River Engineering
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Lecture – 24
River Equilibrium-III

Very good morning all of you for these lectures on river equilibriums in which we will discuss about Lacey's equations river meandering and the regime relationship which is quite important for us to know it how does a river behave under changing discharge or the sediment load conditions that is the bigger questions and that is what we try to address through the regime equations concept.

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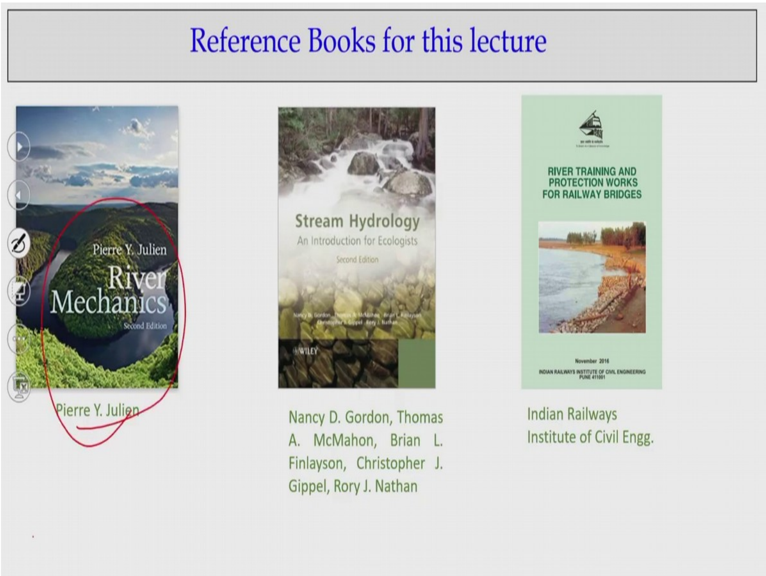

Now if you look it the next part what we are talking about which more or less we are following it Julian book as well as partly we are following it the experience of Indian railways engineers on how to protect the river banks and river training works for the railway bridges. So both the things we are combining it to discuss about what is the regime concept and how we can use the regime concept for the efficient river training works or the bridge protections the extreme plot protections of the bridges.

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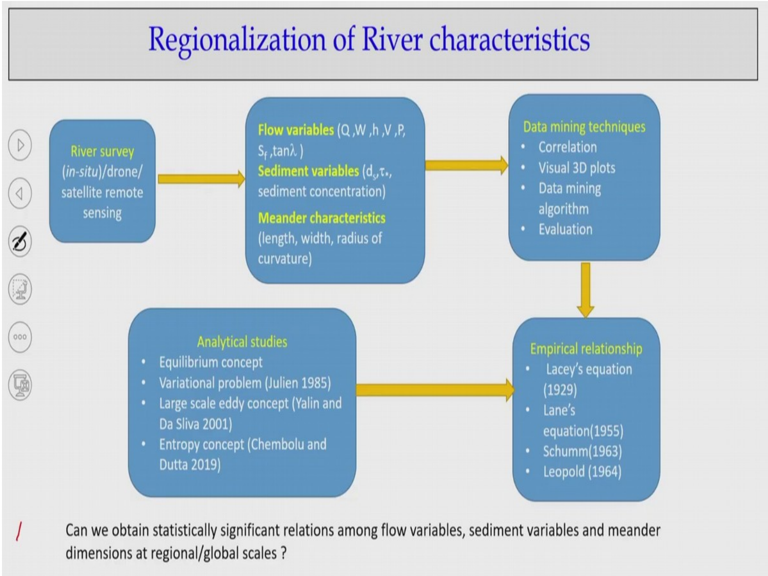

So if you look it that way if I look at the last slides which is again I am repeating it to have a the basic knowledge is that how the things are move it that 1 is the river survey which we can do from the field level of studies you can have the drone level of studies nowadays or today we can also use high resolutions satellite imagery to understand what is the river plan forms and how the river meandering geometries.

Those are things we can understand of the river and its river corridor associations by conducting a thorough survey either at the field scale or using the satellite platforms we can do it. What we target it the flow variables sediment variables and the meandering characteristics. And once you get these all these variable data the flow sediment and meanderings then you try to establish the relationship between that is the reasons you use the data mining tools very older concepts like correlations techniques.

Now they have 3d visualization technique and there are a lot of algorithms the last two decades has been developed for data mining from a large data sets there are a lot of examples and also the evaluations we can have. So the basically is what we have we have this these are the equations the empirical relationship what today we will discuss about the Lacey's concept and we also as discussed earlier the analytical studies focusing on variations problems large scale eddy concept and entropy concept.

We try to establish it this relationship with the physics that is what we try to do analytical solutions of the river flow with certain assumptions to establish this variation concept the large eddy concept with the empirical equations the entropy concept with the empirical equation. So that is the advanced level going on and this is the flowcharts what is there to know it how we can find the regime equations.

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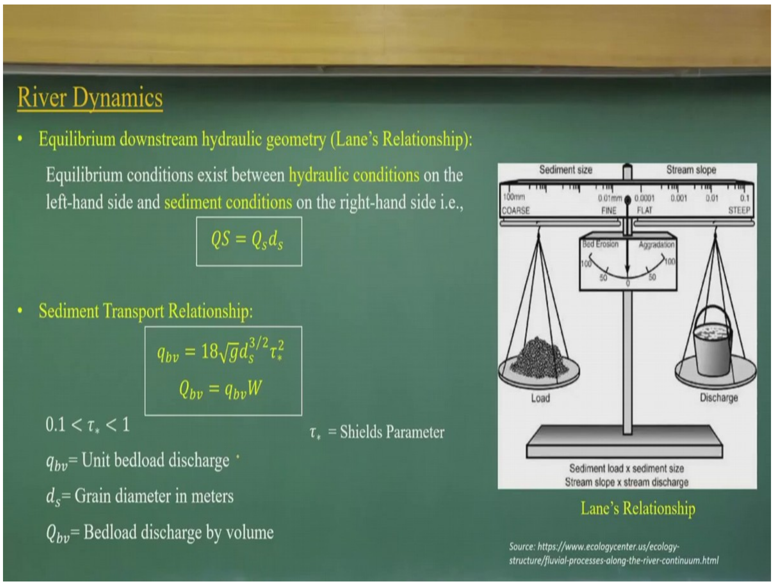

Now let me I go for the next 1 s is very interesting is that and if you look at the graphical Lane's relationships which talk about is balancing the river does a balancing between the stream powers that is what is the energy dissipations and the carrying of the bed loads these are balancing effect is there in a equilibrium river reach. So if you look at that it is a very interesting balance is there and if you try to look it 1 side is a discharge and the stream slope or the river slope that is this side and into the stream slopes it is indicating for us the stream power per unit weight.

What is the stream power is there or the energy expenditures is there that is what is balance with the bed loads and the sediment size. So if there is a unbalance either the bank will go for erosions level or the aggregations or depositions levels. If both are balanced there it is equilibrium states if there is a the higher value of Q and s the stream slope and this discharge the product of discharge.

And the stream flow which is a stream powers per unit weight that is what is indicating is that if it is this is the higher value that has to balance by the sediment size or the increasing the bed load that is what will have the bank erosions process will be significantly go more or if I have a this case you have a aggregations. That is what is my suggestion is that you just sketch these diagrams try to understand it how does a river behaves if we change the sediment load change the discharge or the change the stream slope like we do the sand mining we change the bed slope of the river systems we have been doing the sand mining gravel mining of the riverbed.

So we are modifying the stream slope as we are modifying the stream slope what is going to happen whether this will be aggregations or degradations or you do the sand mining so just try to understanding that if I doing the sand mining which is today is a very critical issue in our countries if you look at that so we you are increasing stream slope or the decreasing the stream slope. So we are modifying the stream slope we are changing this d 50 value mostly we are doing the positives we are armoring the things.

So we have so if you have modifying because of the sand mining the stream slope or modifying this sediment size so definitely there will be change in the bed load also there will be change and because of that change there will be change in the morphology. So that is what you would have to try to understand it when you have a equilibrium river in that position there is a balance between the stream power per unit weight with the product of the sediment load and the sediment size.

So if it is that the balancing is not there then either we can have a bank erosions or we can have a aggradations that means the equilibrium concept will go out it will start either the erosions or aggradations and the river may be morphologically active will be there. So if you look at that its very equilibrium concept with the hydraulic conditions of the left side which is talk about the stream powers or energy dissipations for unit weight and the sediment consents on the right side.

We have a Q_s and that is what Q_s stands for the sediment loads d_s is the particle size as we discussed earlier. So if you understand this figures and I try to tell you that please remember this balance which talk about how we modify equilibrium river if you modify by conducting a sand mining or you in the cases you can increase the discharge or decrease the discharge or so how does it is affects to the sediment size or the load.

If I look at these equations this equation has come with a very simplifications of same regime equations with a some assumptions like if I look at the best transport relationship which is a bed load per unit width is a functions of d s and the shield parameters. So shield parameter is a ratio between the bed shear stress and the weight of the sediment particles. So that is this bed shear stress part is coming here in within the shield parameters. Then if you want to compute is total bed loads which will be the unit bed load per unit width and the multiplications of width of the river.

And that width of the river we can approximate with the previous regime equations where each q bv stands for unit bed load discharge d s is a grain diameters in meters Q b is a bed load discharge by volume.

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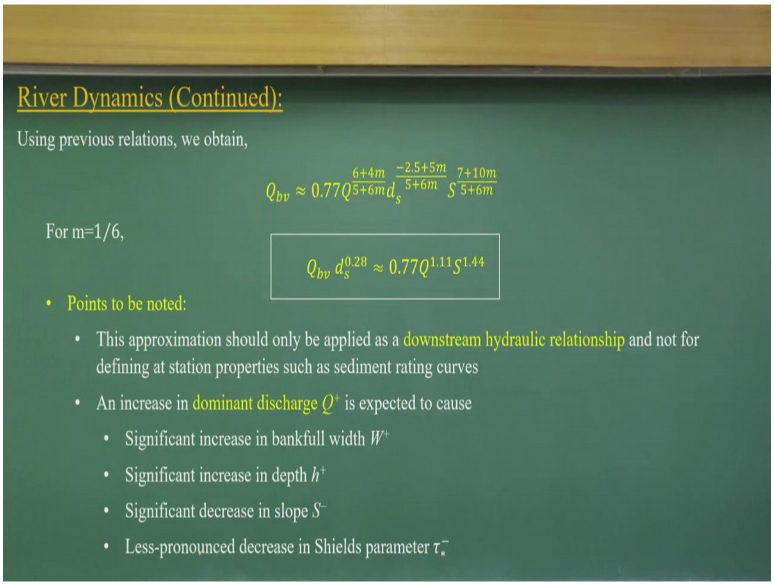

So now if I substitute those equations that are what is I am just subtracting the W value which is a relationship with Q dx and the s value and if I just rearrange it I am getting the same format what is there in the Lane's concept if you look at that. So if you look at that it say just like a Lane's concept where is Q to the power 1.11 S to the power 1.44 and this multiplications are there.

So what it indicates is that if I use the regime equations also I can derive the possible form of this Lane's formulas which establishing a equilibrium between the of stream powers or the energy specification per unit width with the sediment load the river sediment load in terms of the bed loads what is the here. So if you look it that way that is a downstream hydraulic relationship it is not for the defining the station process sediment rating curves you try to understand that it is not for the sediment rating curves.

So if I increase the dominant discharge the Q plus expected there is a climate change and we will have the more of only this dominant discharge is going to increase it. If that is the conditions if I looked that equations what we going to increase to balancing that width can increase it because that is what is here the h can increase it that is there because as this Q is increasing it we have to increase to make a balancing effect with that; so either the bank ful width will be increased the depth will be increased the slope has to decrease that is what is here to or the there will be decrease in the shield parameters.

But those are very long term process to change the shield parameters like d50 values the bed material of the rivers will not change so drastically within the few years within a decade’s it is a very long term process happen for the alluvial depositions. If you look at that way if I summarize that if there is a climate change or deforestations expecting this dominant discharge is in a positive trend.

If that is the conditions from these lacey's equations we can easily found out that river will be response and width to be increased or the depth to be increase slope should reduce. So that is what I am going to try to understand it the regime equations we can put it to know it how river is going to respond it if there is a dominant discharge in a positive trend that means because of the climate change because of deforestations the dominant discharge is increasing it.

If that is the conditions the river width the flow depth is supposed to increase it whereas slope can also decrease its to however this because other part like a d50 values the shield parameter shear stress those are not going to change within a few years it takes longer times it is not a decadent levels it is a beyond the their levels. So changing of the d50 result so if you can understand it if there is a increasing of the dominated discharge that is what is going to affect width and the flow depth and there will be a negative decreasing trend would be there in the slope the river slope.

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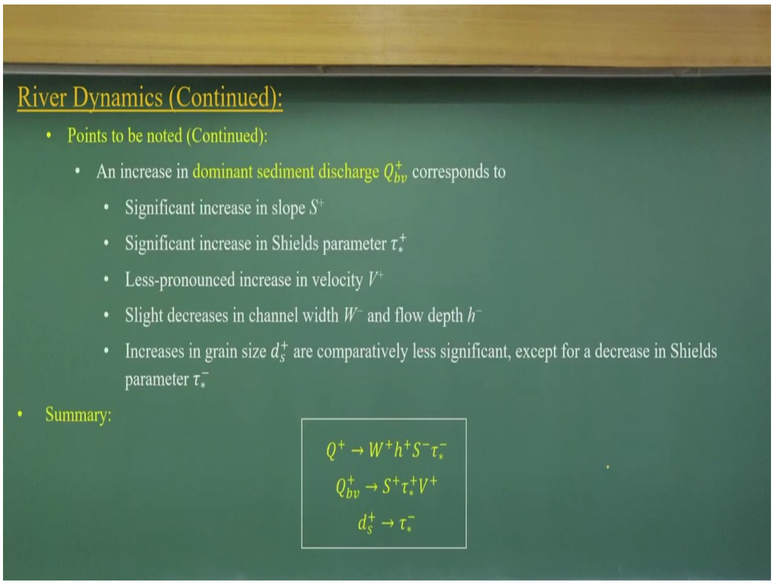

Now if you look at next questions if I look at that the dominant sediment discharge is in positive trend. So if you have look at this Q b into d is equal to Q and s this is the discharge this is the sediment discharge these are d values and s is a slope. If I making this is a positive value so to making the balance the slope has to go increase so that means the shallow slope can go for deeper slope can have a increase in the slope to balancing that or you can have a the velocity can increase it to increasing this part.

Or you can have a significant increase of the shear stress values that is what is the Q b increase means a they are in part of shear stress slightly decrease in channel width and the flow depth that is can be happening. But the grain size distribution comparatively lacks significant except in decrease in the shield parameters. So you try to understand how the river is going to affect it if the dominant sediment discharge increases.

If you look at this increasing the Lane’s concept is a relationship between the dominant sediments discharge with the d values and Q and s that this the discharge and the slope of the river as this Q is increasing trend definitely to balance it either Q to be increase the velocity is to be increasing trend or the slope to be increasing trend or we can find out will be a positive trend increasing on that part and there may increasing in grain size are comparatively less significant except in the decrease in the shield parameters.

So if you can look at this diagram you can try to understand what is happening it when you have a river systems if there is a change of the flow change of the sediment discharge both will be affect in terms of changing this the flow geometry in terms of width depth and the slope and the shield parameters. If our sediment is increasing there is increasing in all these factor the slope the velocities as well as the τ*.

So that way you can try it the conditions where in which conditions we are going to have the dominant sediment discharge will be in increasing trend or same way you can anticipate it if there is a Q will be the negative as you have the reservoirs you can regulate the dominant discharges or or Q b the sediment discharge is a negative trend that way you can also interpret it which you are going to increase which are going to decreases.

So the Lane's equations talks about us how we can anticipate which are going to increasing trend of the flow parameters flow variables or the channel characteristics that we should try to understand it.

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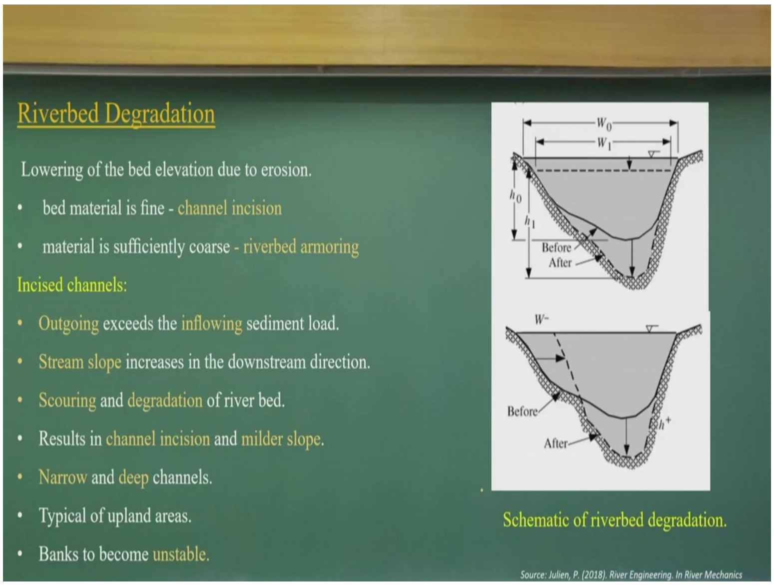

Now if you look it very basic things the riverbed degradations the like for examples you have a river initial level like this the width does not change it but the depth is increasing ho to h 1 so when you have a lowering the bed elevations due to the erosion process. If that is the riverbed shifting the bed material is fine then channel incision will happen is materially sufficiently coarse then river bed armoring is going to happen it.

For incised channel what it happened is that outgoing is exceeds the incoming sediment loads that is try to understand it. Why it happens it the incoming sediment loads is a lesser the outgoing sediment load is more because it is a deepening the channels and the stream slope in increasing the downstream directions which is just a reverse. For a generally you go to downstream stream flow stream slopes should decrease it. But if it is incised channels you will have a increasing trend.

The scouring and degradations of the riverbed that is what you can show it the resultant channel incision, the milder slope, narrow and deep channel and there will be the banks will be the unstable so we can have a reduce the width before and after and the shape can come like this. So you just look at how this riverbed degradation is happens.

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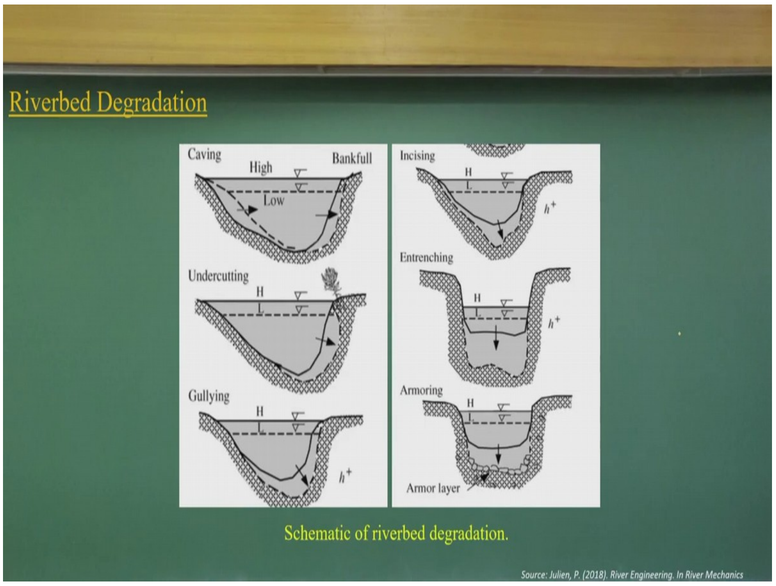

Same way you can graphically you can just to understand it is a very easy things to understand it that you can have a caving process you can have a undercutting process the high flow low flow is there and this is the cutting part is there gullying process and you have a incising process and entrenching process you can have a like this though deepening the channels or you can have the armoring processes are happening it.

So these are just looking the figures you can understand it how the process are happening it and we are not going more details but let us have a the knowledge that as the flow variables are there and different type of different river degradations can happen.

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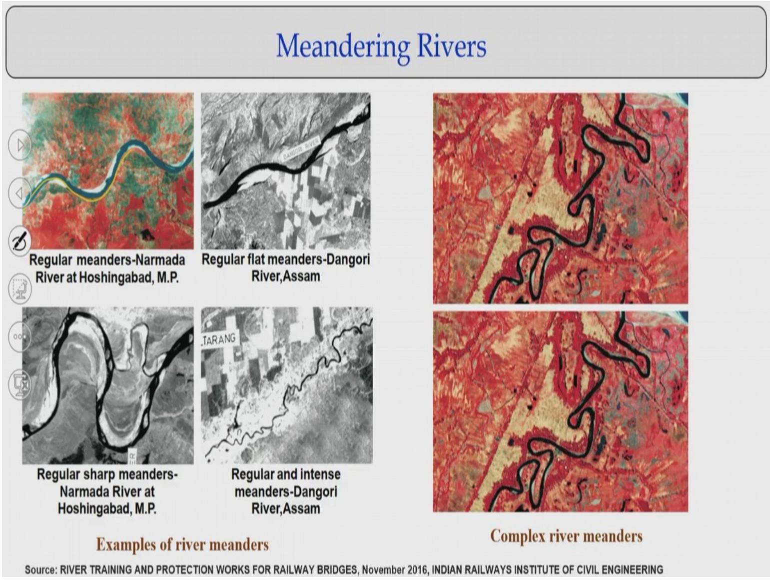

Now if you look at river plan forms if I look it nowadays is too easy from Google earth imagery we can see the satellite data and we can see what is happening to river plan forms that is very easy to look it. Look at these three words with a regular river meanders ok, so it is very easy it is very interesting river meanders which is there in part of the Narmada rivers but here this meander the wavelength or the amplitudes of the meanders are the different.

If you can look at these two rivers which have this but if you look at the sharp river, river meanders can go for like this shape it can go like this shape and come back like this. So if you look it this way river meandering shape can have a like this shape. So it is a quite interesting or if you look at the river which is in Assam's Dangori so if you look at the shapes it is too complex regular intense meanders are there.

The meanders which are clearly visible and there are the countless river meanders like this if you look at these figures okay it is makings I intentionally am sketching it to understand the nature's art form. So sometime it is quite regular rivers meanders and you can have a sometime very complex river meanders we can see it from river it talks about the basic characteristics of the flow variable the bed materials the bank materials all it talks about.

We should try to understand why it is river is a very regular meander to the regular with the intense minders or the complex rivers.

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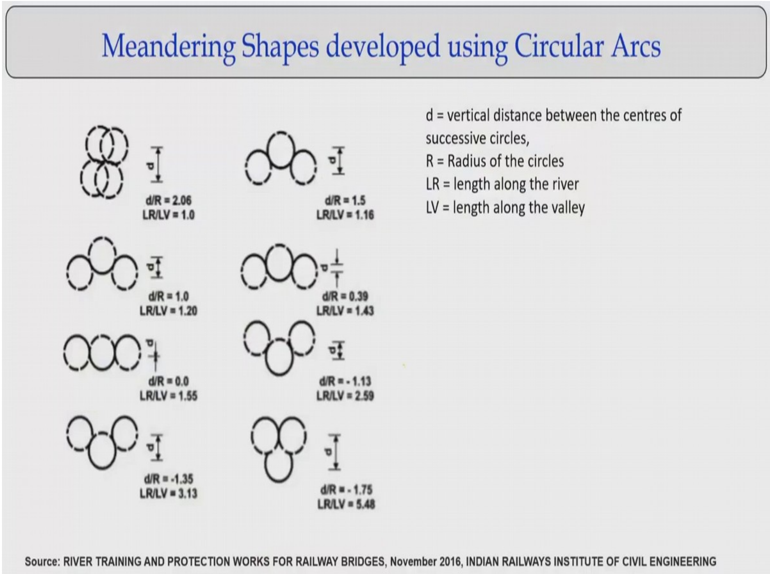

But let us try to understand it simple river meanders when you talk about that how things happens it if you talk about any rivers, river can have a shape like this it is very simple shape it can follow it river is controlled by these two narrow stretches two narrowest routes which we call the nodal. So you can see that in the river many locations there is a nodal locations the constraint reach river cannot have any degree of the freedoms that is the confined it.

So the mostly what it happens to the rivers that when you have the sediment the sediment or discharge the energy dissipations all are changing it, it is all are not a constant for the river systems sediment, discharge, energy dissipations or are changing it. So river what it does it to responds to these its try to make it as different response once at the different times. Like for example it can behave like this again it can follow like this it can happen that.

Because at the nodal reach it is a constant that or it can follow this way. So river with a two constraint locations river can have a different response. To know it to make a these very complex river we always look at a simple way with a circular arcs we can you define it the river behaviors between two constraint locations. How does its behavior with a this may be different years? How the rivers are behaving it we try to make it different circles?

If you look at that case this is the case we are looking at here. This is the case we are looking for here. This is the case we are looking for. This case this is the case is a very symmetric case we are looking from this or this is the case we are looking for the river to go like this or we are looking to river to go like this, this, this. Just you look the shape that is the natural art that is we should try to understand it.

And we with this circular arcs we can define these meanders and that is indicated for us the science to know it what the ratio between d/R d is a vertical distance between center of successive circle and R is a radius of circle LR the length along the river the LV stands for length along the valley. So if you look at that this way river can have this different response and we should try to understand it why does it happens.

And how river is going to respond in different way these are really interesting work and we should look at more advanced levels that how the river is responding between two nodal locations with the different conditions. You can see it in next I will show it.

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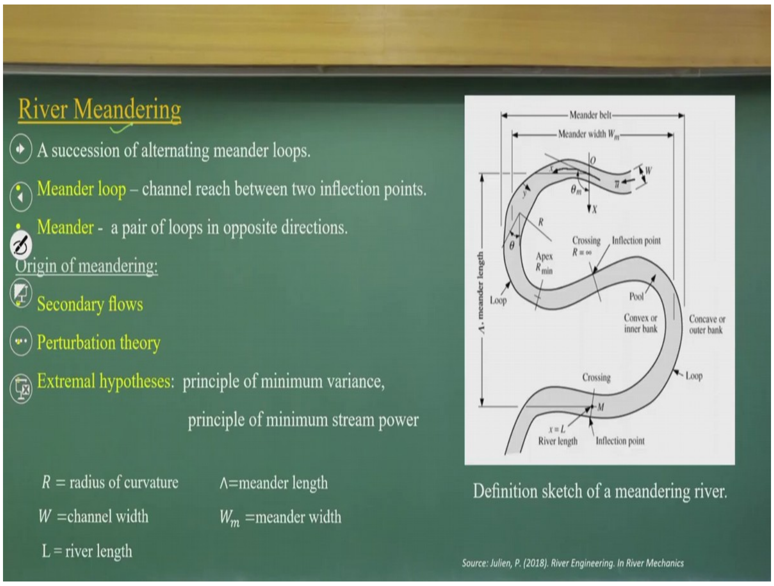

Now if you look it if you go for the next level very simplified way if I make a river meanderings with starting from with a 1 inflections point to another inflections points this is my meanders it is not exactly circular arc the Θm is a maximum angle here and the Θ angle is a changes it is. This is the two crossings and I am defined this is a meander length this is the meander length this is what mender belt, minder width.

So you can see that center to center point of the channels we can define as a meander width we can define a meander belt with a side to side. So if you look it this way if you can define a meander in river and W stands for the width and R is a radius which is minimum here or at this crossing point will be the R will be infinity and you have the radius. If I define it there are many debate about this meandering process there is many say that this is a secondary flow which is playing the major roles.

Perturbations theory there is extreme hypothesis like minimum stream powers and minimum variance concept. So but if you look at that way we try to understand is if that meandering length, meandering width radius of curvature and channel width and channel length and if I consider this Θ is a cos functions along this length this is the x distance along this river. So cos distance along this river if your truck is that and if Θ is varying as a cos function of x, x is along this one s.

If you look at this that case you have a Θ is a functions you can compute the meandering lengths the length along these curves that is what you can get it in these functions. If you compute the sinuosity is defined by the length river length divided by this the meander length the river length divide by this meander lengths if I put it that so I will get it the in terms of Θ times functions.

So this sinuosity is a playing the major roles if you try to look at the earlier figure the satellite imagery we can compute the sinuosity which is the ratio with the length by this meandering lengths by this the meandering length we will get it which is a functions of Θm so we can also get this radius of sub curvatures which are just a geometrical formulas we can establish it and we can know it what will be the radius of curvatures.

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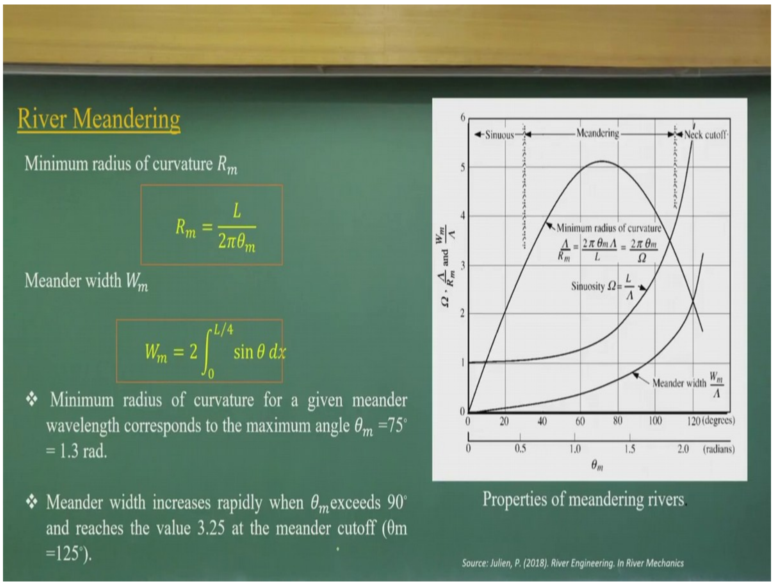

And if I look at minimum radius of curvatures I can get it meandering width also can get it a functions like this and if I plot it that is what is let me looking the properties of meandering river and plot it with sinuosity a non-dimensional forms with meander length by this R m this ratio non-dimensional ratio if I put it what I am getting it that there are three zones clear cut zones here we are putting the Ɵm so when Ɵm in the degree scales is more than 110 then there is a neck cut-off will happen it below 30 degrees you can call it sinuses river then it is called meandering river.

And if you try to plot it how this sinuosity increases is this meandering width by length is increases. How this minimum radius of curvatures is that so that is why we can have a characteristics of the rivers meanders in terms three classifications of sinuosity, meanderings and neck cutoff how do they are behaving of sinuosity that means at the time is increasing your sinuosity is going to increasing meandering width is going to increasing the ratio between W and this of meander length will be increasing trends and you will have the minimum radius of curvatures will follow this.

So these indicating us what is the characteristics happens when you have a minimum radius of curvature for given meanders is coming out to be 75 degrees that is what if you look at that. That is what you can look at that and meandering width in increase rapidly as Ɵ exceeds 90 degree it reaches the value 3.25 at the cut off. So what you are then that it is the value. If you look at this once it reaches around 3.25.

After that this process is cut off it so reaches the value Ɵm exceeds the 90 degree the increasing strength meandering width is increases rapidly this zone and reaches the value 3.2 meanders cut off happens which is a Ɵ will be the 125 degree. So the cut off will happen it here 125 degree. So these are the basic characteristics if you have a knowledge over that looking the meandering characteristics we can identify at what conditions it is going to have the meander cut off.

Now if I look it there is a lateral migrations river migrations river also migrate in the lateral directions. If I quantify the energy gradient along the valley here I am talking about energy gradient along the valley which is the ratio between energy losses over meander having the wavelength and the friction slope as s_o so we can compute what will be the energy losses in the valley directions and the energy losses which is in terms of your the basic the sinuosity functions.

And if you try to look it with Ɵm and the river sinuosity try to understand these figures which is very interesting figures are indicating it that if I put for a river meanders you have a time value which is in a radiance and I also have a ratio between radius curvatures and the width I have the sinuosity values the functional relationship of transversal shear stress will follow like this longitudinal shear stress will follow like this ok.

Just you look it this is a relative shear stress is showing it for the transversal shear stress and the longitudinal direction. So it is quite interestingly at 1.3 for sinuosity the Ɵm values and R m W values at that locations you have a transversal shear stress it is much higher after that there will be decreasing trend and before that so this is a sediment transport if you look it this is a low part and this is the high part is indicating how the sediment transport is happening it.

So let me have a put it the sinuosity varies with a Ɵ the ratio of the shield parameter for meandering channels is a functions of the Ɵm when Ɵm is above 90 degrees since parameters of a meandering channel is less than half of the straight channels. So you can try to interpret this the graphs giving a relationship between Ɵm the sinuosity with a relative shear stress that understanding can give us how does happens the lateral river migrations.

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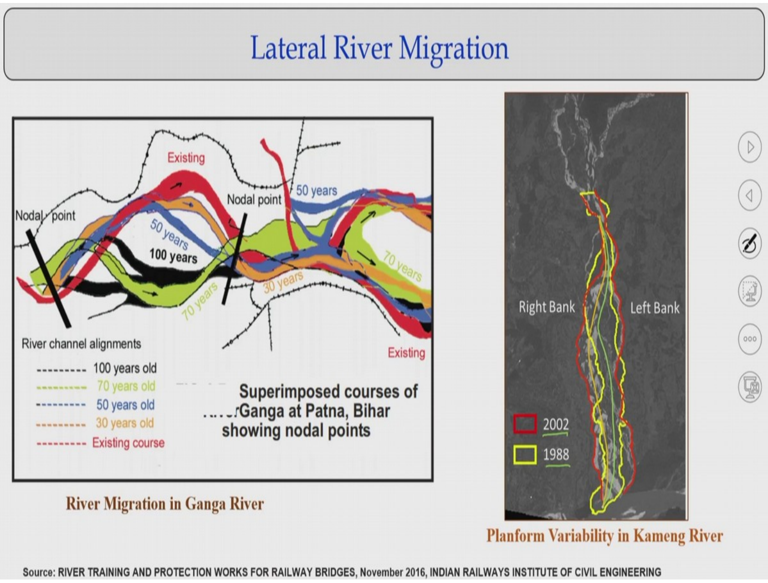

If you look at these figures of the two figures first let us see we discuss about the Kameng rivers which have a 2002, 1988 okay this is a span of 14 years. if you look at that these are nodal points where the rivers are something like this and furthers it changes the rivers the figures are these. So there is a lateral migration of the rivers so if you look at that there are the lateral migrations of a river or I can say it the river we have like the pendulums.

If this is the nodal locations ok the this is the locations of the nodal locations the river is behave like a pendulums so it is go like this just swing it, what is the time periods of this swinging is always a big questions mark what is the time periods? Does it a 4 years does it take 12 years does it does the time periods excess the 50 years. We do not know it that is that is the concept we should look it and if you just try to understand it, it is works like a pendulum and it has the time periods.

And what is that time periods of these lateral migrations that is we do not have much precise answer for that but if you look at that river courses are 100 years old, 70 years old, 50 years, 30 years existing course of river Ganga at the Patna there are the two nodal locations. There is a nodal locations this is also a load and locations the two is confined the nodal locations are there two confined nodal locations are there.

The rivers are weaving its very good pictures which provided by this Indian railways institute of civil engineers you can interestingly look at what is happening this river. How this this rail cutter is existing channels the existing channels are behaving like this just if you look at the 70 years back it was here and these channels again by fracting it here. So the bifurcations are happening here and these are oscillating behavior as I said it in this case it is accelerating between the two points.

If I look at that I have the spring it can accelerated like this it can have a oscillate like this ok just you try to understand it if there is a two points and the string can oscillate its in the lateral directions. And it has a time periods here you can see it river 50 years back that the conditions and the hundred years back and 72 years back it was here. So it is it is just move it from north to south this river flows from west to east as you know it west to east and the northern bank and southern banks.

So if you look at this river very interesting figures are there 72 years back the river used the south bank now it has shifted to the in the northern bank. We do not know how long it will be there may be another 50 years it will be returned back to the south bank and how the things are happening here. So these time periods of oscillations lateral directions all our big questions work for us and we should try to understand our river systems how does they behave it at as a lateral river migrations.

The lot of details nowadays available the old data's and the new data set what we are capturing it we should try to look it how does have these time periods as indicating the two river 1 is the Kameng river other is Ganga river at the Patna locations.

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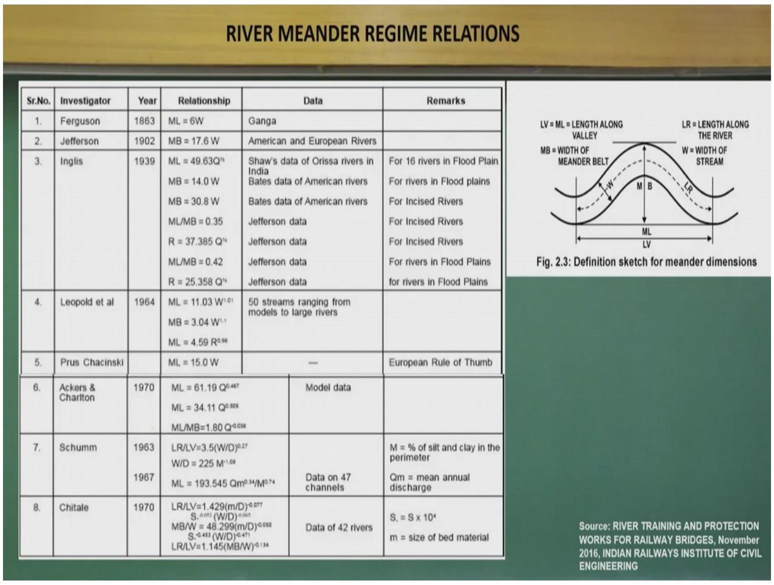

RIVER MEANDER REGIME RELATIONS

Sr.No.	Investigator	Year	Relationship	Data	Remarks
1.	Ferguson	1863	ML = 6W	Ganga	
2.	Jefferson	1902	MB = 17.6 W	American and European Rivers	
3.	Inglis	1939	$ML = 49.63Q^{1/2}$ MB = 14.0 W MB = 30.8 W ML/MB = 0.35 $R = 37.385 Q^{1/2}$ ML/MB = 0.42 $R = 25.358 Q^{1/2}$	Shaw's data of Orissa rivers in India Bates data of American rivers Bates data of American rivers Jefferson data Jefferson data Jefferson data Jefferson data	For 16 rivers in Flood Plain For rivers in Flood plains For Incised Rivers For Incised Rivers For Incised Rivers For rivers in Flood Plains for rivers in Flood Plains
4.	Leopold et al	1964	$ML = 11.03 W^{1.01}$ $MB = 3.04 W^{1.1}$ $ML = 4.59 R^{0.98}$	50 streams ranging from models to large rivers	
5.	Prus Chacinski		ML = 15.0 W	—	European Rule of Thumb
6.	Ackers & Charlton	1970	$ML = 61.19 Q^{0.467}$ $ML = 34.11 Q^{0.506}$ $ML/MB=1.80 Q^{-0.038}$	Model data	
7.	Schumm	1963 1967	$LR/LV=3.5(W/D)^{0.27}$ $W/D = 225 M^{-1.08}$ $ML = 193.545 Qm^{0.34}/M^{0.74}$	Data on 47 channels	M = % of silt and clay in the perimeter Qm = mean annual discharge
8.	Chitale	1970	$LR/LV=1.429(m/D)^{-0.077} S_*^{-0.052} (W/D)^{-0.065}$ $MB/W = 48.299(m/D)^{-0.060} S_*^{-0.453} (W/D)^{0.471}$ $LR/LV=1.145(MB/W)^{-0.134}$	Data of 42 rivers	$S_* = S \times 10^4$ m = size of bed material

Now if you look it coming to a regional relationship which is very interesting to know it that way 1863 Ferguson establish that the ML is a meandering length ML stands for the meandering length is a six times of the width which is necessary to know it to give enough space to the rivers that means if width river is 1 kilometers the meandering length will be the 6 times of that it will be the six times of that that means it will be six kilometers that is what is ML is that.

MV is a width of meander belt so we are talking about this width of meander belt which is in 1902 very simplified I can say that the meander belt if I approximate it is 18 times of W is this their a spatial frequency and it also maintains the river 6 and 18 just try to understand it that means if you width river if I know it its space width of the river is of half kilometers then 9 kilometer is a meandering belt width.

If a river width is a two kilometers then is a 36 kilometer is a meandering belt width. So we should try to understand it not look these equations only which is developed way back in 1863, 1902 its almost 118 years previously there was no satellite imagery and all. So if you look at that way it its talk about a concept that there is a spatial scale of meanderings that meandering length will have 6 time of width maundering belt width will be the 18 times which easily we can remember it. If you are not looking precisely.

So if you look at that English which is considered the American rivers and some of the rivers from Odisha state of India which is such that this ML and MV can have a ratio of MV by ML I can say that it is a closed ratio of 0.35 or I we can approximate is a 0.33 that is the same concept that means the meandering length and the meandering belt will be the three times it is three times that is what is we should try to understand it, It is a three times.

So if you look at that is what is Jefferson's data and with this so if you look at the length and width with the resistance the same way if you look at that Leopold at 1964 considering the large rivers again it has come with in terms of width is a 11 times and MV is a three times ok. So here in case of the large river the ML is coming about to 11 times and the three times of the width and you can look it, it is closer to that.

Same way if you look at that from exponent model data can have a ML MV relationship which is any functions of the discharge and the terms is established with more detail with a W/d ratios and the ML is a function of Q and the m value and CTL 1970 also established more detail between these non dimensional faults which is considering the 42 river data. So what I want to look at that when you look at this regime relationships which is extracted from the river which is way big still is hold good it.

And there is some spatial frequency it is there in a meanderings plan forms which is the 6 and 18 which is easy to remember it. If a width of the river is 1 kilometers the meandering length will be the 6 kilometers and meandering belt width will be the 18 kilometers so that is that is try to understand it. And also we talk about the width and discharge in the same order ok.

If it width is 1000 meters so we will have the discharge about the 1000 dominate discharge so you can you can try to understand it how things are happens it in terms of dominate discharge in terms of ML MV and this. So what I am telling that if you look at this regional relationship what is developed way back in 100 years it also still lets storage to us either we have to accept it or we have to understand considering that we can understand the river.

And more precisely we have a more data now we can always look back at this regional equations how whether they are valid or not valid. Because if you look at these equations they are different but what order of their difference when you talk about the river with the flood plain the incised river the river in the flood plain this is the 50 stream raising it the European rule of thumb.

Thumb rule says that that or you have a silt clay percentage which is control these characteristics mean flow discharge you can have the sum series and you can have this. So we should have a better understanding is that how these empirical equations is providing us the knowledge and those knowledge of river we can implement it when you are trying to design river training works.

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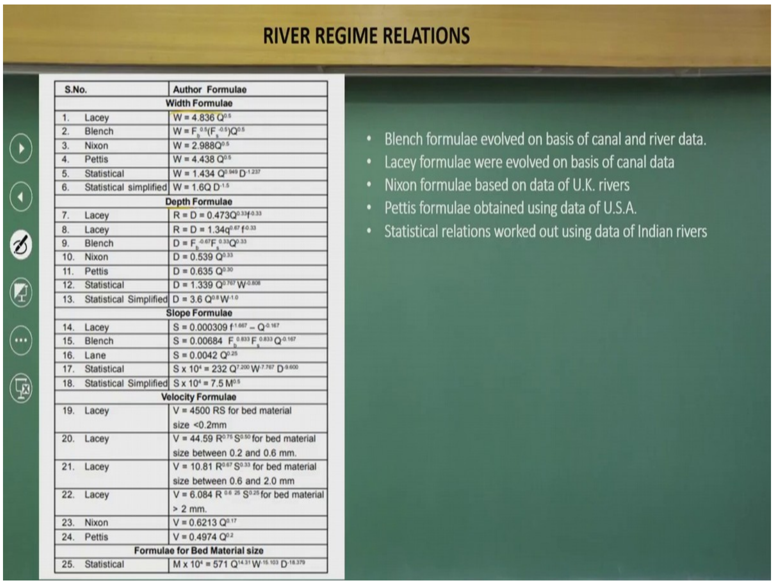

S.No.	Author	Formulae
		Width Formulae
1.	Lacey	$W = 4.836\ Q^{0.5}$
2.	Blench	$W = F_b^{0.5}(F_s^{-0.5})Q^{0.5}$
3.	Nixon	$W = 2.988Q^{0.5}$
4.	Pettis	$W = 4.438\ Q^{0.5}$
5.	Statistical	$W = 1.434\ Q^{0.949} D^{-1.237}$
6.	Statistical simplified	$W = 1.6Q\ D^{-1.5}$
		Depth Formulae
7.	Lacey	$R = D = 0.473Q^{0.33} f^{-0.33}$
8.	Lacey	$R = D = 1.34q^{0.67} f^{-0.33}$
9.	Blench	$D = F_b^{-0.67} F_s^{0.33} Q^{0.33}$
10.	Nixon	$D = 0.539\ Q^{0.33}$
11.	Pettis	$D = 0.635\ Q^{0.30}$
12.	Statistical	$D = 1.339\ Q^{0.767} W^{-0.808}$
13.	Statistical Simplified	$D = 3.6\ Q^{0.8} W^{-1.0}$
		Slope Formulae
14.	Lacey	$S = 0.000309\ f^{1.667} - Q^{-0.167}$
15.	Blench	$S = 0.00684\ F_b^{0.833} F_s^{0.833} Q^{-0.167}$
16.	Lane	$S = 0.0042\ Q^{0.25}$
17.	Statistical	$S \times 10^4 = 232\ Q^{7.200} W^{-7.767} D^{-9.600}$
18.	Statistical Simplified	$S \times 10^4 = 7.5\ M^{0.5}$
		Velocity Formulae
19.	Lacey	$V = 4500$ RS for bed material size <0.2mm
20.	Lacey	$V = 44.59\ R^{0.75} S^{0.50}$ for bed material size between 0.2 and 0.6 mm.
21.	Lacey	$V = 10.81\ R^{0.67} S^{0.33}$ for bed material size between 0.6 and 2.0 mm
22.	Lacey	$V = 6.084\ R^{0.6\ 25} S^{0.25}$ for bed material > 2 mm.
23.	Nixon	$V = 0.6213\ Q^{0.17}$
24.	Pettis	$V = 0.4974\ Q^{0.2}$
		Formulae for Bed Material size
25.	Statistical	$M \times 10^4 = 571\ Q^{14.31} W^{-15.103} D^{-18.379}$

Now if you look it again it is a compiled form of river regime relationship in terms of width, width formula is the depth formula is slope the velocity and the bed material size. If you look at this formulas the lacey's formula comes from evolved from canal data what we discussed in the last class. Nixon's formula is based on the UK rivers. Pits formulas are from USA the statistical methods from this Indian rivers also we have Muddy Branch formulas is from Calan canal and river data.

So if you look at that the canal is more geometrically and the bed material why is not variability is there. But you talk about the river it is having lot of variabilities. So if you look at the Lacey's equations again I put it the w will be the 4.8 times of Q of 0.5, so it is a 0.5

square root the same way if I look at the Pettis formulas which is from the USA data we talk about only the difference between these coefficients 4.4 Q to the power 0.5.

So only this multiplications factors are changing it a to the power a Q v then same way this Nixons also this see if you look at this width are having the more or less the same formulas but in case of Indian rivers we have W is 1.6 Q, d is a flow depth 1.5. So in Indian river it has a different relationship as compared to this why those questions we can always look it. If you look it if I look at the depth formulas it is a very interesting now.

If you look at the Nixons and the Pettis formulas which give is the flow depth EJ functions of 0.539 $Q^{1/3}$ whereas Pettis' formula is just slight bit modified with a 0.635 $Q^{1/3}$ so if you look at that only this coefficients of these two things are changing it so we can know the flow depth if I know the distance accurately the dominant systems.

If I know it accurately for in case of the Indian river as I modified the statistical part which is give it 3.6 q to 0.8 and also a functions with width. So in Indian river this but in case of these Patties formulas is from those USA, Nixon's formulas derived from the UK rivers more less the same. But if you talk about Indian rivers we have the values are there and you know it you can get the flow depth using the lacey's equations.

So it always indicates that we can have a some sort of the regional equation. So same way you can look how the equations are there in case of slope in curves of the velocity and this. So let me put it the velocities is very close to from the pettis equations that 0.5 Q 0.2 so that means if you know the distance you can know this approximate velocity can be there from the Pettis that is that.

But before concluding that these regional equations are good if it say derived it properly with a more reliable hydrologic data like a discharge more reliable discharge data set the flow depth the width if I have a more reliable data set and the deriving of these regional equations really plays the major roles for a river engineers.

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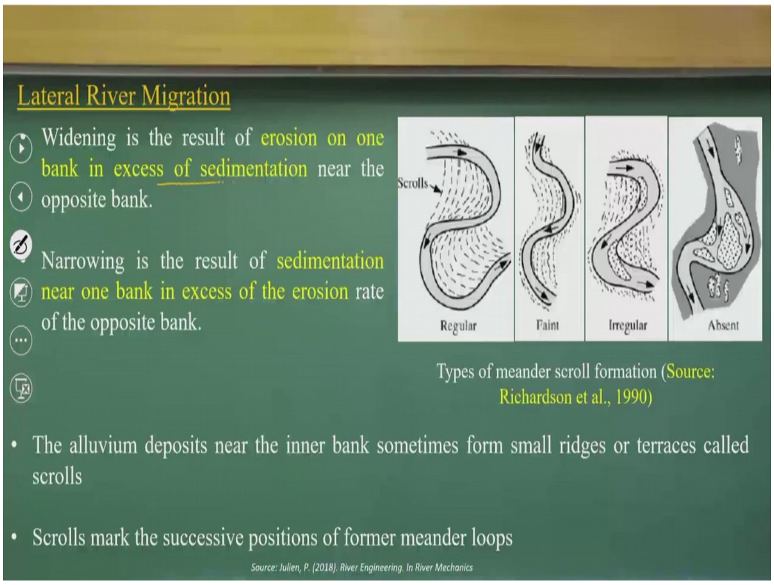

Now if you look at the next levels if I talk about how the lateral river migrations happens it and if you look at these behaviors of winding of the river you do not just have an excess of sedimentations near the opposite banks. If you can look it how does this happen it. We can regularly implant irregular can happen or it can have absence types of meandering curves. It can have a narrowing the results of the sedimentations near one bank excess of erosion rate.

Opposite side and you can understand these things which are very simple way how does river meanders happen city types of scrawling that regular or fent or irregular or in case of absent can also happens it.

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Let us today we let us conclude this lectures having talking about our understanding of rivers if I quote from Nancy's quote that Patna is one of the oldest continuously inhabited river line cities in the world situated on the southern bank of the river Ganga. So what I am to talk about that we should have more knowledge as we are close to habitat to the Ganges rivers is oldest inhabited river line cities you can get the history of the Patna cities and try to know it how things are evolved in a Patna cities which is the river line cities in the world the oldest one and that is the story of the Gangas and the Patna city are as particular to Bihar, thank you.