River Engineering
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Lecture – 22
River Equilibrium-I

Very good morning all of you today will have very interesting lectures on river equilibriums and which talk about how the river reaches the equilibrium positions that is what we today will discuss it. And also I will show a case studies of predicting the river bank erosions in Brahmaputra river so that the part what we will cover today.

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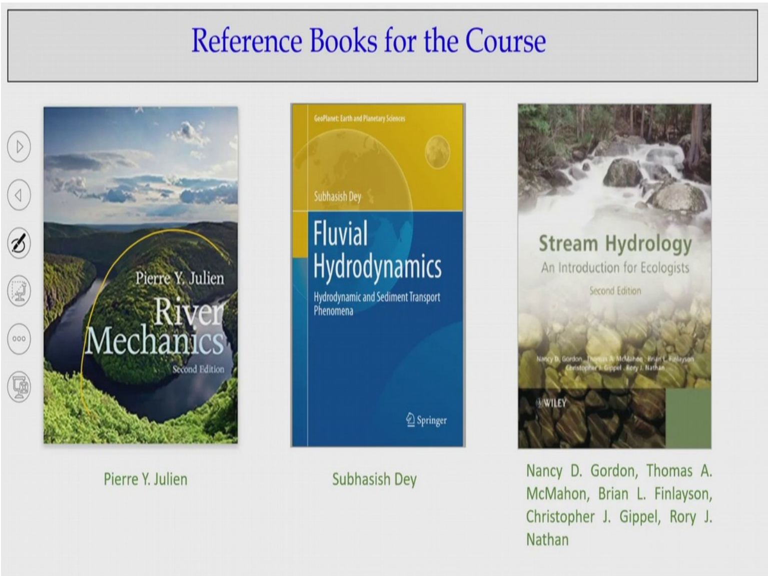

And if you look at that mostly we are following this book P.Y. Julian books and it has chapters on river equilibriums. So we are following that book with some of the case studies from Indian rivers conditions.

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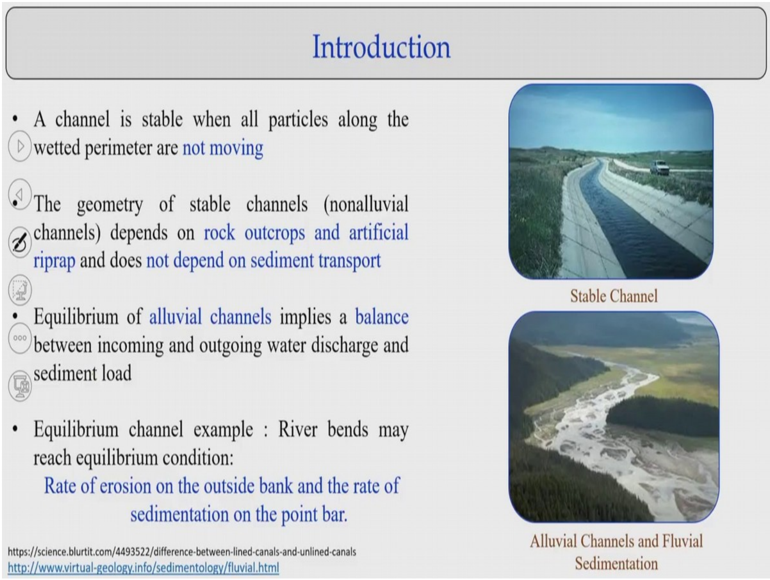

Now if you look at the next part see if you look at that many of the times it was challenging task to design stable alluvial rivers. What could be the cross section, what could be the slope of the channels so that river remains at stable conditions that means there is not significant order of scouring or the siltation process. So there was a challenging task and that is what we solved it by thorough field observations of the rivers and modifying the river such a way that river can come to an equilibrium stage where there is no much change of the channel is a stables.

Where the particles along these wetted perimeter are not moving it which we talk about in terms of the stable channels but if you look at this the stable channel part which is is a concrete line canal but can you make a stable channel of alluvial rivers and the sedimentations if you look at these rivers can you make a stable channels can you make a the river at the equilibrium stage.

What do we mean by that the equilibriums of alluvial channels is a balance between the incoming and outgoing discharge and the sediment loads what is talking about that you say no scouring and no depositions of sediment passing through the particular river reach. The concept is now it's a quite challenging and quite interesting to make a river cross section such a way that the channel bed slope such a way that there will be no scouring and there will be no depositions.

That means that whatever the sediment in flux is coming from a particular reach upstream that should be equal to the sediment outflux coming from that. So if you look at that at the reach levels equilibriums examples will come it when the rate of erosions of the outside of river bank is a rate of the sedimentations on the point bar. So that means we are talking about the reach scale reach scale river equilibriums where the rate of erosions of the outside of a river bank that should be equal to rate of sedimentations on the point bar.

Or we can talk about the amount of the sediments is coming from a upstream a particular reach that should be equal to the amount of sediment out flux from that the downstream rates. So, that means we can say that reach is at the equilibrium stage but not only that it is not easy to achieve that or we can make a flow such a way that the all the particles along the wetted perimeters that means in a bed bank they are not at moving it that is the conditions we do not look it for alluvial channel cases.

But this is the conditions we look at the for the stone riprap or protection system such a way that the particles which is on the bed or the bank in a wetted zones are not moving it that is the channel stability. But besides that we also talk about that if we plot the time versus let be channel depth h if I locate that there will be erosions and depositions and all but if I talk about long term average that is there is constant.

So if I take a long term average if I plot the depth versus time and take a long term for average at a particular stations if that long term average becomes a steady there no trend the increasing trend and decreasing trend. The significant trend then also I can say the river at equilibriums. So this is the concept if you look at that is quite challenging that is the reasons there is 2 way 1 way to try to understand the river mechanics point of view the how how river can be at the equilibrium stage.

Other ways that go to the field collect the river cross section data collect the velocity the discharge area of the flow and then try to establish the reaches where the equilibrium stage is achieved in the last 5-10 years what is that geometric relationship between flow characteristics and degree of freedoms like in terms of width which in terms of the depth in terms of the bed slopes.

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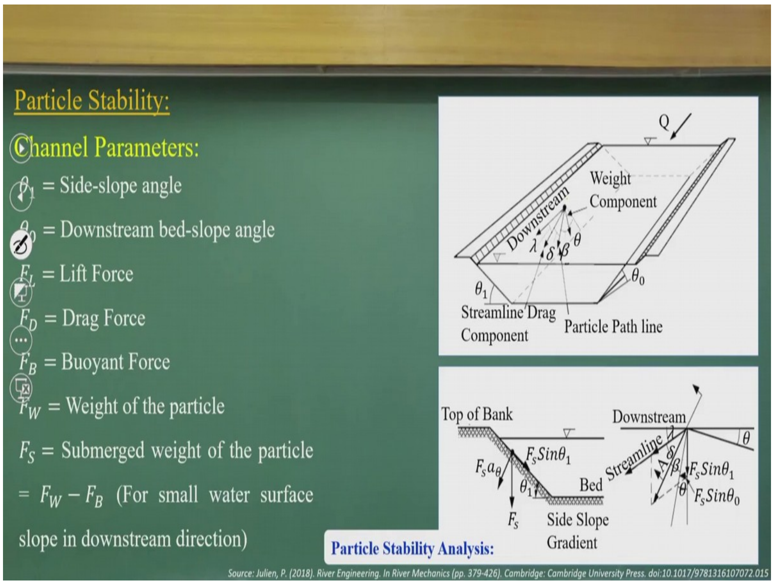

So that what we will be discussing more and more details. Let us go for next ones which is the particle stability. The basically we look it like stone riprap or we try to design a channel such a alluvial channel such a way that there will be no motions of the particles on the bank as well as on the bed so that is what we are looking at. That whether we can design a channel such a way that the particle which is on the bed bank that is not in motions not in a motions not in incipient conditions.

So that means we are trying to look it at what conditions what the configurations of the drag force the lift force and the uplift forces those force how the equilibrium and how they are initiating the bed materials to roll it. So now if you look at that let be a bed materials are here and you have the channels with a Q discharge is coming it it has a side slope **ϴ1,** ϴo is the downstream slope of the channels ok.

The channels also have a slope and if you look at that part now if you look at this component we can see particle path line we can see the stream line components the particles once detached from the surface which is the path is follows it is that what is the particle path line at that point because we are talking about the drag forces and the lift forces. That is what it happens it and we look it what is the stream line components and if I result in the different angle like ϴ, β, α and λ.

So λ is a deviation of the angle from this slope to the stream lines. So the stream lines having the angle of deviations from this slope surface. So, if you look at that part and if you look at this downstream part so you can have the stream lines and you have the the force components in terms of F s force. The F s force is a submerged weight of the particles. So let you look at that if you have a stones you can visualize that stones will have the packing like that so we are trying to look it that is a stone is a particle for us.

But if you look at the sand; so if you microscopically if you look at the sand compositions sand can be located like a stacking of the particles. So if you look at that particles either a stone in a gravel river or if you talk about the sandy river the sand particles this is very finer particle but they are the compositions could be like that.

Because of that we need to find out submerged weight of the particles which you know it very well is a difference between the weight and the buoyancy force that is the differentiate and the small water surface slope in the downstream directions. So you have a channel parameter like Θ1 side slope angles Θo the downstream bed slopes the F L is stands for the lift force. So you can imagine it the particles you are talking about is just starting the incipient motion it is a detaching from that and its moving along the particle path lines.

So you have a drag force we have a buoyancy force and the weight of the particles so thats what again I need to repeat it if you look at that sand particles these are all cohesion less particles we are not talking about the clay we are not talking about compositions of the silt. We are talking about big boulders or we are talking about the sand particles. So if you look at that and we are looking at these particles where it will be stability and these are the force component if you can result it geometrically if you look at that part.

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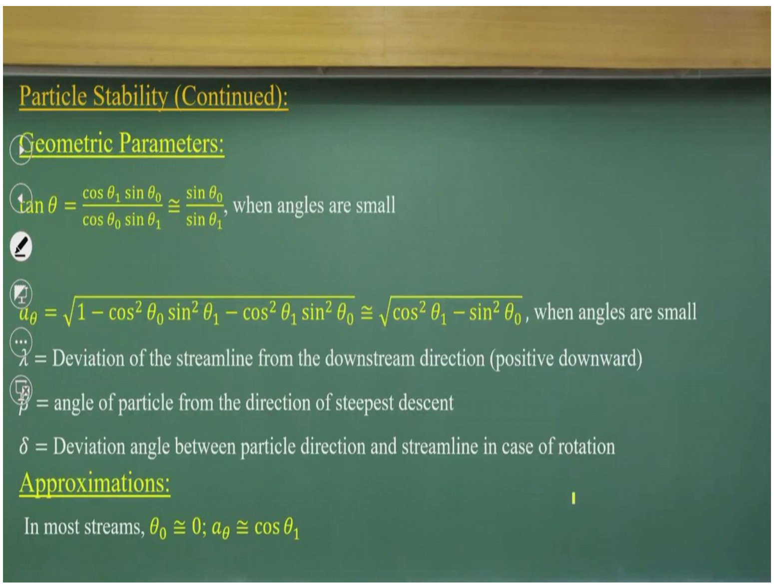

Now if you look at the next part which is more geometric point of view that you can find out the Θ E J functions of Θo and Θ_1, tan Θ we can confine it when the angles are the smalls in most of the times of the alluvial rivers when you design it the downstream slope these slopes are quite gentle similarly a_Θ can be approximated as $\sin^2\Theta_1 - \sin^2\Theta_o$

Basically what I am looking at you want to look at the projections on the plane on the slope the all this component we are looking at the projections on the bank slope. If you look at that and you have the lambda is a deviations of the stream line from the downstream directions positive downward that means how much of angle deviations are there of the stream lines the downstream directions.

The beta is angle of the particles from the direction of steepest descent the deviations of angle between the particles direction and streamline in case of the rotation the particles will be rotated. So if you are approximated most of the Θ, Θo is very close to the 0 and a_Θ can be as close to the cosΘ1 because Θo is very very close to 0 as we discussed is the like Brahmaputra rivers we have the slope gradient 1 is to 10000 scale.

So you can find out what will be the Θo value for that so you can easily cut bar but no doubt in case of the hilly regions it can go up to 1 is to 100. So you can also come the Θo value so it is generally Θo as close to the 0 and we can approach means a_Θ you will be cos Θ_1 so that is the approximations we can do it and its quite valid for the river systems when you do not have a steep slope of the river but that though conditions you should consider all other components.

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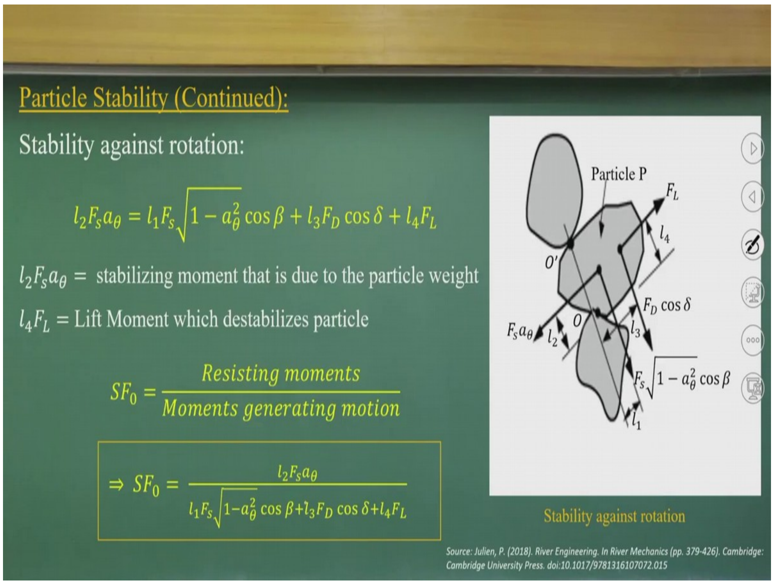

Now if you look at particles levels I am looking at how it is stables that means what are the forces acting on these particles 1 is lift force because the water is flowing through that there is a drag force and there is a submerged weight of the particles. So if you look at that what are the force is a lift force you have a drag force F_D is a drag force F_S is submerged in weight of the particles.

If is that depending on particles size you will have these force acting like a lift force and drag force acting components also you will have the components due to the submerged weight in 2 components will have and they will have a if I to take a O is a point the pivotal point where the particles will be rotate out rotate from that that means particle will be detaching from that. If that is the conditions, if you look at that and you can find they are the distance of l 1, l 2, l 3 and l 4.

So basically I am representing that you microscopically if you look at these sand compositions are the stones packing's and you are looking at a particular stones at what flow conditions it will be lift out from that it will be retained out from that. So if these are the stone 1 2 3 and our target stone is the particle p if is that it will rotate from this because these are the force component will act on these particles.

The lift force the drag force and the submerged weight and they are depending upon particles dimensions they will have a l 1, l 2, l 3, l 4 distance we are looking microscopically we will talk about a sand composites. If it is that what I try to look at how much a movement is working on to rotate this ones 1 is a restoring moments that is what it happens it that the distance into the force component.

And another is the overturning moments that because of F X F D and F L components as you can see these force components. So you can find out the movement of rotations 1 is a restoring another is overturning moment that what we can compute it and you can equate it that is a positions if this force component is larger than this one then it will be overturned that is the reasons the stabilizing movement due to the particle weight and there is a lift moment to destabilize the particles.

You have a lift moment to destabilize. So basically we try to locate factor of safety for overturning will it have a resist ratio between the resisting moments and moments generating the motions or overturning that that is what if I substitute I will get it this ones. The basically I am looking it as f naught should be a much, much lesser than the value of 1. If its value equal to the 1 there is a chance to have the particle will be detached from that rotate from that.

When you do design a alluvial channels we try to look at this SFo the that is a factor of safety for overturning this particle should be lesser than 1 value should be lesser than 1 value.

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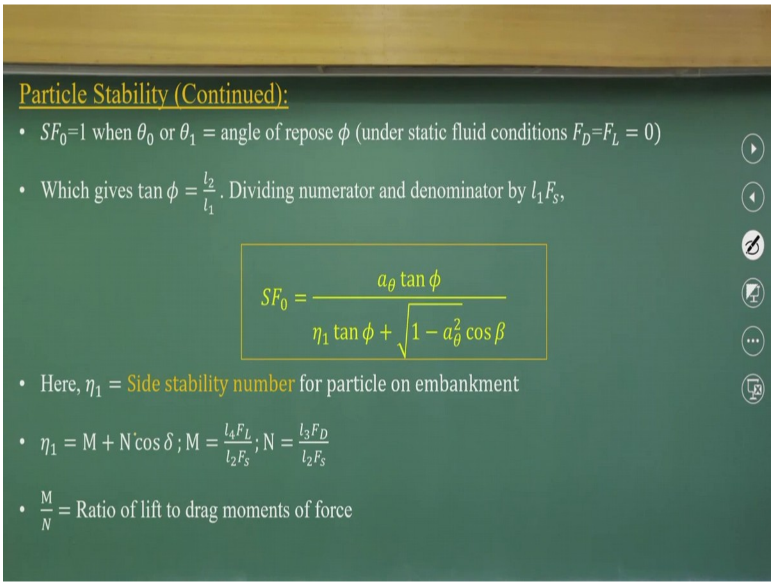

If you look it that way and if I somewhat simplified it that for example when fluid at the rest conditions. So in that case we will not have a drag and lift forces you can see the channels the flow is at the right conditions that means the the factors of t equal to 1 and your the Θo, Θ1 will come you will be the equal to angle of repose and if I have a tanϕ in terms of angle of repose is l by 2 by l 1 then if I just change that equations I will get a factor of safety of overturning is mathematically we are just manipulating it.

To get η functions of a naught 10 of 5 phi is the angle of repose the β part and we have a η1 part. So if you look at this η1 is called stability number of the particles on the embankment on the side. So that is what will be equal to this value m plus delta and m and can be defined like this just we are rising looking it the ratio of the lift to drag moments of the force okay this is just the simplifications of the previous equations.

To look at that the factor of safety is a functions of phi angle of repose it depends upon your stability numbers size stability numbers which is a functions of M and N, M and N ratio representing us lift to drag moments of the force that is the concept we brought it and we try to look it is how these functions relationship is there.

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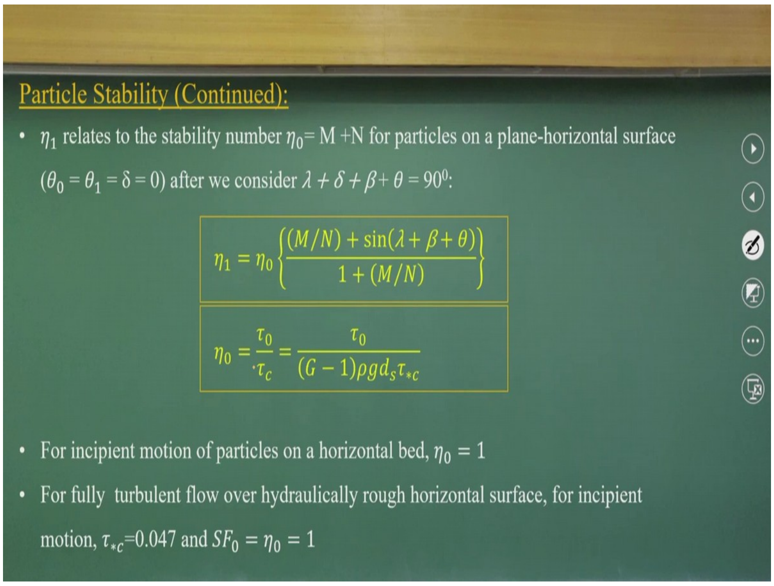

If you look at that further we can simplify that as we go for a plane horizontal surface where you have a Θo, Θ1, δ becomes 0 and this is a sub assumption of angle is a 90 degree and you can simplify the η1 is a function of ηo in the function of M and N α, β and Θ and Θo can divide is a τo is applied shear stress that is what is τo stands for applied shear stress and τ* stands for the critical shield shear stress.

And basically when you have a fully turbulent flow and the hydraulically rough surface at the incipient motions the η_o =1 and the critical shear stress the shield critical shear stress is equal to 0.047 that is what we discussed earlier. So we can find out the η_o part you have a relationship between applied shear stress and the critical shear stress and that is what we define the critical shear stress in terms of shield critical shear stress. And that is what we can have very simple equations to find out what will be the η_1.

Now if you look it next 1 when you talk about its not the it will be rotate on this the plane surface on the bank plane surface. It can rotate to perpendicular to that that means we are looking at particle b which can rotate along these directions perpendicular to inclined surface. You put that you can again come get it the components here there are the 2 components are there 1 is the drag force components and another is submerged weight components.

And if you look at that what is the moment at this point again we can put it to the same conditions are the restoring moment is equal to the yours the overturning moments and that what if you simplify it will get it tan β or beta = $\tan^{-1}$ will be a function of this. So more detailed derivations you can get it from reference like Julian book or respective publications who are not going more details.

But analytically if I consider the particles which are there on the river or the it is bank they are the particles and we are looking at what force components are there because of the flow the drag force the lift force and some modulate and what conditions of the layouts are there that is what is talking about in terms of angles in terms of the path line particle path line in terms of stream, path lines stream lines.

All we can result it to find out the factor of safety of this particle. If I know the factor of safety of the particles that means I can know it at what conditions if a factor of safety is more than 1 no doubt the particles will remove from that the erosions will start it on the bank or the bed. If a factor of safety is lesser than 1 I can say it it is a stable but significantly if it is a much, much lesser than 1 then I can say it the bed or bank cases it remains a stable conditions.

So we try to look it at the particles levels which you know it the river bed does not have a uniform bed materials or the bank materials and the particle level of concept to implement at the rivers is always a questions mark. We can derive a good analytical equation to know it what could be a factor of safety for a particle to initiate the motion so in spanned motions that what we can do it. Looking these safety factors of the particles ok.

Whether it is a greater than 1 its unstable the particles will remove from the bed or bank in that case it will initiate the river is not equilibrium stage or particle number is less than 1 this we can achieve the stable but if your factor of safety is much lesser than 1 then we can say the channels are the stable. But the limitations here that as you know it river banks are heterogeneous mixed bank similar way the bed is a mix is not uniform sand or the uniform the gravels are there.

So those conditions we should look it not only that we should talk about more detail about river bend and the geometric conditions.

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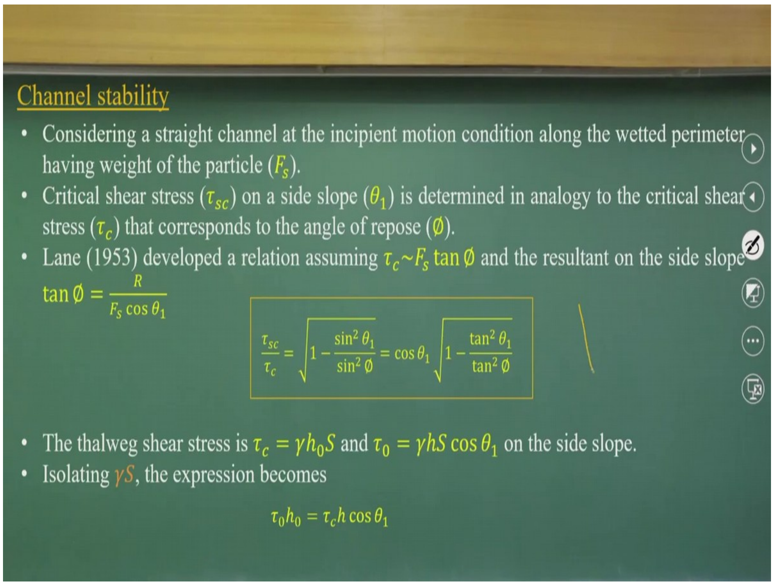

So another interesting concept will let us talk about not the particle level stability talk about channel stability that means I have a river channels ok. So most of the times it will be parabolic shape and I have the flow here I this is the flow is moving with the velocity v and there are the variations of the shear stress the variations of the shear stress happening along the perimeter of the channels. How can I say the channel is stable?

If I consider a straight channel it is and all the particles on the bank or the bed they are at the inspired motion they are about to move out from that bank or the bank materials along these wetted parameters having a weight part of the particles is F S. So that means I consider a wet particles which is on the bank or the wet particles here on the back on the bed I try to look it what conditions it should prevail it that all these things and what could be the shape of these channels such a way that these 2 particles are remains on the same locations they are not we just starting the incipient motions.

So that means we are tracking it if it is Θ1 angle is there and looking it critical shear stress is tau as c along these things use analogous to critical shear stress corresponding angle of repose and if I consider the lanes 1953 the critical c stress is equal to F S then phi, phi stands for angle of repose. And the resultant component on the side slope is tan phi R by F S cos Θ1 I can have a ratio between shear stress critical shear stress on the bank on the side and the relations will be come to a functions of Θ1 and the phi.

So Θ1 is angle, so if I look it even if I have a flow depth is h naught the fluid depth is h naught then I have a the critical shear stress acting on this and applied shear stress on this side flow. And if I just equate all these equations and do isolating this omega s per omega S value S stands for here is the bed slope.

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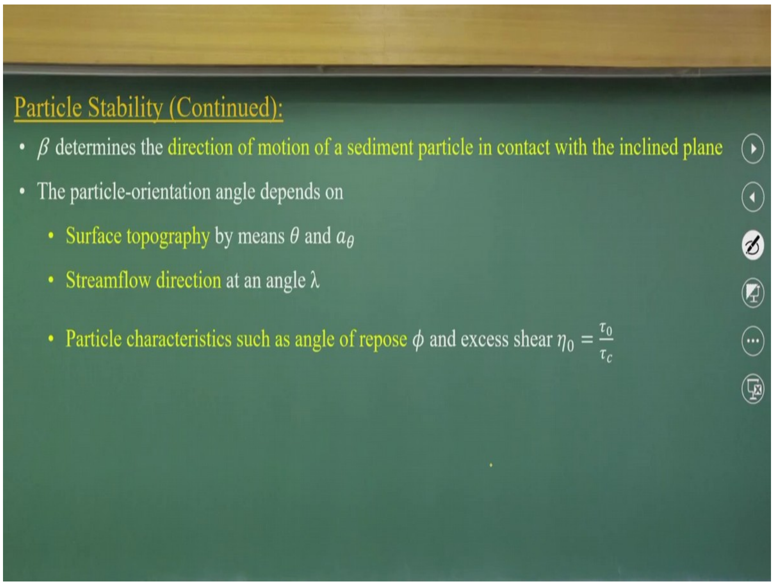

If you look at that parameters and if I make it the simplifications of this.

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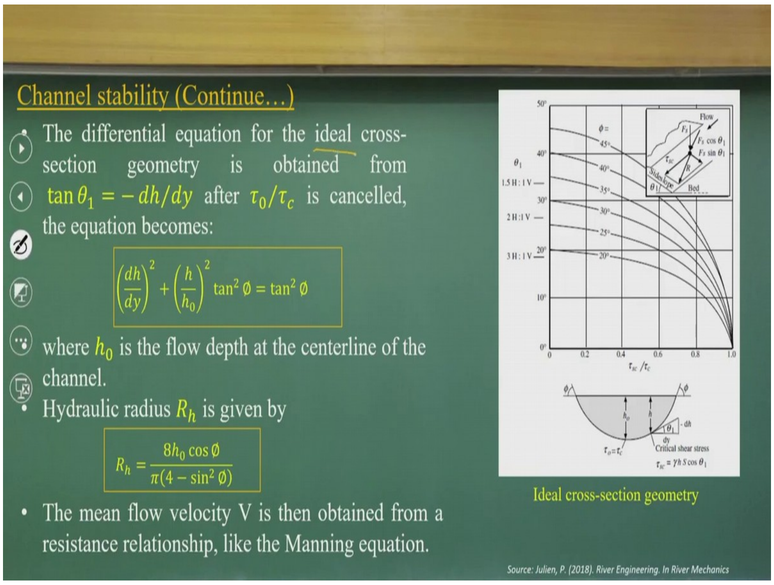

We are going to get it a differential equations of ideal cross sections geometry that is what will be tanϴ1 is dh/dy so this is h naught if you look at that we are looking at τo is equal to applied stress acting on this bank or the bed that is what you equal to the τc that is the incipient conditions. If that is the conditions you tau c is a functions of omega hs cosϴ1 and ϴ1can re write it in terms of geometrically tan ϴ1 =-dh/dy.

And if you cancel it you will get these equations and if I solve these equations h 1 is flowed up center line of the channel the hydraulic radius comes like this. So now if you look it so no doubt the tau sc on the side surface which is much lesser than the critical shear stress on the bed. So if that is the conditions if you look at that the here we have the ratio between tau sc the critical shear stress on the bank divide by the critical shear stress on the bed.

If I consider that the conditions definitely this value should of course this value should be less than 1 and this is the angles okay the ϴ1 angles and this is the different slope 20 degree 25 degree 30 degree and 40 degree of the phi value angle of repose. So we can get this relationship with the solutions of these equations. So this is what is indicating it the shape. The same way for this equilibrium surface will get it this once.

The shape will come it to like this so we can define the shape of the river which is the equilibrium shape. The shape are all these bed material and the bank materials they are for a uniform bed size bed and sediment glue conditions we will have a the relationship between these ones as well as the graphically you can see it how these ratios are varying with angle of repose and the ϴ1, ϴ1 is a downstream slope.

So it is a quite interesting the analytical derivations of the relationship with a side critical shear stress and the critical shear stress as well as getting a equilibrium shape the channel shape for uniform bed and the bank materials. If you know it angle of repose and all we can compute it what could be the channel shapes so most of the times we show the sum of the channel cross sections the data from Brahmaputra rivers and you can see it, it does not follow these ones.

But that means it does not follow these equilibrium constants concept as we are looking at more details and we will do discuss more details in about Brahmaputra rivers and why do not get a equilibrium cross sections. But smaller rivers we generally get a single channels close to this resembled to this equilibrium ideal cross section geometry of a river.

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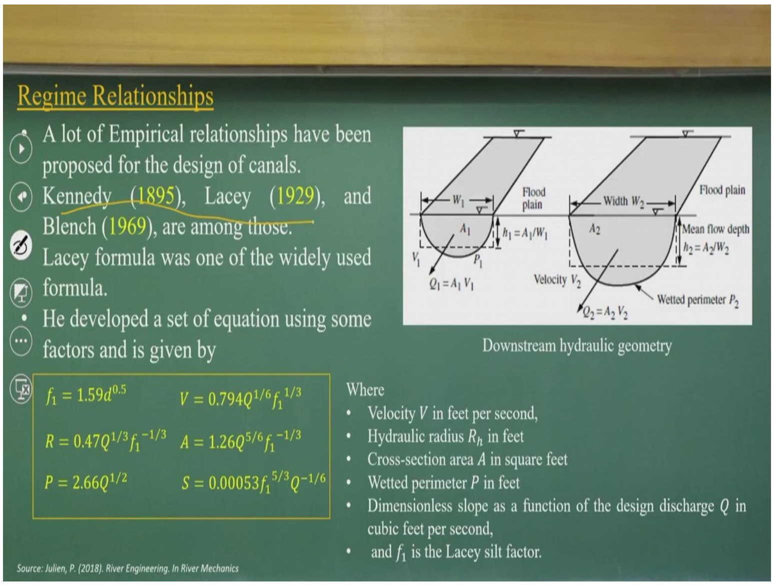

Next very interesting thing is regime relationship. Way back we used to have a constructions of great Ganga canal or Indus canals in Pakistan it was a quite challenging task for the engineers that how to design a slope of the channels and the cross section such a way that unlined canals in alluvial plain of Ganga and also alluvial from Indus such a way that we should get a stable channel cross sections.

That means they are not a significant amount of erosions or depositions are happening it they are not significant amount of changing of the bed width or the change of for a particular constant discharge. So what they try to do it that is that is what is the contributions of Indian engineers by the Lacies, Kennedy Way back in 1929's before our country independence we used to have a to be a leader on designing this alluvial channels.

In terms of getting the field data try to establish the relationship between for a river or stable rivers stable canal reach what is the relationship between geometry of the river with the flow discharge. Because most of the canals we have the constant discharge we do not make a transient flow in that conditions what is the geometry it shapes the rivers. If we follow that geometry of the rivers that means we try to understand from the river perspectives or the channel perspective that how the river shaping it.

And if we try to find out the same geometry of the rivers in geometry and the slope and that empirical relationship will give a design relations. The Lacey equations in 1929 and Blench in 1969's which is very widely used Lacey's equations still now also we have been use it for scouring computations we have been using for designing the bridge piers and we are also we have been using steel.

This Lacey's equations is similar to the meanings equations its empirical natures since it is a field data collected data based a plus a data mining or data science today we talk about. The combinations of both after extensive data collections and the data mining they try to do it establish the relationship which hold goatee for a river or the reach at the equilibrium stage. The relationship what they got it is a functions of controlling part and the dependent part.

So if you look at the river as you say that river is author of its geometry the author of its cross sections and author of its slope. If I talk about that river shapes it is the path, river shapes it is cross sections. If I look at that concept and try to look at that there are the dependent variables like the velocity area if I talk about the velocity and if you talk about the area and if you talk about the relationship with the slopes these are empirical equations are derived for wetted parameters and all what they do it because very easy to know the discharge.

And also its depends upon another particles is a particle dimension DMN is the particle diameters we can consider D50 values can have a silt factors. So the empirical they introduce a factor which is called Lacey silt factors and they establish the relationship of velocity area and hydraulic radius and the parameters wetted perimeters and the slope these are all empirical data collecting the field data do a data mining develop a correlations between the dependent.

And here is independent variable is the discharge and the D50 value that is what they introduce the Lacey shield factors this is very well known the Lacey's equations and the velocity area radius and speed and still we use for designing a online canal scouring depth of plot plane width all while we do it based on this Lacey's equations which is way back in 1929 still it has a lot of relevance to a to hydraulic engineers or the sediment engineers to know it how they have divide these empirical equations which is still has a lot of utility even if you have a lot of understanding more.

So this is called regime relationship and that is you have to try to understand it and try to make it how it is very good equations has come up in terms of Q. And so this is now if you look it that is what is representing you can make it as equivalent to rectangular cross sections with a plot plane and river and you can know it whether the river is equilibrium conditions if it follows these regime relationship.

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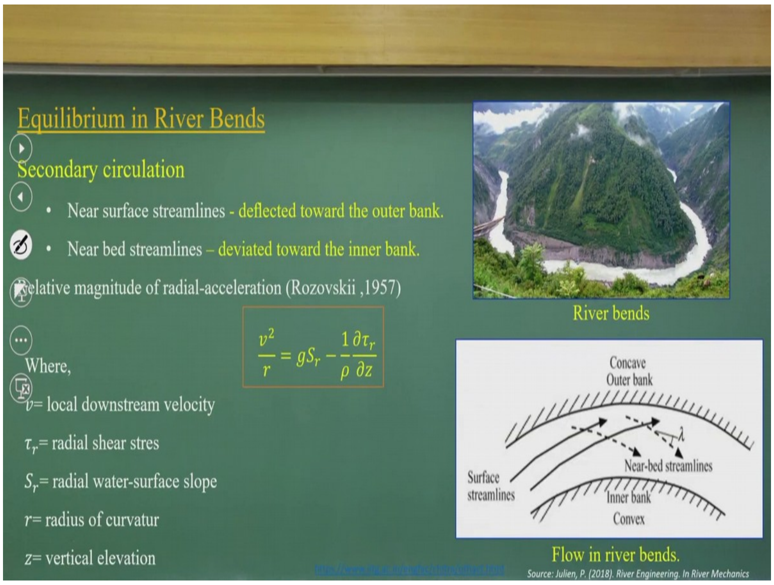

Now if you look it very interesting part if you look at this large gorges in Brahmaputra rivers still it is a inaccessible to these river bends which is there in part of China and India border and 1 of the largest gorge is there and huge energy is dissipated in these 3 gorge still we have a lot of questions mark on these gorges what it happens to that. So let me come back to the river bend a simple river bends if you make it.

We can understand it that will have a surface stream lines will have the surface stream lines like this and you will have a the near bed stream lines very interesting that you will have a suppose surface stream lines which are attacking this outer bank you have a near bed stream line which scours this bed materials and bring it to the inner bend so that is the reasons point bar formations happens it. So the you have this outer bank this surface you can look it and there is angle there is a angle of deviations of nearby stream lines.

So how much of angle of deviations are happening it that was also play the major roles. Now if you look it if I have a river bend ok and if I consider river bank at the equilibrium stage what do you mean by that? That the force components are some of the net force acting on this control volume should be equal to the 0 that is what the equilibrium conditions. That means we look at that centrifugal force per unit mass that is the accelerations is equal to balance by this unbalance the pressure force components.

And also the unbalance the force due to the shear stress components. So ready so So stand for here radial water surface slope r is a radius of curvature z is in vertical directions. See if you look at that what we are looking at centrifugal force per unit mass that is the accelerations this is the unbalanced pressure force because there will be super elevations per unit mass that is what also the shear force per unit mass that is what we have done it.

For equilibrium condition that is the net force acting on this control volumes is equal to 0 here as the water is rotated and you will have a centrifugal forces per unit mass you look at the pressure force difference what is comes it and the shear force per unit mass that is what we equate here.

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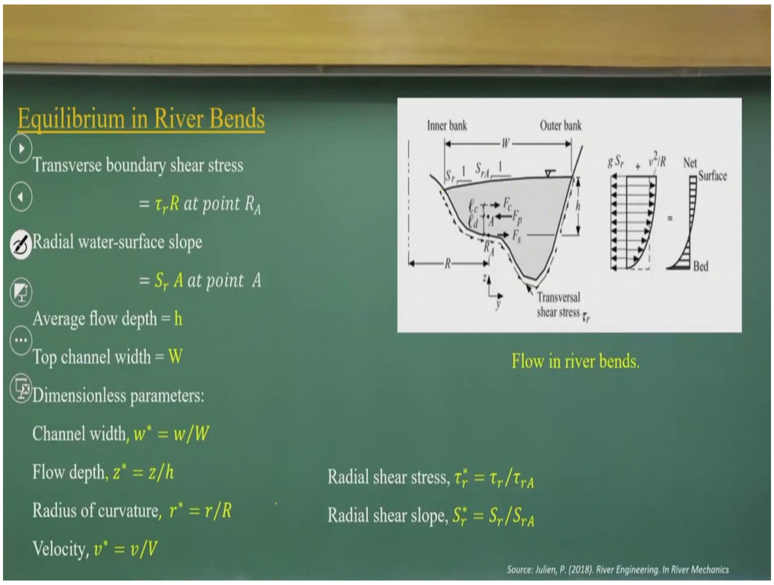

Now if you look at the figure levels that you have the river like this and you have the slope of the free-board this is the inner bank this is the outer bank you have a W is a width r is a radius and you have a z and y directions tau r the subscript r is a transversal shear stress. So if you look at that g S r can have a this directions if you look it and v square by r which is a centrifugal forces components that is what will be net will come like this you can see that there will be negative and the positive part net force acting that.

So transverse boundary shear stress we can we can have a radial sales force part and we can average flow and all so we can make a non dimensionally try to look this part but I try to convince you that you take a control volumes and try to look it what are the force components are there and that the force components we are looking at how it varies along the depth that is what is the showing it the net components of the shear stress component how its acting it that is what is showing it.

And you can have the super elevations and we can do a non dimensional things which if you want to have interest you can follow this P Y Julian books but I will be just summarize this if I make it a non-dimensional way to make it in terms of fluid volumes the reach length and making a dimensional less volume parameters. And the same equations we are just doing a integrations volume integrals things.

Then also we can have a moment big equilibrium at the point a this is because of shear forces this is because of centrifugal accelerations that is the part. If I look it and we can have a concept to try to look at what is the moment equilibrium happening at the point A that is the more details we are not going it but if you are having much more interest you can look at this components how its working on this.

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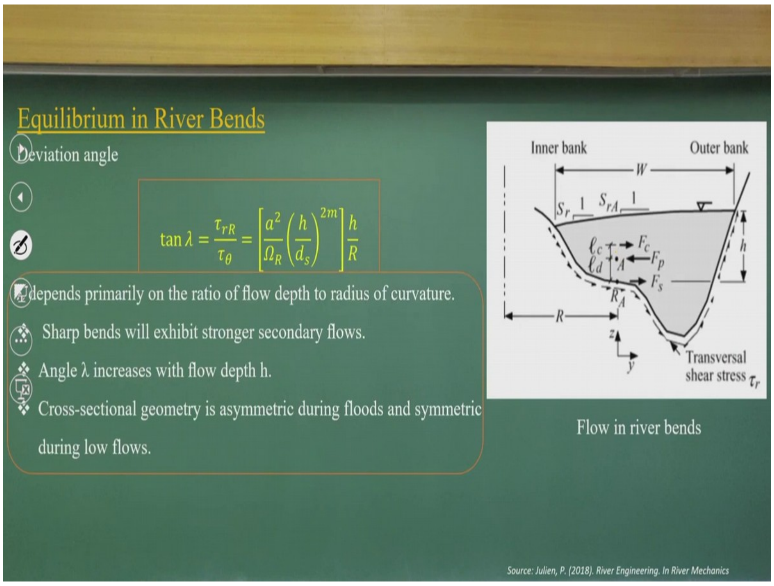

Now if you look it very interestingly if you can see this deviations angles can have a function of τ_r and τ_Θ and which will be functions of equilibrium momentum h/ds. So h/ds is representing relative submergence h/r is a functions if you look it r is a radius h is a flow depth so tan λ this angle of deviations it has a function of this it depends primarily on the ratio of flow depth and radius curvatures that is what you can look it.

And sharp bends will exhibit stronger the flow so if I have a bend is sharper then you have a more the stronger the secondary flow will happen it and angle λ is increases with the flow depth the cross sectional geometry is asymmetry when during the plots. And symmetric during the low flow let me I explained that by sketching the figures see if you look at this river in a flood period. So what will happen it the mostly geometry will be asymmetric in case of the plot periods and it will have a higher depth at the outer bank.

Higher depth at the outer bank as the lambda value is changes but when you come it to the low flow periods the thalweg line will come closer to the central lines so that means the thalweg line the deepest point of a channels its oscillates it during the plot it reaches to the bank and after the plot when you have a less flow it again come back the deepest points is again come to the center line of a river bank.

That is the it depends upon the centrifugal force acting on which is balancing the counterbalance by the unbalanced pressure force in radial directions as well the shear stress acting on this. So that is the reasons we have a the oxidations of thalweg lines during the flood periods its closest to the outer bank as has come to as the lower periods this thalwag line the deepest channel depth line that what will be shifting towards to the center point.

So in that period we will have a symmetric cross section so during the plot period you will have a cross sections like this, this is the flood period but during the low flow period you may get the cross sections will be the symmetric cross section that is the because of the hydrodynamic behavior and the shear stress distributions what it happens in a river bed during the plot and the low period will have a asymmetric and the symmetry conditions that is the dynamic of the river banks.

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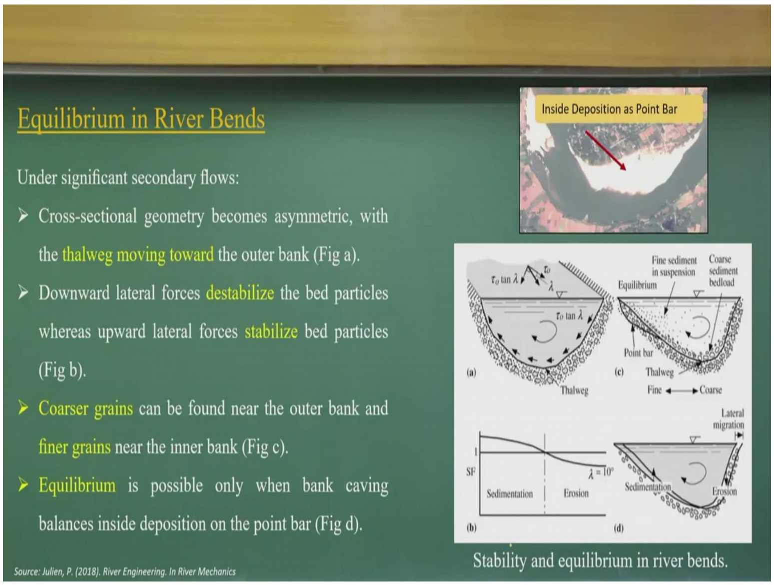

If you look at that point and if I go for very interestingly look at these figures what it actually happens it ok. So when you have a very, very high flow conditions you can see whenever river bed is there; there is a point bar depositions are there and you can see that it will be a Thalweg lines so you can see there is a secondary current and the thalweg line since the bed materials can have the mixed bed materials would have a bigger size and smaller size you can have a finer coarser depositions.

The coarser materials will be in this side outer bank and in our bank will be that you will have a point bars the fine sediment particles will be here the coarse sediment particle will be here; so you can see the bed material compositions are changes it as the shear stress distributions are changing it and there will be sedimentations and erosions patterns. But when you go for lambda is much, much larger then you can have a lateral migrations of the it is a erosions of this bank and the depositions are here.

So point bar formations will happen it so very interesting figures how the river works it during the extreme floods and the low flow when the river bends are there. So if you can try to understand it sketching these figures which is a part of everywhere engineering curriculums that you can sketch the figures and you can try to look it how does a river behave in during a flood periods. How does a river behave in a bend during the low periods.

How the Thalweg lines are shifting it during plot periods during the low periods how these bed materials armoring are happening it the coarser of bed materials and the finer bed metals finite sediment suspensions are happening it. All we can understand it and try to interpret the river how it is happening the dynamically when a flood is passing through a river bank. So that is what again I can repeat it that part the cross sectional geometry becomes asymmetric and Thalweg moving towards the outer bank.

Downward lateral forces destabilize the bed particles whereas upward lateral force to stabilize the bed particles. And coarse grains can be found near the outer bank finer grains bed materials you can find in the inner bank. The equilibrium is possible when the erosions part balancing inside the deposition of this. So then you will have a river bank will be stabilized conditions.

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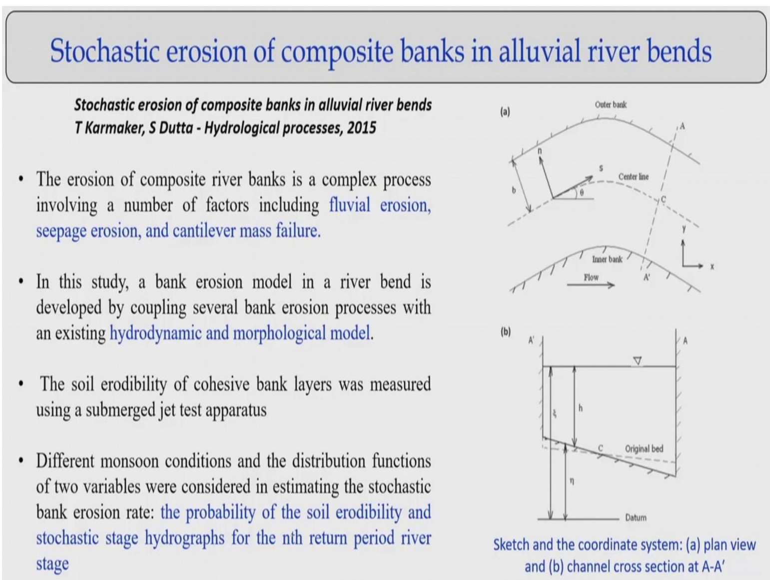

With this let me I have a 1 of the case studies what we did it extensively in 2015 we published these journal papers with stochastic erosions of composite banks in alluvial river banks. Basically talking about the Brahmaputra Rivers we talk about fluvial erosions seepage erosions, cantilever mass failures we develop a models which is the hydrodynamic morphological models. I am not going detail of modeling.

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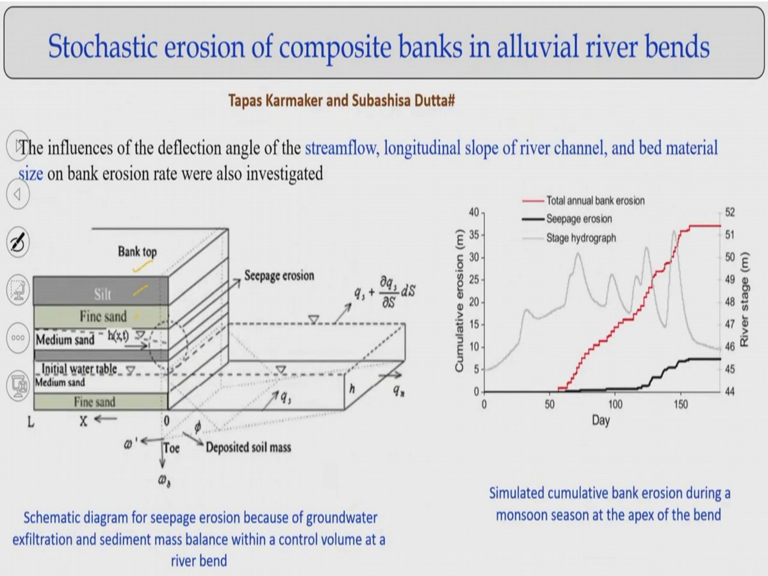

How we have defined this geometry of this part and if we look it how this stratified bank of Brahmaputra rivers have a silt, fine sand, medium sand the clay particles water tables and all and if you look at the total bank erosions. How its varies with the time cumulative erosions that is what we predicted and is showing is the seepage erosions which we fill out with the people we introduce the seepage erosions is also a significant part river like Brahmaputra rivers.

So we are part of that and we also have a series of publications on seepage areas like a large river like Brahmaputra river where groundwater table fluctuations are there that is that is what we try to look it and I am not going more details you can look back this paper which is there in hydrological process.

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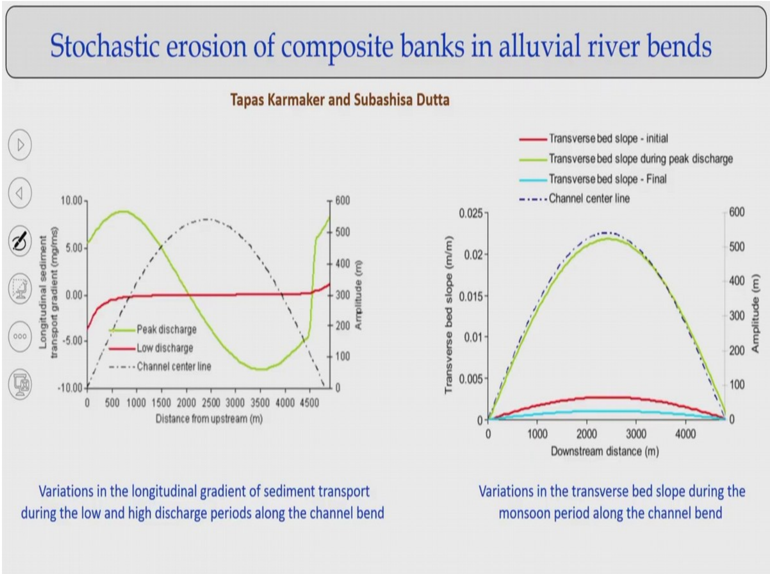

And we try to look at how river bends transport bed slope center lines how the peak discharge low discharge channel central lines how it is varying it how these amplitudes and all it is quite interesting to know it how a river bends behaves and different and when you have active of bank erosions bed transport the flow behaviors that change it how things are have changed how the thalweg lines are changing all we can have an understanding on this.

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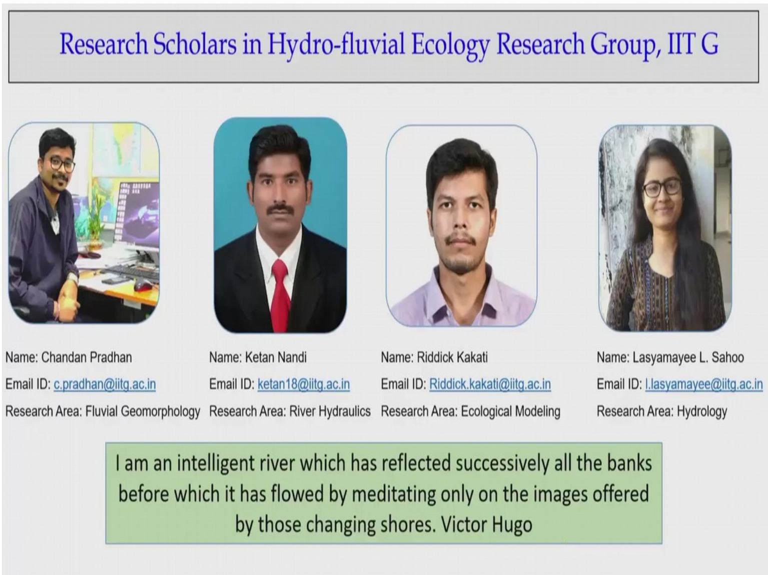

No doubt who are interested you can go through that but let me quote it as quoted by Victor Hugo I think you do believe on that I am a intelligent river smart river which has reflected successfully all the banks before which it has flowed by mediating only the images that is offered it is a clear cut talking about the rivers is too dynamic and too intelligent. And try to balancing of the hydrodynamic the sediment and that is what is reflects us and with this let me conclude this lecture, thank you.