Pavement Materials
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Lecture 03
Particle Size Distribution Part - 2

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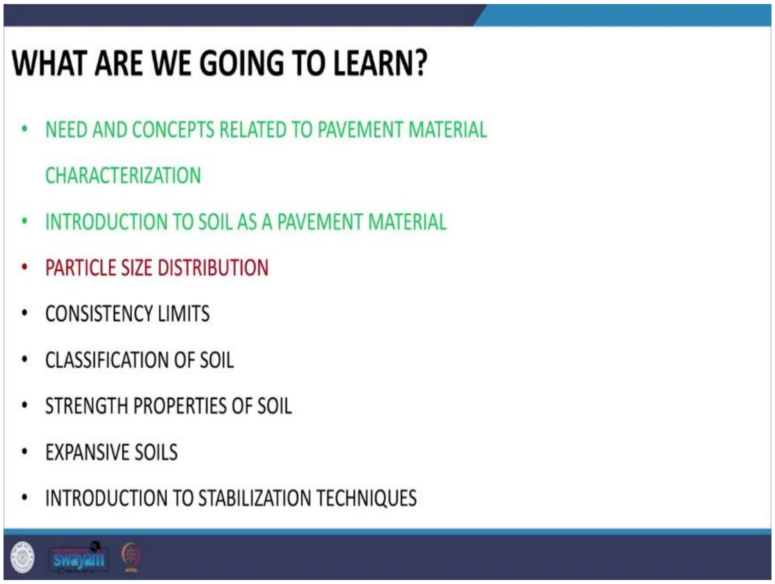

WHAT ARE WE GOING TO LEARN?

- NEED AND CONCEPTS RELATED TO PAVEMENT MATERIAL CHARACTERIZATION
- INTRODUCTION TO SOIL AS A PAVEMENT MATERIAL
- PARTICLE SIZE DISTRIBUTION
- CONSISTENCY LIMITS
- CLASSIFICATION OF SOIL
- STRENGTH PROPERTIES OF SOIL
- EXPANSIVE SOILS
- INTRODUCTION TO STABILIZATION TECHNIQUES

Hello everyone, welcome back. If you remember in the last class, we were discussing about the use of hydro meter for evaluating the particle size distribution of fine grained soils.

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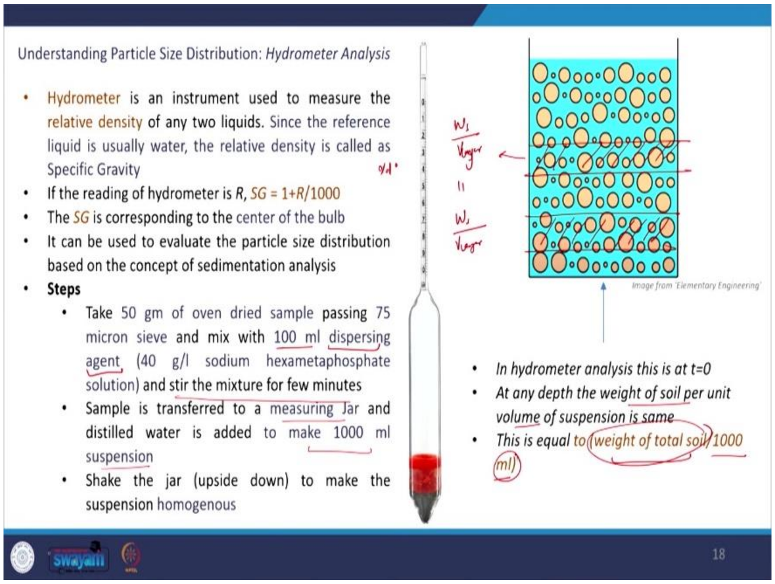

Understanding Particle Size Distribution: *Hydrometer Analysis*

- Hydrometer is an instrument used to measure the relative density of any two liquids. Since the reference liquid is usually water, the relative density is called as Specific Gravity
- If the reading of hydrometer is R, $SG = 1+R/1000$
- The SG is corresponding to the center of the bulb
- It can be used to evaluate the particle size distribution based on the concept of sedimentation analysis
- **Steps**
    - Take 50 gm of oven dried sample passing 75 micron sieve and mix with 100 ml dispersing agent (40 g/l sodium hexametaphosphate solution) and stir the mixture for few minutes
    - Sample is transferred to a measuring Jar and distilled water is added to make 1000 ml suspension
    - Shake the jar (upside down) to make the suspension homogenous

- *In hydrometer analysis this is at t=0*
- *At any depth the weight of soil per unit volume of suspension is same*
- *This is equal to (weight of total soil/1000 ml)*

And in this direction we also talked about the sedimentation analysis and the use of Stokes law to find the relationship between the effective height He and the diameter of the particular particle. And then we started talking about hydro meter, we saw the hydro meter and we then we tried to understand the different parts of the hydro meter, how the readings look like and then how the specific gravity of the solution or the material in caution can be calculated using the reading of the hydrometer.

So, now, let us start talking about the steps that are involved in using the hydro meter for particle size distribution analysis. So, the first step is that we will take 50 gram of oven dried sample of soil which are passing 75 microns. So, we are trying to analyze those finer particles or soil that passes 75 micron particle distribution of which we cannot analyze using a conventional sieve analysis. And then we take this 50 gram of oven dried sample and we will mix it with 100 ml of dispersing agent.

So, usually a 40 gram per liter of concentration of sodium hexametaphosphate solution is used as the dispersing agent and the use of this dispersing agent is to prevent flocculation of the soil particles if you remember, we talked that the soil particles of various smaller size they have surface charge and also they have the tendency to agglomerate.

So, this sodium hexametaphosphate solution, it will help in keeping this particle separated from each other. So, that is the use of this dispersing agent. So, we will mix it with 100 ml of dispersing agent and we will state the mixture using a mechanical mixer. So, we will stay it for a few minutes ensuring that the sodium hexametaphosphate solution has you know, properly D flocculated the fine grained soils.

Then this sample is then transferred to a measuring jar. So, I have the measuring jar as an example with me, so, this is a typical measuring jar. So, this mixture which I have just prepared, I will put it in the measuring jar and then this entire measuring jar I will fill with distilled water such that the total volume is 1000 ml alright. So, this is what I will do. So, the sample is transferred to the measuring jar and distilled water is added to make 1000 ml of the suspension. So, the total volume will be 1000 ml

Then we will shake the jar upside down to make the suspension homogeneous because you see we have initially we filled the soil with the dispersing agent in this particular jar and then we added distilled water from the top. So, it may happen the soil particles are still settled at the bottom or randomly moving in the jar but it is not homogeneous in nature. So, once we have filled it with 1000 ml we have a cap here a rubber cap we can close it and we will just shake it in this way upside down or upside down. So that the entire soil particles which will have occupies equal volume at different levels.

When I say equal volume at different levels, which means after doing this step the suspension will look something like this. So soil particles of different sizes will be distributed homogeneously in that particular jar and this is T = 0 we have not yet started the experiment. So, T = 0 since it is in homogeneous conditions. So, if you take any particular area or two different areas, let us say two different areas you take.

So, here the weight of the solid per unit volume of the suspension and here the weight of solid per unit volume of the suspension will be equal to each other, which also means that these two layers will have same value of density or same value of specific gravity is not it. So that means that T = 0 the specific gravity is equal at all different locations in the measuring chart. Since we are talking about per unit volume of the suspension. So, T = 0 if I am interested to know the weight of the soil per unit volume, I already know this because I know what is the weight of total soil I have used to prepare the suspension and I know the total volume of the cylinder is 1000 ml at each layer the ratio will be same.

So, it can be directly calculated as weight of the total soil taken divided by 1000 ml. So, this is again one of the important points to make because this step we will use in the calculation of percent finer when we are going for the calculation this I will discuss in the next slide.

So, before I proceed to the next slide, one more important point, which I should mention here is, so, you try to imagine this is T = 0, what will happen after some time.

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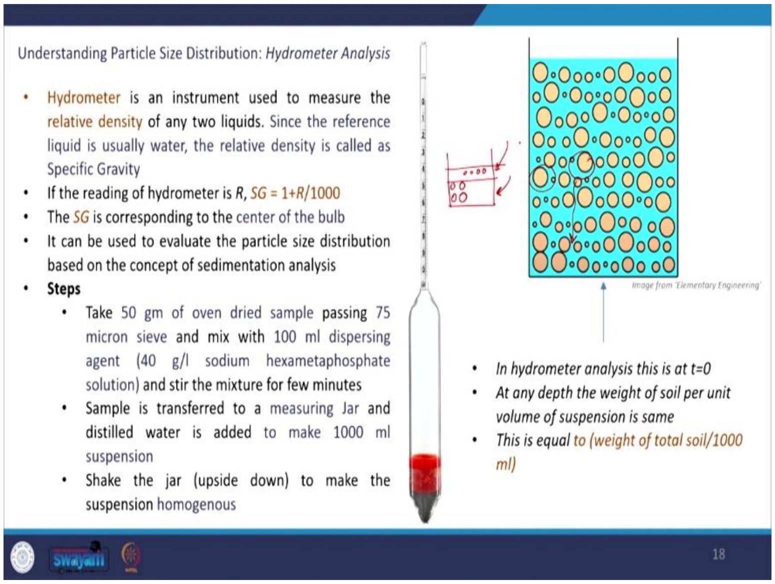

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Image from 'Elementary Engineering'

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- *At any depth the weight of soil per unit volume of suspension is same*
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Let us say T = T what will happen. So, T = T, you can now understand because we have discussed about the sedimentation analysis and Stokes law that these larger particles will move faster than the smaller particles. So, T=T, you will have smaller particles here and larger particles will be moving down.

So, which means that the suspension will no longer be homogeneous. In other words, I can say that after some time, the lower part of the jar will have higher density in comparison to the upper part, which means, there will be a non-uniform distribution of specific gravity of the solution at different times and on the upper layer the specific gravity of the density will be less in comparison to what we will see in the lower part. Alright.

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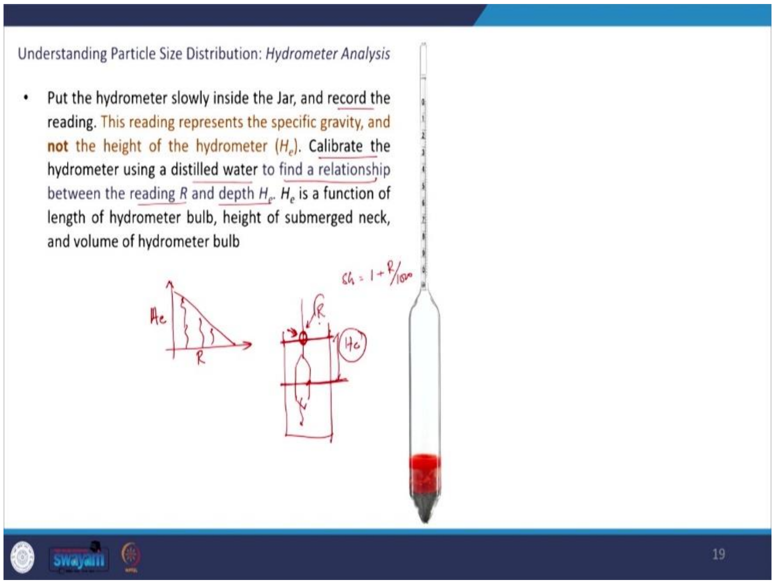

Understanding Particle Size Distribution: *Hydrometer Analysis*

- Put the hydrometer slowly inside the Jar, and record the reading. This reading represents the specific gravity, and **not** the height of the hydrometer (H_e). Calibrate the hydrometer using a distilled water to find a relationship between the reading R and depth H_e. H_e is a function of length of hydrometer bulb, height of submerged neck, and volume of hydrometer bulb

$SG = 1 + R/1000$

So, then what we will do once we have shaken the jar, we have made the suspension homogeneous in nature, you just try to imagine that if you have the suspension here, then what I will do, I will very slowly insert this hydrometer inside the suspension and I will leave it so, it will stay stable at the particular position depending on the type of suspension, and then I will record the reading.

So, I have the hydrometer here, and it is giving me the value of specific gravity at this particular point at the middle. And accordingly if this is the top surface of the solution. So, I will note the reading here, this reading, which I am seeing here, this represents the specific gravity I am getting the value of R, which I can use to calculate the specific gravity as I know that this is equal to 1 plus as I discussed in the previous slide, $1 + \frac{R}{1000}$. Alright, so, this I know, but I do not know this particular height, the reading which I am taking this is not the height reading this is the reading to get this specific gravity, this is how the hydrometer was calibrated, but I do not know what is the effective height at this particular position.

So, what manufacturers do they usually calibrate the hydrometer using distilled water to find the relationship between reading R and the depth He. Because you see depending on the specific gravity of different location in the suspension, this hydrometer at different times will occupy different positions alright at different positions, it is going to give different values of R and different values of R will have different values of effective height.

So, they already do this background work while calibrating the hydrometer and they will give us a relationship between the value of R and the and the corresponding He so for any value of R I will know that what is the value of He alright. So, He also we can get if we know the value of R again this is something which you have to remember,

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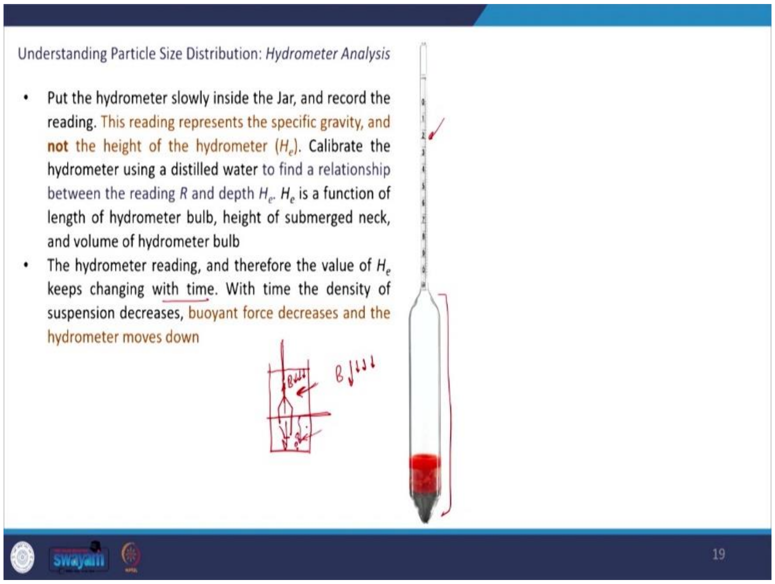

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- The hydrometer reading, and therefore the value of H_e keeps changing with time. With time the density of suspension decreases, buoyant force decreases and the hydrometer moves down

Just for your information though we are not discussing in detail about the calibration process, but during the calibration, they do a derivation in which we will see or you can see that the value of effective height is basically a function of the length of a hydrometer bulb which is this one, the height of the submerged neck.

So, if in the experiment if this is the solution and this is the position of the hydrometer then this is the length of the neck. This is the length of the neck submerged inside the water and the volume of the hydro meter bulb. So, in this they assume that the volume of the hydro meter is only equal to the volume of the hydro meter bulb and they do not consider the small volume of the stem of the hydrometer anyways, we are not going to discuss in detail about the calibration process.

And then the hydrometer reading and therefore the value of He keeps on changing with time I hope you understand why because as I mentioned in the suspension, larger particles will settle. So, if let us say T = 0 this is the position of the hydrometer, let us say T = 0 this is the position of the hydrometer and this is the reading which you get alright. So, this is where the hydrometer is taking the reading.

So, as time progresses larger particles start settling down, the top of this particular jar will have lower density in comparison to the bottom part. Therefore, you see the weight of the bulb is fixed the weight of the hydrometer is fixed. So, the buoyant force will keep on reducing with time once the buoyant force reduce the hydrometer will start moving down because of the weight the hydrometer will start going down. So, therefore, now you can understand that at different times we will have different values of He which will keep changing depending on the density how the density is changing.

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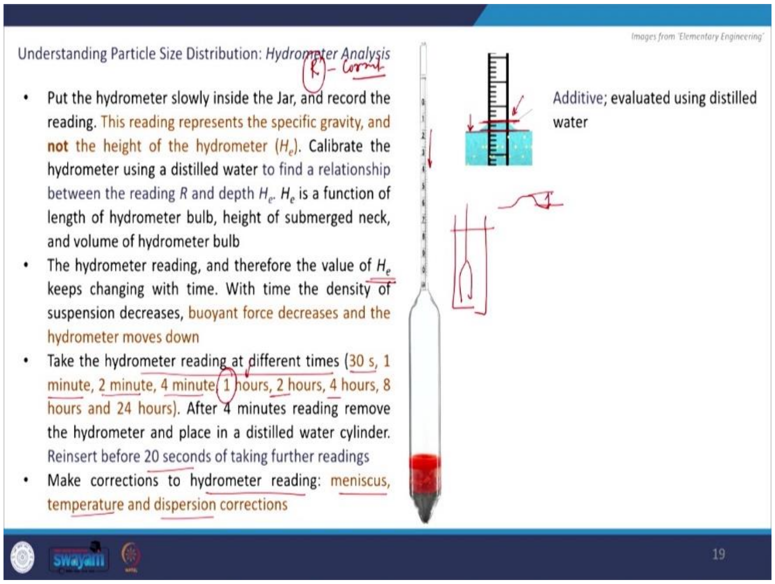

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Understanding Particle Size Distribution: *Hydrometer Analysis*

R – Correct

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- The hydrometer reading, and therefore the value of H_e keeps changing with time. With time the density of suspension decreases, buoyant force decreases and the hydrometer moves down
- Take the hydrometer reading at different times (30 s, 1 minute, 2 minute, 4 minute, 1 hours, 2 hours, 4 hours, 8 hours and 24 hours). After 4 minutes reading remove the hydrometer and place in a distilled water cylinder. Reinsert before 20 seconds of taking further readings
- Make corrections to hydrometer reading: meniscus, temperature and dispersion corrections

Additive; evaluated using distilled water

So, what we do in this process we take the hydrometer reading at different times the typical time are 30 seconds, after 30 seconds we will take the reading after 1 minute, 2 minute, 4 minutes, after 4 minutes what we will do we will take out the because our next reading is going to be after 1 hour which is a considerable period of time.

So, we very slowly take out the hydrometer from the suspension and this hydrometer we dip basically in another jar having only distilled water so, that we can have the cleaning of the hydrometer and then just 20 seconds before our next time that is 1 hour we will remove it from the distilled water jar and put it in the suspension which we are trying to analyze.

So, this we will do keep doing that is keeping it in the distilled water again keep it in the suspension and at different times like after 1 hour we will take the reading again remove it keep it in the distilled water then just 20 seconds before 2 hours we will put it inside the jar again take the reading take it out put it in the distilled water again just 20 seconds before 4 hours we will put it and so on. So, we will do it and then we will keep recording the reading. So, which means that we time I will have different readings of the hydrometer which means different specific gravity values and corresponding to different readings I will also have the different values of He.

Now, an important step is to make correction to the hydrometer reading. So, at different times though I have got the reading let us say that the reading is R so, these R I have to correct, and why are these corrections required the first correction is due to the meniscus, second is due to the temperature and third is due to the dispersion. So, why is the meniscus correction required because when you dip the hydrometer in the suspension, the reading which you take because of the surface tension, the suspension will move upwards.

So, when you see it with the eye and the suspension is opaque in nature, so, you take only the top surface this is the reading you are taking, but the actual reading should be this particular reading. So which means and you see the reading of the hydrometer increases as you move from top to bottom.

So, when you are taking the reading it is actually taking a lower reading, but ideally you should have taken a higher reading, which means that this corrections should be positive in nature and how do you find out that how much correction is required it is very simple, you just take the jar you take a distilled water, which is not opaque you can see everything you dip the hydrometer in it here also you will get the because of the surface tension you will get the changing meniscus, but here you will be able to see it very clearly because it is a clear solution. So, you just note down the difference and the same difference, you use it as a correction in the reading for the suspension.

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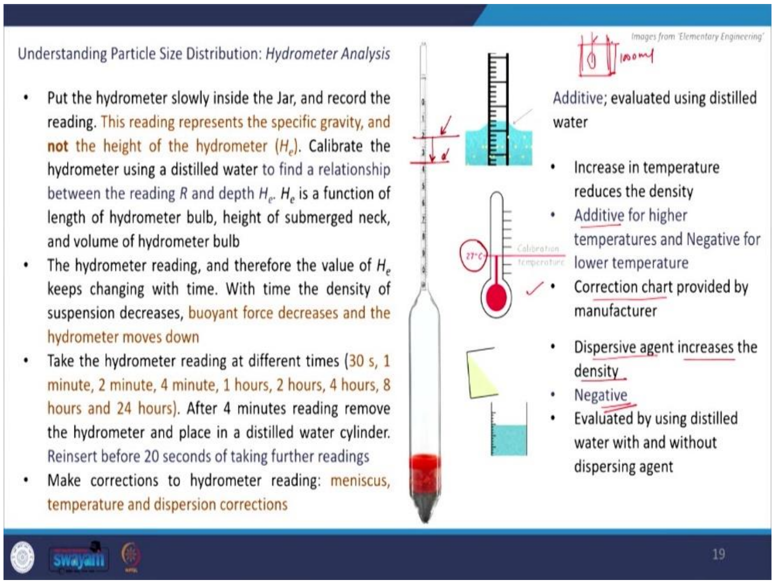

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Images from 'Elementary Engineering'

Additive; evaluated using distilled water

- Increase in temperature reduces the density
- Additive for higher temperatures and Negative for lower temperature
- Correction chart provided by manufacturer

- Dispersive agent increases the density
- Negative
- Evaluated by using distilled water with and without dispersing agent

So, this is first correction. The second correction is the temperature correction we all know that with increasing temperature the density of any suspension will usually reduce. So, if the density decreases, try to understand it in this way if the density decreases, the buoyant force will decrease. So, the hydro meter will move down when the hydro meter moves down before I proceed further, just like to mention that the hydro meter is usually the standard temperature is 27 degrees Celsius.

So, let us say that the at 27 degrees Celsius this was the reading I am supposed to have. But since the temperature has increased, the hydro meter has moved down. I am recording actually this reading, but I should have recorded this which means from 2, I should have gone to 4. So, therefore, again if the temperature is higher than 27 degrees Celsius, then the correction factor will be additive in nature I have to add it. Similarly, if the temperature is lower my hydrometer will move upwards that it should have been at 27 degrees Celsius, so, the correction factor will be negative.

So, this temperature correction which we have discussed that this is usually provided by the manufacturer. So, we will have a correction chart for different temperatures for suppose if it is above 27 degree as I said the correction factors will be additive in nature if it is lower than it will be subtractive in nature and this is usually provided by the manufacturer the next correction is basically the dispersive agent correction because the suspension which we are looking at is does not only have the soil particles which we are trying to analyze it rather also has the dispersing agent present in it.

So, we have to remove the effect of dispersing agent so, that we get the correct reading now, the addition of dispersing agent it will obviously increase the density of the suspension. So, you can understand that if the density of the suspension increases the buoyant force will basically increase the hydrometer will move up in comparison to what it should have been without the dispersing agent. So, here we get a higher reading, but the reading should have been smaller. So, the connection is negative with nature.

So, to get this particular correction again we will can use the distilled water as the reference. So, what we can do we can use a distilled water with 1000 ml let us say take the reading of the hydro meter here, then what we can do, we can use because you see here what we have done in our suspension.

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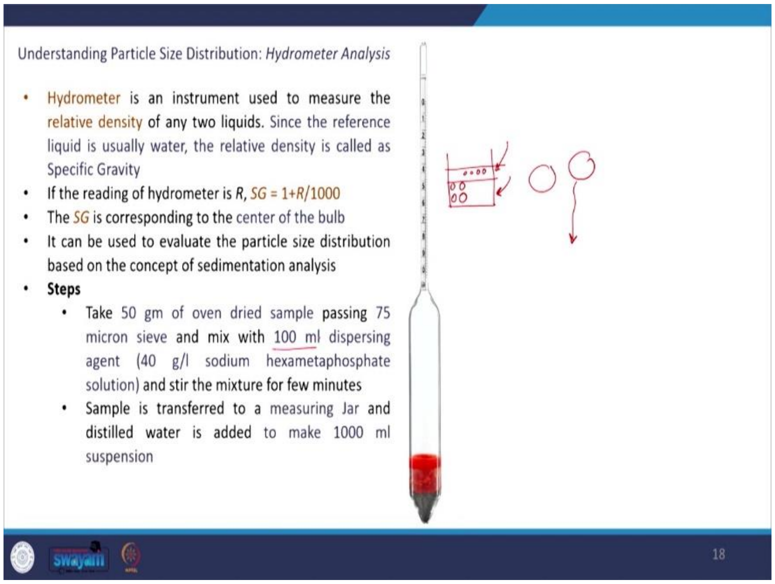

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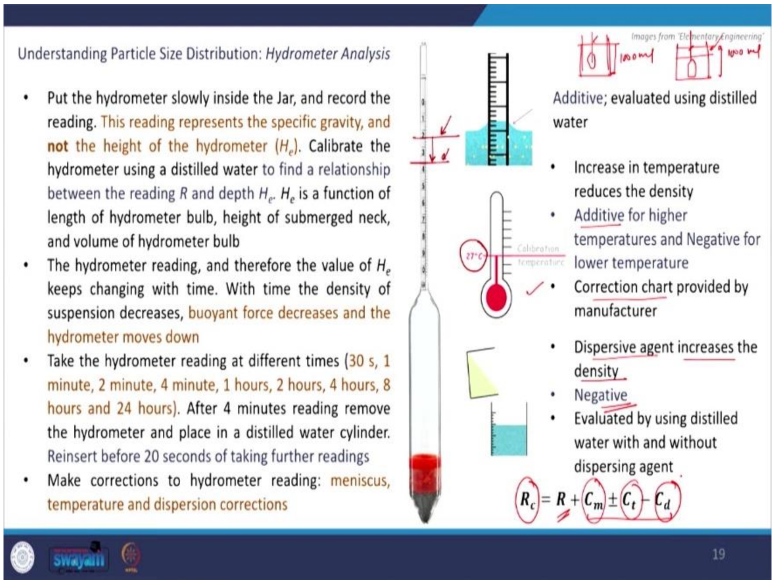

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$$R_c = R + C_m \pm C_t - C_d$$

If you remember in this particular slide that here we had 100 ml of dispersing agent. So, the similar quantity by volume you can we can use here and then the amount of distilled water will be reduced such that the total volume is again 1000 ml. So, this total volume we will keep constant and will add equal amount of equal amount of dispersing agent as we are using in the experiment.

And then again we will do the hydrometer analysis and we will take the reading and the difference in this reading will give me the correction factor to be applied. So, and finally, we will calculate the corrected reading of the hydrometer which will be the reading R and then with all the corrections the meniscus correction, the temperature correction and the dispersing agent correction. So, I hope these steps are clear to you.

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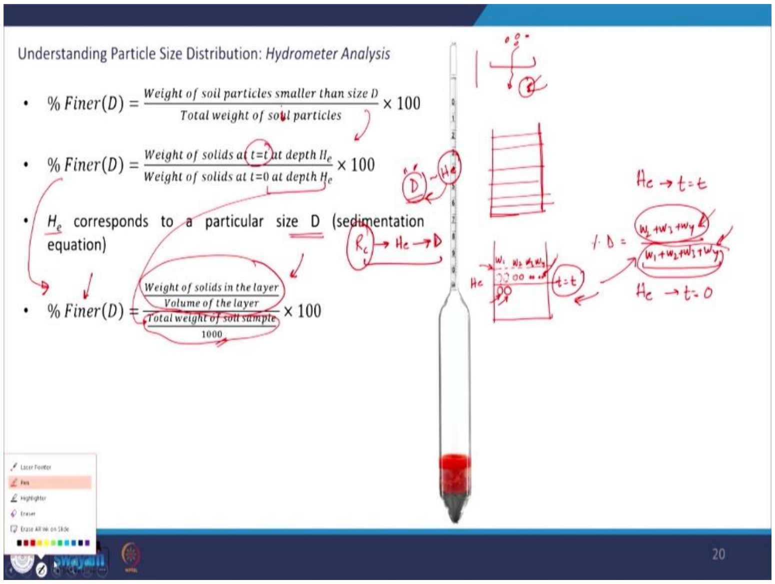

Understanding Particle Size Distribution: *Hydrometer Analysis*

- $\% \, Finer(D) = \frac{Weight\ of\ soil\ particles\ smaller\ than\ size\ D}{Total\ weight\ of\ soil\ particles} \times 100$
- $\% \, Finer(D) = \frac{Weight\ of\ solids\ at\ t=t\ at\ depth\ H_e}{Weight\ of\ solids\ at\ t=0\ at\ depth\ H_e} \times 100$
- H_e corresponds to a particular size D (sedimentation equation)
- $\% \, Finer(D) = \frac{\frac{Weight\ of\ solids\ in\ the\ layer}{Volume\ of\ the\ layer}}{\frac{Total\ weight\ of\ soil\ sample}{1000}} \times 100$

And now we move forward to calculate to see the calculation of percent passing or percent finer and how it is related to the hydrometer reading. So, let us first define percent finer. So, percent finer is weight of the soil particles smaller than size D divided by the total weight of the soil particles multiply by 100. I hope you understand this right that this is what we discussed it percent passing is the weight of soil particles smaller than size D even in the sieve analysis the example which we took that we are taking let us say 100 gram of soil passing it through the sieve and we are noting down how much soil is passing. So, this fraction we are trying to determine So, weight of soil particles smaller than size D divided by total weight of soil particles multiplied by 100.

Now, when we are doing the hydrometer analysis, what will be this formula in the terms of the different heights or effective height which we get from the reading of the hydrometer. So, I will try to explain it in this way time T = 0 all the portions of the hydrometer as we discussed will have the same density because the distribution of the material is homogeneous. But let us say that we are looking at D now, again I would like to make a comment here that D is again related to He so, if you know He you also know D at any time T, so let us say I am looking at a particle D so at I am trying to find out that what is the weight of soil particle smaller than size D.

So At what time will I get that I will get it at a time when basically at a time T when this particle of size D or these particles of size D, have just crossed that particular level at which I am doing the measurement H e or the I am noting down the hydrometer reading and only the smaller particles are above it only the smaller particles are above it, in the homogeneous condition these particles were here, but after some time because larger particle will settle down these particles have come here.

So, weight of the soil particles smaller than size D I will get at time T = T, so, weight of the solids at T = T, because, you see, if I am trying to find out percent finer then let us say this is W 1, W 2, W 3, W 4. So, percent final for size D using in this particular picture, it will be $\frac{\mathrm{W}\ 2+\mathrm{W}3+\mathrm{W}4}{W1+W2+W3+W4}$ and this denominator this was present at what time at T = 0 you see when everything was in this particular line.

So, I hope I will just give you some time to see this picture again and then this is what I have written here and then I have tried to explain this with respect to different times. So, this is what I am trying to find this I will get at time T = T this I will get corresponding to the height He at T = T and the denominator I will get corresponding to the height He at T = 0. So, I hope you know this is the most important part which you need to understand in order to be comfortable with the analysis of analysis we are doing using the hydro meter. So, I hope this is clear to you.

Now, as I mentioned He corresponds to a particular size D which we also we have seen the relationship using the sedimentation equation. So, if you have the reading of the hydro meter, you have the value of

He if you have the value of He you also have the value of D so, these three are known just by knowing the value of Rc.

So, now usually this equation is represented as weight per unit volume of the suspension because we do not know at this particular position what is the exact volume of the suspension. So, the same equation or the same weight of solids at T = T, I can express in terms of weight of solids per unit volume at T =T per unit volume of the suspension and this is what I have written here.

So, percent finer is equal to weight of the solids in the layer per unit volume of the layer divided by the total weight of the soil. And you see this way I have written this because this is a T = 0 and if you remember we have discussed in previous slides that at T = 0 different locations will have the same density which is actually equal to the weight of soil sample divided by the total volume of the suspension which is 1000 ml which we have taken. Now, our target in order to calculate percent finer this is already known to us. So, our target is to calculate this.

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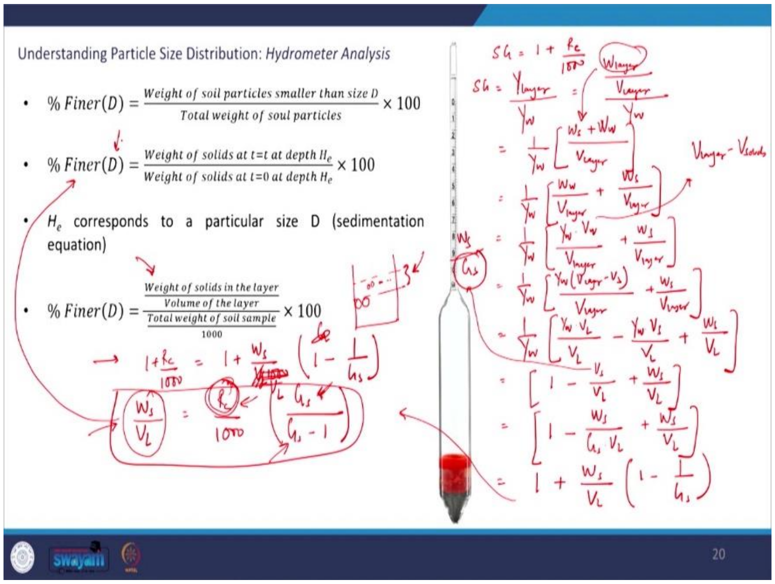

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$$\rightarrow 1 + \frac{R_c}{1000} = 1 + \frac{W_s}{V_L}\left(1 - \frac{1}{G_s}\right)$$

$$\frac{W_s}{V_L} = \frac{R_c}{1000}\left(\frac{G_s}{G_s - 1}\right)$$

$$SG = 1 + \frac{R_c}{1000}$$

$$SG = \frac{\gamma_{layer}}{\gamma_w} = \frac{\frac{W_{layer}}{V_{layer}}}{\gamma_w}$$

$$= \frac{1}{\gamma_w}\left[\frac{W_s + W_w}{V_{layer}}\right]$$

$$= \frac{1}{\gamma_w}\left[\frac{W_w}{V_{layer}} + \frac{W_s}{V_{layer}}\right]$$

$V_{layer} - V_{solids}$

$$= \frac{1}{\gamma_w}\left[\frac{\gamma_w \cdot V_w}{V_{layer}} + \frac{W_s}{V_{layer}}\right]$$

$$= \frac{1}{\gamma_w}\left[\frac{\gamma_w (V_{layer} - V_s)}{V_{layer}} + \frac{W_s}{V_{layer}}\right]$$

$$= \frac{1}{\gamma_w}\left[\frac{\gamma_w \cdot V_L}{V_L} - \frac{\gamma_w V_s}{V_L} + \frac{W_s}{V_L}\right]$$

$$= \left[1 - \frac{V_s}{V_L} + \frac{W_s}{V_L}\right]$$

$$= \left[1 - \frac{W_s}{G_s \cdot V_L} + \frac{W_s}{V_L}\right]$$

$$= 1 + \frac{W_s}{V_L}\left(1 - \frac{1}{G_s}\right)$$

$\frac{W_s}{G_s}$

20

So, now, I will try to explain that how this calculation can be done how we can obtain the numerator. So, as I mentioned that the specific gravity using the hydrometer reading can be calculated as $1 + \frac{R}{1000}$ let us say, so, specific gravity is what Rc because this is the corrected reading specific gravity of N Just I will draw it again to explain you that we are trying to see this case here, I am trying to see this case here and I am trying to see the weight of solids per unit volume of the layer in this particular case the numerator T =T.

So, specific gravity is basically equal to γ of this particular layer divided by the unit weight of water the basic definition. So, γ of layer can be written as weight of the layer divided by the volume of the particular layer divided by γ_W. So, this I can write as $\frac{1}{\gamma_W}$. So, weight of layer is basically equal to the weight of the solid present in the layer plus the weight of the water present in the layer divided by the volume of the layer.

This weight is equal to the summation of this weight $\frac{1}{\gamma_W}$. So, this I can write as separating weight of water by volume of layer plus weight of solid by volume of layer weight of water I can write as gamma of water into volume of water divided by volume of layer plus weight of solid divided by volume of layer volume of water I can write as volume of the layer minus volume of the solids is not it, so, this is what I am writing $\frac{1}{\gamma_W}$.

So, this is $\left[\frac{\gamma_w\,(V_{layer}-V_S)}{V_{layer}}+\frac{W_S}{V_{layer}}\right]$, just simplifying this expression now, separating it this is $\left[\frac{\gamma_w\,V_L}{V_L}-\frac{\gamma_w\,V_S}{V_L}+\frac{W_S}{V_L}\right]$, so, if we take γ_w s 1 then I get I am just putting γ_w s 1 so, I get this as $\left[1-\frac{V_S}{V_L}+\frac{W_S}{V_L}\right]$.

Now volume of solid if I know the specific gravity of the soil, so, volume of the solid I can write as $\frac{W_S}{G_s}$ now, here I should know the specific gravity of solid also, so, $\left[1-\frac{W_S}{G_S.V_L}+\frac{W_S}{V_L}\right]$. So, if I simplify this I can write this as $\left[1+\frac{W_S}{V_L}\left(1-\frac{1}{G_S}\right)\right]$. Alright.

So, if use come here, then this is $1+\frac{R_C}{1000}=1+\frac{W_S}{V_L}\left(1-\frac{1}{G_S}\right)$, is not it, I hope this is straightforward from here if I want to find $\frac{W_S}{V_L}$, I will get it as $\frac{R_C}{1000}\left(\frac{G_S}{G_S-1}\right)$.

So, this is the final expression which we get here. I know the specific gravity of the soil I am for which I am doing this particular test, I know the value of R_C and therefore, I know the I can calculate the value of W_S by V_L at different times at different times T because R_C will change with T. So, at different time T since I have the value of R_C, I can calculate W s by V_L and therefore, at different times T I can calculate percent final that particular size D I, I can calculate the percent finer corresponding to that particular size D I.

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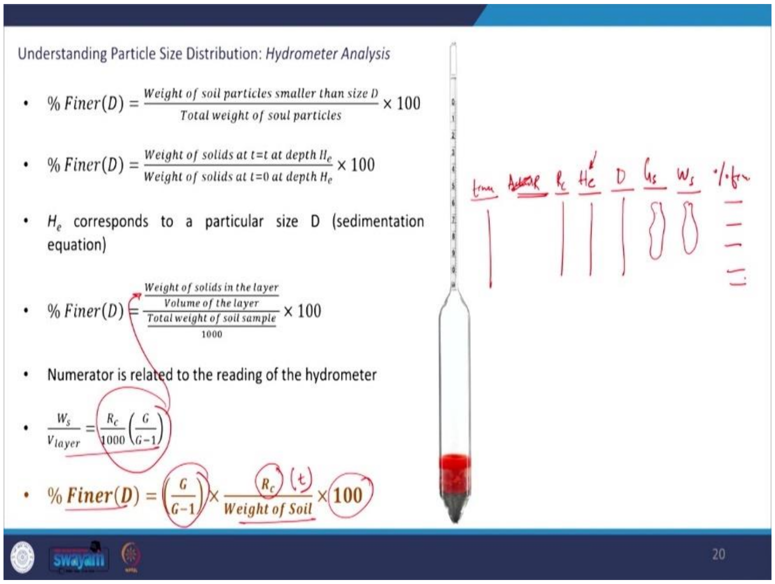
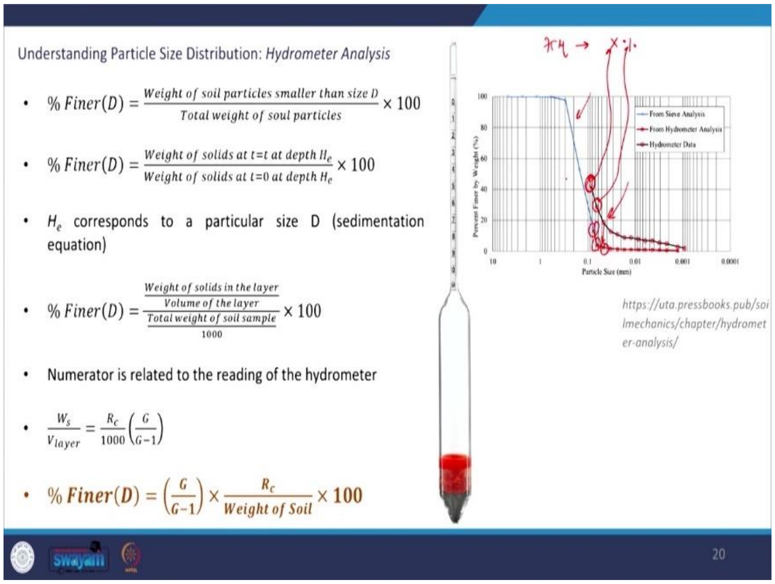


Understanding Particle Size Distribution: *Hydrometer Analysis*

- $\% \, Finer(D) = \frac{Weight\ of\ soil\ particles\ smaller\ than\ size\ D}{Total\ weight\ of\ soul\ particles} \times 100$
- $\% \, Finer(D) = \frac{Weight\ of\ solids\ at\ t=t\ at\ depth\ H_e}{Weight\ of\ solids\ at\ t=0\ at\ depth\ H_e} \times 100$
- H_e corresponds to a particular size D (sedimentation equation)
- $\% \, Finer(D) = \frac{\frac{Weight\ of\ solids\ in\ the\ layer}{Volume\ of\ the\ layer}}{\frac{Total\ weight\ of\ soil\ sample}{1000}} \times 100$
- Numerator is related to the reading of the hydrometer
- $\frac{W_s}{V_{layer}} = \frac{R_c}{1000}\left(\frac{G}{G-1}\right)$
- **$\% \, Finer(D) = \left(\frac{G}{G-1}\right) \times \frac{R_c\ (t)}{Weight\ of\ Soil} \times 100$**

time ~~Actual R~~ R_c H_e D G_s W_s % finer



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#4 → x %

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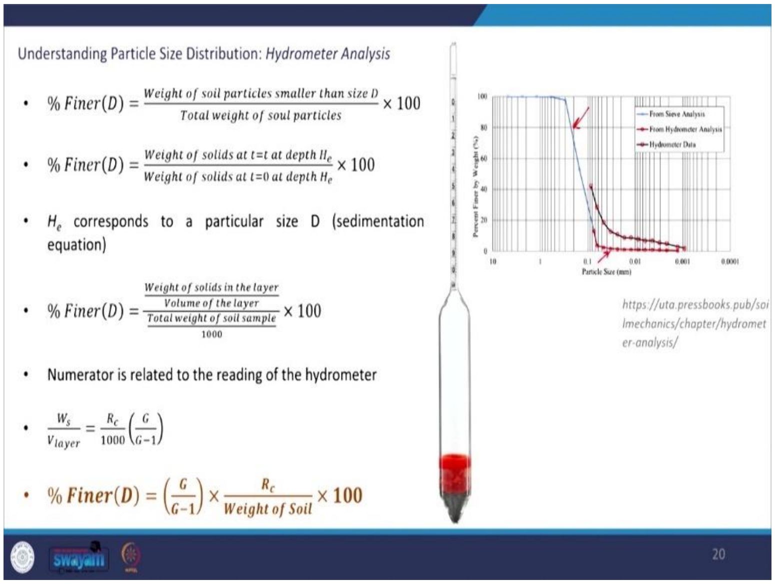

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https://uta.pressbooks.pub/soilmechanics/chapter/hydrometer-analysis/

So, as I said that numerator is related to the reading of the hydro meter and this is what we have derived. So, if I put this expression here, I get $\%Finer\ (D) = \left(\frac{G_S}{G_S-1}\right) X \ \frac{R_C}{Weight\ of\ Soil} X\ 100$, R_C which depends on time divided by the weight of soil multiplied by 100 Very simple. So, in the actual experiment, what kind of table will I have for example, I will I can have time a different time I will have the actual reading or the value of R of the hydrometer then I will have the corrected Reading R_C here applying all the corrections of the three parameters we discussed.

Since we have R_C we also have the effective height based on the hydrometer calibration. Once I have the H e value I also have the value of D because I know the this is based on this Stokes' law G of the soil I have to find out from laboratory test. I know the weight of soil which I have used and I can calculate the percent finer.

So, at different time different R_C different H_e different D, G_S will remain same then W s will remain same and correspondingly percent finer I can calculate. So, I hope that you know this is clear that how we use the hydrometer analysis to calculate the percent finer corresponding to different sizes and then we plot it in the combined curve.

So, this blue part of the curve which you are seeing is from the sieve size analysis, this red part on the top is from the hydrometer analysis and then we will shift this curve here by applying a correction to this reading. Because this is a continuous process for example, if 75-micron passing is X percent. So, this percentage I will multiply with X percent to get these particular values alright. So, I will just shift the curve corresponding to the total material passing 75 microns and I will get the sieve size distribution total sieve size distribution curve which is this one, so,

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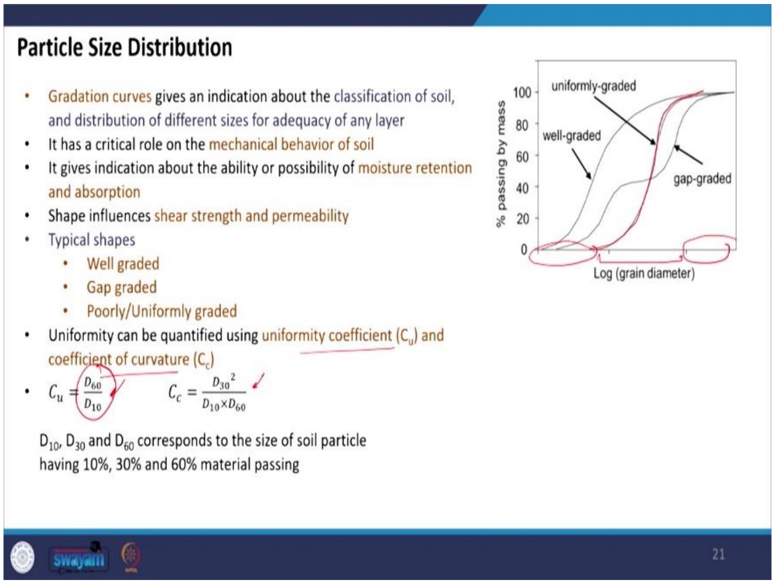

Particle Size Distribution

- Gradation curves gives an indication about the classification of soil, and distribution of different sizes for adequacy of any layer
- It has a critical role on the mechanical behavior of soil
- It gives indication about the ability or possibility of moisture retention and absorption
- Shape influences shear strength and permeability
- Typical shapes
  - Well graded
  - Gap graded
  - Poorly/Uniformly graded
- Uniformity can be quantified using uniformity coefficient (C_u) and coefficient of curvature (C_c)
- $C_u = \frac{D_{60}}{D_{10}}$ $\quad C_c = \frac{{D_{30}}^2}{D_{10} \times D_{60}}$

D_{10}, D_{30} and D_{60} corresponds to the size of soil particle having 10%, 30% and 60% material passing

I hope that this is clear to you now, a few concluding points about the particle size distribution concepts which we have discussed that gradation curve as I mentioned gives an indication about the classification of soil we will see about that about the classification process, it tells us about the distribution of different sizes for adequacy of any layer because for any given layer there can be requirement of some particle size distribution. So, I have to ensure that the soil or the material which I am using does it have that required criteria alright.

So, it has a critical role on the mechanical behavior of the soil because let us say if you have a soil mass where you have only single sized particles, that particular type of layer or that particular type of soil will have very high permeability, but very low stability. On the other hand, if the voids between larger particles are filled by smaller particles, which means you have a soil when you have different sizes of aggregate particles, that type of soil mass will have low permeability, but it will have higher stability.

So, the mechanical behavior is also directly related to the particle size distribution of the soil particles. It gives an indication about the ability or possibility of the moisture retention and absorption depending on the amount of let us say finer particles we will have amount of let us say a clay particle which will have in the soil mass.

So, that will tell me how this material will behave when moisture changes or moisture comes in contact with that particular soil mass. Shape also influences the shear strength and permeability, which I just discussed that if you have better interlocking, which means you have particles of different sizes, but the permeability will be less so, shear strength and permeability can be opposite to each other.

When there are typical shapes which are which are defined by looking at the serve size distribution curve. So, these are usually categorized in three classes, we have well graded soil. So, this is a well graded soil you see you have particles of different sizes in this particular soil mass all four different sizes of particles are present, then you have gap graded samples.

So, this is a gap graded, where you have some materials, finer particles, you have coarser particles, but these particles are missing, which means this size is same material passing this size, same material passing this size, same material passing this size, same material passing. So, this particular size range is missing in this particular type of a particle size distribution.

And then we have poorly graded or uniformly graded which you see here. Here, you have only particles of limited size for example, you do not have these sizes here. You do not have these sizes here you have only particle of the size. So these are mostly single sized particle and that is why this will have high permeability but less stability and it is not very desirable from the point of view of appropriate strength in the structure.

Now this uniformity I mean the distribution of the particle, they can also be quantified. Now this is what we are discussing visually. You see the shape looks like this. The shape looks like that, but the shape can also be quantified using different parameters.

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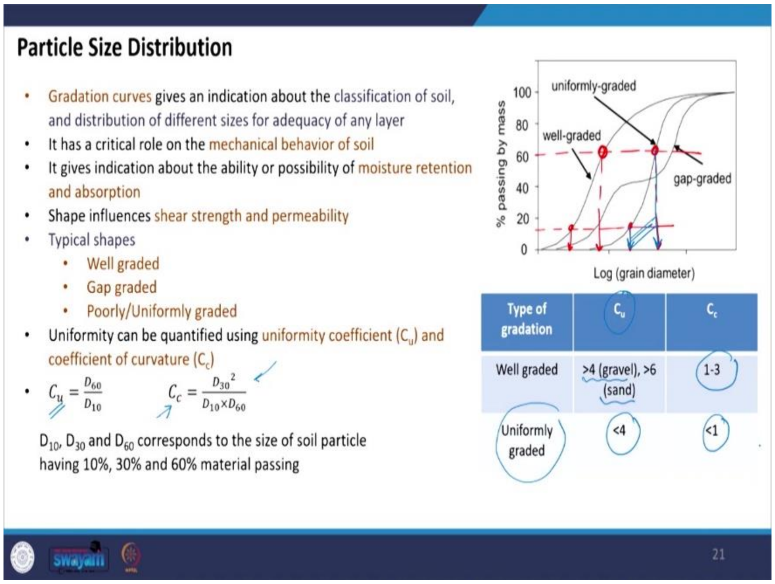

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D_{10}, D_{30} and D_{60} corresponds to the size of soil particle having 10%, 30% and 60% material passing

Type of gradation	C_u	C_c
Well graded	>4 (gravel), >6 (sand)	1-3
Uniformly graded	<4	<1

For example, commonly two different parameters are being used that is uniformity coefficient C_U and coefficient of curvature C_C. So, this is the definition or formula for C_U and C_C. So, C_U is $\frac{D_{60}}{D_{10}}$ and now, what is D 60? D 60 is the size corresponding to which 60 percent of the material is passing let us see this curve.

So, I will just draw a straight line here. So, in the welded structure, this is 60 and in the usually grid structure this is D 60.

So, this is D 60 in these two curves and similarly, D 10 is the size D corresponding to which 10 percent of the material is passing. So, if you come here and just draw a line, so, this is D 10 for the well graded structure and this is D 10 for the poorly graded structure, I will just use a different color to set the difference alright. Now, just by looking at the curve, what you can see, let us say I want to do some analysis for C_U and try to tell something about or quantify something about the curve.

So, you see in case of well graded structure, the value of C_U will be higher, because D 60 and D 10 will be separated from each other by some amount alright. But in case of poorly graded structure, they are they will be very close to each other, which means the ratio of D 60 by D 10 will be less. So, this is again one indication. So, based on this already we have some specifications existing that tells us about the particle size distribution or quantify the particle size distribution of the curve.

Similarly, we have C_C and other parameter which is defined as $\frac{{D_{30}}^2}{D_{10} X D_{60}}$. For example, if it is a well graded structure then as I said the value of C will be higher if it is a gravel it is greater than 4 for sand greater than 6. If it is a uniformly graded or poorly graded it is usually less because you do not have many particle sizes in that particular curve. Similarly, the value of C_C ranges from 1 to 3 for well graded structure and it is usually less than 1 for poorly graded structures. Well, this is all about the particle size distribution and we will stop here today and in the next class we will take upon a new topic that is consistency of soil and we will discuss about it. Thank you.