Soil Mechanics
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Lecture - 6

In the previous class, we have studied about Particulate arrangement in coarse-grained and fine-grained soils, about loose and dense matrix of sand deposits, forces between the clay mineral particles and their structural arrangement.

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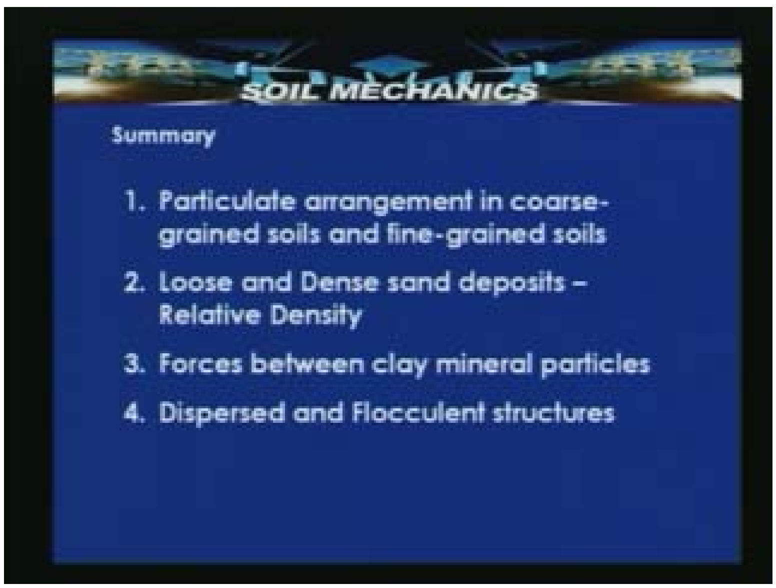

In this lecture, we will be learning about the index properties and soil classification systems. Basically we will try to the get index properties of both coarse-grained soils and fine-grained soils in order to classify the soil or to group the soil. These Index properties refers to those properties of the soil that indicate the type and condition of the soil, and provide a relationship to structural properties such as the strength and the compressibility or tendency for swelling that is increase in volume or permeability that is the ability to drain the water.

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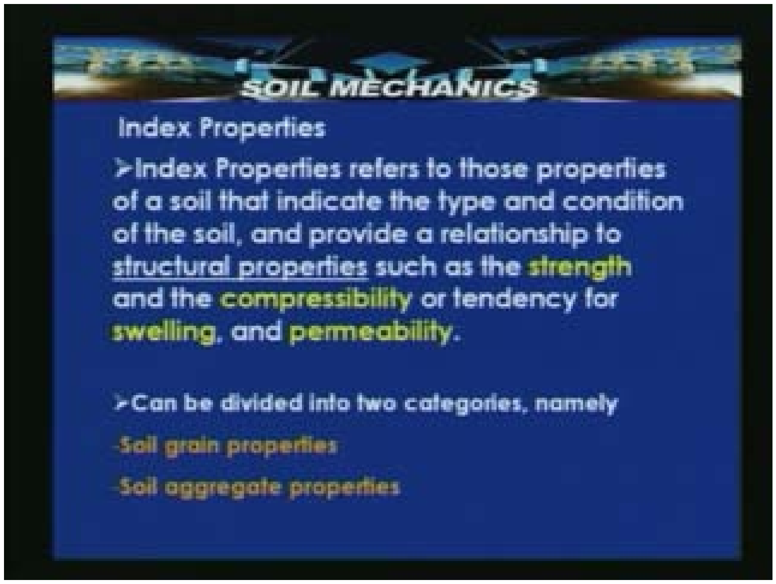

Basically these soil index properties can be divided into two categories, they are: soil grain properties and soil aggregate properties. The development of the ability to think of soils in terms of numerical values of their index properties should be one of the foremost aims of every engineer who deals with Soil Mechanics.

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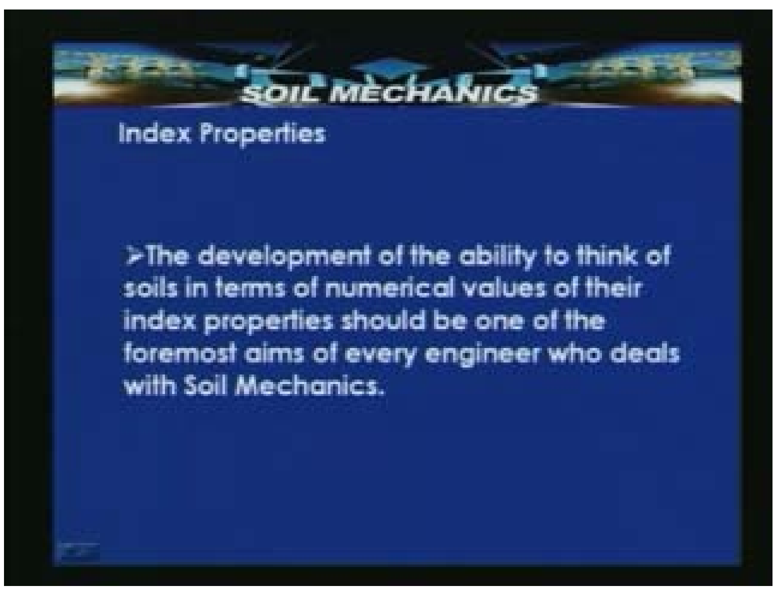

Now let us look into the type of the properties which come under soil grain properties. The soil grain properties are the properties of the individual particles of which the soil is composed, without reference to the manner in which these particles are arranged in a soil mass. For example, Mineralogical composition, Specific gravity of solids, Size and Shape of Grains form the example of soil grain properties.

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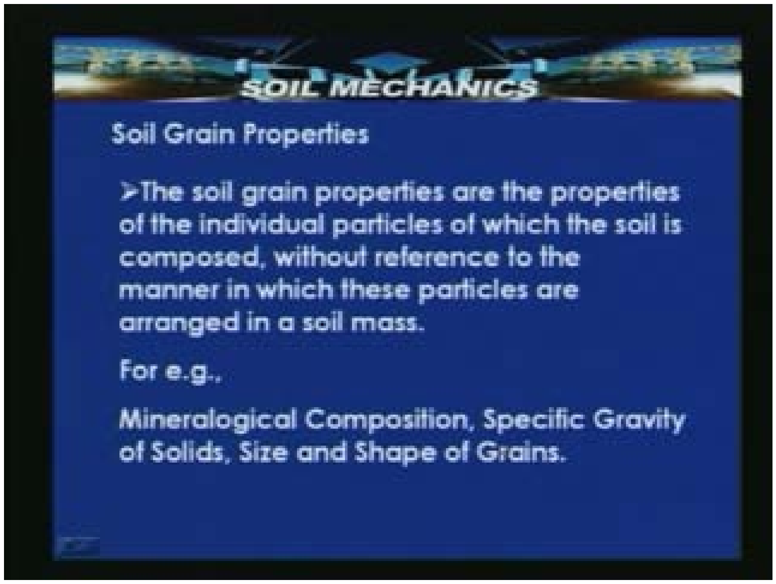

Coming to the soil aggregate properties; in this slide, we will try to understand about the soil aggregate properties. The soil aggregate properties are the properties which are dependent on the soil mass as a whole and thus represent the collective behavior of soil. Soil aggregate properties are a function of stress history, mode of soil formation and the soil structure. That is, arrangement of the soil particles, mode of soil formation and the stress history that is the type of the stresses to which the soil is being subjected. Here, soil aggregate properties aggregate refers to the soil itself. It may differ in Porosity, Relative Density, Water and Air content and Consistency.

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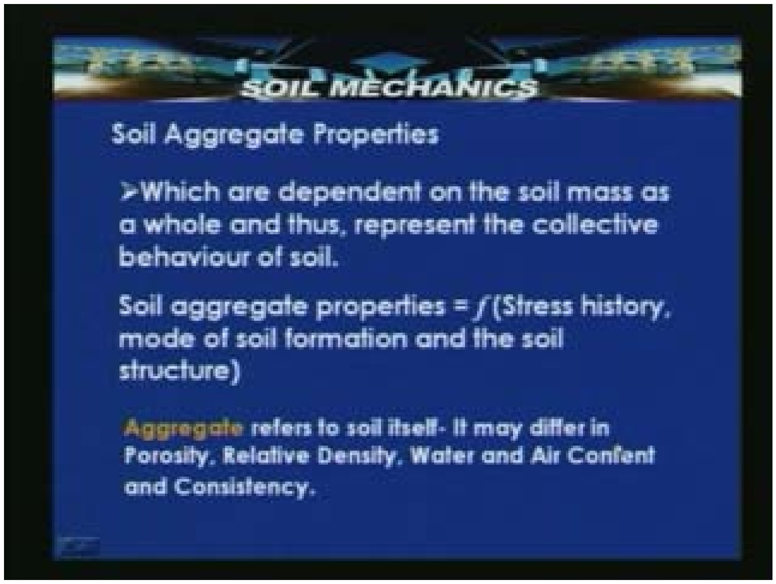

Soil aggregate properties basically depend on the soil mass as a whole and thus represent the collective behavior of the soil. Basically it is the function of a stress history, mode of soil formation and soil particular arrangement. Out of soil grain properties and soil aggregate properties, soil grain properties are widely used. Although soil grain properties are commonly used for identification purposes, the engineer should realize that the soil aggregate properties have a greater influence on the engineering behavior of a soil, because most of the engineering structures are founded on the natural deposits or undisturbed soil mass.

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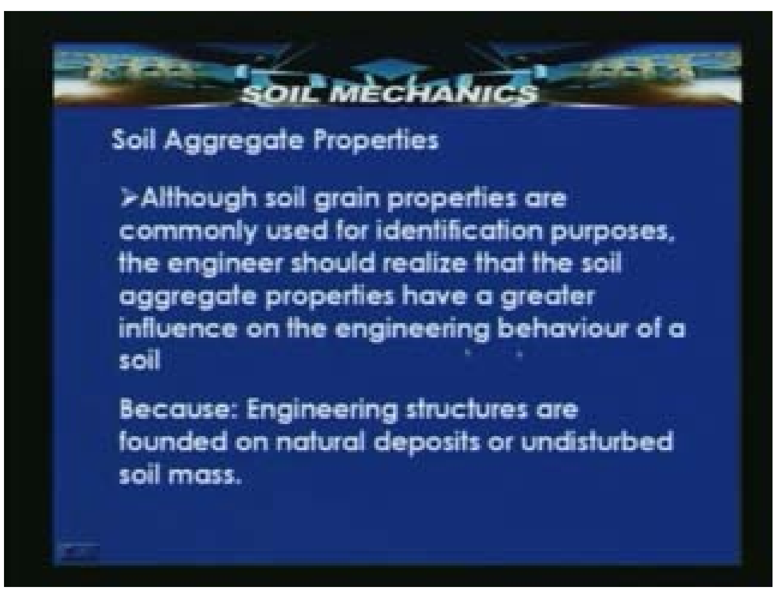

In this slide, we will look at the different types of index properties. They are basically divided into two major categories one is Grain Size Distribution and consistency limits. Under Grain Size Distribution there is a mechanical analysis and hydrometer analysis depending upon the size of the grains of soil. Under mechanical analysis, another category is subdivided into a dry method of analysis and wet method of analysis. Hydrometer analysis is generally used for fine-grained soils. Mechanical analysis which is also known as sieve analysis is used for determining the gradation of coarse-grained soil particles.

The second part is that, basically these consistency limits are meant for fine-grained soils. Basically we tend to determine various physical states of soil with water like liquid limit, plastic limit, plasticity index and shrinkage limit, these are basically for fine-grained soils. Once we have these index properties in terms of numerical values, it will be possible for us to classify the soils or group them with identical index properties. In this lecture what we will be looking is, to understand the Grain Size Distribution and what are the different methods available for determining the gradation of coarse-grained particles as well as fine-grained particles.

In the next lecture under part two, we will be seeing the index properties of fine-grained soils and will try to classify the soil based on the index properties that are obtained from the Grain Size Distribution of the soil as well as from the consistency limits.

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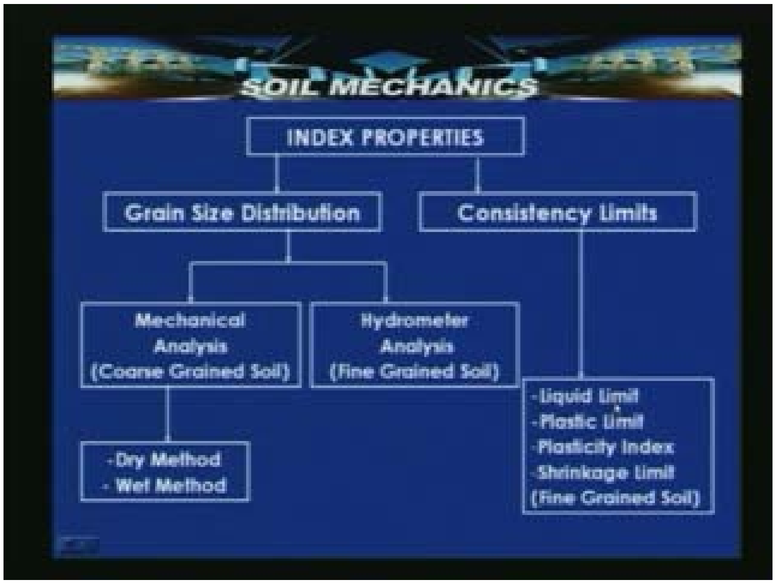

Let us look into the Grain Size Distribution. In soil mechanics it is virtually always useful to quantify the size of the grains in a type of soil. Since a given soil will often be made up of grains of many different sizes and sizes are measured in terms of Grain Size Distributions. GSD that is Grain Size Distribution assists in providing rough estimate of the soil engineering properties. If we know the GSD then we will be able to guess the rough engineering properties of soil.

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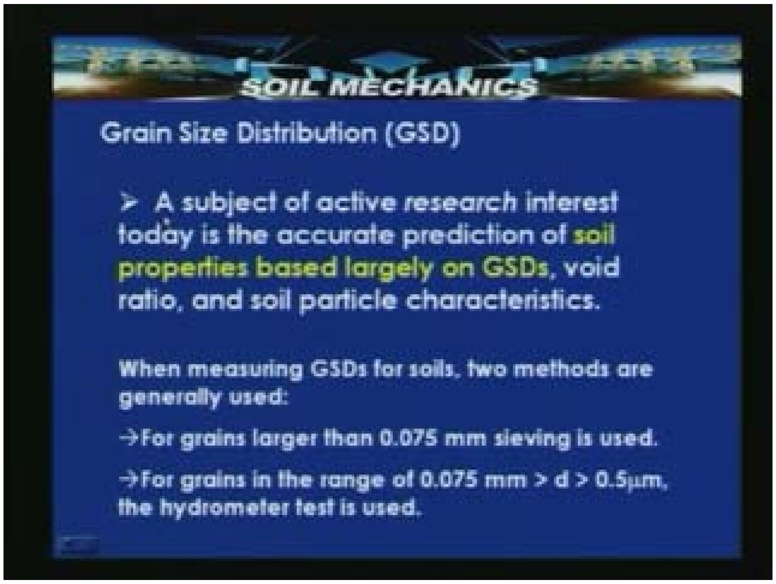

Here if you look into this, now-a-days a subject of active research interest today is the accurate prediction of soil properties based on Grain Size Distributions, void ratio and soil particle characteristics. Now an active research is going on in the arena of Soil Mechanics, today accurate prediction of soil properties is carried out based largely on the GSDs (Grain Size Distribution curves). When measuring the Grain Size Distributions for soils two methods are generally used. For grains larger than 75 microns or 0.075 mm, sieving analysis or mechanical analysis is used. For grains in the range of 0.075 mm to finer than 0.5 micrometer that is for grains less than 0.075 mm the hydrometer analysis which is based on the sedimentation analysis is used. For grains larger than 75 microns, sieve analysis is used. For grains in the range of 75 micron to 5 micron the hydrometer analysis is used. For grains less than 75 micron hydrometer analysis is used.

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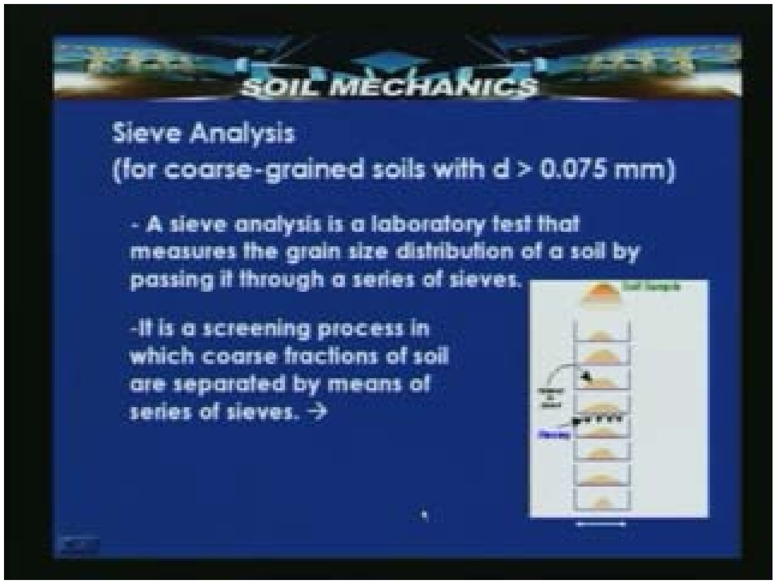

Let us look into the procedure of the sieve analysis which is basically used for coarse-grained soils that is the particle greater than 75 micron or 0.075 mm. A sieve analysis is a laboratory test that measures the Grain Size Distribution of the soil passing through a series of sieves.

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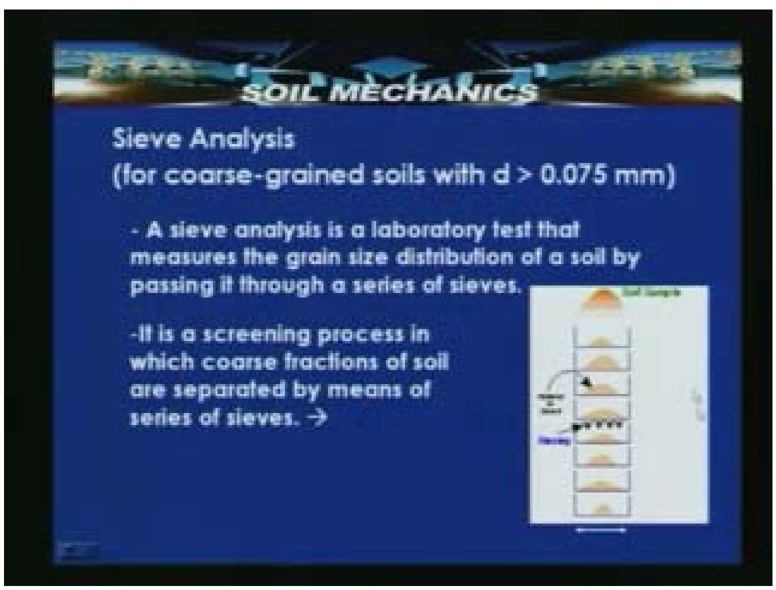

It is nothing but a stack of different sizes where this can be a sieve of size of 4.75 mm, this can be a sieve of size of 75 micron, this can be a sieve of 19 mm and this can be a sieve of 75 micron. Once the soil mass of known weight is placed on the sieves and when it is subjected for shaking in the horizontal direction like this as shown here then the amount of the soil particles which are retained in each sieve indicates that the particles larger than the particular size are retained in that particular sieve. So each sieve has got different sizes representing the equivalent diameters of the particles. It is a screening process in which coarse fractions of soil are separated by means of series of sieves. Here you can see, this particular portion of the soil is actually passed through these two sieves and collected here. This is the portion of the soil which is passing through this particular sieve which is above this. Thus it indicates that the particles which are passing through this sieve are finer than the sieves sizes which are lying above. With this method what we do is that we segregate the soil into different compositions of equivalent diameter of particles to determine the Grain Size Distribution.

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In this slide what we look at is that the different sieves of sizes are given. This is i is equal to 1 indicates a 3 inch sieve and i is equal to 2 indicates 1 5 inch sieve. This indicates that 3 inch is a sieve or a square mesh size. Up to a large number of sieves that is up to 4.75 mm the sieve number is indicated by the size of the mesh itself. We can see here that 0.375 inches is the sieve number and the particle diameter equivalent also is 0.375 inches, this is in the range of the gravels. From 4.75 mm onwards to 75 micron size the sieve numbers are categorized like 4, 6, 20 100 and 200. Number 200 indicates the sieve number for soil with 75 micron particle size. Larger sieves are indicated by the opening sizes.

For example here, number 8 sieve indicates that number of holes per inch are 8 which means that the number of 64 holes will be there in a square inch. So, size of the hole or a size of the mesh will be less than 1 by 8th of the inch because the width of the wire will be coming into the picture. So here in sieve analysis what you have seen is that a stack of sieves with varying number of sizes to segregate the particles ranging from 3 inch to 0.053mm size. With this what will happen is that we will be able to segregate gravels, sands and fines which includes silt and clays. In this slide what we are seeing is a mesh with opening size which is indicated by a sieve size which gives particle size of d which represents the equivalent diameter. Basically the soil particle cannot be of a regular shape it can be of any shape but finally it gives which is in terms of the equivalent mesh size of the sieve.

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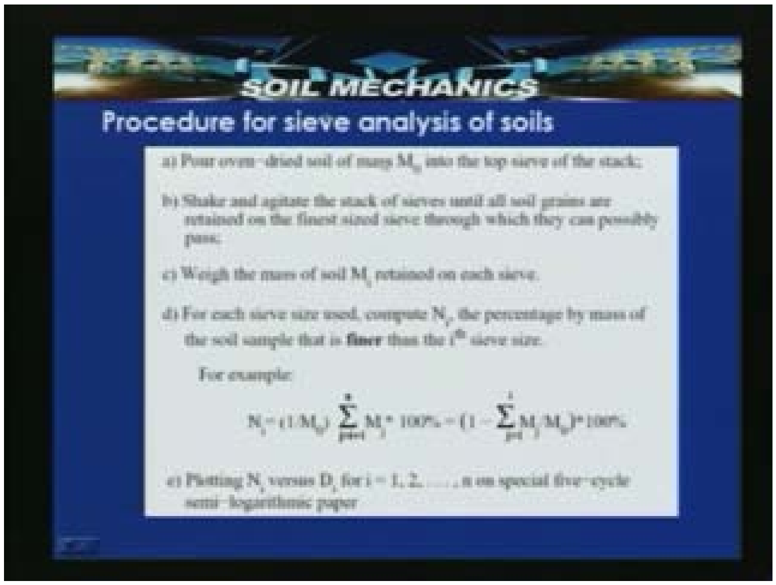

The procedure involved for the sieve analysis of soils is, we have to take the oven-dried soil mass M_0 in the top sieve then shake and agitate the stack of the sieves until the soil grains are retained on the finest size sieve through which they can possibly pass. So weight of the mass of the soil M_i retained on each sieve has to be determined. For each sieve size used, compute Ni (percentage finer), the percentage by mass of the soil sample that is finer than the i^{th} sieve size. For example, N_i is equal to 1 by M_0) sigma (M_j into100 percent) is equal to [(1minus sigma (M_j by M_0)) into 100 percent]. Here sigma ranges from j is equal to (i plus 1) to n or 1 to n.

Once we get this percentage finer, when you plot with the particle size on the semi logarithmic paper, then we will get the Grain Size Distribution curve. The procedure involves; taking a dry mass of soil and place in a sieve shaker and subjected to shaking for about 10 minutes, so that the particles are agitated and separated into number of sieves, then collect the mass of the soil which is retained in each sieve. Once we get the weight of the mass of soil which is retained in each sieve and determine the percentage finer, plot this percentage finer on the y axis with the grain size or the particle size on the x axis on the logarithmic scale to get a Grain Size Distribution curve.

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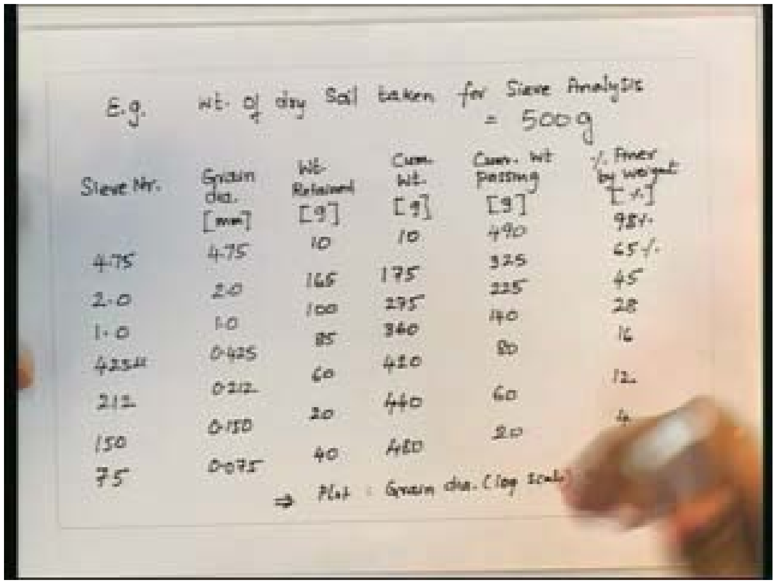

For example, let us assume that we have taken a dry soil of 500g in weight. Let us assume that we are having sieves like 4.75 micron, 2mm 1mm and 425 micron, 212 micron, 150 micron and 75 micron. Let us assume the grain diameters are equivalent to the sieve numbers here that is in the form of 4.75mm, 2mm and 1mm up to 1mm sieve, then 425 micron sieve that is 0.425mm, 212 represents grain diameter of 0.212mm and 150 is 0.15mm and 75 micron is 0.075mm.

Once after subjected to shaking, let us say that these are the weights which are retained in each sieve. For example, 4.75mm sieve, the soil retained is 10g out of 500g. It indicates that 490g weight of the soil is passed through this particular sieve. Similarly, determine the weight of the soil retained in the sieve number 2 and determine through all the sieves. So the next step is that, determine the cumulative weight. So once we get the cumulative weight we can find out cumulative weight of the passing. That is nothing but the total weight of soil mass taken in the analysis is taken as 500g so 500 minus 10 that is, the cumulative weight is 490g so 500 minus 175 is equal to 325. Similarly, 500 minus 440 is equal to 60g, 500 minus 480 is equal to 20g.

Now we determine the percentage finer which is nothing but the cumulative weight of the passing to the original weight of the soil that is 500g into100 which gives us 98 percent, 65 percent and 45 percent, 28 percent and 16 percent, 12 percent and 4 percent. This indicates that 98 percent of the particles are finer than this 4.75mm size. That means only 2 percent of the particles are coarser than this particular size. Once we get the percentage finer and grain diameter we can get the Grain Size Distribution curve. Once we have this distribution then we can determine the gradation like this.

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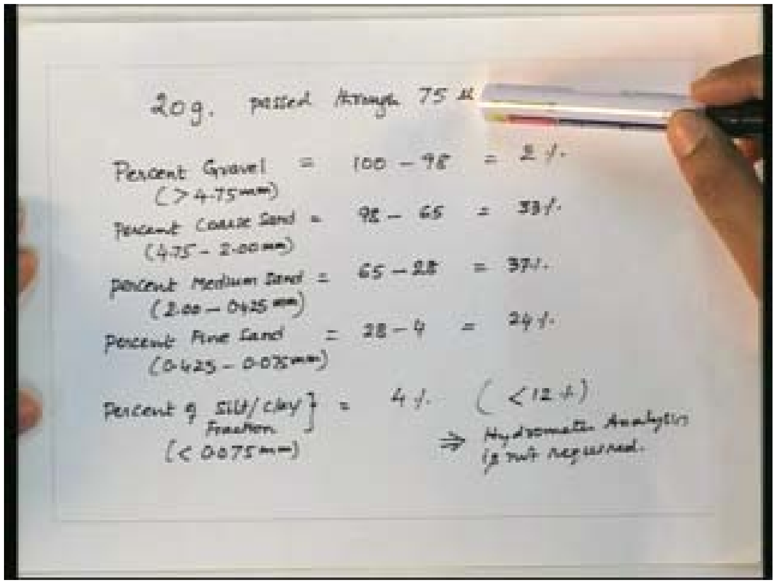

We have seen in the previous example that only the 20g of the soil which passes through 75 micron sieve. So this gives us the percentage gravel in a soil matrix which is greater than 4.75mm is equal to 100 minus 98 is equal to 2 percent. That is 2 percent of the soil mass represents the gravel size particles. Percentage coarse sand again is in the range of 475 to 2mm represents 33 percent. Percentage medium sand represents 2 to 0.425mm represents 65 minus 28 is equal to 37 percent. Percentage fine sand represents 28 minus 4 is equal to 24 percent. Percentage silt clay fraction passing through 75 micron sieve is 4 percent, that we have only registered about 20g.

Suppose if the percentage of the silt and clay fraction passing through 75 micron is less than the 12 percent then the hydrometer analysis or wet mechanical method of analysis is not required, that is the sedimentation analysis is not required, but if the percentage of the silt fraction is greater than 12 percent, then it is required for us to determine the fine grain fraction size to assess the percentage of the clay particles and percent of the silt particles which can be determined by hydrometer analysis. So what we studied is to segregate the soil particles and get percentage gravel, percentage sand and percentage clay. Once the fines percentage is found to be less than 12 percent, then we said that the hydrometer analysis or further the fine grain analysis is not required. If it is found to be more than 12 then we are required to do the fine grain analysis which is generally based on the sedimentation analysis that is carried out.

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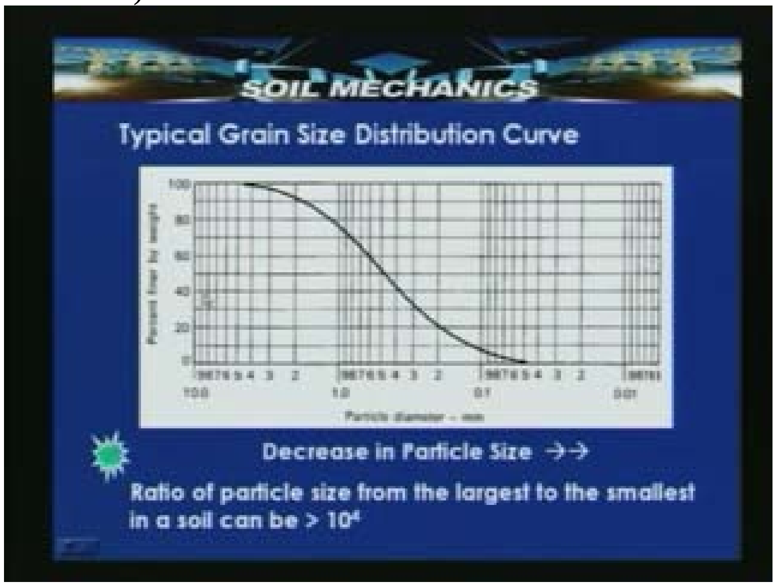

Based on the previous discussion if you look, we can plot the typical Grain Size Distribution curve like this, percentage finer by weight on the y axis and particle diameter or the grain diameter on the logarithmic scale. Here we can see, the particles can vary from 10mm or greater than 10mm up to 0.01or less than 0.01mm. All these particles can be represented on a semi logarithmic curve like this. You know the decrease in particle size can be seen in this direction from left to right. The ratio of particle size distribution from the largest to smallest in the soil can be greater than 10 to the power 4 times, that is the smallest to largest particle can have in the range greater than 10 to the power 4 times that is somewhere around 10,000 times.

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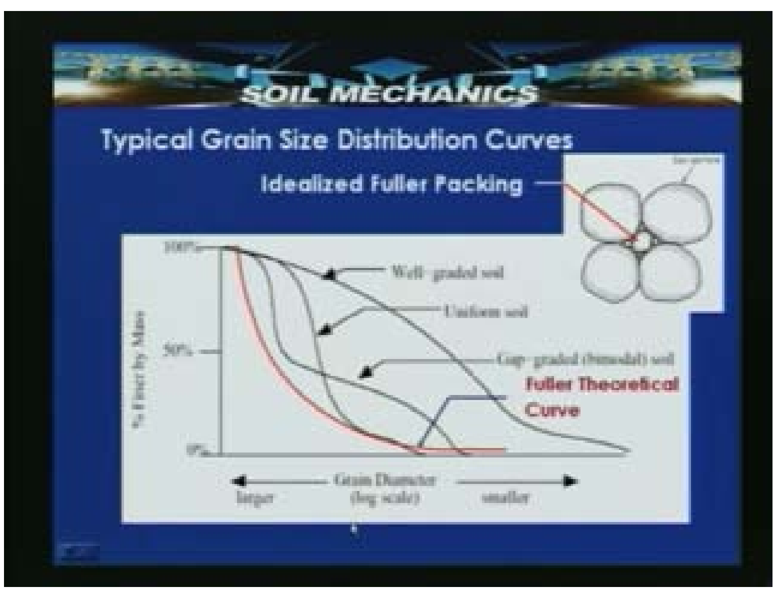

Now, let us look into typical Grain Size Distribution curves. If you look into a typical Grain Size Distribution curves we see that the percentage finer by mass is represented on the y axis and the grain diameter is represented on the x axis, here you can see the larger particles and here you see the smaller particles.

Different curves are represented which indicate different types soils with different compositions of the grains. This curve which is extending from left hand side to right hand side is named as well graded soil. This curve represents uniformly graded soil. Uniformly graded soil or a purely graded soil is nothing but the soil that is supposed to have uniform size particles. Suppose in a curve if you get a kink here, something like this, they will be uniformly graded to some extent and then there will be an absence of some certain particles. This type of curve is called gap graded or bimodal soil. The soil can be well graded or it can be uniformly graded. This is an example for the desert soils where the soil grain particles are uniform in nature.

Suppose if you have got larger particles and the voids are filled with smaller particles of different sizes then we say that this is an idealized filler packing where soil particles shown here is filled with the voids and in between the soil particles are filled with grains of different sizes. This actually indicates idealized filler packing. Suppose if we have this type of filler packing existing in the nature then the Grain Size Distribution will be something like this, so this is called a filler theoretical curve. So, what we have seen is that different types of soil combinations can be possible, like it can be well graded or uniformly graded or gap graded. So having seen the sieve analysis for particles coarser than 75 micron let us look into the procedure for fine-grained particle analysis that is particles passing 75 micron.

We said that this analysis is required to be carried out if the percentage of the particles is more than 12 percent. That is the finer particles present in fines are more than 12 percent then we are required to do this particular analysis. This analysis is called sedimentation analysis. It is assumed that, as a first approximation, that fine-grained soil particle can be idealized as small spheres. All the particles are idealized as small spheres.

We knew that most of the fine-grained soil particles exceptionally leaving the silt particles and clay particles are all plate shaped particles. In the sense the plate shaped particles may be far from the spherical particles. There is one limitation in this particular method, but we will be discussing in detail in the due course of this lecture. As a first approximation, we assume that all fine-grained soil particles are idealized by small spheres.

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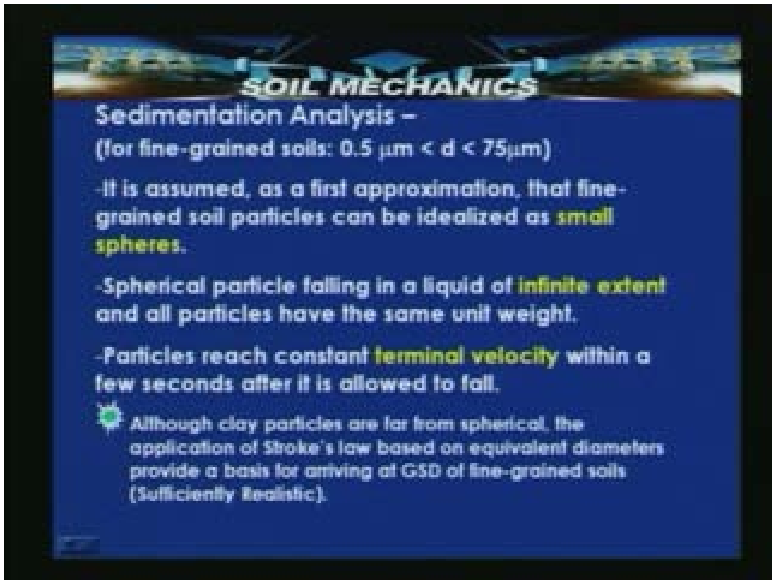

Spherical particle falling in a liquid of infinite extent and all particles have the same unit weight. Here we are assuming that the spherical particle falling in a liquid of infinite extent and all particles have the same unit weight. We are also assuming that the particles reach constant terminal velocity within a few seconds after it is allowed to fall. That means particles reach the constant terminal velocity within a few seconds after it is allowed to fall. We are saying, although the clay particles are far from spherical, basically the sedimentation also is carried out by using Stroke's law. Stroke's law is based on equivalent diameters that provide a basis for arriving at the Grain Size Distribution of the fine-grained soils. This is a sufficiently realistic assumption to arrive at the fine-grained soil percentage. Let us look into what this sedimentation analysis procedure involves, the theory behind sedimentation analysis. As I said earlier, this particular sedimentation analysis is after Sir George Strokes, 1891.

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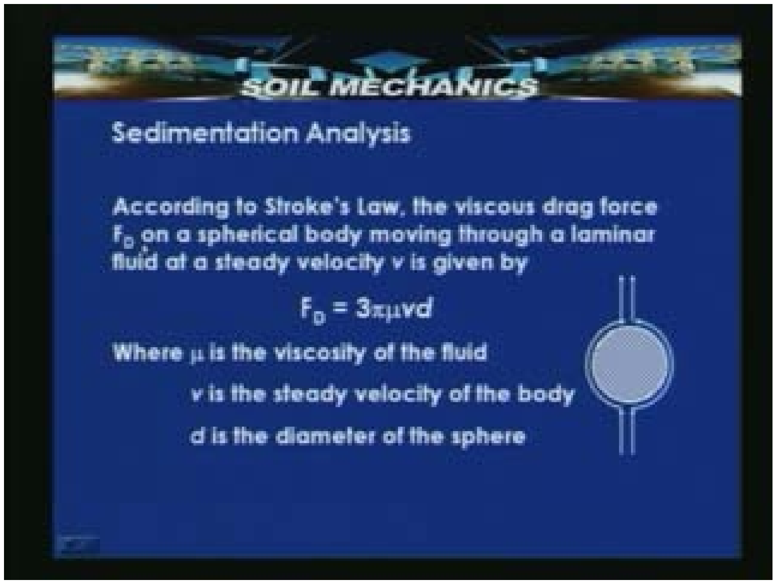

According to Stroke's law, the viscous drag force F_D on a spherical body moving through a laminar fluid at a steady state velocity v is given by: F_D is equal to 3 into pi into mu into v into d. That is, suppose if we have got an idealized spherical particles that is equivalent spherical particles, the drag force surrounding the particle when it is settling in laminar fluid is given by: F_D is equal to 3 into pi into mu into v into d, where mu is the viscosity of the fluid, v is the steady velocity of the body and d is the diameter of the sphere.

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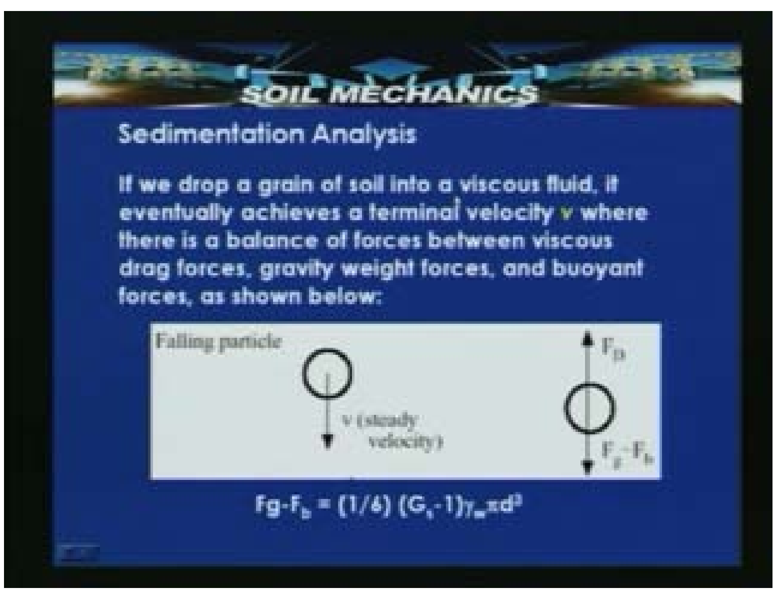

Once we get the drag force on the soil particle, let us see if you drop a grain of soil into a viscous fluid it eventually achieves a terminal velocity v where there is a balance of forces between the viscous drag forces and gravity weight forces. The gravity weight forces in a sense are in fluid Medium and the buoyant weight forces will come into the picture. Suppose if you consider a falling particle with steady velocity v it has got the forces where one force is the drag force which is acting upwards and the buoyant force which is the difference of the gravity weight force of the particle minus the buoyant weight so the net force which acting is (F_g minus F_b).

Thus, the buoyant weight can be determined as: The buoyant weight, (F_g minus F_b) is equal to (1 by 6) into (G_s minus 1) into (gamma w)(pi)d cube where d is the diameter of the equivalent sphere, G_s is the specific gravity of the particle under consideration, gamma w is the unit weight of water. So (F_g minus F_b) is given by is equal to (1 by 6) into (G_s minus 1) into (gamma w)(pi)d cube. Now from this we have got, considering the equilibrium of the particle between the forces, F_d which is acting upwards and net force which is the difference of the gravity force due to the buoyant nature in a laminar fluid medium. Once we take the vertical equilibrium we will be able to derive the Stroke's law. This law is used for determining the particle sizes of the fine-grained soil fraction.

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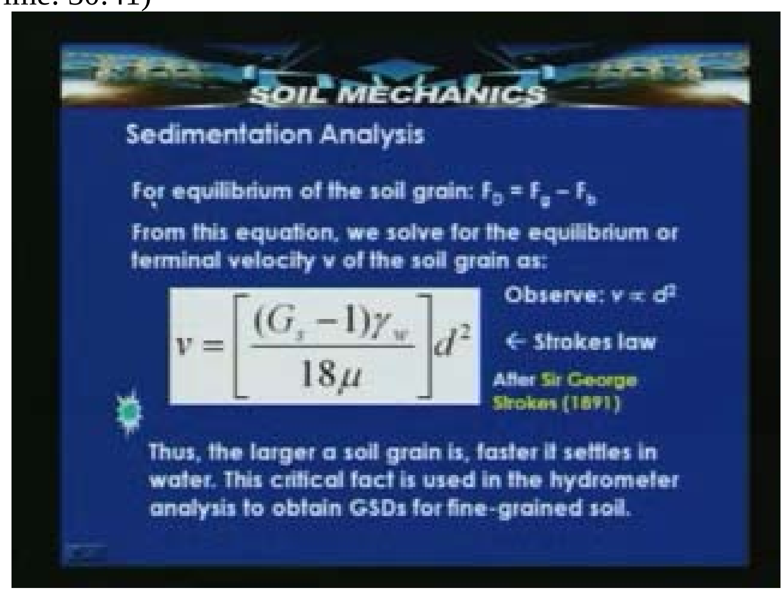

For equilibrium of the soil grain: F_D is equal to (F_g minus F_b), where F_D is the vertical drag force, (F_g minus F_b) is the net force which is acting downwards on the soil particle which is idealized by a sphere. From this equation, when we solve for equilibrium the terminal velocity of the soil grain is obtained as: v is equal to [((G_s minus 1)(gamma w)) by 18 into mu]d square, so v is proportional to d square. So this particular equation is named as Stroke's law and this is after Sir George Strokes (1891). So observe that v is proportional to square of the particle size. Thus, the larger a soil grain is the faster it settles in water. This critical fact is used in the hydrometer analysis which is used for determining the fine-grained soil fraction to obtain the Grain Size Distribution for fine-grained soils. Here what we derived is that by considering the equilibrium of the soil grain we have derived and established its Stroke's law which we said that v is equal to [((G_s minus 1) (gamma w)) by 18 into mu] d square. With this we said that v is proportional to d square, that means larger a soil grain is the faster it settles in water. This critical fact is used in the hydrometer analysis to obtain the Grain Size Distribution for fine-grained soils.

Now, let us look into the process of the sedimentation of the dispersed suspend. The theory of sedimentation is based on the fact that the large particle is suspense at liquid settles more quickly than the small particles. Just now we discussed that v is proportional to d square which indicates that the large particle tends to settle faster than smaller particles assuming that all particles have similar densities and shapes. If all particles are of a single size with effective diameter d by knowing the terminal velocity we can calculate the time for the dispersion t_d is equal to [18(mu) z by (G_s minus 1)(gamma w) d square]. This is actually obtained from the Stroke's law. The velocity which a falling particle reaches is known as the terminal velocity. That is why we have used the new terminology here, the velocity which a falling particle reaches is known as the terminal velocity.

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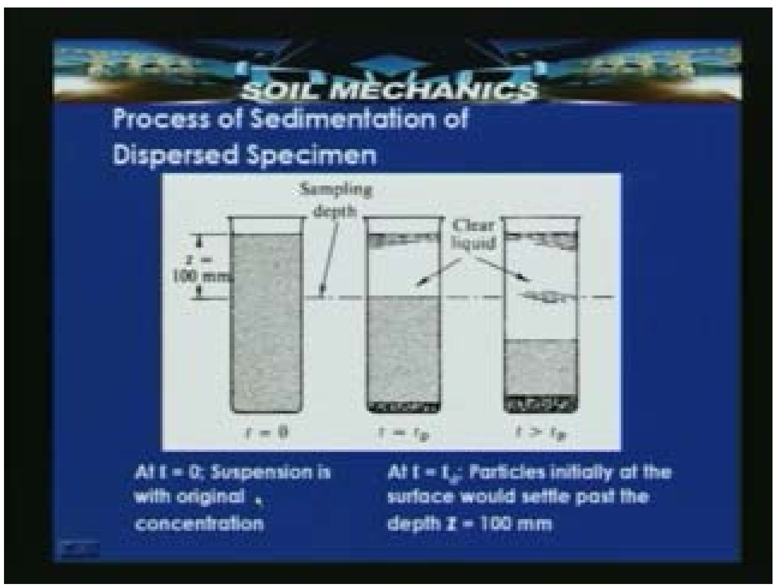

Let us consider here a jar having a soil suspension. That is, a fine-grained soil fraction is mixed with water. Let us assume that this is the suspension state at time t is equal to 0; the suspension is with original concentration. Basically in the fine-grained soil fraction first, before preparing the suspension it is required to treat the soil because there may be a possibility of having organic matter. So, to remove the organic matter it has to be treated with H_2O_2 to oxidize the organic matter and to create a dispersion of the soil particles because we are interested in determining the particle to particle or a grain to grain size. So to prevent conglomeration of soil particles and to separate them we use a dispersing agent. So that, once we treat a pretreated soil, that is mixed with a known amount of volume of water and made as suspension.

Once the suspension volume is known, time t is equal to 0 once it is left on the table or a laboratory desk then this is the state at this particular point. Let us assume that, z is equal to 100mm is the reference depth where we are trying to understand. After elapsing a time t is equal to t_d, then what is happening is that you see at the top the clear liquid is shown here and then below you see a soil suspension is still at original concentration and then some settled particles here. It indicates that the particles which are settled are already coarser in size, then the particles which are moving around here are finer in size and they take certain time to come for sedimentation.

After the time t greater than t_d, you see here the clear liquid range increases and deposition of the soil particles also increases. At time t is equal to t_d; the particles initially at the surface would settle past the depth z is equal to 100mm. At time t greater than t_d you see an increase in the soil particle deposition. This particular slide indicates the variation of the initial unit weight of the soil suspension. At a particular depth if you see soil suspension is undergoing a change in the unit weight. Suppose if you are able to determine this change in the unit weight of the soil particle then you will able to arrive at the gradation of the fine-grained soil suspension.

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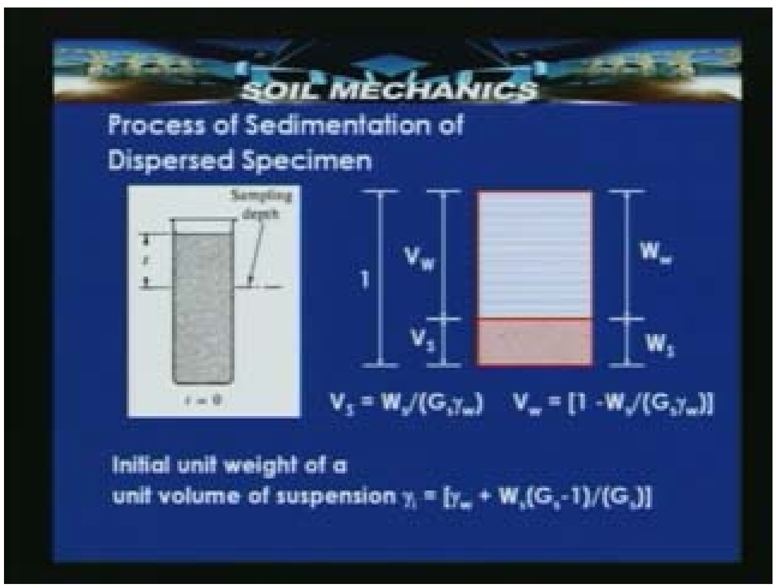

Let us consider a suspension with original concentration at time t is equal to 0. This can be represented as a phase diagram with weight of solids, weight of water, volume of water and volume of solids. The total volume is equal to (V_w plus V_s) is equal to 1. Weight of solids and weight of water is represented here. Volume of solids can be written as: V_s is equal to [W_s by G_s (gamma w)] and volume of water is equal to (1 minus V_s) and V_s we have written in terms of [W_s by G_s (gamma w)], where G_s is the specific gravity of the soil under consideration. So this equation is written like this: V_w is equal to [1 minus W_s by G_s (gamma w)]. Initial unit volume of a suspension is given by gamma i is equal to [(gamma w) plus W_s (G_s minus 1) by G_s]. If you see here, this term is actually changing the initial unit weight of the soil suspension which is more than the unit weight of the water. So initial unit volume of a soil suspension is given by: gamma I is equal to [(gamma w) plus W_s (G_s minus 1) by G_s].

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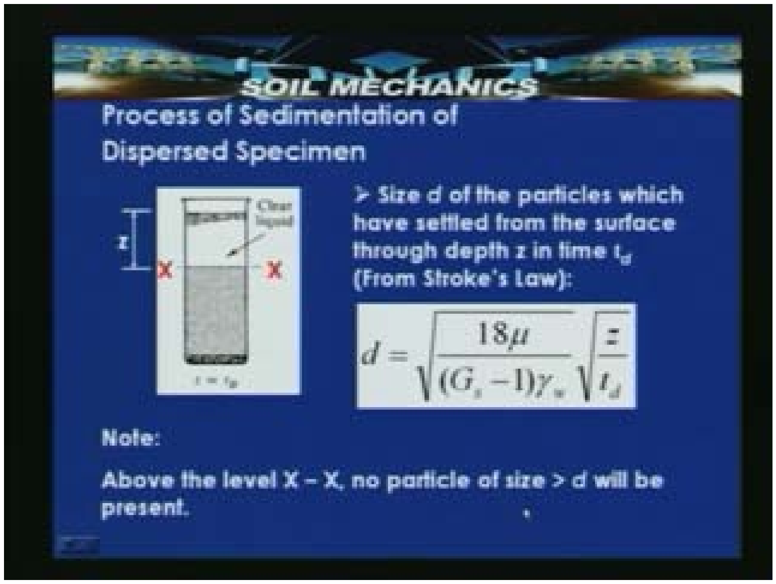

As the time elapses, let us assume that at time t is equal to t_d at level X - X that is at the depth z from the surface if you are interested in determining the particle size then that can be determine. Now, as shown here in this slide at level X - X which is the depth z units from the top surface the size d of the particles which have settled from the surface through the depth z in time t_d is given as: d is equal to [square root of (18mu by (G_s minus 1) into (gamma w)) into square root of (z by t_d)]. That is derived from the Strokes law. Here z is the depth at which we are measuring this and t_d is the time at which this we are measuring the particle size d. Here it indicates that above the level X minus X no particle of size greater than d will be present. That means all the particles which are coarser are already settled and then only the particles which are finer are below this level X minus X.

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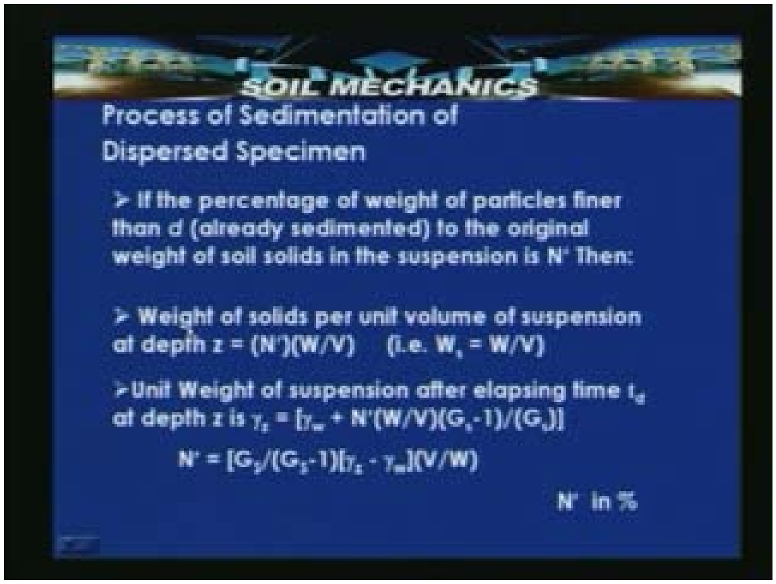

So, from the process of sedimentation of the dispersion, if the percentage of weight of the particles finer than d (already sedimented) to the original rate of the soil particles in the suspension is N dash, then we can determine the weight of the solids per unit volume of suspension at depth z as n dash into W by V. Here I have written n dash as W by V which is nothing but W_s is equal to W by V. W is now treated as a weight of the solids in a known volume of unit volume. So weight of the solids per unit volume of suspension at depth z is given by (N dash) into W by V) where W_s is equal to W by V.

Unit weight of suspension after elapsing time t_d can be determined at depth z is (gamma z) is equal to [(gamma w) plus N dash (W by V) into (G_s minus 1) by G_s)]. From this rearranging the terms we get the percentage finer N dash as [G_s by (G_s minus 1)] into [gamma z minus gamma w] into V by W so N dash is expressed in percentage. Therefore once by knowing (gamma z minus gamma w) we will able to determine the N dash that is the percentage finer. In order to arrive at this percentage finer two different methods are generally involved. One is pipette analysis and other one is the hydrometer analysis. Out of these we will be discussing hydrometer analysis method for determining the percentage finer N dash.

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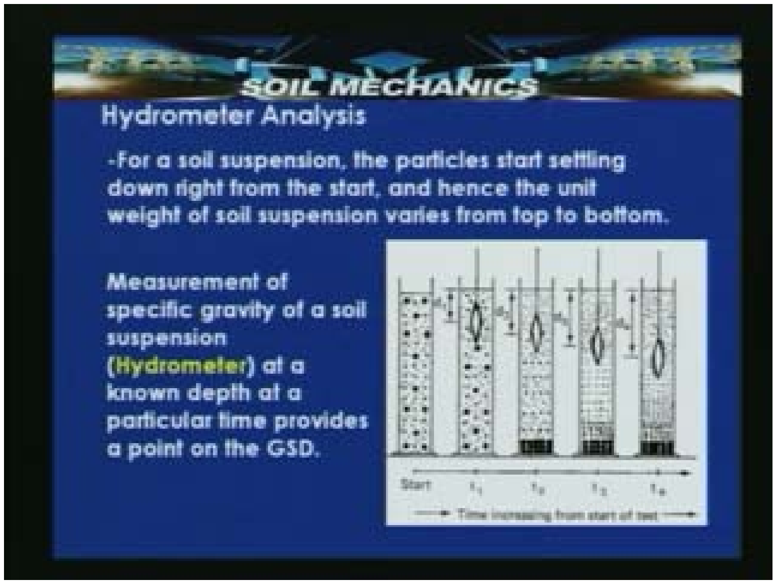

Let us assume that, for a soil suspension the unit weight varies from top to bottom for the particles settling down right from the start. Consider that, this is the soil suspension initially at time t is equal to 0. Once the particles tend to settle at time t_1 this will be the status. As increase in the time from the start of the test you see that the deposition of the soil particles is at the bottom. With this you see that the particles tend to settle with time. So it takes certain amount of time to undergo a change in the density from the initial state to the final state. This measurement of density or the measurement of the soil specific gravity of the soil suspension can be initialized by a device called hydrometer at a known depth and at a particular time provides a point on the grain soil distribution curve. This is an ideological representation of a hydrometer.

The hydrometer is nothing but a device or a bulb which has got a stem and which is filled with led particles. It is graduated in such a way to give the specific gravity of the soil particles suspension. If it is at a depth d_1 then we are able to access the specific gravity at this particular depth. You can see an increase in the height of this suspension after immersing this hydrometer. The original height of the suspension increases because of the immersion of the hydrometer. We will discuss that later to include this effect into consideration. Measurement of the soil specific gravity of the soil suspension at a known depth at a particular time provides points on the grain soil distribution curve.

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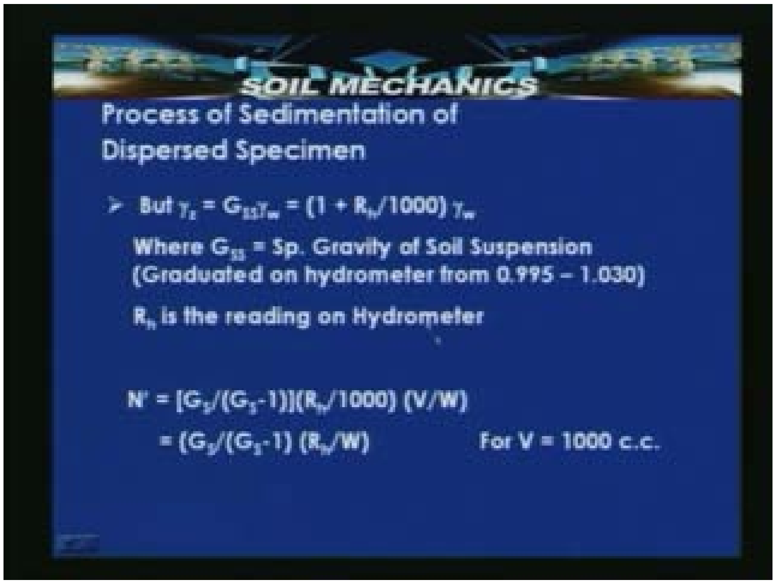

As we see here, gamma z can be written as: gamma z is equal to (G_{ss} into gamma w), where G_{ss} is the specific gravity of the soil suspension. That is (gamma z by gamma w) is nothing but which is is equal to Gss. At time t is equal to t_d Gamma z is the initial weight unit weight of the soil suspension at depth z. t_d is nothing but a elapsing time. You know the relation now gamma z is equal to (G_{ss} into gamma w) is equal to [(1 plus R_h by 1000) into (gamma w)]. This R_h is nothing but reading on the hydrometer. So that graduated reading on the hydrometer will be reading. Then G_{ss} is nothing but the specific gravity of the soil suspension.

Generally the hydrometer is graduated with following readings like 0.995 to 1.030. Now by rewriting this, the previously derived expression will be modified as: N dash is equal to [G_s by (G_s minus 1)] into (R_h by 1000) into (V by W). Instead of R_h by 1000, previously we have (gamma z by gamma w). After simplifying this by writing (gamma z by gamma w) is equal to Gss is equal to (1 plus R_h by 1000) so [(gamma z by gamma w) minus 1] is written like [(1 plus R_h by 1000) minus 1] so finally we will have (R_h by 1000) into (V by W). For V is equal to 1000 c.c., then we can write N dash is equal to [G_s by (G_s minus 1)] into (R_h by W). We are able to measure the reading on the hydrometer and W is the weight of the solids. Then we can determine N dash is equal to [G_s by (G_s minus 1)] into (R_h by W). G_s is the specific gravity of the soil solids.

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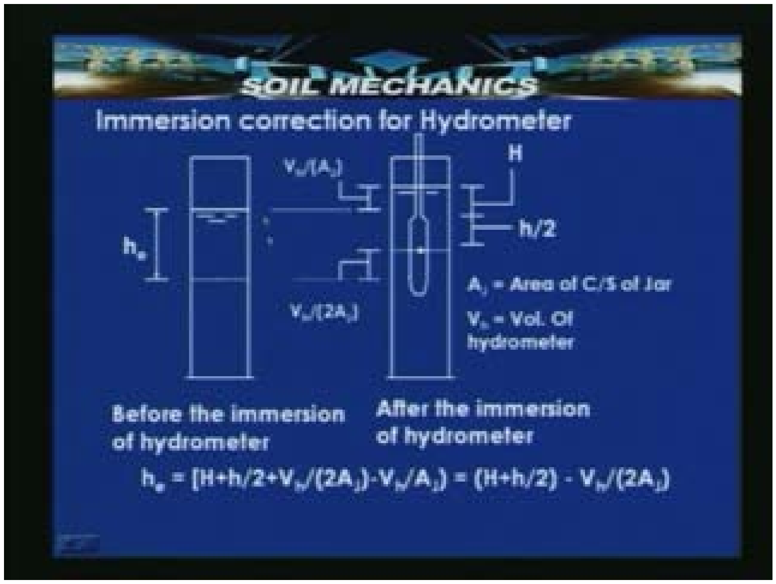

As I discussed the hydrometer is required to be connected for immersion correction, because generally this correction is required after immersing the hydrometer for more than 4 minutes. Initially this correction is not required, but after elapsing a time of 4 minutes this correction is required to be implemented.

Let us consider a jar with suspension, if you see here, this may be the reference depth which h_e then we can say h_e is determined here. After elapsing time t_d, we can say that the increase in the height of the suspension is V_h by A_j and the center of the hydrometer is V_h by $2A_j$, this is approximated from the c_g, if the weight of this is more than the weight of the stem it is approximated that the rise of the hydrometer with reference to the centre of gravity of hydrometer is around V_h by $2A_j$. V_h is nothing but the volume of the hydrometer, A_j is the area of cross section of the jar which is approximated now at mid height V_h by $2A_j$, at the stem level it is V_h by A_j. H is the height from the stem to the top surface and h by 2 is the height from the c_g to the neck of the bulb. This is the before immersion of the hydrometer and this is the after immersion of the hydrometer. Now h_e can be obtained which can be written as [H plus h by 2 plus (V_h by $2A_j$) minus (V_h by A_j)] is equal to (H plus h by 2) minus (V_h by $2A_j$) and after simplification this equation reduces to this.

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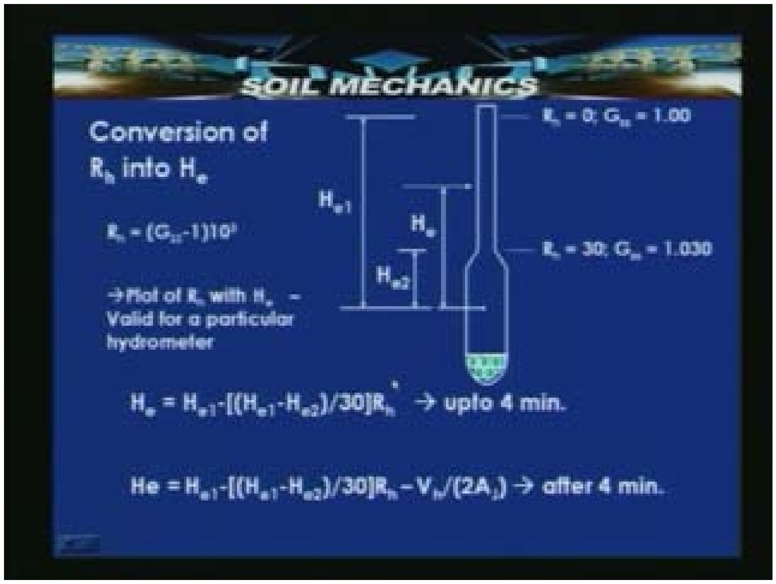

Once we get this, we are required to convert the reading on the hydrometer into the effective height h_e. Based on this we can substitute this effective height in the Stroke's law to determine the particle size. We said that the reading on the hydrometer is equal to (G_{ss} minus 1) into 1000. That is R_h is equal to (G_{ss} minus 1) into 10 cube. Here a typical hydrometer is shown. The bottom of the bulb is filled with led shots to give the vertical stability to the hydrometer. The reading on the hydrometer graduates like R_h is equal to 0; G_{ss} is equal to 1 and R_h is equal to 30; G_{ss} is equal to 1.030. With this now h_e is the effective height, so for typical hydrometer it is required to determine the H_{e1} and H_{e2}. This can be determined first by putting a hydrometer on A_4 size diagonally, top and bottom of the hydrometer is noted and then the neck is pointed out here. Then with this we can determine the mid point that is the centroid of the hydrometer.

By arriving that H_{e1} and H_{e2}, as the reading on a hydrometer varies from G_{ss} is equal to 1; R_h is equal to 0 to R_h is equal to 30; G_{ss} is equal to 1.030. With these we will able to estimate H_e is equal to H_{e1} minus [(H_{e1} minus H_{e2}) by 30]R_h. This is basically applied for up to 4 minutes and H_e is equal to H_{e1} minus [(H_{e1} minus H_{e2}) by 30]R_h minus (V_h by $2A_j$) this is due to immersion of the hydrometer connection and is required to be made after 4 minutes. Once we measure R_h and by correcting the immersion correction we are converting that into effective height. From there by substituting the Strokes law, we will able to estimate the particle size at particular time.

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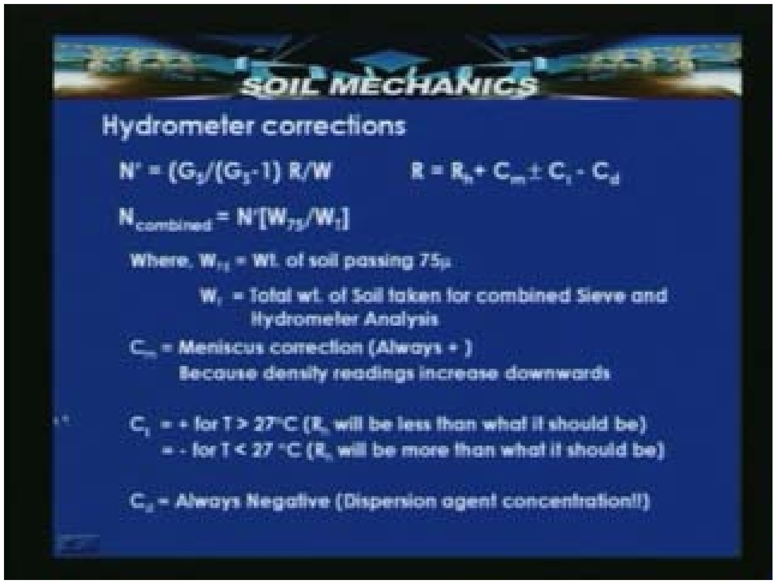

Now, coming to this, whatever we have seen previously the percentage finer N dash is equal to [G_s by (G_s minus 1)] into (R by W)]. This R indicates that which is nothing but R is equal to R_h plus C_m plus or minus C_t minus C_d, where C_m, C_t, C_d are the hydrometer corrections. C_m indicates hydrometer corrections per meniscus correction, C_t indicates for correction for temperature and C_d is the dispersion agent correction. After incorporating these corrections N dash can be obtained as: N dash is equal to [G_s by (G_s minus 1)] into (R by W)] where R is equal to R_h plus C_m plus or minus C_t minus C_d. Here once we get in this N combined can be obtained as: N combined is equal to N dash into [W_{75} by W_t]. That means W_{75} is the weight of the soil fraction passing 75 micron, W_t is the total weight of soil taken for combined sieve analysis as well as hydrometer analysis.

Once we get the N dash we can add these points to the sieve analysis curve. The points which are obtained from sieve analysis or mechanical analysis can be added. Then what are these hydrometer corrections? There C_m is the meniscus correction because this is always positive as the density readings increases downwards and will be measuring the lower readings. An account for that the C_m - the meniscus correction which is required to be applied is always positive. Then temperature, the hydrometer is generally calibrated for temperature T is equal to 20 degree C. For T greater than 27 degree C R_h will be less than what it should be. For T less than 27 degree C, R_h will be more than what it should be. That is C_t is equal to temperature correction is minus for temperature less than 27 degree C because the reading on the hydrometer will be more than what it should be so to compensate for that, the correction has to be minus. And temperature correction for hydrometer is positive for the temperature is greater than 27 degree C and R_h will be less than what it should be. C_d is always negative because we add the dispersion agent like sodium carbonate, sodium hexametaphosphate to segregate the soil particles. Hence we will able to determine ideally the finest particle sizes.

We have seen Strokes law application for determining the fine-grained soil fraction analysis. We also said that the first and foremost assumption is the platelet particles or the fine-grained soil particles are idealized as small spheres. The soil particles are not truly spherical; they are far from the spherical. So soil particles are not truly spherical and sedimentation is done in a jar.

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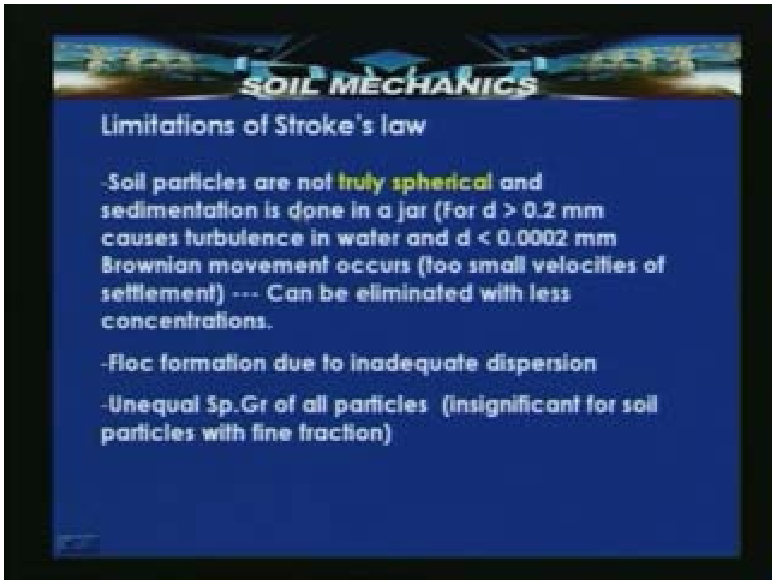

It is assumed that the sedimentation process is undergoing an infinite extend medium but we are doing in a jar of limited dimensions. For d greater than 0.2mm causes turbulence in water and d less than 0.0002mm the Brownian movement occurs which means the bombardment of the particles (too small velocities of settlement), this can be eliminated with less concentration. Even for soils with Bentonite soil it is advisable to take the soil solids percentage in the suspension as small as possible.

One more limitation is that there may be a possibility of flock formation due to inadequate dispersion. Though we pretreat the soil there may be a possibility that still flock formation exists and unequal specific gravity of all particles insignificant for all soil particles with fine fraction also exist. It is assumed that the specific gravity soil particles are constant. Due to this, there may be an error which may cause because of the unequal specific gravity of all particles (insignificant for the soil particle with fine fraction). So to a great extent these problems can be minimized to give the realistic results of the fine fraction analysis. By using this particular hydrometer analysis we can assess the soil fractions realistically so that we will be able to use and estimate the fine soil particles sizes.

In the next class we will be looking into the gradation of the soil matrix which is used to determine and classify the soils. And then we will also see various physical states of fine-grained soils with water.