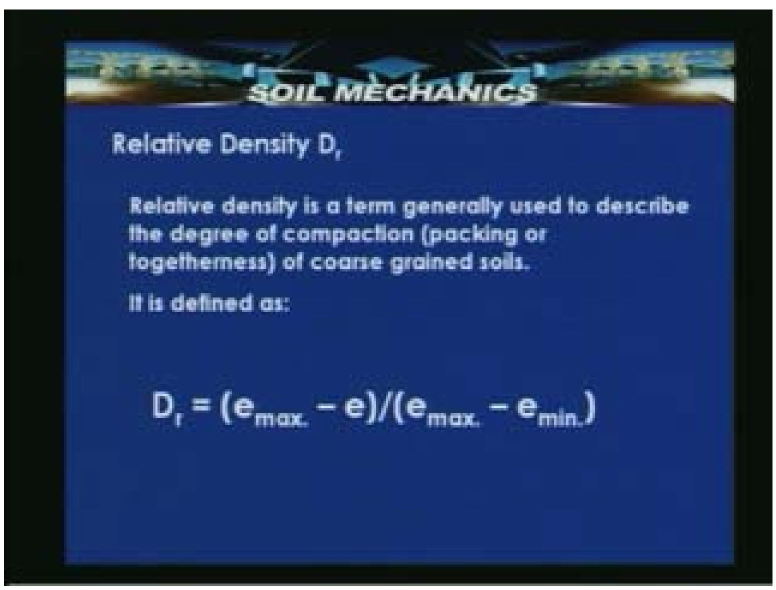

Relative density is a term generally used to describe the degree of compaction packing or togetherness or compactness of the coarse-grained soils. It is defined based on maximum void ratio, intermediate void ratio or insitu void ratio and minimum void ratio. The relative density is given like this: D_r is equal to (e_{max} minus e) by (e_{max} minus e_{min}). This is the range between maximum void ratio and minimum void ratio which may be possible for a particular type of coarse-grained soil. Here e_{max} is the maximum void ratio and e is insitu void ratio. With this we will be able to obtain the degree of compaction of a particular soil. So if you look at this scale here, at e is equal to infinity the unit weight of the soil is 0. At the e is equal to e_{min} the soil can have gamma d_{max} that is maximum dry unit weight. At e_{max} the soil can have gamma d_{min} that is minimum possible dry unit weight of a soil. So the range which is indicated between e_{max} and e_{min} is relative density. It has got a range from 0 to 100 which is generally indicated in percentage D_r is equal to [(e_{max} minus e) by (e_{max} minus e_{min})] into 100 .This can also be represented by this equation: (gamma d_{max} by gamma d) into [(gamma d minus gamma d_{min}) by (gamma d_{max} minus gamma d_{min})].

If you know the maximum void ratio and minimum void ratio of a given soil which is being used for filling or compacting in a particular area and by knowing the insitu void ratio, we will be able to determine the compactness or the degree of compaction at particular time. So it can be indicated with percentage and D_r is equal to [(e_{max} minus e) by (e_{max} minus e_{min})] into 100 which can be also be indicated in terms of unit weights as (gamma d_{max} by gamma d) into [(gamma d minus gamma d_{min}) by (gamma d_{max} minus gamma d_{min})] into 100 . This gives the possible degree of compaction of coarse-grained soils.

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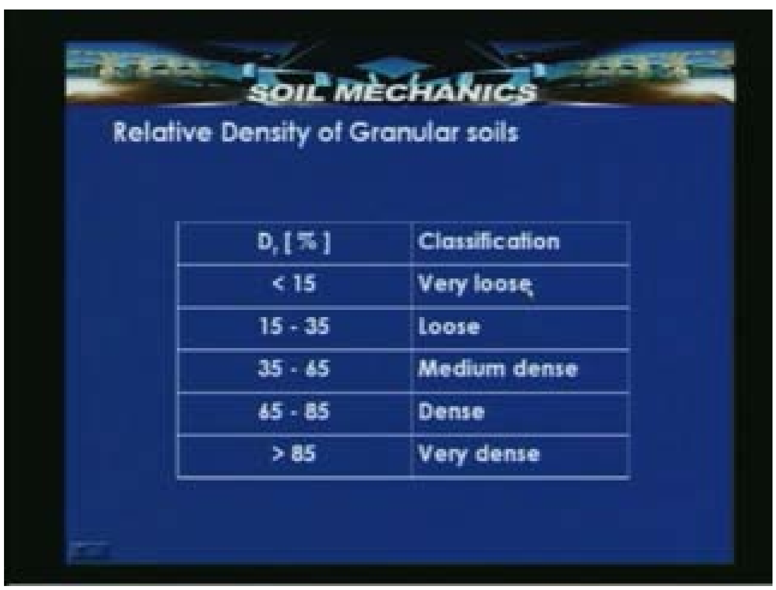

Relative density for coarse-grained soils, particularly for granular soils can be indicated with this following classification. D_r is the relative density, if it is less than 15, the state is reported to be very loose. If the relative density is in the range from 15 to 35, it is indicated as a loose state. If it is 35 to 65, it is indicated as a medium dense. If it is 65 to 85, it will be a dense state. If it is greater than 85, it is indicated as a very dense state. So the soil with a relative density greater than 85 percent indicates a very dense packing. The soil with the relative density less than 15 percent indicates a very loose packing.

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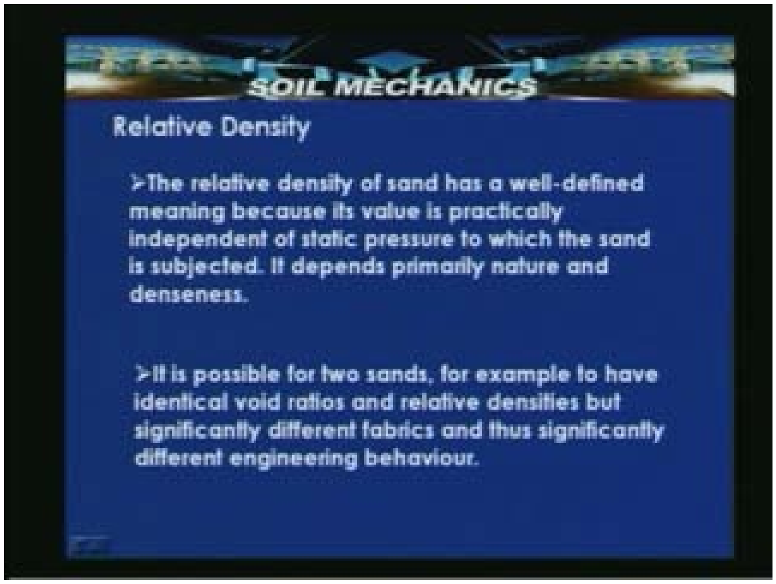

The relative density of sand has a well-defined meaning because its value is practically independent of static pressure to which the sand is subjected. Primarily it depends on nature and denseness of the arrangement. So it is possible for two sands, for example to have identical void ratios and relative densities but significantly different fabrics and thus significantly different engineering behavior. So two sands, even if they have identical void ratios and relative densities but it is possible that, their single-grained arrangement can be different can yield to a different engineering behavior. The relative density of sand has a well defined meaning, because its value is practically independent of the static pressure to which the sand is subjected. The next soil structure is defined as a Honeycomb structure.

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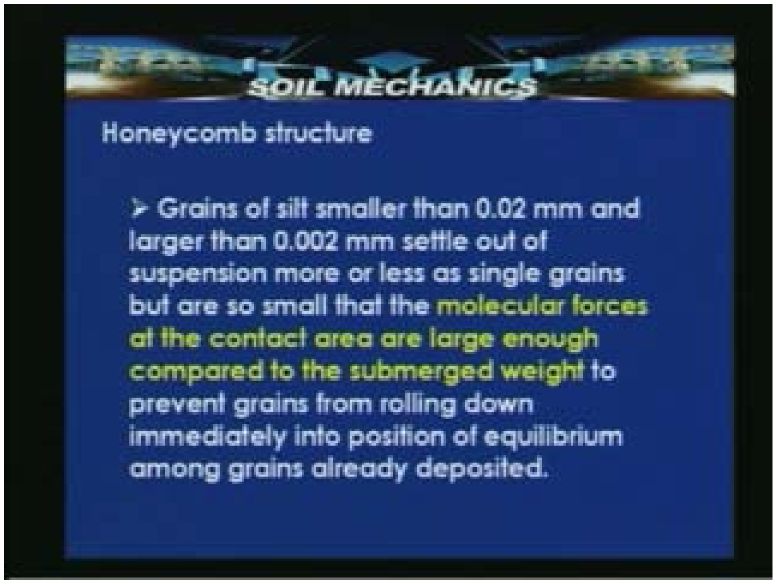

This is for grains of silts smaller than 0.02mm and larger than 0.002mm that is 2 micron. The settle out of suspension more or less as single grains but are so small, that the molecular forces at the contact area are large enough compared to the submerged weights that is the gravity forces to prevent the grains from rolling down immediately into the position of equilibrium among grains already deposited, that is indicated here.

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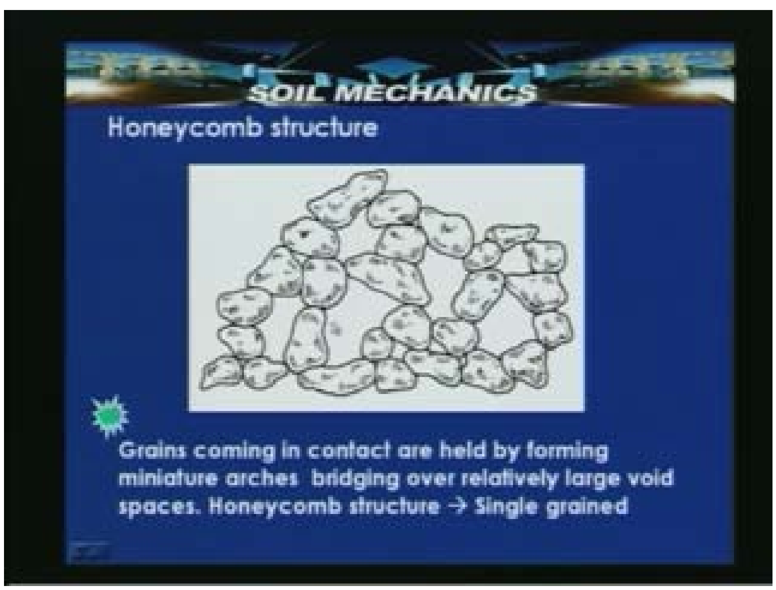

If you see here because of the contact points the molecular forces dominate the submerged weight forces. With that they form miniature arches and create a structure called a Honeycomb structure with large void ratios. So, grains coming in contact are held by forming miniature arches and bridging over relatively large void spaces. Void spaces like this can exist in their Honeycomb structure. Once the arches of this honeycomb structure collapses they deduce to a single-grained particle arrangement. So the second type of soil structure arrangement is for silt to clay particles. So, as long as these arches are stable the Honeycomb structure is stable. Now, having seen structural arrangement of the particles for silt and sand particles and gravel particles, let us look into the structural arrangement of clay soils that basically represents fine grained soils.

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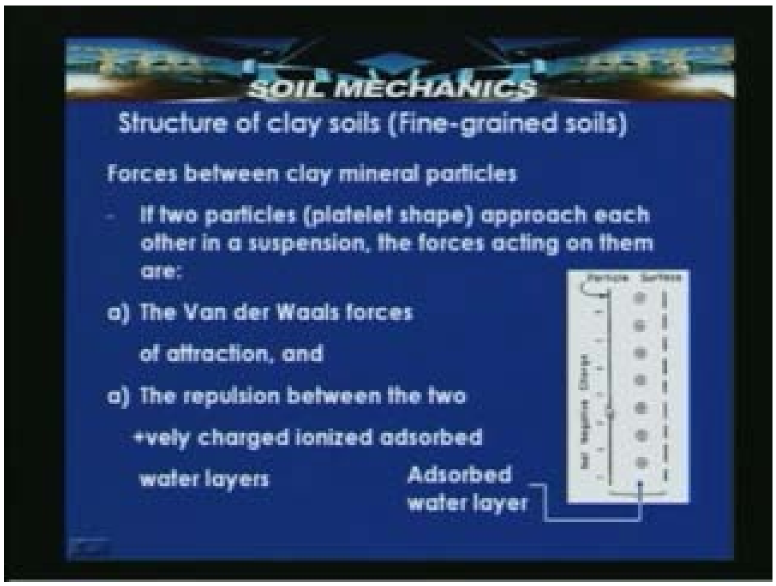

For this, we again have to look into the particle forces and behavior and their influence in forming the structural arrangement in case of clay soils. The forces between clay mineral particles are described as follows: If two particles (platelet shape) approach each other in suspension, the forces acting on them are: The Van der Waals forces of attraction, there will be certain forces of attraction between the particles and repulsion is between the two positively charged ionized adsorbed water layers. If you see here, the clay particle surface is represented with net negative charge and the rigid layer is with systemized arrangement of the ions very close to the particle. When adsorbed water layer comes in contact with another particle it imposes that particle hence the repulsion exists between two positively charged ionized adsorbed water layers. In addition to this, the particles also will have Van der Waals forces of attraction. So these two influence in making the particles settle with the suspensions.

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Let us look how these two attraction and repulsion forces influence this particle arrangement. At very small separations, the Van der Waals forces are always larger, and particles which approach sufficiently closely will adhere. However, the Van der Waals forces decrease rapidly with increasing separation.

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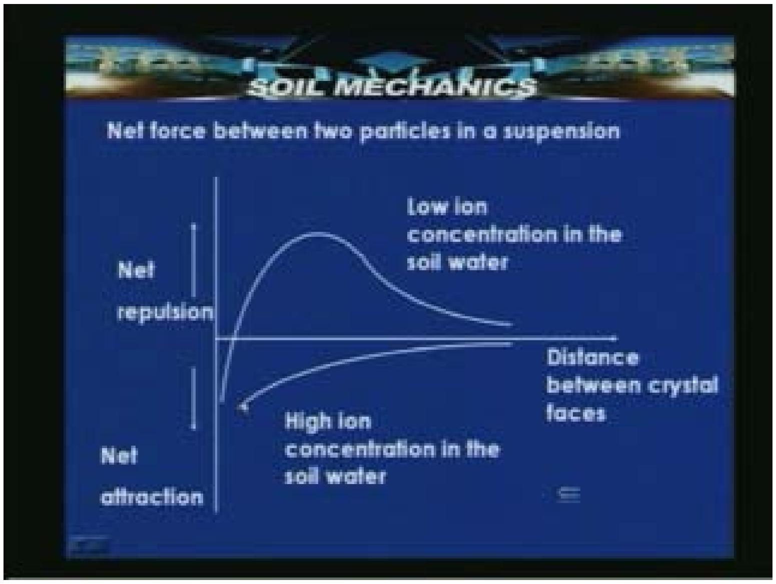

If you look into this diagram the net force between two parallel particles in suspension is shown and on this axis distance between crystal faces is shown here. With an increase in the distance between the crystal faces, you can see the decreasing attraction force. So particles are very close to that, they have a strong attraction. That is because of the Van der Waals forces as told here. At very small separations the Van der Waals forces are always larger, and particles which approach sufficiently closely will adhere. However, the Van der Waals forces decrease rapidly with increasing separation. Here a clay particle with around an absorbed layer is shown and they subjected to repulsion. If the absorbed layer is thick, the repulsion will be large at distances from the surface at which the Van der Waals forces are small.

That means if you look into here, for a particular distance away from the clay space or clay particle, there will be net force repulsion can dominate and for very close to the particle there may be a chance that the Van der Waals forces of attraction dominate. These two will determine the particle arrangement for the fine-grained soils. So if the adsorbed water layer is thick, the repulsion will be large at distances from the surface at which the Van der Waals forces are small. With this, because of this region the particles will remain in a dispersed state settle independently when net force is repulsion. That means that when repulsive forces over come these Van der Waals forces of attraction, then it results in a dispersed state. Particles will remain in dispersed state and they settle independently without being come in contact with each other.

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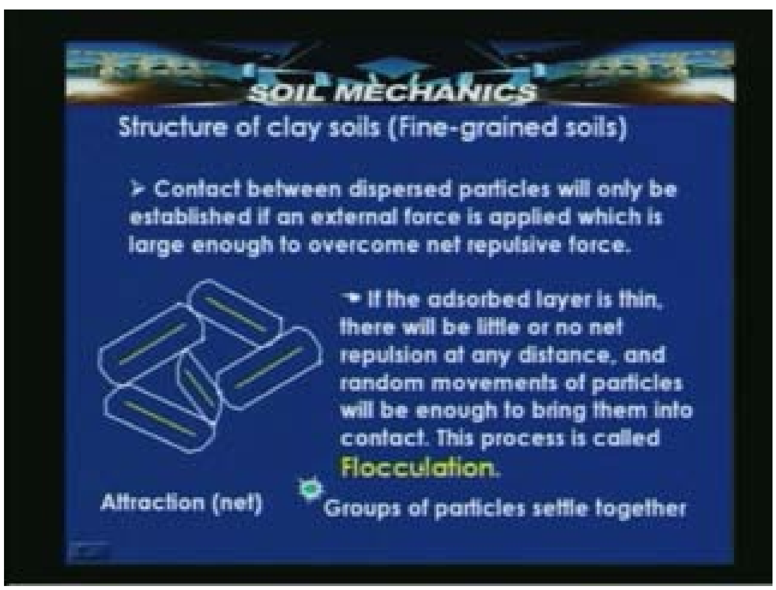

However, the contact between the dispersed particles can be established if an external force is applied which is large enough to overcome the net repulsive forces. Suppose if these dispersed particles can be pushed together by applying an external force which should be large enough to overcome the net repulsive force. So contact between dispersed particles will only be established if an external force is applied and which is large enough to overcome net repulsive force.

In previous case if the adsorbed layer is thick and at a certain distance from the clay particle and if the net force is repulsion we say that there is a possible state of arrangement that is called a dispersed state, where the particle settle independently. In the other case, if the adsorbed water layer is thin, there will be little or no net repulsion at any distance, and random movements of particles will be enough to bring them into contact. This process is called Flocculation. You can see the particles flock with each other and form a contact like this, in which where the attraction is the net force here. The attractive forces are dominating the repulsive forces which make the particles to remain in contact with each other and it forms with this type of pore void spaces in between these particles. The groups of particles settle together or flock together, so this particular relation is called flocculation or flocculated structure which we are going to see now. That's what it has been shown here, net force between two particles in a suspension, in case of a low ion concentration you can see that there is a predominantly a net repulsion is dominating.

In case of a high ion concentration in the soil water, then net attractive forces dominate here. When the particles come in contact when they settle in a suspension, and in case of a high ion concentration in the soil water that can result in a flocculated type of arrangement. If net repulsion is dominating, in case of a low ion concentration in the soil water that can result in a dispersive type of arrangement.

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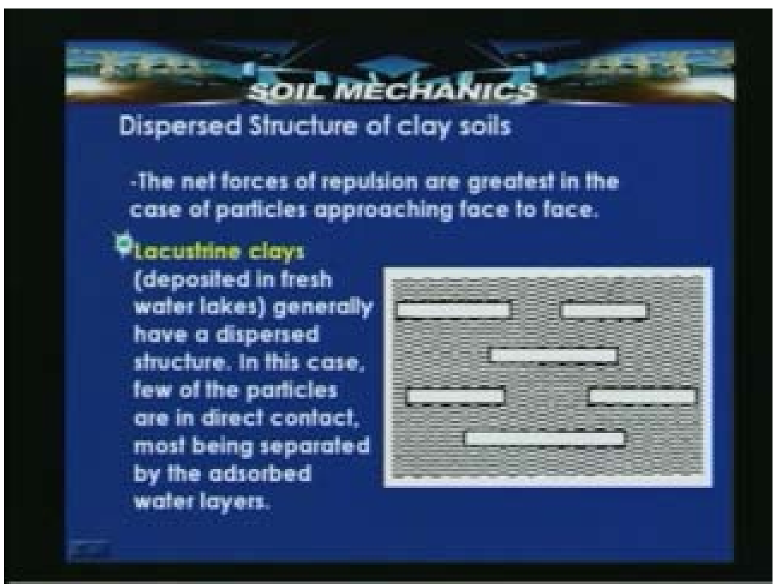

Let us look into these two structures which we defined from the influence of their particle forces and their behavior. One we said that the dispersed structure. So the dispersed structure of clay soils, the net forces of repulsion are greatest in the case of particles approaching face to face. So the particles can come here as shown here face to face in the soil water. Because of the low ion concentration and thick adsorbed water layer, the net will be repulsion. This type of deposit is possible for lacustrine clays that is deposited in fresh water lakes, generally have a dispersed structure.

In this case, few of the particles are in direct contact, most being separated by the adsorbed water layers. So a dispersed structure can be there in lacustrine clays that deposited in fresh water lakes, generally have a dispersed structure. In this case few of the particles are in contact and most being separated by the adsorbed water layers.

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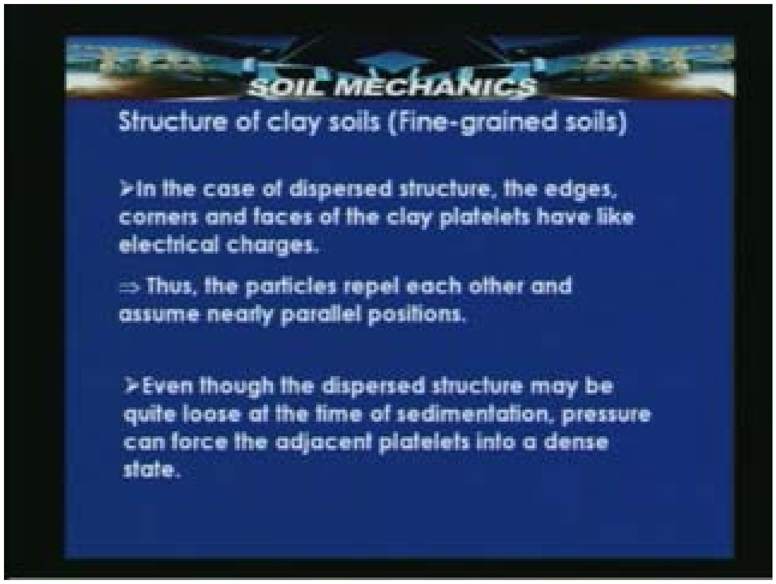

In the case of dispersed structure the edges, corners and faces of the clay particles have light electrical charges and because of these the particles repel with each other and remain in nearly parallel positions. So, parallel arrangement with face to face repulsion will be there in the dispersed structure. So even though the dispersed structure may look quite loose at the time of sedimentation pressure can force with the help of an external force which may be possible with the loading and that can force the adjacent particles into a dense state.

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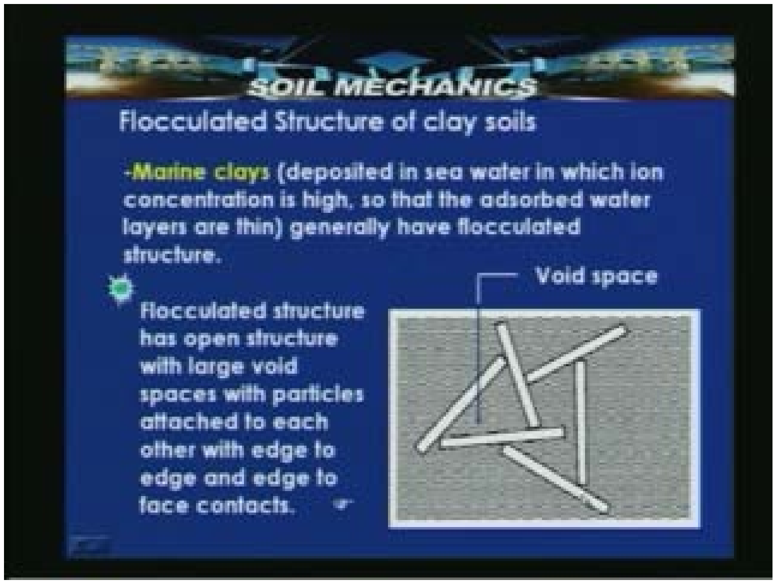

Now we are going to see Flocculated structure of clays. It generally occurs in marine clays deposited in sea water in which ion concentration is high so that the adsorbed water layer is thin and they generally have a flocculated structure. Marine clays in the coastal sides have flocculent structure. Flocculated structures have open structure like this, either edge to face interaction or face to edge interaction that can be seen between different particles and they form a open mesh structure with large void spaces. So here the edge of this particle is attached to the face of this particle.

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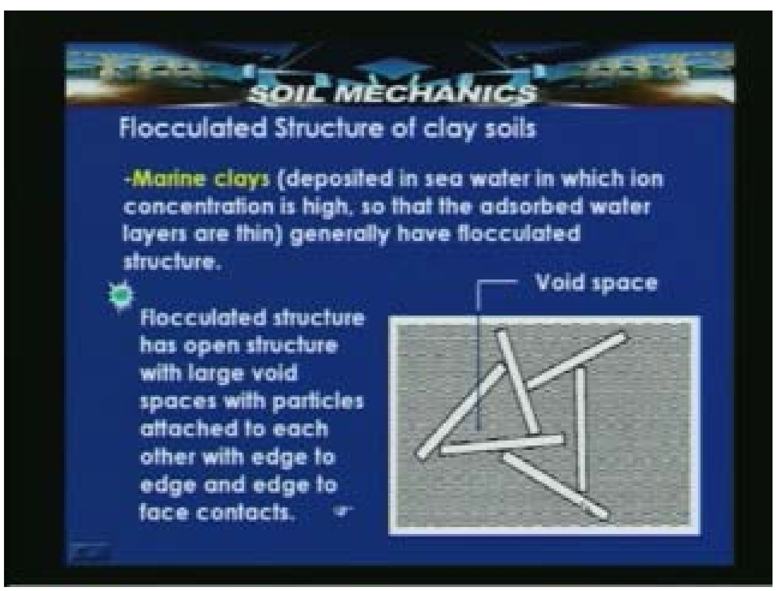

In the case of flocculated structure the particles assume a loose but fairly stable structure. That can be maintained as long as the electrical charges on the edges of the platelets remain opposite in sign to those on the faces of the particles. So the degree of looseness of a flocculated arrangement is a function of nature and amount of electrolytes present during sedimentation.

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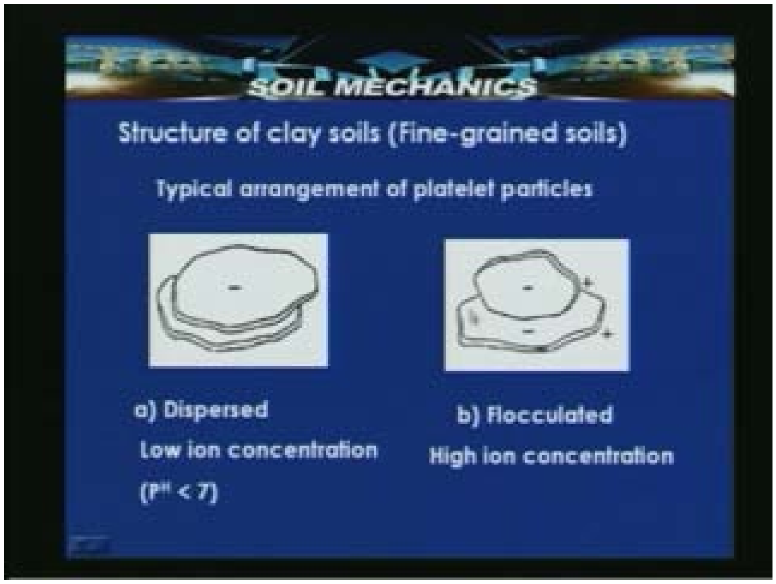

Here a typical arrangement of the platelet particle is shown. Here a typical plate shaped particle is shown as dispersed arrangement in the low ion concentration where the medium is predominantly acidic medium which can yield to a dispersed state. For practical significance this can be there in quite lakes or lacustrine place. Another arrangement is a flocculated arrangement which can be there for marine clays with high ion concentration where you can see edge to face attachment can yield to an open mesh flocculated arrangement.

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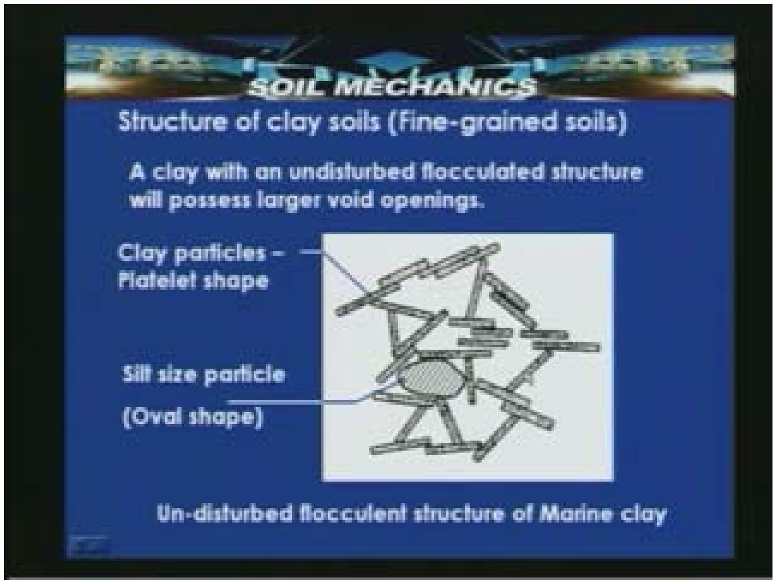

Here a structure of undisturbed flocculent structure of the marine clay is shown here. This particle represents the silt size particle with oval shape and they also get formed and attached to with these clay particles with platelet shape. The clay particles are represented by a platelet shapes which is shown here. Clay with an undisturbed flocculated structure will possess large void openings. So the soil formed with flocculated structure has larger void openings.

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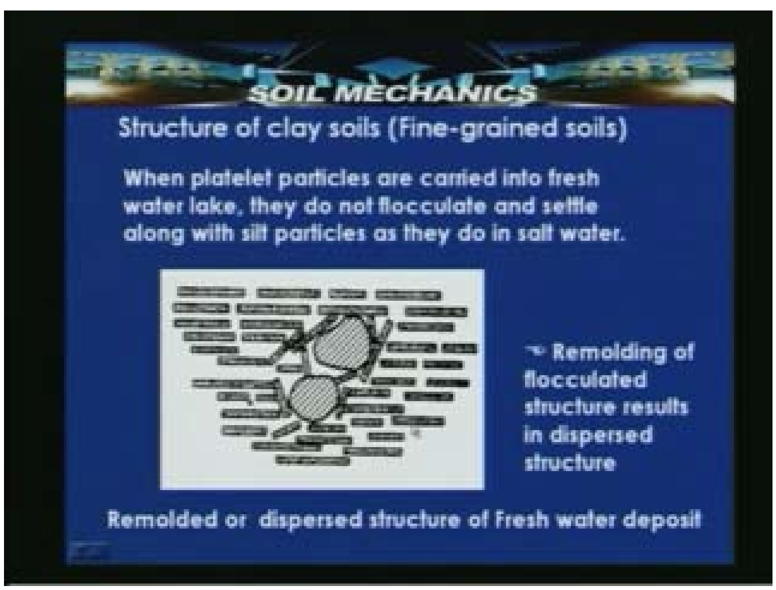

When platelet particles are carried into fresh water lake, they do not flocculate and settle along with the silt particles as they do in the salt water. So here a remolded or dispersed structure of the fresh water deposit can be seen with parallel arrangement of the clay particles in between the silt particles are shown here. So if you remold any soil with flocculated structure that results into a dispersed structure. Here, this also represents remolded of the dispersed structure of fresh water deposits.

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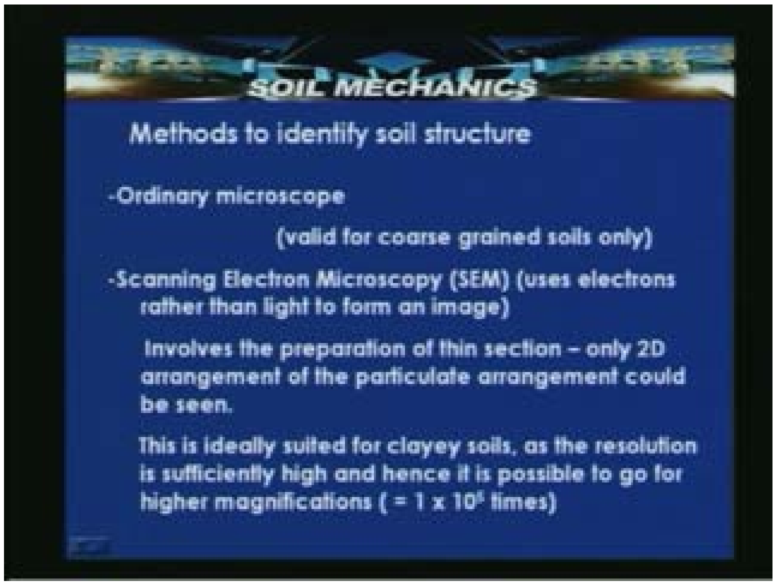

We have seen different particle arrangements as we said that single-grained arrangement can be there for Bulky particles. Honeycomb structure can be possible for silt particles predominantly. While coming to the clays representing fine-grained soils can have flocculent structure or dispersed structure. It depends upon the environment in which the suspension is occurring. Then the question will come, how to identify the soil structure. The one of the methods for coarse-grained soils is to use ordinary microscope which is valid for coarse-grained soils only.

For particle arrangement in case of a clayey soils, scanning electron microscopy (SEM) method is widely used. In this scanning electron microscopy, it uses electrons rather than light to form an image. It involves the preparation of thin section and allows us to look at the 2D arrangement of the particulate arrangement only. So this is idealized ideally suited for clayey soils, as the resolution is sufficiently high and hence it is possible to go for higher magnification. One can go up to 10 power 5 magnifications. Scanning electron microscopy is used for obtaining the 2D arrangement of the clay soils. Let us discuss the procedure about scanning electron microscopy.

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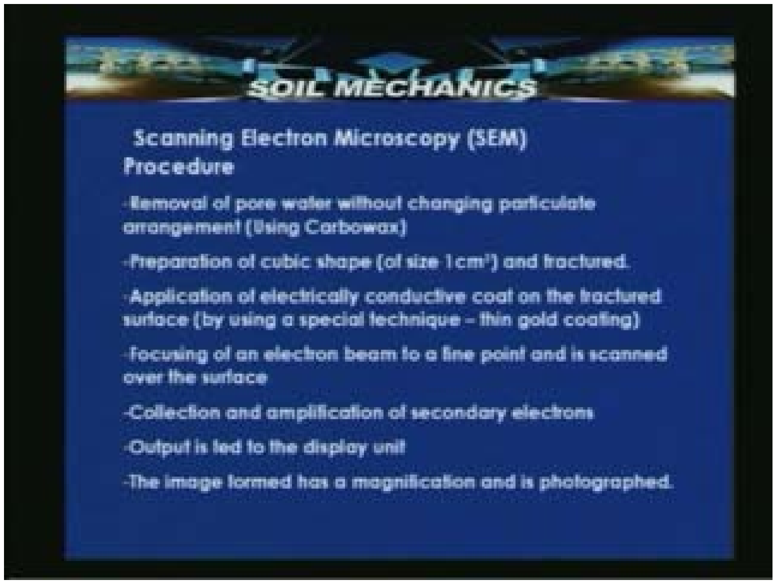

It involves sample preparation. First is that removal of pore water without changing the particular arrangement generally carbowax is used. The preparation of the cubic shape of size 1cm cube and fractured. Then application of electrically conductive coat on fractured surface by using a special technique, generally in this thin gold coating is applied with sputter coat. The focusing of an electrical electron beam to a fine point and is scanned over the surface. Then the collection and amplification of the secondary electrons in an electrical gun electron gun and the output is fed from the electron gun to the display unit. The image formed has a magnification and is photographed.

So the procedure for obtaining the particulate arrangement through scanning electron microscopy involves removal of the pore water without changing the particulate arrangement, generally the carbowax is used which melts at 55 degree centigrade. The preparation of the cubic shape of size approximately 1cm cube and it is required to be fractured.

The application of the electrically conductive coat on the fractured surface by using a special technique, generally thin gold coating is given and focusing of electron beam to a fine point and is scanned over the surface. After that the collection and amplification of the secondary electrons in the electron gun and their output is fed from the gun to the display unit which gives the image has a magnification, is photographed to know about the particulate arrangement of clay soils with the help of the scanning electron microscopy method. In this lecture, we have seen about the particulate arrangement in coarse-grained soils and fine-grained soils.

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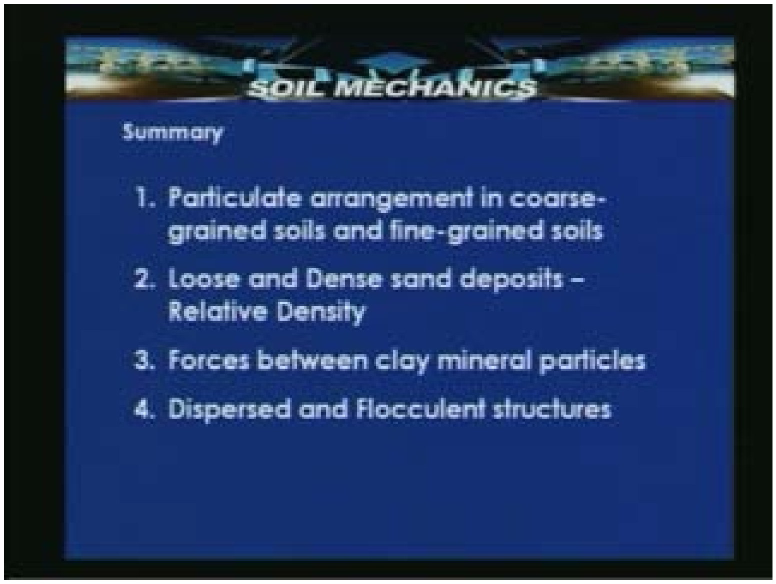

We said that different types can be possible as per the classification of the Terzaghi and Casagrande: Single-grained, Honeycomb and flocculated or dispersed and we also discussed about loose and dense sand deposits which are possible and an important parameter called relative density for coarse-grained soils have been defined. We also deduced the reasons for different arrangements for dispersed flocculent structures and the forces between the clay minerals with Van der Waals forces of attraction and repulsion forces between two adsorbed water layers which may determine the forces between the clay particles have been discussed which yield to dispersed and flocculent structures.