River Engineering
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Lecture – 02
Basic Properties of Sediment

Good morning to all of you. This is part of hydro-fluvial ecology lab. We are going to have next lecture on river engineering and here in this lecture, I will talk about basic properties of sediment.

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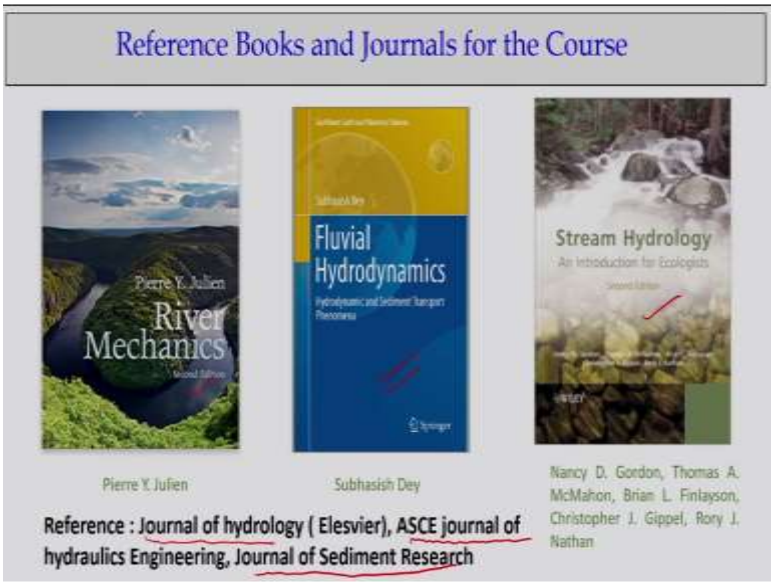

If you look at these 3 books what are there, is very tactically these are selected for river engineering looking the present context, like the first books on P. Y. Julien's River Mechanics, which talk about basic mechanics in river engineering. The second book which is Fluvial Hydrodynamics, which talks about the advanced level of river engineering where turbulence properties, the sediment transport properties in present era, how we can model it, how we can understand it more detailed mathematical way.

No doubt another book which we have selected is a stream hydrology an introduction for ecologists. So, this is the perspective of ecologist point of view what should be the river and how we should understand the river mechanics. Not only that, we will go through a series of journals like the Journal of hydrology, American Society of Civil Engineering journal of hydraulics engineering. Then we will also talk about Journal of sediment research.

Just into before starting this class, I want to say it, this is a class what have been designed for the faculty, the engineering students and river engineers who are in the field to take decisions for a river management. So looking that this aspects, the course has been designed. It is not for a theoretical presentations of river engineering, but it gives a practical perspective of river engineering especially in the developed country like India.

How we can manage the river in better socio-economic benefits looking for as well as not the short terms as the long terms.

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Let us go through today's lecture content. We will talk about river dynamics. We will talk about the river surveys and then we will go about the properties of sediment particles like particle size distribution curve, which you may have knowledge in geotechnical engineering. Then we will talk about very simple concept of size and shape of the sediment particles and we will talk about how this sediment mixtures and size distribution concept and angle of repose.

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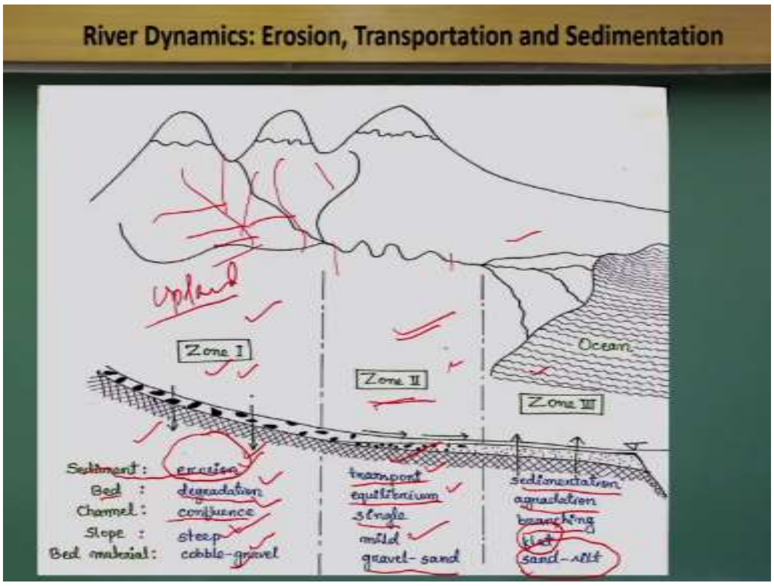

Let us start the very basic understanding. Look at the sketch of these figures. As you know it from basic undergraduate levels, the river starts from the uplands, the hilly areas, those uplands are managed as zone 1 because in that upland you will have an erosion process, it will be active process. There are many tributaries they will actively erodes either from the surface erosions, the bed erosions or the bank erosions.

So you will have a significant erosion process which is going to happen in zone 1. Bed conditions, the riverbed conditions will be in degradation. That means, more deepening and drifting of channels will happen. Channels will have more confluencing zones that means many tributaries are joining each other, so you can see that many confluence zones will happen. When you look at this upland hilly area, the water and sediment flow originate from the hill slopes.

The slope here is a steep slopes and most of the bed materials in the river will be gravel or cobbles. So, basically if you look at the zone 1 which is upland area, the source of water and sediments, it has the dominant process of erosion process, the riverbed will be degradation state and you can see the channels are confluencing each other and slope will be steep and bed materials more often we can see the gravel bed materials and the size of the bed material is much larger as compared to next zone.

Let us come to zone 2, which is mostly in the fluvial plain regions, where you have basically the transport processes. That means whatever the water sediment process collected in zone 1 that would goes through this stretch of the river, which is the zone 2 reach of the river. It just transport the process of water and sediment and the nutrient. So, these are the transport mechanisms. It may have the aggradation-degradation, but overall it will be the equilibrium positions.

That means there is a change that much significantly the fluvial geometry of the river at these zone as compared to zone 1 or the zone 3. The channels more or less will be the single channels and the slope will be the mild and here you can see that there is a composition of the gravel and the sand. So, you go to the zone 2. So, upland to the middle reach, then we have the lower reach of the river.

Where whatever the sediment carries by the river, it cannot have the transport capacity to carry beyond that part. So, that is the reason it starts depositing the sediment particles. So, there is a sedimentation process happened. Because of the sedimentation process happens, the channels become aggradation states, means it is arising, the channel bed will be the rising state and you can see there is lot of branching of the channels it happens at this reach before reaching the oceans or the lake.

More or less the channels slope will go flat and the bed materials or bank material compositions would be sand and the silt. So, I have given very simple pictures if you start from upland and travel to the middle land and the low land, you can see that how the rivers behaves in 3 different zone. Upland areas, you will have erosion process will be activated, zone 2 there will be transportation process happening.

When you go for the zone 3 you can see the sediment texture process. The morphology behaviors will be the different. The slope will be different and the process are different. We should try to understand the river mechanics by doing a field visit because that is the more important. To do any river studies, first we should visit the river that is what we are showing in the next slides.

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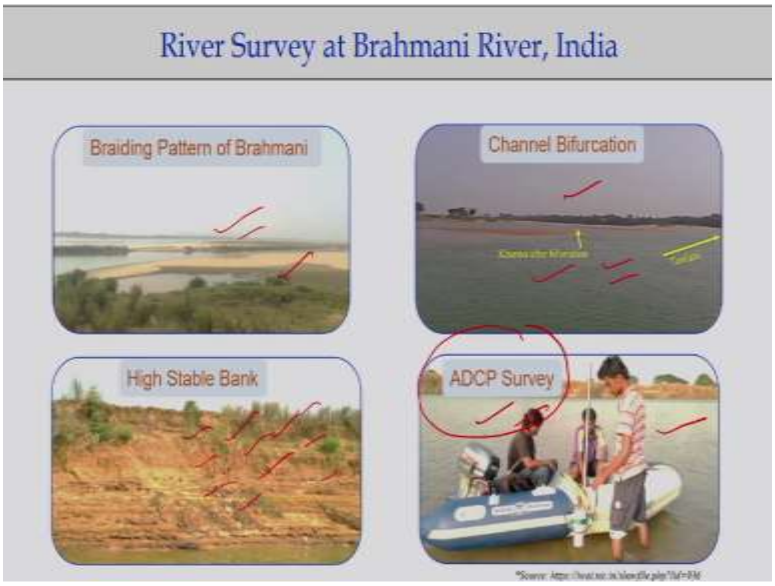

If we look at that what the study we have done it for Brahmani river, Odisha in India. So, basically if you look at the snapshots which you in general see this picture of rivers, but in river engineering, I can interpret many things about this river systems. Like if we look at these figures, you can see is the river is a braiding patterns, it is a multiple channels. The channel bifurcations are there, the channel diversions are there.

So, you can see from these figures there are channel bifurcations. You can see this bank materials, you go to take the photographs and see the bank mental, how does it look? What are the compositions it has? Is it a sand, is it a clay or is it sand and clay compositions? You try to analyze it, not only that you try to understand what type of stratifications are there. Whether the vegetation presence is there?

If the vegetation presence is there, what is the strength of the soil, is increased or decreased? So, all these things we try to understand when you do a field visit, take a photograph and analyze it at very preliminary level and we can go up measuring this velocity distribution, the discharge, the sediment concentrations like equipment like Acoustic Doppler current profilers.

We can do very extensive river survey to quantify how much of water flow is there, how much sediment flow is there and how does it varies from locations to locations. We can do the river survey, we can collect the field photographs to try to understand how things are changing.

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So, same way if we look at this what we do is many of the river we have intervention systems. Last 100 years we have intervened the river in different ways like for examples there is barrage structures, there is intervention. Because of this intervention, how this river mechanics changes, the sedimentation changes, how river flow changes, how the morphologies are changing it?

So, those understanding we should have like because of this intervention systems, because of having the barrage, having the small weir structure, you can see that there is a weir, over which the water is spilling. So because of that we can see that way back, 100 years back, the weir structures because of it is totally silted. That means you can see that in this photograph that weir is totally silted up.

So, all these informations about the river and the river behavior we should understand when you go for a field visit, take the photographs, analyze that what is happening to this river, what could be happened and what is going to affect it? Those the understanding in terms of water, the sediment and the nutrient understanding with the different mathematical models, physical models.

The field studies gives us a very synoptic response of the river systems, which looks like vary at a distance is a complex but we can look at how it behaves in a simpler form. So, basically this course is designed for you to understand so complex systems of water, sediment, nutrient, society, how complex systems you can understand with our existence knowledge on river engineering. So, that is the reason you see this is sandbar formations.

If you look at that it also says a story, but we should try to understand why does the sandbar formation happen? What is the behavior behind that? All we can study, all we can interpret if you have a knowledge on river mechanics.

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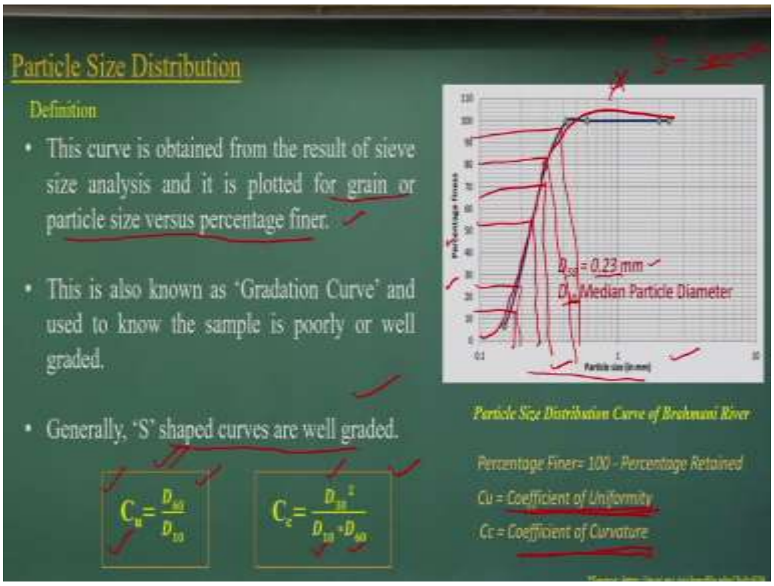

Now, go to very basic things that what do we do is we bring the soil bed samples. We go to the field, from the bed level we bring the soil samples. So, we should bring enough number of the soil samples to the lab and do a particle size distribution curve analysis, which is simple thing. Through the sieving analysis, we can find out the particle size distribution curve or if we have a particle size that are very smaller, we can use the hydrometer analysis.

So we can get a particle size distribution curve of bed materials or the bank materials. Basically, it is the gradation curve is a plotted or it is a particle size versus percentage of finer. If you look at this x axis and y axis, this is a particle size which is in logarithmic scale in millimeter level, you have a percentage fineness, beyond this this much of a percentage finest pass through that.

That means if I talk about D50 = 0.23 millimeters that what is indicating for me that 50% of the bed material particle will pass through 0.23 mm size of the sieve. In similar way you can interpret for 80%, 90% we can interpret also for 10% or any percentage. So, this is a percentage of finer. That means you can have a sieve size, you can find out how much is passing out, how much it is retaining it, that percent is in volumetrics you can obtain the percentage of finer.

The most of the time this particle size distribution curve is S curve, the shape of this curve is close to the S curve. To define it, is it a well graded, well composed in a different size, we quantified it into two basic terms, in terms of coefficient of uniformity and coefficient of curvatures

Coefficient of uniformity (Cu) = D60/D10

That means from the particle size distribution curve, you can find the 60% finer value, 10% finer final value, that ratio will show us coefficient of uniformity.

So, the particle size distributions as you can understand it, river does not have any uniform distributions, you will not have a single distributed same size of the sand, same size of gravels, always there will be mixtures, that the reason we should try to understand the river mechanisms first by taking the bed samples and see this particle size distribution curve, how does it happen in terms of coefficient of uniformity and coefficient of curvatures.

Which is in a function of D30, D60, D10 which is similar things we might have the knowledge from geotechnical engineering.

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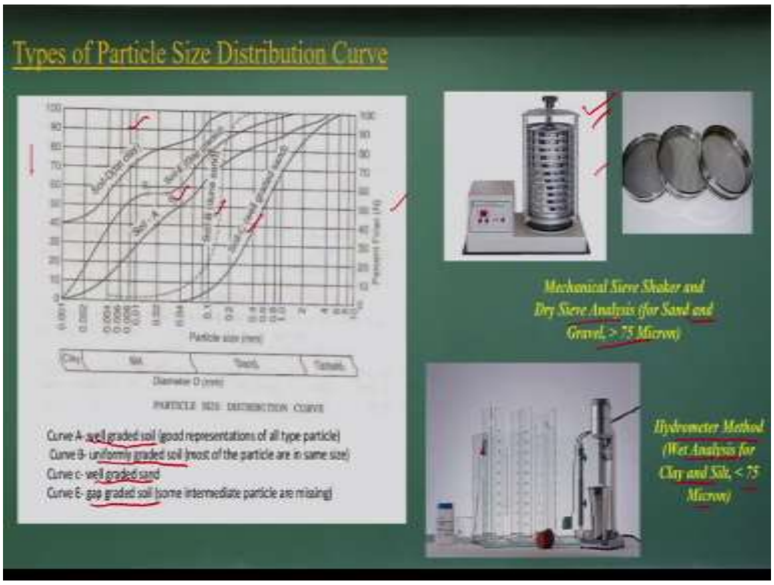

Now if you look at that we define based on the particle size distribution curve, the type of the soils if it is well graded soil, uniformly graded soils, well graded sand and the gap graded soils, all are the different soil characteristics. If you look at the A, B, C, D curve, the particle size and the percentage of finer. So, you can see this S curves for different type of the soils and based on that we define the type of the soils.

We use mechanical sieve, which is a very simple equipment to take the particle size of having different sieving sizes and you just do mechanical sieving with dry soil sample, the sieve analysis be done for the sand and the gravels. Whereas hydrometer methods we follow it for wet analysis for the clay and silt where we have the size is less than 75 microns. So, we can see the photographs of hydrometeor.

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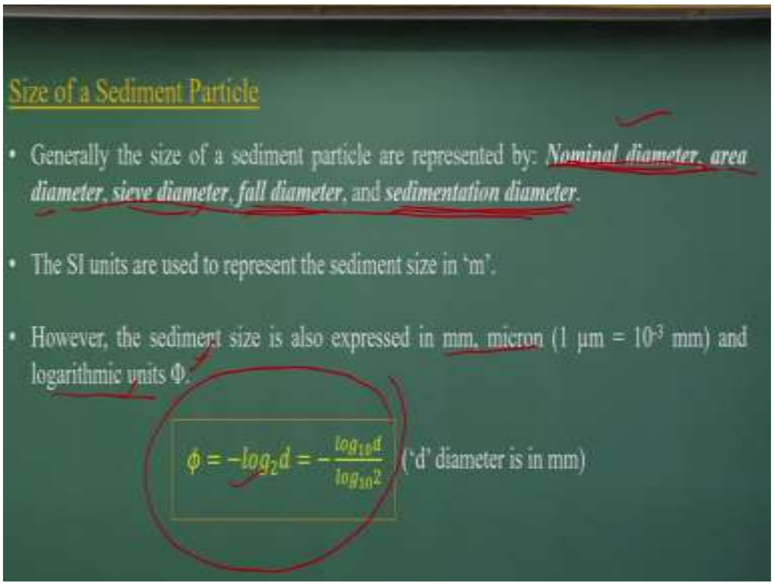

Let us come to the next one is about size of a sediment particles. When we talk about sediment particles that means sediment particles are transport process, the erosion process and the depositions process, aggradations, transport and the degradation. These process all depends upon definitions of diameter of sediment particles. We do not define in terms of only physical diameter of the sediment particles.

You can understand if you take a sediment particles any river bed materials, you cannot have a uniform size. Also their shape, size also matters it, how it will be transported, how it will be deposited, how it will be start to eroding it. So, that is the reason we define in different diameters like the area diameters, nominal diameters, sieve diameters, fall diameters and sedimentation diameter.

So, we can see, understand it, you cannot have a sediment with a uniform size, that is the natural process. So, we will have the mixtures of the sediment particle sizes. So, looking that we define the sediment into the 5 different diameters. Nominal diameters, the area diameters, sieve diameters, fall diameters and sedimentation diameters, and most of the times we do not define the sediment in terms only the millimeter or micrometres, also a logarithmic unit of the ϕ which is given here.

We can define it in terms of ϕ to scale off because you can have a very, very finer particles, coarser particles or medium particles. To define the range, we adopt a logarithmic units of the ϕ to define the sediment particles, which is an international standards to define the sediment particles.

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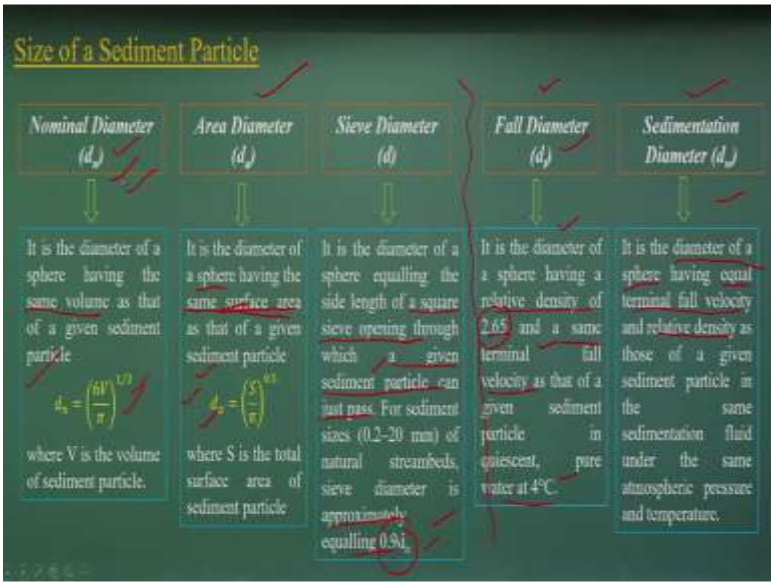

Now, let me talk about these 5 different diameters we use to define a sediment particle size. One is nominal diameters which are very simple things. You take a sediment particle, you consider as equivalent as a sphere, what could be the diameter that is what will be the nominal diameters. That means, you take a sediment particles which will be so finer or you can have a gravel, you can look at that once, you make it as equivalent it is a sphere.

If it is as equivalent to sphere, what could be the diameter, that is what is the nominal diameter, but if you look it because many of the process you talk about the surface area, not the volume. So, when you talk about the surface area, then we call as equivalent surface area. Here, we have considered the volume, but here we consider in terms of surface area, we do not bother about the volume of that one.

So, if that is the case, what could be the equivalent diameters of your sediment particles? If I consider an equivalent sphere of the same surface area that is the area diameter. Now let us commit how do we quantify these diameters, it is not easy to measure a simple sediment particles and go to microscope and measure the things, we cannot do that way. What we generally do is to perform the sieve analysis.

That means, let us quantify in terms of sieve diameter, but in a sieve what do we have? We have opening which is the square opening. We have the square opening, so we try to locate that if a given sediment particle can pass through that, then we call it that is a sieve diameter. So, we try to find out the sieve diameter of that which is the equivalent of 90% of the d_n value.

So, instead of going to measure the individual diameters at the volumes level or the surface area level, we just do the sieve analysis. From the sieve analysis, we try to relate it as theoretically we know it, it would be the 0.9 of the d_n value that is what we compute the d_n value. Now, if we look at the other two diameters, fall diameters and sedimentation diameters, many of the sediment transport process that sediment it try to fall down.

So, we try to know it what could be the fall velocity. So, we try to find out in a two way again as equivalent to a sphere, find out of having a relative density of the sand which is 2.65 with a temperature of 4 degree that diameters we call is fall diameter. So, this is related to the sediment fall, the sediment deposition process what it happens. When you consider that, we will talk about the fall diameters.

The sedimentation diameter if you look at the next level where you try to find out diameter of a sphere having equal terminal fall velocity, relative density will have the same. In earlier case in fall diameters, the relative density we have considered 2.65, but in this case of sedimentation diameter, the relative density will be the same as the material relative density that is the reason we would call sedimentation diameter.

So, if we look at that any size of the sediment particles or the group of the sediment particles, we define them in different diameters and each one has a own utility in terms of sediment transportation process, the deposition process, like the sediment processes, we are more concerned about the fall diameters, sedimentation diameters where we talk about the buoyancy forces.

The things we can talk about the nominal diameters is about the volumes, and where is the aerial diameters we talk about if there are any processes happening there, nutrient contents and all in a sediment process that is what we talk about at the surface area levels. So, these 5 diameters look at very theoretically, but please try to understand it these 5 diameters we use it to define the sediment properties for different process.

Depositions, the lifting process, the nutrient carries and the middle one the sieve diameter which is easy to measure the sieve the diameter of the sediment particles just doing a sieving and can establish links between the other part. So, please have a look at these 5 diameters, the nominal, area, sieve, fall diameters and sedimentation diameter.

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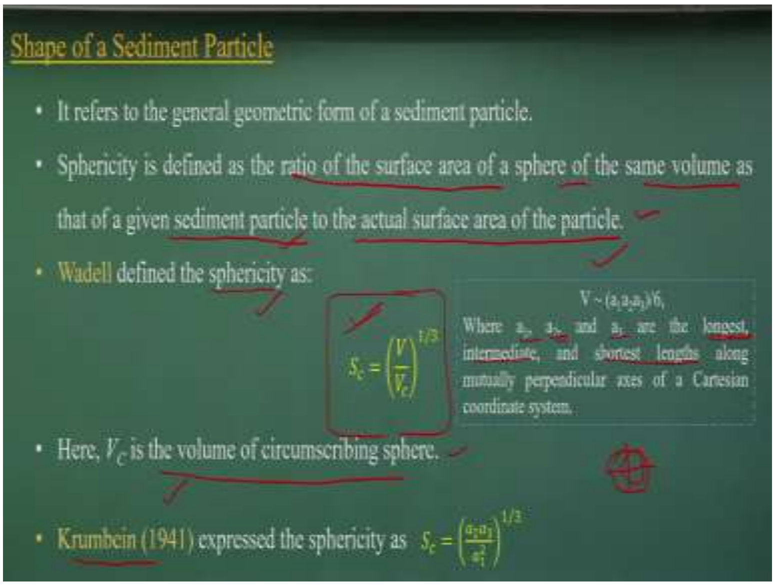

Now, if we look at how do the shape of the sediment particles which is necessary for if we talk about nutrient transport or you talk about the sediment remain in the floating conditions. Again we define as a sphericity as equal to the sphere, what could be the shape that is what we define with this empirical relationship that if it is equivalent to a sphere that means any of the surface area of the sphere, the same volume as given the sediment particles to actual surface area the particles.

That what is defined as a sphericity and is a simple equation and you can define it because volume is a 3 dimensional component, we do this (1/3) to compute any dimensional component, but if you do not have the sediment particles as close to the spherical shape, you can have a 3 dimensional lengths in longest, intermediate and shortest lengths. So we can have a longest part, we can have an intermediate part and shortest part.

So, 3 perpendicular axis we can measure at once and you can compute the V values. Same way you can have V_c is the volume of circumscribing sphere that is the equivalent part and there are other people who also defined the sphericity as a functions of a_2, a_3, a_1. The a_1 is the longest length, the a_2 is intermediate length and a_3 is the shortest length. So, it needs to have microscope for smaller particles or if you have a gravel, you can measure with a scale.

You can measure it, but if you have the sand you cannot measure it, but if you have a gravel you can bring it and can measure this a_1, a_2, a_3 and you can compute it what could be the sphericity which the formulas are given here and basically has equivalent properties.

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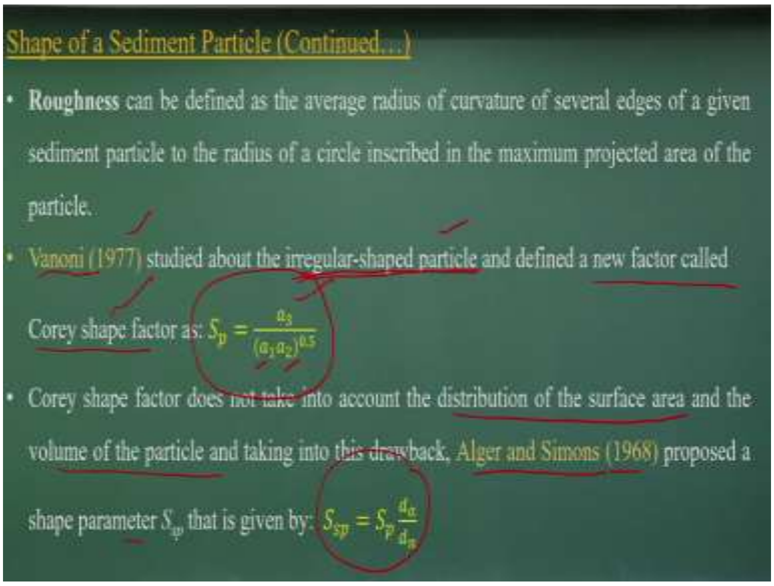

Same way, there are other researchers also given these relations, like Vanoni in 1977 defined a new factor is called Corey shape factor which is functions of same thing a_1, a_2, and a_3. So, definitely, this it is valid for irregular shaped particles. Similar way, we can have another equation in 1960s, here he has proposed the shape factor given by again the modifications upon that which consider the distributions of the surface area and volume of the particles.

This look like empirical equations, but this is what conducting a series of experiments taking the sediment particles, they established it as equivalent factor for Corey shape factors or the shape factors proposed by Alger and Simons in 1968.

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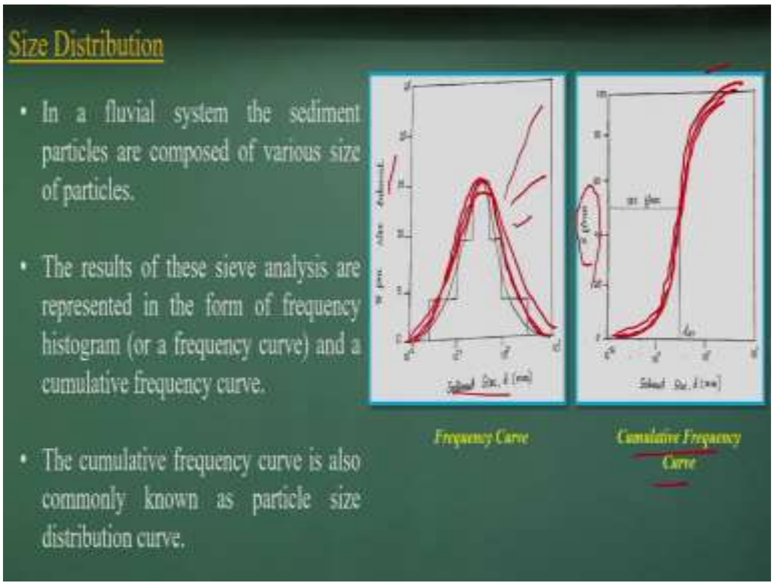

So, basically let us come back to the very basic concepts we use it that when you take sediment from the rivers as I said it earlier, it will not have uniform distributions. They will be different group of different size of sediment particles will be there. What do we do it, we do the sieving analysis. At different size of the sieves, we do the sieving analysis, we find the percentage of finer.

But if you put in the percent of a size involved and the particle size and draw this curve, more or less it will follow the frequency distribution, normalized frequency distribution curve that is what we get, that is what is the nature when you take the sediment particles from any rivers, it follow this, mostly it follow this normal distribution curve, percentage of size into sediment size, but if you make it a percentage finer you will have a cumulative distribution curve.

Which is so often you use in any statistical analysis, the normal distribution curve has probability distribution function, cumulative distribution curve is a probability density function. So, if you look at these distributions which follow many the populations, any populations you can see that it follow a certain distribution to the normal distribution curve and the cumulative of that this is what the cumulative frequency curve.

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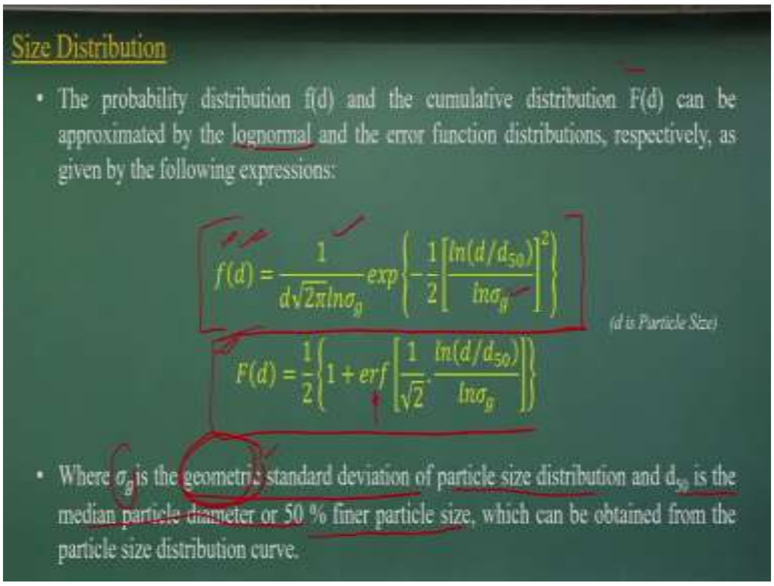

Recently people tried to fit a normal distribution curve and tried to find out whether you can define the sediment particles in terms of distribution function, so not just a 50% finer value or d50 or d80 or d90 instead of that try to understand the sediment properties in more details, they follow a probability distributions concept like if we look at that it has given us the distributions file which is log normal distributions file.

And if you do a cumulative function we simply have an error functions on these. So, we can have a distributions file like this. So, you can find out if we know this d50 value you know the σ_g value, you can compute for a particular d what will be the probability distribution function and what could be the cumulative distribution function.

I just encourage all of you to just use a MATLAB or any mathematical software to just draw different d50 value and σ_g value to draw the normal distribution curve followed by the cumulative distribution curve. So, if we look at σ_g here is defined as geometric standard deviations. Again I am highlighting, it is not a standard deviations, it is a geometric standard deviation of particle size distribution, that you try to understand it.

The soil composition what we will get it after sieving it, it follow the normal distribution curve, but it does not follow the standard deviations, it follow geometric standard deviations. How to quantify this? The d50 is a 50% median value diameter or 50% particle size, which we can obtain from curve.

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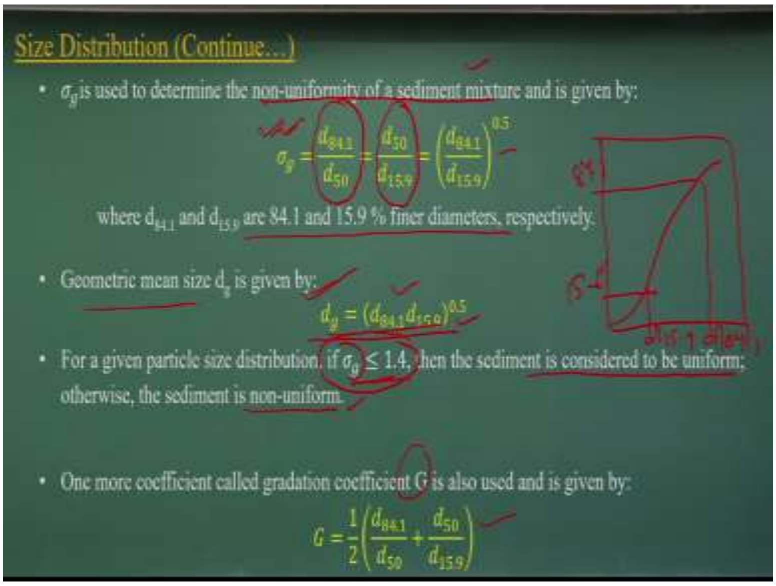

Now, let us talk about how to compute the σ_g which is geometric standard deviation, how to compute it, which will be functions of non-uniformity of sedimentary mixture that is what we are talking, which will be a function of σ_g will be a ratio between d84.1 and d50. So, the particle size for the 84% finer, the particle size for the 50% finer which we can get it from particle size distribution curve or you can have it equal to d50 divided by d15.9

And all you can compute in the finer diameters, you can find out what will be the geometric standard deviation or there is a geometric standard deviations in terms of d85. So, that means again I have to draw it. So, you have a particle size distributions for the 15.9% finer you can get d15.0 similar way you have 84.1 so you can get a d84.1 and the square root of the product will give you the geometric mean of that.

If the geometric standard deviation is lesser than 1.4, then we call, the sediment can consider as uniform, otherwise non-uniform sediment deposition. Many of the times we do the flume experiments to tell it is a uniform sedimentary distributions or non-uniform distribution that is what we quantify in terms of geometric standard deviations, which we compute prom particle size distribution curve.

More coefficient called gradation coefficient which is again capital G, which is a function of d50, d85 and d15.9.

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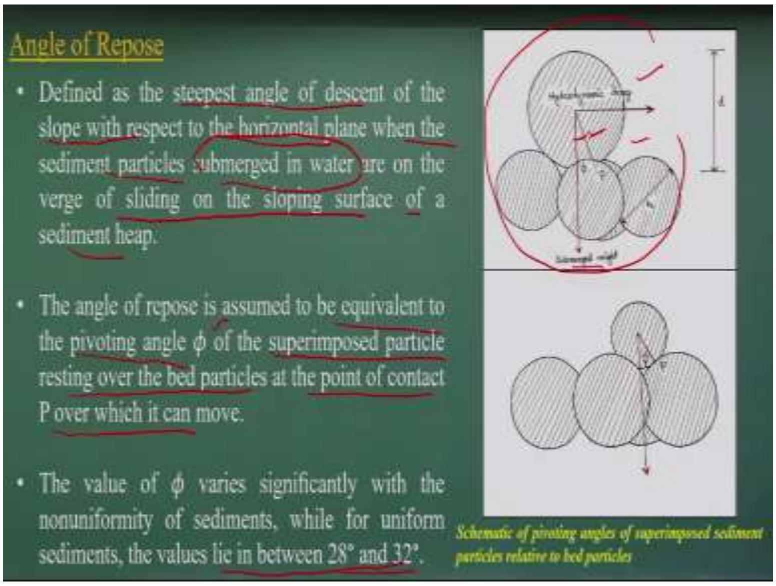

Now, if we look at these other parts what we are talking about the angle of repose. If you look at that in a river, there will be sediment depositions. We try to look at what could be the angle of equilibrium angles that sediment deposition can have in it. We can do a very simple experiment, take the sand and just pour the sand if you see that it remains at a particular angle, beyond that in start falling.

So, this is the concept we will talk about how that angles happen, the steepest angle of the descent of a slope with respect to horizontal plane. If you look at these ones when the sediment particles submerged in the water on the verge of the sliding on the slope surface on a sediment heap. You can conduct this similar experiment, very simple experiment. You have a container, just fill up the sand and you see that at what point that slope will maintain it.

You create the heap and you try to look at what is the angle it can maintain or, the sand particles if you look at the microscopically, there will be a hydrodynamic drag, there will be submerged weight, there is a balance in between that, that angles would define as angle of repose. This is equivalent to pivoting angles of ϕ which is superimposed particles resting on the bed particles at the point of contact over P it can see these figures.

This this angle is known as angle of repose. This is what is necessary for us to know the sediments, the heap is stable or not stable and these values for the sediment varies from 28 to 30 degrees and most of the times we consider is 30 degrees enough for angle of repose.

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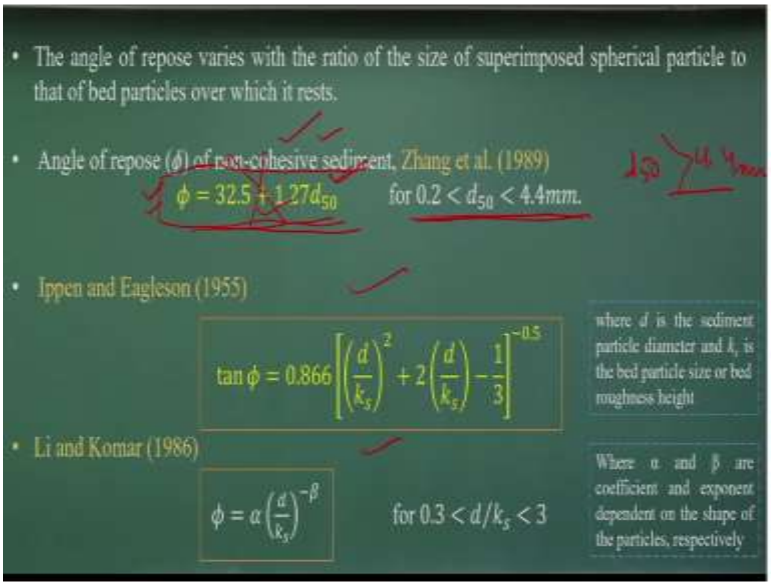

Many of the times we go for more details like for a non-cohesive soils like sand soil, we try to find out what could be the angle of repose with these empirical equations, which establish a relationship between angle of repose and the d50, d50 stands for diameter at the 50% finer. So, we can empirically establish it what could be the angle of repose if we just know the d50 value.

So, we can find out the angle of repose, but this equation is valid for this range of the d50 which is vary from 0.2 to 4.4 millimeters. This is the range this equation is valid. Whenever you apply the empirical equations look at these valid range because these equation is established for this range, which is valid for this equation, so please do not use these equations the d50 beyond 4.4 mm because this equation is not valid for that.

So, try to understand the empirical equations are developed for a certain range of the data and that is what we should look at before applying this equation. Same way, we can have more details to determining this angle of repose. So, please go through the books of fluvial hydrodynamics or these materials to have a look about these empirical equations.

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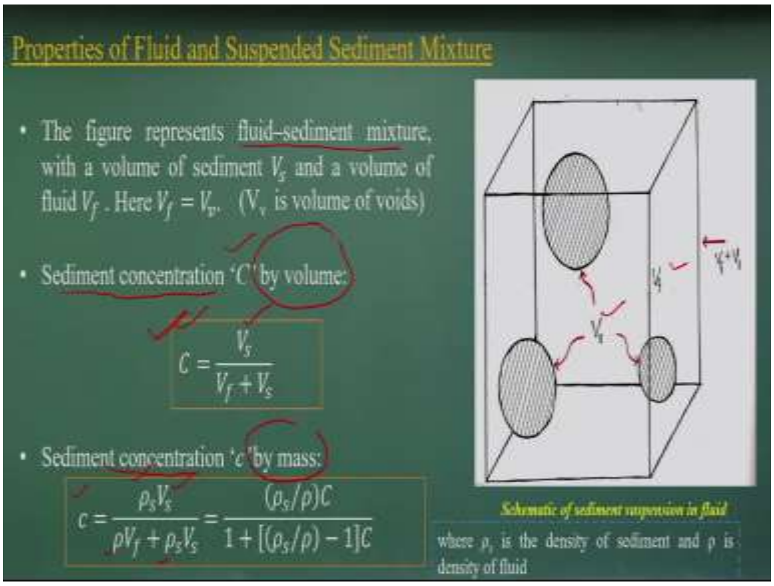

And before ending this class let me bring a very simple idea. If you look at this sediment carrying the river systems that means water is there and the sediment particles are there. That means volume of the fluid and volume of the sediment. In the river, we have 2 compositions, one is water and other is volume of the sediment. So water fluid and sediment mixtures that we have.

So, if that is there, if I have to quantify what is the sediment concentration in terms of volume that means how much of concentrations I have. The volume of sediment divided by the total volume which is equal to $V_f + V_s$, so that is what in terms of volume how much of area is occupied by the sediment particles. Let us talk about the sediment concentrations C by the volumes. When we talk about the volumes we can have a volume of sediment by the total volume which is equal to $V_f + V_s$.

So, we can get the volume, the sediment concentrations. So it is a very simple way to know it how much concentrations are there. Higher the presence of the sediments, higher the sediment concentrations, so C will be the higher value. If low sediment concentrations that mean V_s will be the less, C will be the less, but many of the times we do a mass conservation properties.

We do not look at the volumetric levels, when you do the mas conservation properties, we multiply the density with the volume to get the mass like what could be the mass of the sediment particle are there which will be equal to $\rho_s V_s$, where ρ_s is density of sediment particles and V_s is the volume of the sediment particles. Same way, if I just multiply it, I will get the sediment concentrations by mass, this is by volume, that is the difference.

So, we talk some time the sediment concentration in terms of volume point of view or in terms of mass point of view. So, the C value will be the different and many of the books will define it with a capital C or small c for sediment particles by mass.

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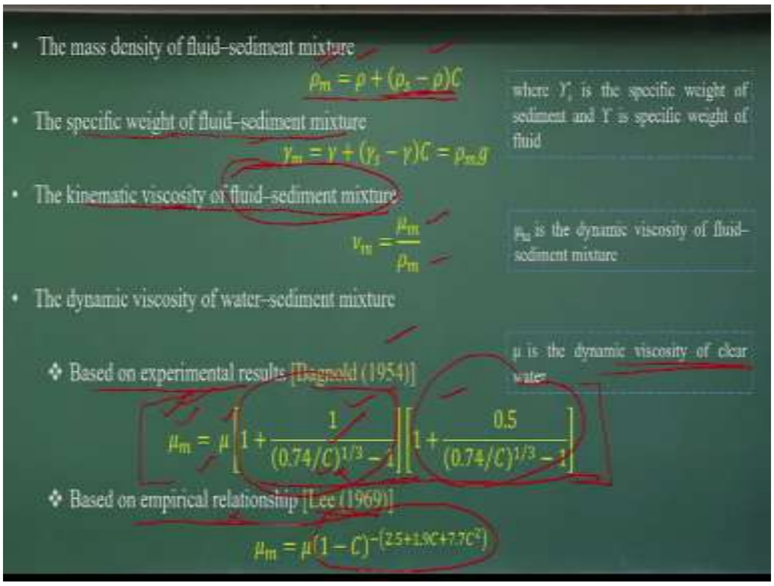

Besides that, we talk about a mixtures, fluid and sediment is there but we do not try to make it the different, we mix it. So, we can have a simple linear mixing concept, you have a ρ, you have a ρ_s, you have buoyancy force part. So we can compute what could be the mass density, what amount of mass will be there. Similar way we can have the specific weight, which is obtained by

$$\gamma_m = \rho_s g$$

The kinematic viscosity for the fluid and sediment mixtures also we can define, like fluid mechanics the dynamic viscosity by ρ and the dynamic viscosity from the experimental results if you look it, it has been established in functions of capital C. Here the μ stands for dynamic viscosity of the clear water. As the sediment concentrations changes, the kinematic viscosity of this fluid and sediment mixture changes.

And experimentally it is established that it follows as functions of μ is the dynamic viscosity of the clear water with a multiple constant as it is given it as multiple constants, which is a function in terms of capital C or there is an empirical relationship which is Lee 1969 it has given is in terms of a power functions. So, these are all empirical equations to establish to find out what is the kinematic viscosity of fluid-sediment mixtures.

Because when a river is flowing, it is not only water is flowing, it is flowing water and sediment. So, we need to know what could be the viscosity, which will be the functions of the mu is as equivalent dynamic viscosity of clear water and function of C the sediment concentrations in terms of volume, volumetric sediment concentrations.

These are the empirical equation is established per Lee 1969 and Bagnold 1954. It establishes what could be the as equivalent is kinematic viscosity of fluid and sediment mixtures.

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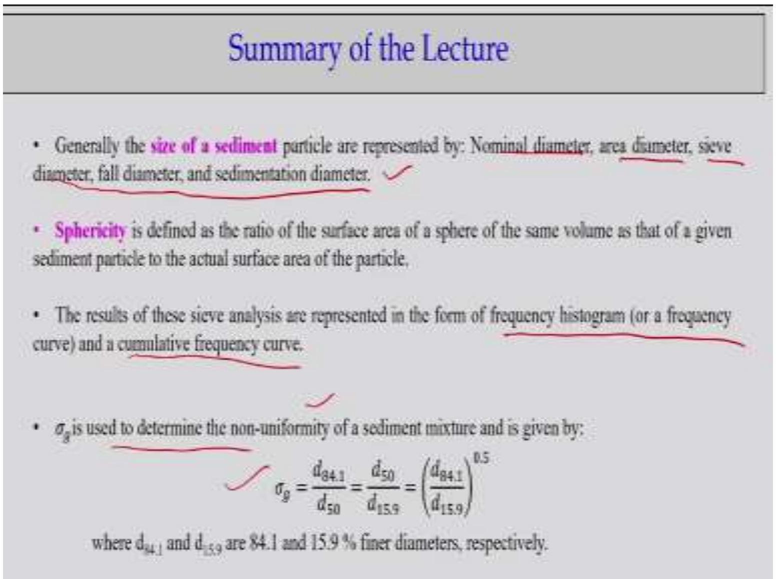

With this let me come to summary of these second lecture. Most of the things we have talked about mostly we are bringing in the concept is that like nominal diameters, area diameters, sieve diameters, fall diameters and sedimentation diameters. We talked about the frequency curve, we talked about cumulative frequency curve. We also talked about how we define it, whether the sediment mixtures are uniform or non-uniform.

And we talked about geometric standard deviations what we use to find out what could be the sediment and whether you can consider uniform sediment or non-uniform sediment.

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With this let me thank our group. We have been extensively working on river morphology, river hydrodynamics across the Indian rivers, global scales, we have been doing lot of river studies. No doubt we will give you to lot of explores of what level of the difficulty we will face, how to solve this complex problems in different part of the world. So these are my research groups who have been preparing this material for you Chandan Pradhan, Ketan Nandi, Riddick Kakati and Sahoo.

End of this lecture let me talk about the quote as given by Vinita Kinra if Ganges is the mother, Himalayas is the father. One nurtures and nourishes, the other provides and protects. So looking this quote, we should look at the river beyond just a water pro system. With this, let us conclude this lecture. Thank you.