Pavement Materials
Professor Nikhil Saboo
Department of Civil Engineering
Indian Institute of Technology Roorkee
Lecture 02
Particle Size Distribution Part 1

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Hello everyone in the last lecture in fact, the first lecture in this particular course, we started discussing about the needs and concepts that are related to characterizing the pavement materials in the laboratory. We also started just started discussing about soil as a pavement material and as I mentioned that we will continue our discussion further by understanding the soil as a pavement material.

And today we will also touch upon the introductory portion related to particle size distribution of soil. So, just to continue what we were discussing, we mentioned that soil can be divided into various categories.

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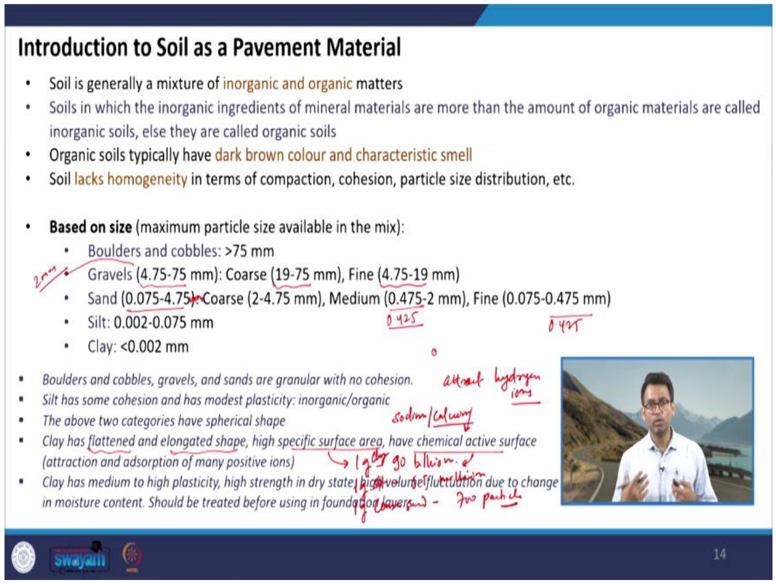

Soil can be of inorganic as well as organic nature and if it is inorganic nature, it is usually decomposed from the parent material and it appears in the surface of the earth. So, finally, soil is a mixture. So, if you take any soil, it will not be probably only from one source, it will be a mixture, it will be a mixture of inorganic and organic matter and these matters might have accumulated in the soil from different sources.

Now, when I see a soil how do I say whether the soil is in organic or the soil is organic, it depends on the proportion of the inorganic and organic ingredients that are present in the soil. So, soil in which the inorganic ingredients of mineral matters are more or dominant in comparison to the organic material they are usually called as in organic soils, but if the organic materials are dominant, they will be called as organic soils.

So, the organic soils they are not desirable as a pavement construction material and they appear to be dark brown in color and they have very characteristic smell. One interesting thing about organic soil is that many of the organic soils are very good for improving the fertility of the soil. However, the it is used in pavement construction is restricted because these type of soils they have a tendency to change the volume significantly with changes in moisture content and this can significantly harm the stability of the pavement structure.

Usually a soil lacks homogeneity, it is an inhomogeneous mass as I mentioned it is a mixture. And this inhomogeneity can be in terms of compaction characteristics can be in terms of cohesion characteristics, two soils can have very different cohesion characteristics, two soil can have very different compaction characteristics in terms of particle size distribution, two soils can have varying particle size distribution depending on the source depending on the way the soil was build up, etc.

So, this heterogeneity in the soil, it makes soil very as a very unique material if you talk about construction and also a very critical material to understand in the laboratory, because the pavement structure has to rest on this material. So, if this material is not understood properly in the laboratory or if we miss out some of the critical components of analyzing this material in the laboratory, this can lead to failure in the pavement construction or the pavement structure.

So, now, let us see or let us start talking about the basic characteristics of the soil and let us begin by talking about the division of the soil based on their sizes. And when I am saying the size of the soil here, because as I already mentioned that soil is a mixture. So, in that particular mixture, I am looking at the maximum particle size that is available and based on the maximum particle size I am going to divide the soil into different categories.

So, depending on the size it can be categorized as boulders and cobbles. So, boulders and cobbles are soil particles with size more than 75 mm. Then we have gravels, gravels are those soil particles whose size ranges from 4.75 mm to 75 mm. Some of this specification also used 2 mm as the dividing criteria rather than 4.75 mm. So, they say that greater than 2 mm and less than 75 mm are gravels.

If we consider that it is 4.75 to 75 mm we can further divide the gravels as coarse gravel, coarse levels are those whose size ranges from 19 mm to 75 mm, whereas, they are fine gravels if the size ranges from 4.75 mm to 19 mm. As I mentioned that some of the specification have divided gravels into two category into three categories rather than two categories, that is coarse, medium and fine.

Then we have sand whose size ranges from 75 microns to 4.75 mm. So, under this we can further have coarse sand, which are materials whose size ranges from 2 mm to 4.75 mm, we have medium sand, whose size ranges from 475 micron to 2 mm. So, some of the specification has used this as 4200.4 to 5 mm also. And we have fine sand that are larger than 75 micron, but smaller than 0. 475 mm or 0.425 mm.

Further we have silt which are further smaller particles whose size ranges from 0.002 mm to 75 microns. And further below we have clay which are particles which have size less than 0. 002 mm. Now, some of the salient features based on these sizes are that boulders and cobbles and gravels they are granular and in fact sands they are granular particles and they do not have cohesion, they do have internal friction they have the capability to interlock with each other, but they do not have cohesive properties between the particles.

Now, the cohesive properties start building up in the soil from silt. So, silt is the first category based on size which has some cohesion in it. And silt can have materials both from organic as well as in organic origin depending on the source. These two categories including boulders, cobbles, gravels, sands, and silt they are more of spherical in nature, if you see the shape of the soil particles in it, they are more of spherical in nature.

On the other hand clay which is the lowest category, they have more of flattened and elongated shape, they have very high specific surface area and they have chemically active surface. Now, this chemically chemical active surface also makes the clay as one of the very peculiar material and very critical material when we see them from the perspective of pavement construction.

For example, they attract high hydrogen ions when they come in contact with the moisture. In fact, they attract sodium and calcium ions when basically they are stabilized or we use some form of stabilizing agents. Talking about the high specific surface area in clay, one of the literature sources states that if you try to compare different types of soil particles, then 1 gram of clay has almost 90 billion particles.

Whereas, 1 gram of -- This is clay. Whereas, 1 gram of silt has almost 5.5 million particles, whereas, 1 gram of coarse sand has only 700 particles. So, this tells us that in per unit weight how many materials can be accommodated and you can see that in clay we can have a very huge quantity of material indicating the uniqueness of its size and the specific surface area.

Now, clay has usually medium to high plasticity that depends on the type of minerals that are present in clay. For example, one very specific mineral is montmorillonite. So, such type of clay has high plasticity they are not very desirable for using as a foundation layer in the pavement. Whereas some of the other minerals like kaolinite they are more stable in nature.

But it is also very interesting to note that in general we do not characterize the soil based on their chemical or mineralogical properties which are more difficult to determine, rather than we use indirect measurements which we will be discussing further through our discussion, which are used indirectly to get an idea about the behavior of the soil about the plasticity characteristics of the soil.

Anyway, so, as I mentioned that clay has medium to high plasticity, it has very high strength in dry state and it is very weak in presence of moisture, especially in presence of excessive moisture. And those clay particles which have very high expensive nature or shrinkage characteristics like they change their volume drastically with increase in reduction in moisture content needs to be first stabilized before they can be used for the construction as a foundation material in pavement construction.

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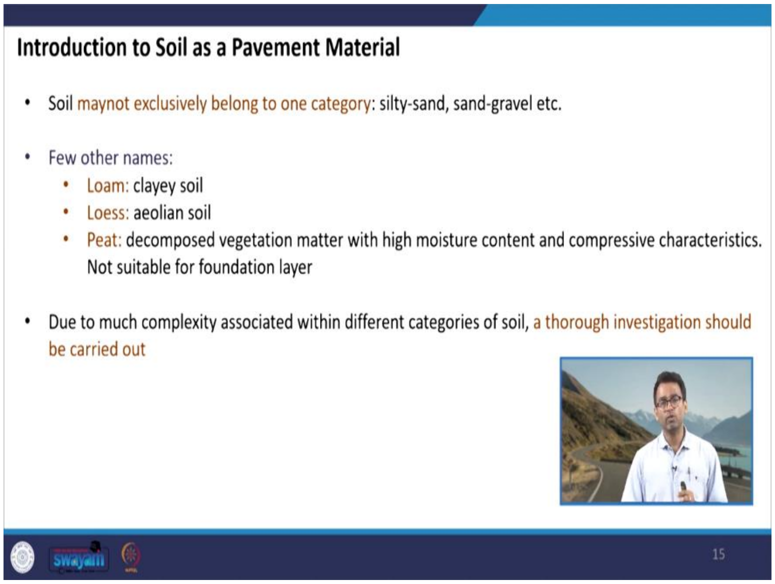

So, one of the important point here to remember is that soil exclusively do not belong to any category even depending on the sizes. So, as I said soil is a mixture, so, it can be a silty sand for example, it can be sand, gravel, soil, etcetera. So, it can be combination of two to three different types of materials, which we have just defined based on the sizes.

Now, some of the other names of soil which you can find in various specifications or textbooks, they are as follows. For example, you will read about loam, so, loam is basically nothing but a type of clay soil having the properties which we have already discussed. So, this is just a terminology. We have another terminology like loess. So, this is soil from the Aeolian origin. For example, like the one we talked about like calcite material or sand dunes, which gets transported through winds.

Then we have peat. So, peat is basically a decomposed form of soil which we get from the vegetation matter, this type of soil has very high moisture retention capacity and very high compressive characteristics and therefore, they are not at all suitable for the use in foundation layer.

So, due to so much complexity heterogeneity associated with different categories of soil, which we have been discussing, it is important as I already mentioned in the last lecture, that a thorough investigation should be carried out in the laboratory before you can use the soil for construction, because you have to remember the entire pavement structure has to rest on the foundation which is made up of soil. So, you have to ensure that that particular material has desirable properties.

desirable properties.

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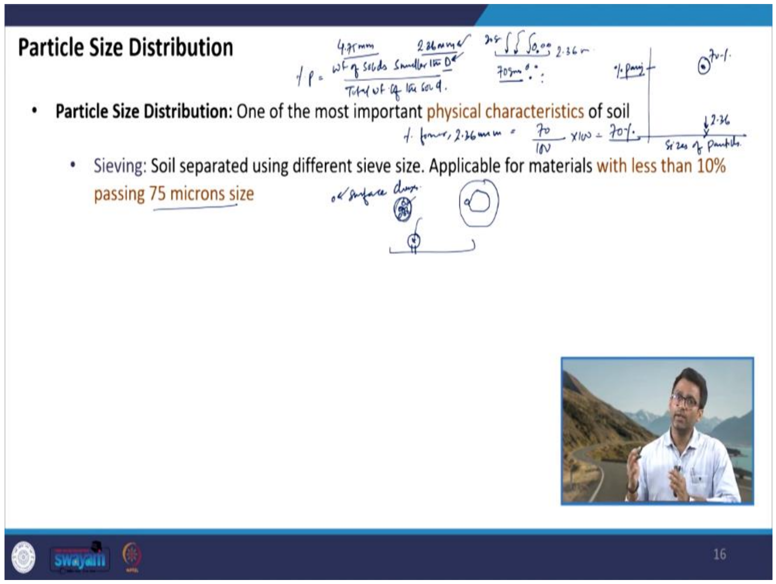

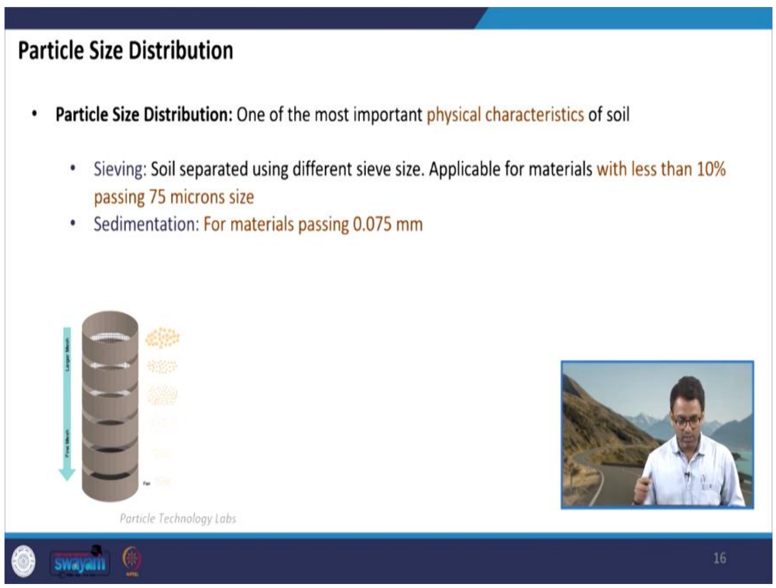

So, now, let us start our discussion on particle size distribution. Now particle size distribution, it is one of the most important physical characteristics of the soil, because the particle size distribution in any given soil mass, it tells us about various strength properties, various functional properties or we cannot say it exactly tells us, but it gives us an indication about the strength characteristics about the functional characteristics of that particular soil mass.

So, particle size distribution can be done through sieve analysis. So, in the particle size distribution what we do basically, we are trying to see that what is the corresponding to the different sizes of particles present in that soil mass, I am trying to see what is the percentage passing each particular size. What do I mean by this?

Let us say that, in that particular soil mass we have soil particles of the size of 4.75 mm let us say or we have soil particles of size of 2.36 mm. And let us say we have taken 100 grams of the soil mass and say that, when we take a sieve, we will talk about sieve analysis, when we take a sieve we allow the material to pass through this 2.36 mm sieve. We see that how much material gets retained and how much material actually passes.

So, the percent passing is basically calculated as a weight of the solids smaller than D in our case, let us say we are trying to see that what is the percentage passing 2.36 mm sieve, so here D will be equal to 2.36, divided by total weight of the solid. So, if we have taken 100 gram of soil, in that 100 gram when we passed it through 2.36 mm sieve let us say that 70 gram of the material passed through 2.36 mm sieve and 30 gram got returned which means 30 gram of the sample have size more than 2.36 mm and 70 gram of the sample had a size smaller than 2.36 mm.

So, the percentage final then 2.36 mm will be, so percentage final here in case of 2.36 mm it will be equal to how much, the weight of solids smaller than 2.36, so 70 grams divided by total weight so 100x100. So, you see that we have 70 percent of the material that are finer than 2.36 mm. And accordingly corresponding to the 2.36 mm sieve I have to mark 70 percent and I get one particular point.

Similarly, for other different sizes also I will do the same procedure and I can get percent passing through different size sizes of particles in the soil mass. So, the sieve analysis is typically done when the total amount of, when we have less than 10 percent material passing 75 microns sieve. The reason being that particles which are smaller than 75 microns, they are mostly as we have discussed in the last lecture are basically silt and clay particles.

Now, these particles if the amount of particles are more than what may happen that especially if you talk about clay particles, they have surface charge, they are very small in size, they have surface charges, they can get, they attract other particles. So, they can stick with other particles of similar size and they also have a tendency to stick with particles of larger sizes.

So, let us say if they stick together in this form and we do a conventional sieve analysis though the individual materials are very small, but when we are taking a sieve of a particular size this entire flock it will get retained here but ideally they should have passed because they contain individual smaller sized particles. That is why in those soils which have considerable amount of filler or materials passing 75 micron sieve the conventional sieve analysis may not work.

Now, it can, as I said it can also get attached to other particles, it can get attached to the sieve itself. So, that is why the calculation of weight becomes difficult and inaccurate and we end up doing wrong calculations and finding out the wrong percentage passing. So, the conventional sieve analysis is mostly applicable for more coarser particles.

Specifically, if the soil mass has less than 10 percent material passing 75 microns sieve. If the soil mass has more than 20 percent material passing 75 micron sieve, then we have to go for sedimentation analysis. Before discussing sedimentation analysis as I was discussing about the sieve analysis, let me just show you some of the sieves, which I have with me presently just to give you an idea about how sieve's look like.

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So, you see this is a sieve, you can see we have square apertures here corresponding to a specific size. So, this is basically a 19 mm sieve in my hand. Similarly, for different sizes because our soil mass will have particles of different sizes. So, I am interested to know what are those different sizes. So, these are some standard sieve sizes which are defined by the highway agencies for example in India 19 mm is one of the standards sieve.

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Similarly, we have another sieve. So, this sieve in my hand this is a 4.75 mm sieve. So, you can see that the size of the aperture is smaller than the previous one. So, this is a 4.75 mm sieve again one of the standard sizes.

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Then we can have further smaller sizes for example, if I am interested to know the percentage of silt and clay particles or uses 75 micron sieve, so you can see that how fine this mesh is and then below this typically in the sieve analysis below this we typically use a pan which is not a sieve but a collector. So, the total material can be collected in the pan and the corresponding weights retained in different sieves and then the pan will give us the percentage passing various sieve sizes. So, this is about sieve analysis. So, this is shown here.

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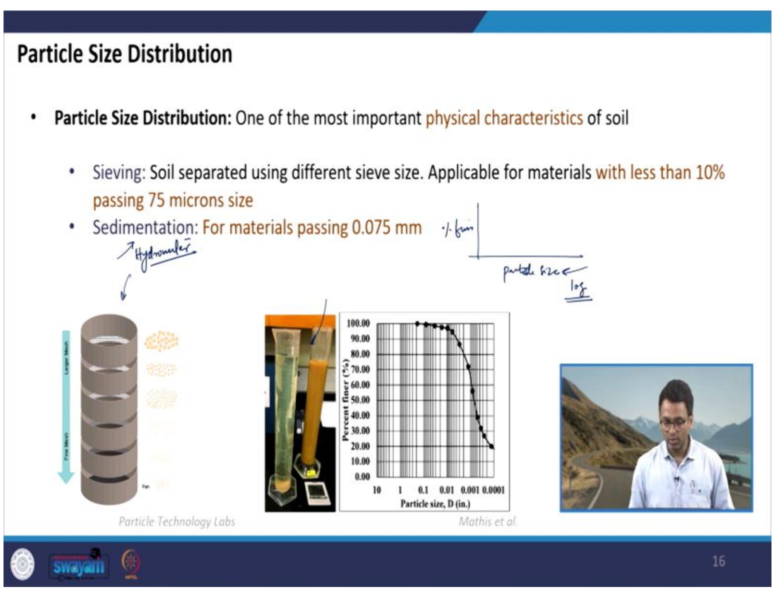

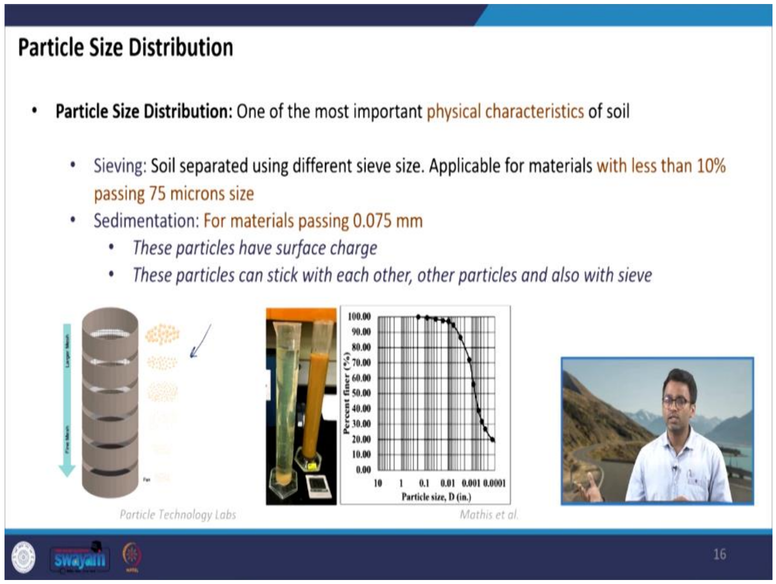

And then as I was saying if the soil mass has very considerable amount of materials passing 75 micron and I am interested to know the sieve size distribution, because probably the sieve size distribution is going to affect the stability of the structure for which I am using the soil I have to do is I have to go for sedimentation analysis.

So, specifically it is not called a sedimentation analysis, but we call it as sieve size distribution or particle size distribution using a hydrometer method. But the hydrometer method is based on the principles of sedimentation and that is what we are going to discuss. So, this is a laboratory picture of sedimentation or hydrometer analysis in progress.

And ultimately what we get is the percent finer and as I said we plot it in a graph where in the y axis we have percent finer and in the x axis we have the particle size. One point which I missed that usually this scale is a log scale, so it is a similar graph where the y axis is arithmetic scale and the x axis is a logarithmic scale.

And then we corresponding to different sizes, we plot the graph and try to see try to analyze the graph visually to understand what type of soil it is, what characteristics the soil may have. We will discuss more about the graph in the subsequent slides. So, as I said that these are some of the reasons that the smaller particles will have surface charge they have the tendency to stick with each other with other particles for which we cannot use the conventional sieve analysis.

So, now, let us because you see conventional sieve analysis, using sieve, they are more easy to understand which means this particular method it is very straightforward, but the theory behind a hydrometer analysis is a little more intense I can say and it is sometimes to students it appear to be very confusing when they are trying to analyze the materials in a smaller than 75 microns and trying to understand the hydrometer analysis.

So, let us try to spend some time in understanding this procedure. So, before I jump into the exact procedure of using the hydrometer analysis for sieve size distribution of particles smaller than 75 microns, let me try to explain you something about the sedimentation process or the theory of sedimentation we use in the hydrometer analysis.

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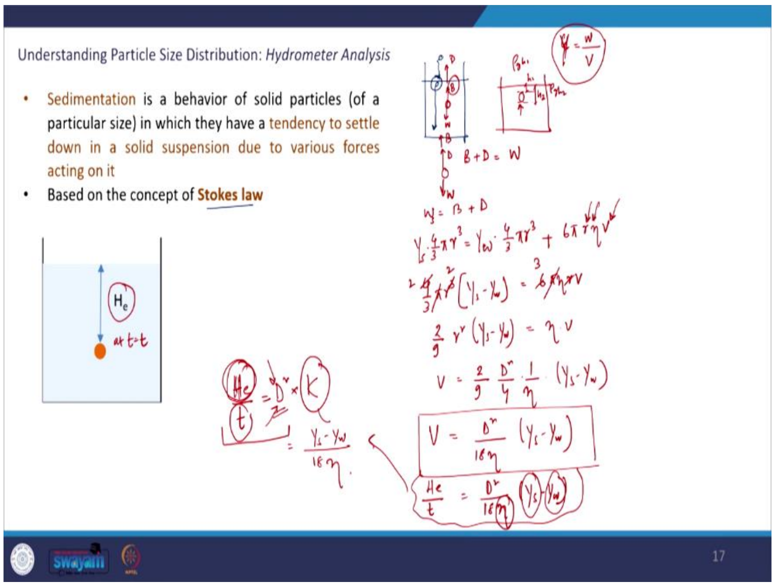

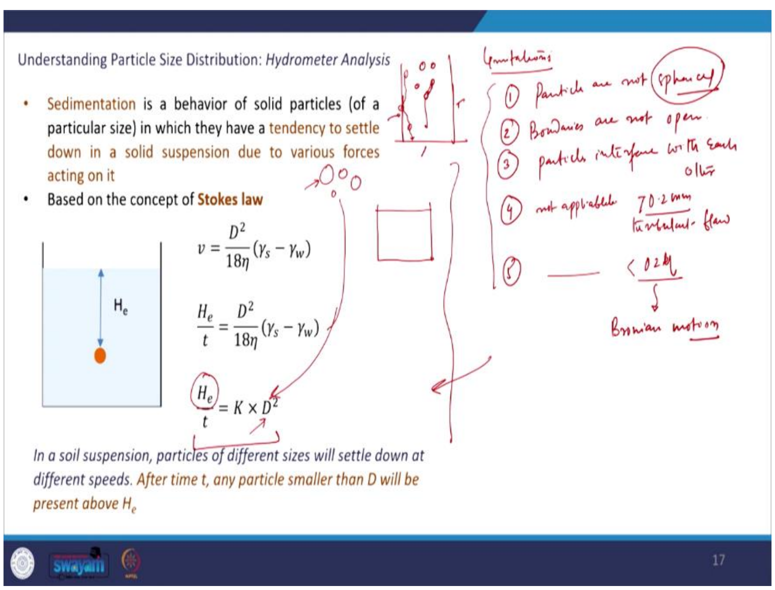

To define sedimentation, sedimentation is basically a behavior of solid particles of a particular size in which they have a tendency to settle down in a solid suspension due to various forces acting on it or in any suspension due to various forces acting on it. So, which means that if I take a beaker and if I fill it with water and if I just allow a soil particle to drop inside, so it will have a tendency to settle down because of different forces acting on it.

So, let us try to first understand that what are the forces, what is the equilibrium condition and then based on the stokes law, how do we use, how do we define a relationship between various parameters related to the movement of this particle inside this solution. So, the concept of sedimentation as I said is based on stokes law.

So, if you try to see a particle here, if you try to see a particular particle here, so what will be the forces acting on this particle the forces acting on this particle will be the weight of this particle. Then since this is a liquid we will have a buoyant force and we will also have a drag force acting on it.

So, I hope we understand it buoyant force is basically a function of the difference in pressure which is at the top and at the bottom, if this is h2 If this is h1, so this is ρgh1, this is ρgh2 and this difference create the buoyant force and the force is equal to the weight of the water displaced by the equal volume of solids. And then we have the drag force which is a resistive force acting in the opposite direction.

So, in equilibrium condition what will happen, so this is the drag force, this is the buoyant force, this is the weight of the particle. When the equilibrium condition is achieved, this particle will be moving at a constant speed inside that particular solution. So, in that situation we can write that in equilibrium condition B+D = W or let me write it as the W =B+D.

Now, we know the general relationship between specific gravity weight and volume. So, specific gravity or the density or the unit weight is basically equal to the weight divided by volume. So, I will use this particular relationship. So, here I can write WS as γ_S ×volume of the particle, if I am considering the particle to be a spherical particle which is the basic assumption for the derivation of the stokes law, it will be equal to $\frac{4}{3}\pi r^3$, where r is the radius of the particle.

Buoyant force becomes equal to again the unit weight of water into the equal volume of water which is displaced by the solids. So, it is $\gamma_W \times \frac{4}{3}\pi r^3$,. So, and drag force it can be derived, for spherical particle flowing inside the solution it is equal to $6\pi r\eta v$ where r is basically the radius η is the viscosity of the liquid, v is the velocity or the terminal velocity of movement of the particle. So, I hope that these terminologies are now clear to you.

So, if we rearrange this we can get that $\frac{4}{3}\pi r^3 \times (\gamma_S - \gamma_W) = 6\pi r\eta v$. So, if we just do some calculations here, we can write that $\frac{4}{3} \times r^2$ because one r from here will get cancelled here. So, $r^2 \times (\gamma_S - \gamma_W)\ \pi$ will also get cancelled becomes equal to ηv or $v = \frac{2}{9} r^2$. So, r I can write as $\frac{D}{2}$, so this becomes $\frac{D^2}{4} \times \frac{1}{\eta} \times (\gamma_S - \gamma_W)$.

So, the final expression for terminal velocity becomes equal to $\frac{D^2}{18} \times \frac{1}{\eta} \times (\gamma_S - \gamma_W)$. So, this is the basic equation we are looking at. Now, if the velocity is constant let us say at time t, at t equal to t this particle has moved to a height of He from the surface. So, the speed I can substitute as a $\frac{H_E}{t}$ becomes equal to $\frac{D^2}{18} \times \frac{1}{\eta} \times (\gamma_S - \gamma_W)$

So, this is again another expression available with me. Now, in this particular expression if few of the things become constant for example, if the suspension which I am taking is a single suspension, so η for that at a particular temperature will be constant. So, the viscosity of the suspension or the solution at a particular temperature will be constant. γ_S is the, if I am using a similar material, so the value of γ_S for that particular material is also constant, γ_W is constant anyway, so these are all temperature dependent but I am assuming that the temperature has been fixed.

So, therefore, the value of $\frac{H_E}{t}$ can be written as $D^2 \times K$. This K is a constant which is basically equal to $\frac{(\gamma_S - \gamma_W)}{18\eta}$. From this analysis we get a relationship between the height of fall of that particular particle at any time t with the value of D. That means, that if I know He at any time t I can know that what size of particle is present at that particular location.

Alternatively, if I know the size of the particle, so, I can determine that at any time t what is the effective height at which it will reach during the flow. So, I hope again these concepts are clear to you this derivation is clear to you because we will use this idea while understanding about the hydrometer analysis and it is used in the calculation of percent passing 75 micron sieve or developing the sieve size distribution curve for the materials passing 75 micron sieve.

Once we know this concept, let us try to understand it a further that in a soil suspension the particles of different sizes will settle down at different speeds. So, you can understand if it is a soil suspension, then we will have particles larger size, smaller size, medium size. So, if you see this particular relationship, you can understand that the height at which the particle will reach is a direct function of the size of the particle.

So, at any given time t the depth of particle of larger dia will be more than the depth of particle of this smaller dia. In other words, the speed at which the particle of larger size will fall will be higher than the speed at which the particle of smaller size will fall, is not it? So, I hope that this is clear to you.

So, and we will be using these concepts as I said as we discuss further, but before that, let me try to point out some of the limitations of using stokes law because these limitations will directly affect the result of the sieve size distribution curve, which we are going to derive and or which we are going to understand.

So, if I want to point out some of the limitations of the sedimentation analysis which is based on the concept of stokes law, so one of the problem is that particles are not spherical, because my derivation was based on the assumption that the particles are spherical but smaller particles specially clay particles, which we also discussed in the last presentation are usually not spherical, they are more flattened in shape.

So, again this assumption is going to cause some of the error in the final result we are going to derive. Then the boundaries are not open, which means it is not specifically a freefall. So, we have some defined boundaries. So, therefore, if a material falls from here if the material is here, then it may happen that while falling it can strike the edges of the cylinder because of which there will be disruption in the movement of the flow as per our assumption.

So, this can affect the results. Then the third problem is that particles interfere with each other. So, we have several particles here. So, while moving it may happen that this particle can interfere with this particle and then it will accordingly affect the results. Another issue is, now these are some specific issues that this method is not applicable for materials greater than 0.2 mm because materials greater than 0.2 mm can cause turbulent flow within the solution.

Also this method is not applicable for very small particles specifically when the size is less than 0.2 micron, the reason being very small particles lead to the occurrence of Brownian motion which will further affect the results based on the assumption. However, this limitations we should remember, but we are going to use the same concept in developing the sieve size distribution curve for the fine grained soils.

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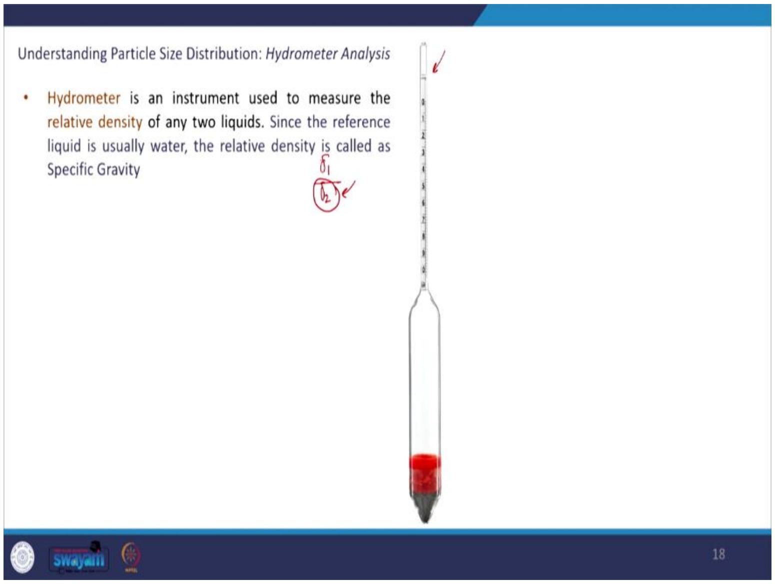

So, now, let us move ahead and as I mentioned that this is also called as hydrometer analysis and what is a hydrometer, hydrometer is an instrument which is used to measure the relative density of any two liquids which means density of liquid 1 by density of liquid 2. Now, since the reference liquid in our case is water, we also call it as specific gravity. So, we can say that hydrometer is basically used to measure the specific gravity of a particular solution we are interested in. So, this is how the hydrometer looks like.

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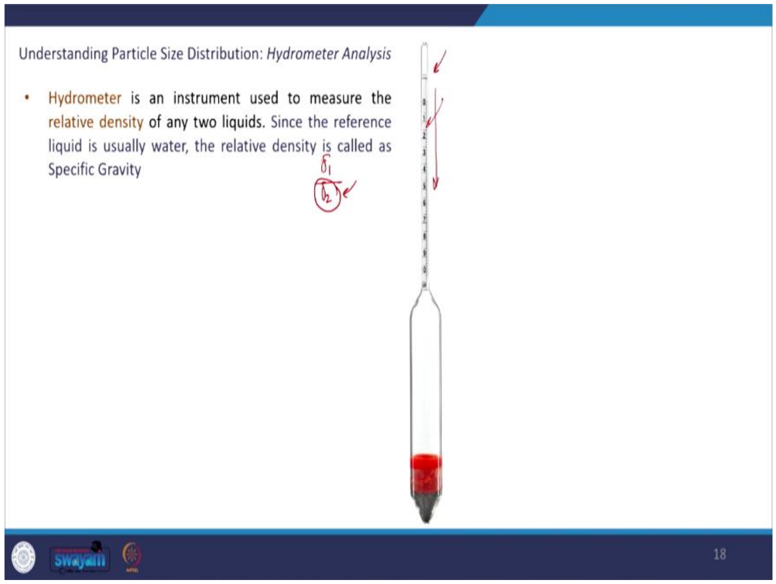

I also have the hydrometer with me just for some ready reference for you. So, which is very similar to the one which you see in the picture. So, you see this hydrometer has basically two parts it has the stem and it has the bulb. So, and there are markings in this hydrometer which you can see here, which is also shown in this particular picture in this slide.

And then you can see some mass here. So, this mass is basically the blast material, this can be made up of mercury and or lead. So, this is used basically to make the hydrometer stable. So, this is used for stability. So, this is how the hydrometer looks like and these readings basically in the hydrometer are used to directly calculate the specific gravity of that particular solution which we are trying to analyze. So, I hope that the visualization of hydrometer is now clear to you. Now, few things to remember.

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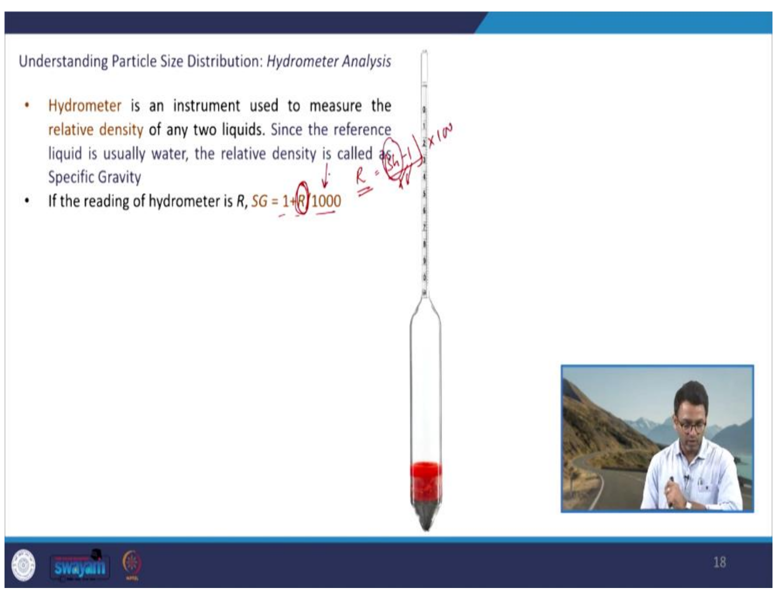

Now, this also depends on the type of hydrometer we are using, but most of the time the reading of the hydrometer is noted as R when I see that reading is noted as R, so R is not directly the specific gravity of the material we are analyzing. So, specific gravity is equal to $1+\frac{R}{100}$. So, this is again something we can remember.

Some of the hydrometer reading directly gives us the specific gravity and sometimes we use the value of R rather than specific gravity to note the reading of the hydrometer which means when we will be noting the reading of the hydrometer the reading will be basically (SG- 1) $\times$1000. So, in order to get the specific gravity, I have to use this particular formula if I have the reading of the hydrometer.

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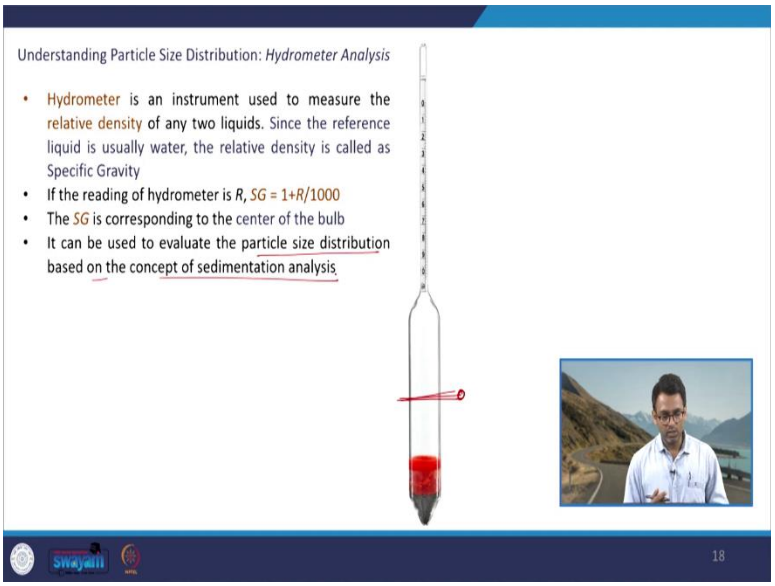

One more important thing about hydrometer is that the specific gravity we measure is basically at the center of the bulb. So, we are measuring the specific gravity of the solution or any material of interest at this position. So, again this is something which we have to remember about the hydrometer and this is how the hydrometer is calibrated.

In our case, we are basically not trying to measure the specific gravity of the solution here, but we are going to use this procedure to evaluate the particle size distribution based on the concept of sedimentation analysis. So, now, let us look at the steps that are involved in the process while evaluating the particle size distribution.

So, today we will stop here and I want you to remember this particular slide which we are discussing. We will start our discussion right from this particular point. And we will see the steps that are involved in using the hydrometer for analyzing or for evaluating the particle size distribution curve for the fine grained soils. Thank you.