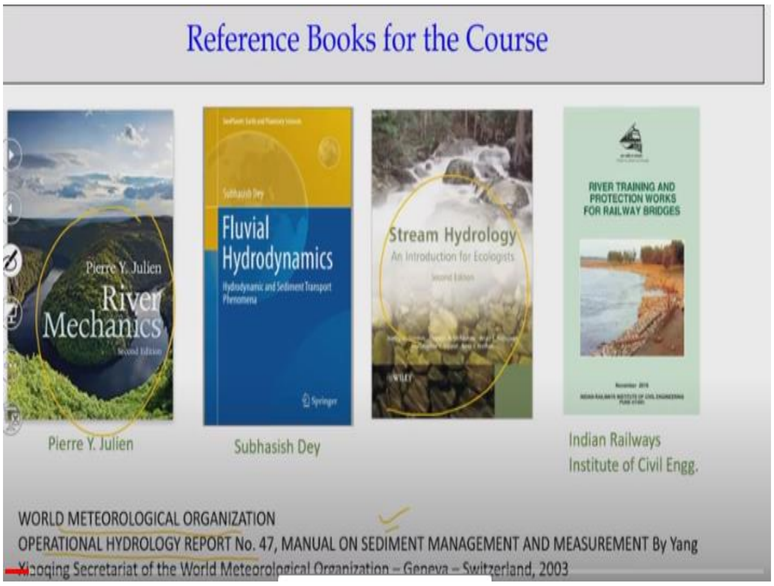
River Engineering
Dr. Subashisa Dutta
Department of Civil Engineering
Indian Institute of Technology-Guwahati

Lecture - 12
Sediment Transport in River-II

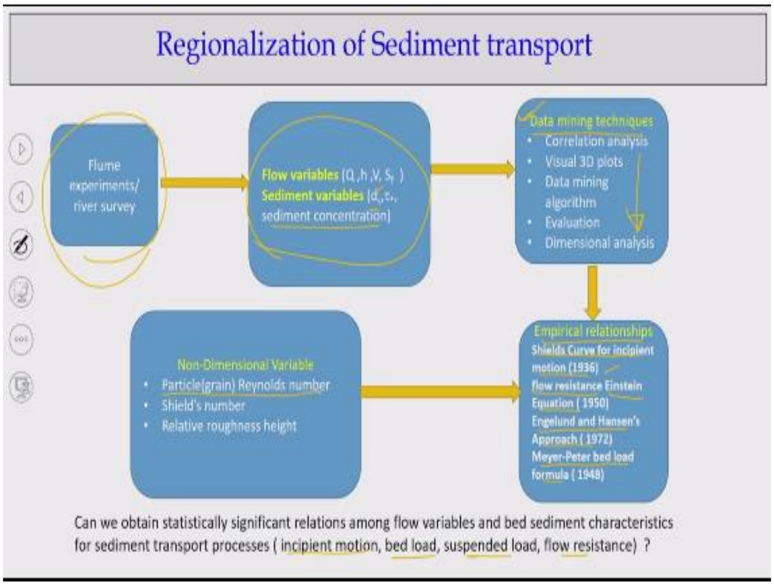
Very good morning to all of you for these lectures, which we have been continuing on sediment transport in rivers. So continuing of that we will discuss more details how we can quantify how much of sediment transport in a rivers.

(Refer Slide Time: 00:49)



Looking that I just added one of the very good publications okay, which is Operational Hydrology Report 47, which is a manual for the sediment management and the measurements. That is what we will be following this chapter exclusively. As well as we discuss about this book and the river mechanics books. That the emphasis what we will do it.

(Refer Slide Time: 01:23)



Let us understand what is the basic concept when you talk about sediment transport mechanisms like incipient motions, the bed load, the suspended load, then the flow resistance in alluvial rivers. What are the basic concepts? The concept is started from experimental flumes. The series of the experimental flume as well as the river survey were conducted many part of the world. Basically in Europe and United States of America.

So try to look it with a relationship with a flow and the sediment variables. Most of the often we can measure the discharge, we can measure the velocity, we can measure the flow depth, we can quantify the friction slopes. So similar way we can compute these, get the sediment concentrations the bed load rate we can get the particle size distributions curve.

So those data, compile it and analyze it with a new today's concept is called the data mining concept which is earlier way back in 1950s or the pre and post of the World War II. People have been using that techniques not in under umbrella of data mining concept, but the same concept of correlations analysis, visual plot analysis with a different non dimensional forms.

Today we are talking the same concept with more probabilistic frameworks, with more advanced algorithms to mining the data to extract the information or the relationship between dependent and independent variables which we are looking it that if you can measure the flow variabilities and particles, sediment particles, the bed particle, bed material characteristics, we can compute how much of sediment loads are there.

Or can you compute how much of the bed loads are there. That is what we do it and that is the reasons if you look it there are empirical equations developed. As I said it, it is a close to the pre and post World War II. The shield numbers for the incipient motion, which are still extensively used with a new data sets and all but it is a cross validated that. The flow resistance in alluvial rivers, which is a major emphasis.

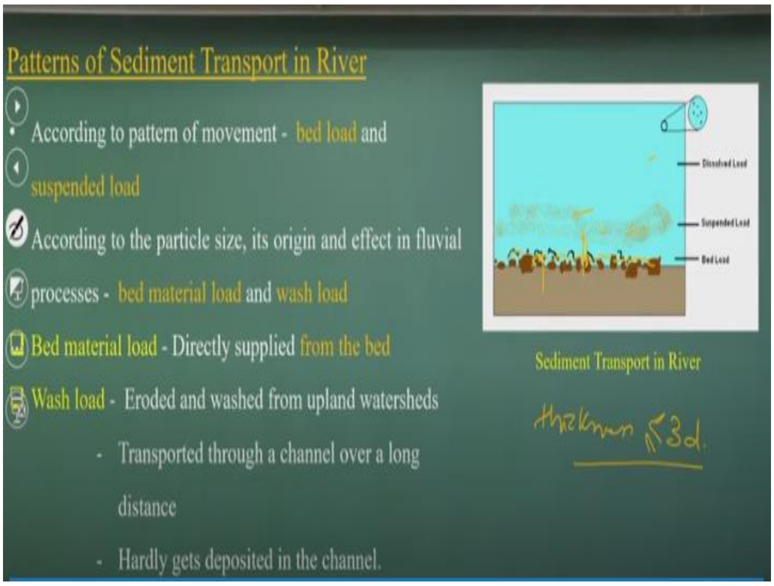
That is what also it look in a two forms in Einstein's equations. I will just focus in 1950s, then Engelund and Hansen approach in 1972. Then I will talk about the Meyer-Peter bed load formula, which is 1948. So if you look it that, these are the equations already conducting a series of experiment at the flume levels, collecting data from the field levels. Smaller rivers or the bigger rivers, compiling all the data.

Conducting the data mining concepts to establish the relationships. That is the relationship are the empirical relationship. Introducing a new concept like these particles Reynolds numbers as we discussed in the last class or the Grain Reynolds number, the both are the same. But many books they use particles Reynolds numbers or the Grain Reynolds numbers. The shield numbers, the Einstein's the parameters.

So many of the new non-dimensional forms is introduced to establish these empirical relations even in relative errors. So the question is that what we are doing can you obtain a statistical significance between the flow variable and the bed sediment characteristics for a sediment transport process like incipient motion, bed load, suspended load, flow resistance.

That is the basic question so for today we are going to address. So this the basic conceptual framework. So sediment transport if you look it, it is a complex and the stochastic nature. But, many scientists they try to make it solve these problems using a set of non-dimensional equations, data analysis establish the empirical relationship.

(Refer Slide Time: 06:01)

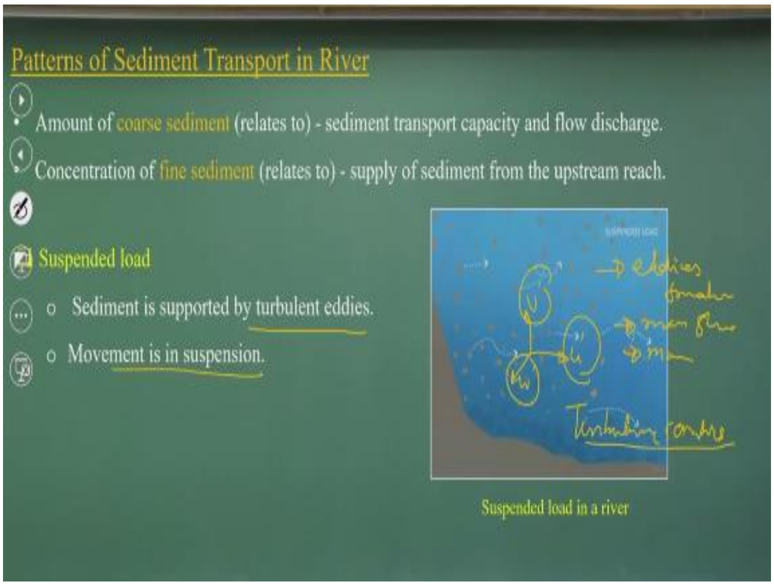


So looking that let us come back to the figures what is showing clearly. You can understand it this bed loads are happening it here. So bed loads are happening, okay. And there are the bloom of suspended loads and some dissolved loads are there basic mechanism. So these the process of the bed load for bed materials is going to the bed load, which is a very thin layers along the bed, which will be the dimensions of thickness.

That what will be just lesser than of the 3d values. where, d is the representative dimensions for the particles, bed material particles. So basically if you look it that and there is a very thin layer of bed loads which move along the rivers. And then there are actions of the sediment particles from bed to the suspended or suspended to the bed. That is the process happens it.

That is the diffusion process what is going to happens it. It is a continuous process. So the wash load which is eroded and washed from upland areas and hardly gets deposited in the channels. That is what we are not focusing more.

(Refer Slide Time: 07:27)



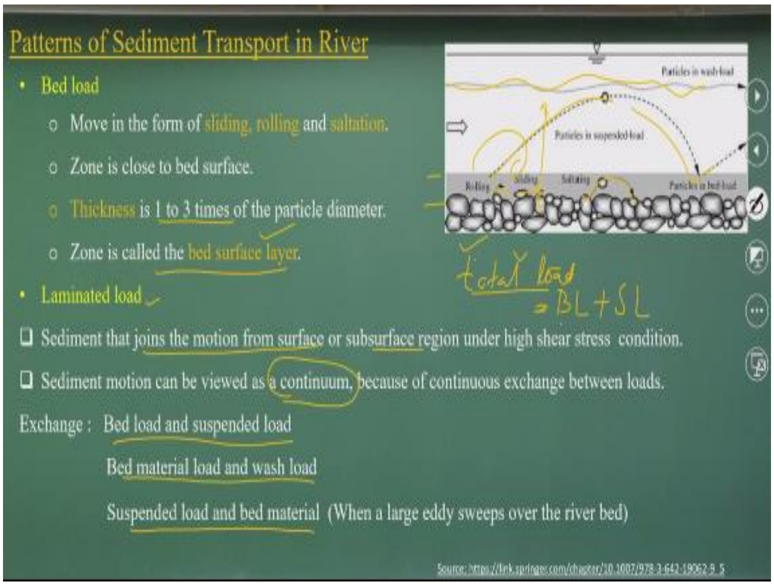
Now if you look it microscopically what is actually happens when you have the flow through that the suspended load. The basic concept is the turbulence if I put it. It all depends upon this fluctuating velocity components which are there in three dimensional directions. And which is responsible for generating eddies, generating the mass exchange between the layers in different directions.

It also generating the shear stresses or equivalent force component because of the fluctuating velocity components these are responsible for eddies formations, the mass fluxes due to the movement of fluxes. And those are responsible to keep the sediments in this suspended states. That is turbulence characteristics playing a major roles.

Those are the studies recently many people are doing it, which is one of this Professor Subhasish Dey book. You can refer it. But here in these lectures I am not going to that detail. But now the people are relating the turbulence characteristics with the bed loads with suspended particles and the incipient motions. But as this course is meant for the river engineering point of view so we will be not going to much details on the turbulence characteristics.

But overall it is the sediment that is supported by these turbulence eddies and movement in a suspension state. And the turbulence decreases the intensity decreases then it again start depositing this suspended particles.

(Refer Slide Time: 09:37)



Now if you look it bed loads, as I just discussed is that it can move as rolling, as sliding, it can have a saltation, and there will be particles moving it. And there are the particles going up, come down like this. And there is wash load, which does not come back. If you track the particles it just goes through as a suspensions level. Does not participates in the process of depositions, erosions of the riverbed.

So if you look it that this thickness is 1 to 3 times of the particles diameters. This zone is called bed surface layer. This is the small layers with the bed loads are moving. This is a thin layers where the bed loads are moving it. That is the bed surface layers. The laminated loads with the sediment that join the motions from the surface subsurface region under high stress conditions.

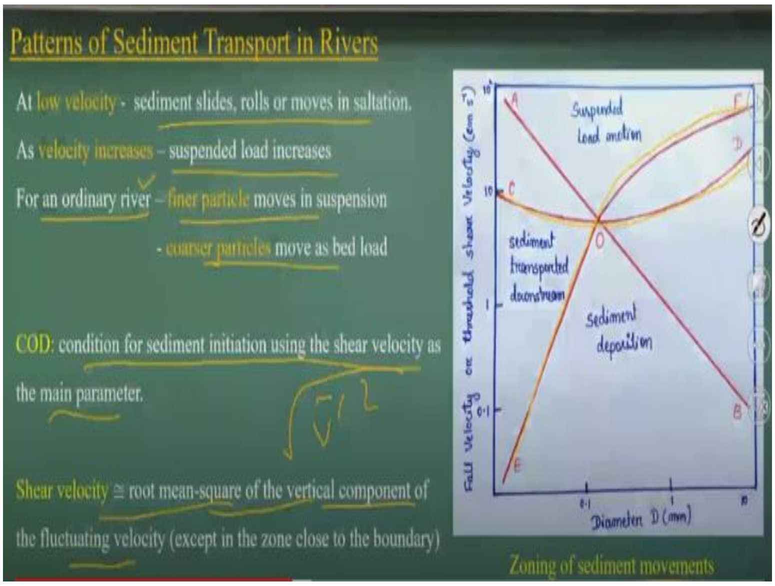
If you have a very extreme flood conditions, that is what it happens it. And as says that, the sediment motions we cannot separate between the suspended load and bed load separately. Sometimes we combine that, we call the total load which is the summations of bed load and the suspended load. So we target about that. We do not separate between that.

But some of the empirical equations we have, where we can locate what could be the bed load, what could be the suspended load. And there are the empirical equations are there, we can compute the total loads. So that is, the bed load, there is exchange between bed load to suspended load, bed material to the wash load and suspend load and bed material. So all the process are happening.

Sometime it happens is that this bed materials which is there that can join directly from the bed to the suspended layers. Or you can have the bed load to suspended load and suspended load to bed load that exchange happens. That is the reasons it is called is that the sediment motions as a continuum.

You say because of continuous exchange between these loads. That is the concept we can understand it.

(Refer Slide Time: 12:02)



Now if you look it that what type of patterns of sediment transport happen in river. If you look it that at the low velocities, the sediment slides, rolls, moves just initial stage with a very low velocity and the stream powers is very low. In that case, you can observe any of the flume or the river that the sediments are just starting it, starting the bed load motions, just rolling and sliding it.

If you further increase the velocity or the stream power, what will be that? Suspended load will be increases and that is what is the finer. But in case of the river if you look it, when you conduct the experiment, the uniform sand experiment in the flume that characteristics is different. Because when you go for real river case, you will have a non-uniform sediments.

The sediment of coarser grain and the final grain. What actually happens in the river cases, the finer particles they remains in the suspended case load and the coarser particles like gravels and all they remain as a bed loads. So that is what is happens in any ordinary rivers you can see these finer particles at the suspended load, because you can understand from that.

And the coarser particles move at bed load. Now if you look it that if I plot very interestingly is that joining of the sediment movements. That is what we are talking about here. It is what is indicated for us is that if you look at that, the x axis is the diameters and y axis is the fall velocity, sediment fall velocity as we discussed in very beginning in the class.

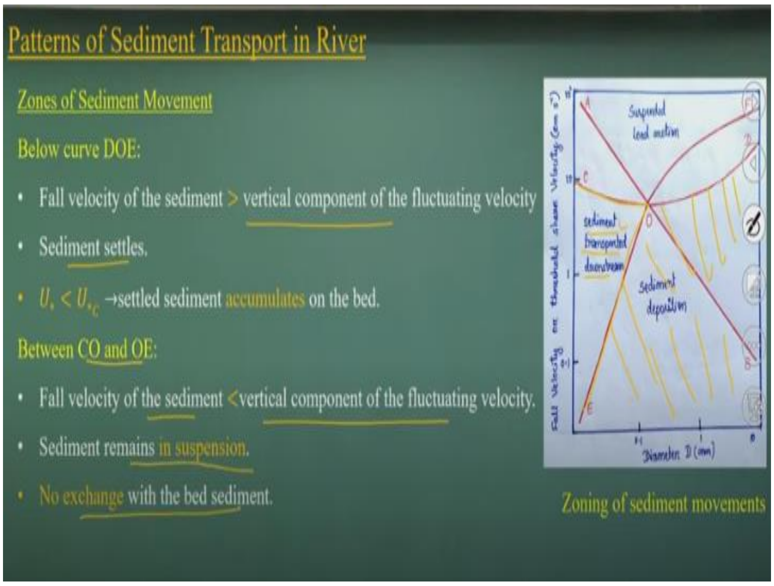
Threshold shear velocity if I plot on that the sediment fall velocity is the graph of E and F. So as the diameters increases the sediment fall velocity is going to increase it. But if you try to look it what is this threshold shear velocity beyond that is sediment start the motions. That means incipient motions. That the conditions is happens it the line which will cross through the COD.

And this line of A and B is representing out particles Reynolds numbers how it is changing it. So if you look it that these two curves if I try to introduce for you these two curves are indicate for us different regions. For example, if we look at the COD is the conditions of sediment initiation using the shear velocity as that means incipient motions. More detail we will discuss in the shield curves.

So the shear velocity is nothing else is a root mean square of the velocity component, vertical component of fluctuating velocity. So that means V' that the square root mean of that. It could be the time average components. So this is what it indicates what is the shear velocity components.

If you want to talk interest more the turbulence things you can understand is what is the shear velocity because of fluctuating velocity components. Because of the fluctuating in velocity component in vertical directions.

(Refer Slide Time: 15:40)

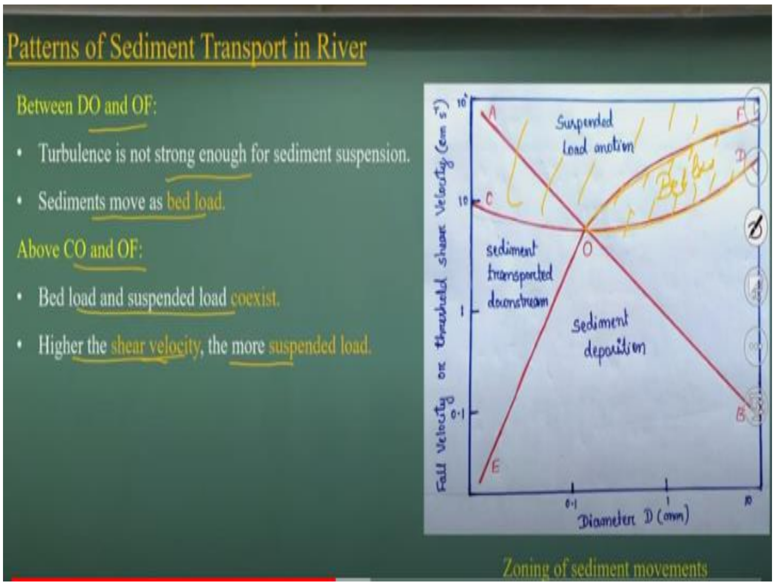


So if you look it that curves and the zone of the sediment zones first I can look at this curve between the area which is covered by DOE. So that means I am talking about this is the regions, DOE regions. This is the regions what it actually happens it if you look it that the fall velocity is greater than vertical component of fluctuating velocity. That is the reasons sediments try to deposit it. Sediment try to deposit it.

So that is the reasons what will happen the sediment will be try to deposit. So this is the sediment deposits regions. Here the fall velocity is higher than the fluctuating velocity component. Region between CO and the OE. CO and the OE if you look at this part. Why it actually happen in these regions that the fall velocity is a lesser than the vertical component of fluctuating velocity.

Because of that what is actually happens that sediment particles which is transport from the upstream, they do not settle there. They transport to the other part. That is the reasons sediment transported to downstream directions. The sediment whatever generated it that does not settle there. That is what is transported to the downstream. So this is the regions where you will have the sediment transport downstream. The sediment remains in the suspension. No exchange with the bed sediment.

(Refer Slide Time: 17:28)

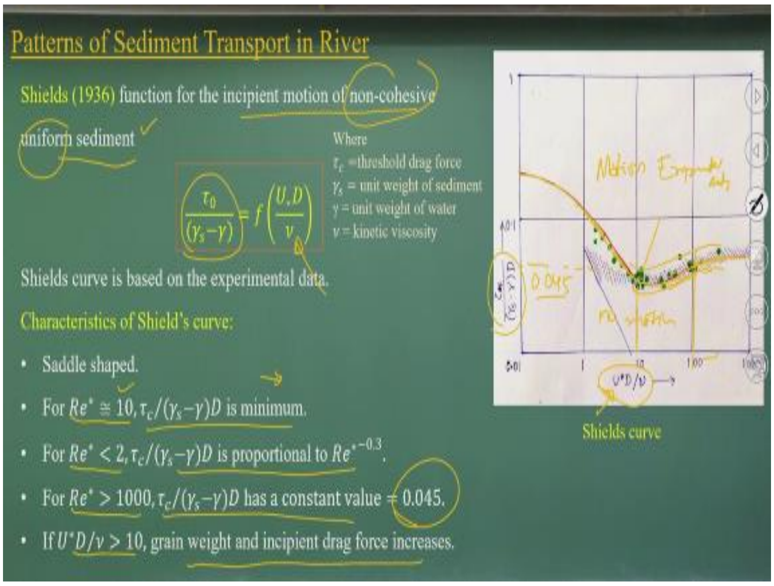


Now if you look it next things what we are discussing the distance between DO and OF. So DO this is the regions. In these regions if you look it that the tolerance is not strong enough for sediment in suspension. The sediments move as a bed load. So this is the part the sediment move as bed load.

Beyond the curve, the above CO and OF the bed load and suspension loads coexist, higher the shear velocity that. So this is the regions falls between the suspended load. So if you look it that, if I just plot the diameters and the fall velocity or threshold shear velocities which is in cm/s, clearly it indicates for us that there are the four zones it happens it.

Suspended load zone, the sediment transport downstream zone, sediment deposition zone, and the bed load zones. Here it can have the suspended and the bed load, both combinations can happen it.

(Refer Slide Time: 18:48)



Now if you are looking that let us go for the next levels that to know it at what time the sediment start moving it. That is what the incipient motions. This the experiment can be done it any flume if you have with a sediment the uniform sand then you increase the flow or change the slope of channels if you have a tilting flume. So you can try to know it at what conditions the bed particles which are there they start moving it.

Since the process is stochastic and complex we do not look it a single particles to move it because even if you call it a uniform sense, but that still is a gradations are there. And there are the many neighborhood problems are comes it that. That means not only the particles work like individuals. And still we are talking about non-cohesive materials, bed materials like a sand or the gravels.

So if you look it, try to look it that is what is the huge experiment conducted with Shield 1936 to find out the incipient motions for non-cohesive uniform sediment, okay. Both the things is uniform and non-cohesive is there. What he got is very interesting that is the particles Reynolds numbers or the Grain Reynolds numbers is a functions of the Shield numbers which is.

And that functions plotting all these, these are the dots are all experimental data. And they try to look at these functions how does these functions varies. And how we can derive it this is the motions, is a no motions,. This is the motions, this is the no motions of the sediment zones.

So if you plot between these particles Reynolds numbers or the Grain Reynolds numbers and the Shield numbers which is a ratio between the shear stress by the submerged weight of the sediment particles. Those if you plot it the functional behaviors like this is quite interesting. It follow a saddle and as these are experimental data and the process is the complex and stochastics you will not get a single value. It will get a range of the data range.

We will get the data range because of uncertainty involved in the experiment, uncertainty involved in the data collection and uncertainty itself in the process which we are not looking that much of details what it happens at the particles levels. So if you look it that the dividing this line between the sediment in motions or not in motions that is the line which is the Shield curves is indicates for us.

It says that this it follows very interestingly. If you look at these curves that when you have the Shield number their particles Reynolds numbers is equal to 10. That is the value is that we get the minimum value. So that means a critical shear stress divide by the submerged that will be the minimum.

That is the minimum force is necessary to start the motion of the sediment particles. Particles Reynolds numbers is lesser than 2 where there will be a proportionality. So these are the linear proportionality zones. The proportional to the particles Reynolds numbers. When you have a Reynolds numbers, particles Reynolds number more than thousands these values is comes to closest to a constant values.

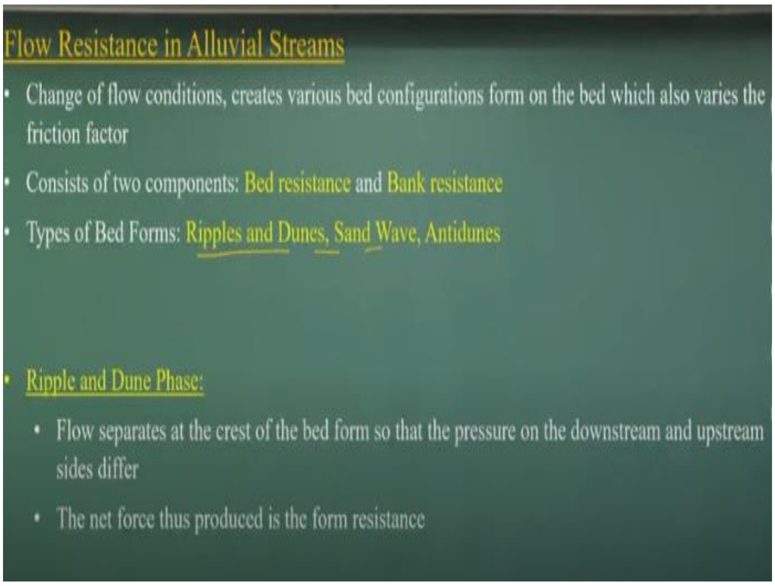
As you go up beyond 100 you can say that more or less it is a constants and that values is coming out to closest to the 0.045. So many of the times we try to locate that means incipient motions are independent to the particles Reynolds number. These curve is a similar nature of the curves of pipe flow, where we compute the friction factors.

The nature of the curves are same as we are changing for hydraulically smooth zone to the rough zones. As you go for the hydraulic rough zones, the shear stress necessary to bed particle to move it, it becomes independent to the particles Reynolds numbers or the Grains Reynolds. Beyond these 10 grain weight and incipient motions are increases. Okay, there is slight bit increasing patterns are there.

Please try to have interest about this Shield curves as a river engineers or field engineers we should have a good confidence on the how to draw a Shield diagrams and how we can use the Shield diagrams to know it whether the river is at the mobile conditions or the sediment is at the transport conditions or sediments are not in a transport conditions.

That is what we can quantify it because it does not need much to do it. Because all the parameters you can get it from riverbed materials.

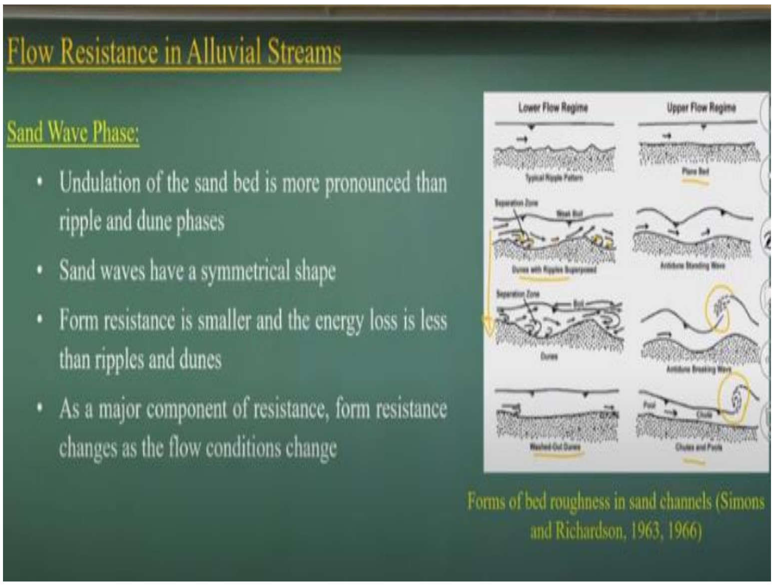
(Refer Slide Time: 24:50)



Now if you look it if I talk about the flow resistance, in alluvial rivers. When you talk about the flow resistance in alluvial rivers, if you know it the alluvial rivers having different bed forms. As we discussed in the last class that the ripples, dunes, sand wave, and the antidunes. We need to look at the bed resistance and the bank resistance because most of the times the river is much wider.

So the bank resistance will neglected and we focus on the bed resistance. So basically what is that you will have the ripples and dune phase we are not going much as I discussed in the last class, that how the Mannings roughness coefficients varies as we changes from the bed forms. That is what we discussed more details. So I am not going more details and you can see.

(Refer Slide Time: 25:52)

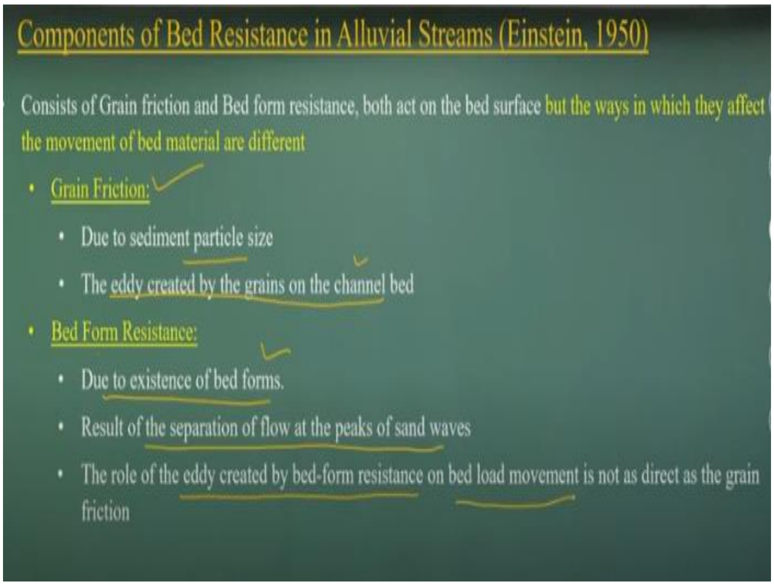


More interestingly if you look it that when you talk about this flow resistance equations that means we are talking about energy dissipations. So here the bed forms if you look it when you have a deep with rivers, there are lot of flow separations and turbulent structures happens it. The similar way in chutes and pools that will be wave breaking process are happening it. If you have a boils formations and all.

So those are also responsible because of the bed forms more the energy dissipations. So that is what will be coming to the flow resistance equations as compared to the plane bed as compared to the washout dunes or the antidunes with breaking or this antidune of the standing wave. So these the roughness the dunes with ripples, dunes these safe the beds forms are the play major roles having a local turbulent structures like formations of eddies, the formations of boils.

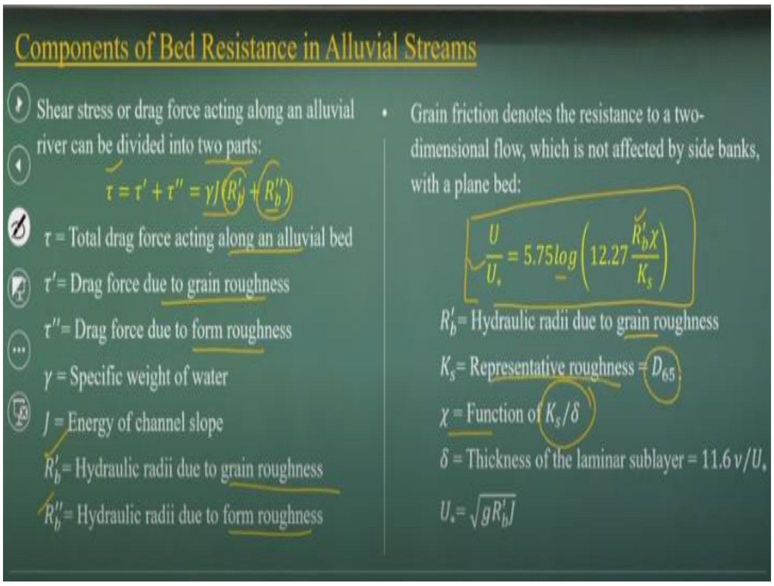
Those creates dissipates the energy. That is the points we are trying to highlight it and that we locate in form of energy dissipations, in the form of an energy dissipations we look it that part.

(Refer Slide Time: 27:22)



Now if I go for next, there will be a grain frictions. This is because of the particle size, and eddies is created by the grain on the channel bed. Bed form resistance due to existence of the bed forms and the result of the separation of flow at the peak of the sand waves. Role of eddies created by bed form resistance, bed load movement is not as direct as the grain frictions. That you try to understand it.

(Refer Slide Time: 27:50)

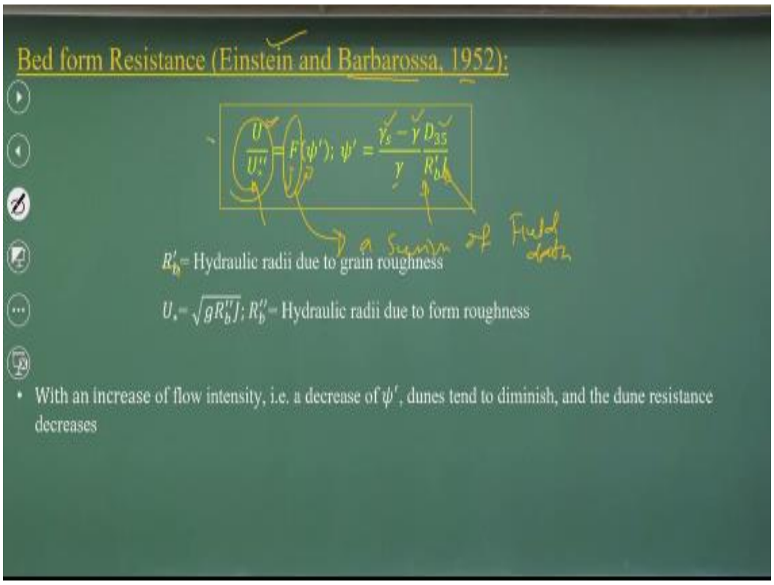


Now if you look the bed resistance in alluvial rivers it has a compositions of two part. The shear stress we can divide into two parts. One is the total drag force along the alluvial rivers can be define it one the drag force or the shear stress per unit area. That is what easily grain roughness and form roughness. And that what again we can write it the shear stress is a form of friction slope and the hydraulic radius.

So we defining this hydraulic radius separately for grain roughness and the form roughness. That is you try to understand it. And the last class we discussed that we can define the velocity distributions of a channels which will be a logarithmic velocity distributions. Here we are using the log okay. Not natural log that is the difference is there. Is the shear velocity.

Here we have introduced that the grain roughness can have R_b'. The Ψ is a functions with a function of K_s/δ. δ is the thickness of laminar sub layers. K is the representing roughness which in generally consider a D 65. And this is the shear velocity. So this is the velocity distributions we consider it as the two dimensional flow which not affecting and with a plane bed. That is the conditions what we consider it.

(Refer Slide Time: 29:31)

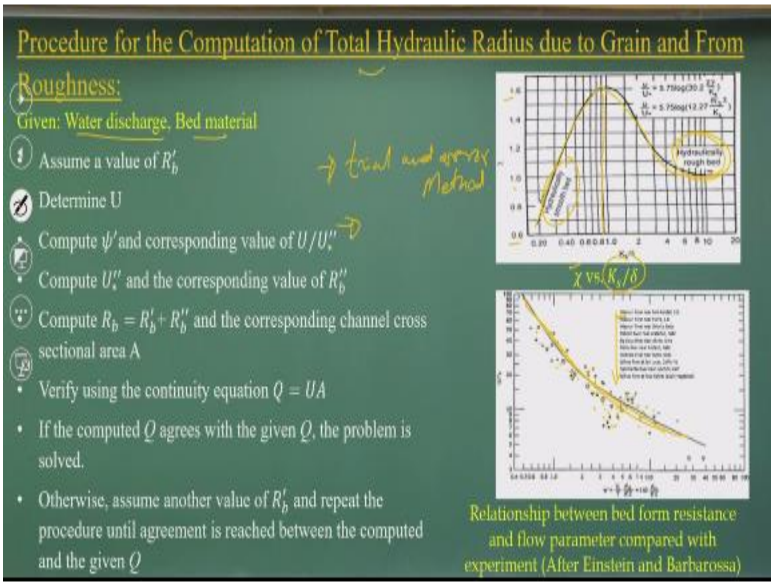


Now if you look it next equations, which is very interesting equations by the Junior Einstein, Barbarossa 1952. He tried to establish between these two ratios, the U_2' represent the shear velocity due to the forms, okay. Shear velocity due to the forms and the friction velocity.

This ratios will have a functions of Einsteins parameters, which defined as the unit of weight of the solids, unit weight of waters D 65 and R_b' is equivalent hydraulic radius considering the bed form and J stands for the friction slope. So if you look at that and he tried to find out what could be the relationship functions of F considering the series of the field data set.

That this relationship the f function he established from the field data. He just identified two non- dimensional parameters. One is the ratio between the velocity and the shear velocity due to the bed forms. This ratio is a functions of a parameter which is defined is Einstein parameters, the sediment Einstein parameters which is the functions of D 35, functions of the hydraulic radius for the grain resistance. And you have energy slope that is the relationship is that.

(Refer Slide Time: 31:29)



And if you try to look it next slides, we can see it this is the functions what you can see that how Ψ the velocity distributions is varies between these ratio between K_s/δ. That is what you can see it. This is hydraulically smooth regions. This is a hydraulically rough regions. Okay how Ψ values vary from 0.6 to 1.6 and it become 1 when you have a K_s/δ?

δ stands for the thickness of laminar sub layers. That becomes 1 when it is more or less it is the highest Ψ factors we consider. And then it is becomes to be in comes to 1 value when you have a hydraulically rough beds. The same way this Einstein parameters, the functions is behave like this and these are all field level of data. These are all field level of data.

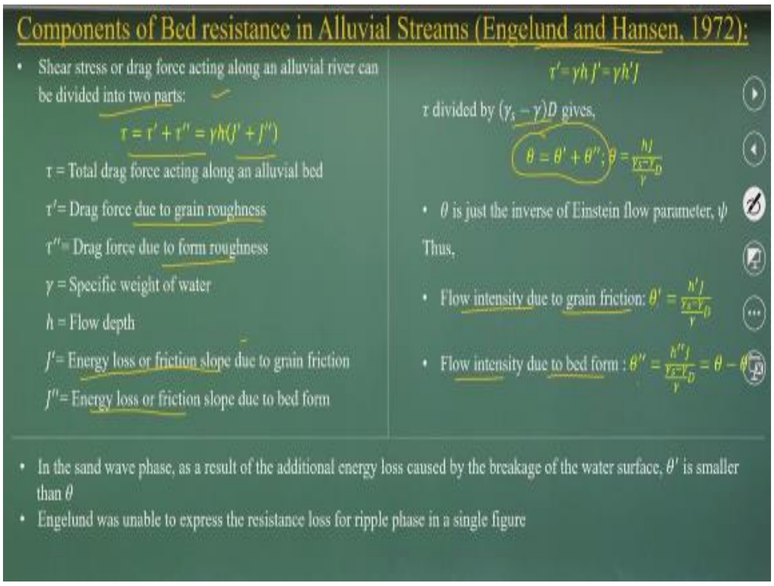
That is the reasons I again emphasis that we need to have a data from the rivers. If we do not have the data from the rivers, we cannot conceptually much more than whatever is existence equations. And each rivers tells a different story. That is the river characteristics. So if you look at that, these are the Missouri rivers and different rivers in mostly from the United States.

And those river data if you plot it that and try to establish these equations. That is what is there and here it is there how to if a given water discharge is there and bed materials can you compute the total hydraulic radius due to grain and form. Basically the same concept that we are using the Einstein equations and we are trying to velocity distribution equations we are trying to find out the discharge.

So because these are nonlinear equations, we follow a trial and error methods, trial and error methods. But today because we have a lot of mathematical tools, so I do not think that we should look at this trial and error methods how to do it, but as a student you just look how to do the procedures. Because you have two nonlinear equations. To fit that nonlinear equations, you have to do a hit and trial methods till these that the discharge and bed material characteristics is satisfied.

And that is what we do it. So there are called the trial and error methods, which is a stepwise it is given it how you have to do the trial and error methods. But what I do encourage is because now there are lot of mathematical tools are available. So we can solve these equations using that tools, not the trial and error methods.

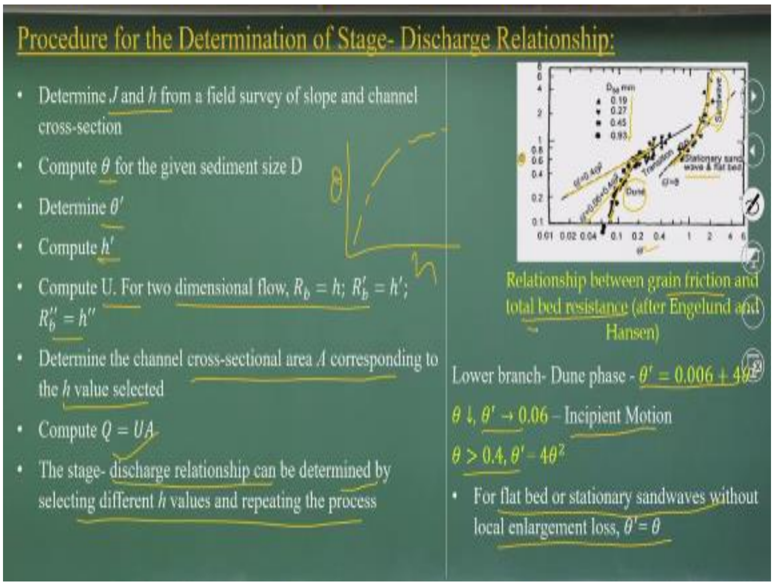
(Refer Slide Time: 34:42)



Same way if you will look at the Engelund and Hansen 1972. He actually introduced the new concept is that the shear stress acting along alluvial river can be divided into two parts. Again the same concept. The will be the drag force due to the grain and the form roughness and J here he is putting it this energy losses component or friction slope component can define in two different way.

And he tried to establish is Ө and Ө' which is τ divided by this submerged unit weight of sediment particles. And if you just look it, reframe it and look it that flow intensity due to the grain and flow intensity due to bed form in Ө', Ө'' and you can have a this equations form.

(Refer Slide Time: 35:48)



And he also established empirical relationship with a different bed forms like a dunes form, sand waves, the stationary waves and all the data D 50 values of different data they plot it, they get the characteristics like this. To follow these ones he established the relationship between the grain frictions and total bed resistance. So Ө' is the grain frictions and Ө is the total bed resistance.

He established the data and approximate the data with a differently linear ranges, different linear features to solve these ones. That is the reasons he has put in different equations. If you look at the incipient motions that are there for flatbed and this theta dash will be equal to theta. That is, that is what it is indicating it your case when you have that.

So here also there is a procedure how to have a stage discharge relationship. Again using that equations, because this graphical data that is the reasons again you have to have a hit and trial methods like first you determine J and h from the field data, compute the Θ from since you know the Θ value, you can compute the Θ' which is the grain frictions, the resistance relationship between grain frictions.

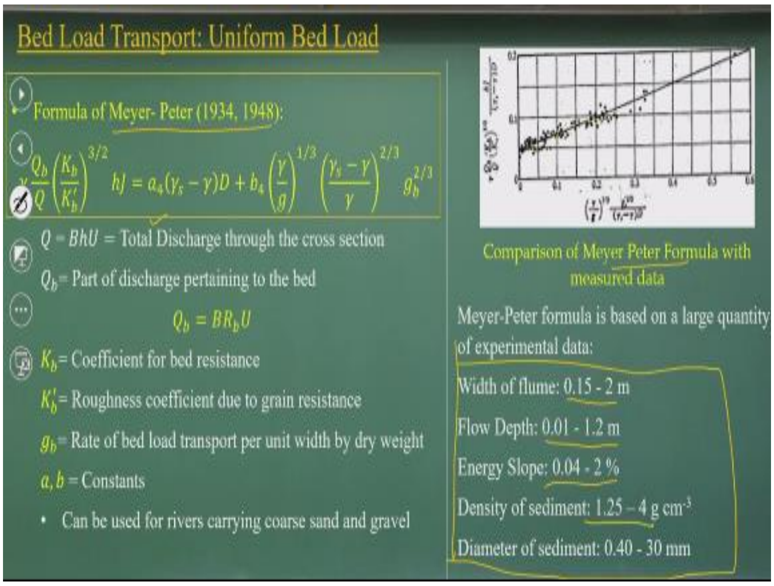
Then you can get the h' and then you compute the U for the two dimensional flow, you can make it hydraulic radius with a different things. And determine channel cross-section area corresponding to the n. Then compute the discharge. That is what will be stage discharge selecting different h values repeating the value. So you change the each values, compute what could be the Q value.

As the h and friction slopes are changing it so for a different cross sections, you will have a different discharge. So that is the reasons we can develop a rating curve h versus Q which takes care of the bed form resistance and establish a relationship. So that is what is theoretically, using these bed forms resistance and the grain resistance, we can establish the rating curves, the stage discharge relationship.

That is what is mathematically here we are doing it. If you have an h value, you have energy slope. Then you can from the cross-section data and then you get the Θvalue, Θ' value, h'. Then use that relationship and try to find out that flow area, velocity compute the discharge. Again, you compute the different h. That is what is procedure and finally, you get the points and you can fit a curve.

You can fit a curve to find out what could be the rating curves. So this is another way. If you have a cross section data, if you have the slopes. That is the biggest issue that energy slope. If you have the energy slope data and the flow depth date accurately, we can establish the discharge using this relationship. It is a quite interesting for us.

(Refer Slide Time: 39:33)



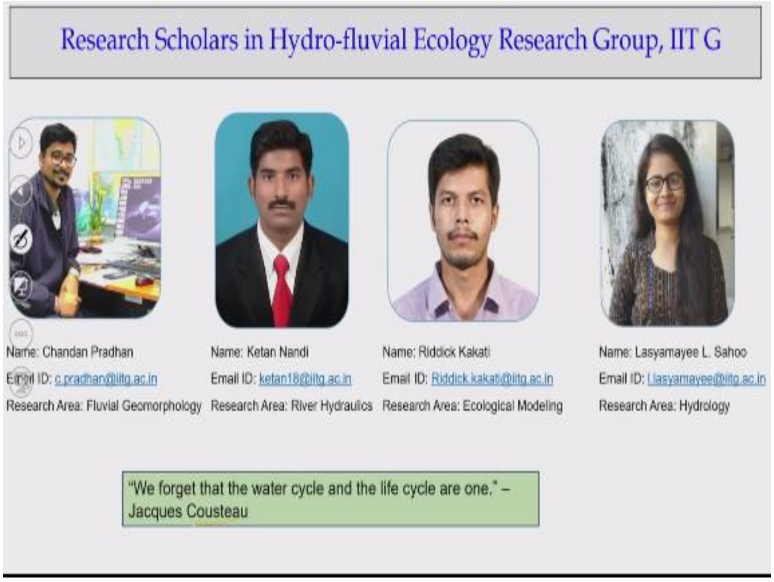
Now before concluding these lectures I am just introducing the similar way how much of bed load is a transport is you can establish a we can have empirical equations. That is what is by Meyer-Peter is a long back is 1948, established a very complex equations. If you look it that it is a very complex equations establishes between the path of discharge pertaining to the bed, the coefficients of the bed resistance, roughness coefficients, rate of bed load, these a, b are constants.

See if you look at these equations is a very complex equations. They established way back in 1948 to compute the bed loads. And this is the data which is indicating for us that Meyer-Peter formula with a major data how accurate it is. So that is a comparison formula. And this is the data what is he use it. The range of the data, what is he used a large quantity of experimental data like the flume considering from 0.1.

Width of the flume is 0.15 meter to 2 meters. Flow depth is 1 centimeter to 1.2 meters. Energy slope from 0.04 to 2%. The density is also varying 1.25 to 4g. Diameter of sediments also goes to the up to 30 mm. So it is a huge data there, it is a data mining. So if you try to look it now the present concept we can talk about this is the data mining.

The huge data, wide range of the data, experimental data used for different depth, flow depth, energy slope. And analyzing that they established these equations. So next class we will just discuss more about this.

(Refer Slide Time: 41:37)



With this let me conclude this today lectures talking this quote that Jacques Cousteau, We forgot that the water cycles and the life cycles are one. With this let us conclude this today lecture. Thank you.