River Engineering
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Lecture - 17
Jet Scour and River Navigation

Welcome all of you for this course on River Engineering and if you look at this course, already we discussed about bridge scour. Today, we will further discuss about jet scour as well as we will also discuss about the national waterways or how we can have an advanced technology for navigating the rivers or the national waterways. So that is the concept. We will discuss more detail today and looking that I have emphasized now.

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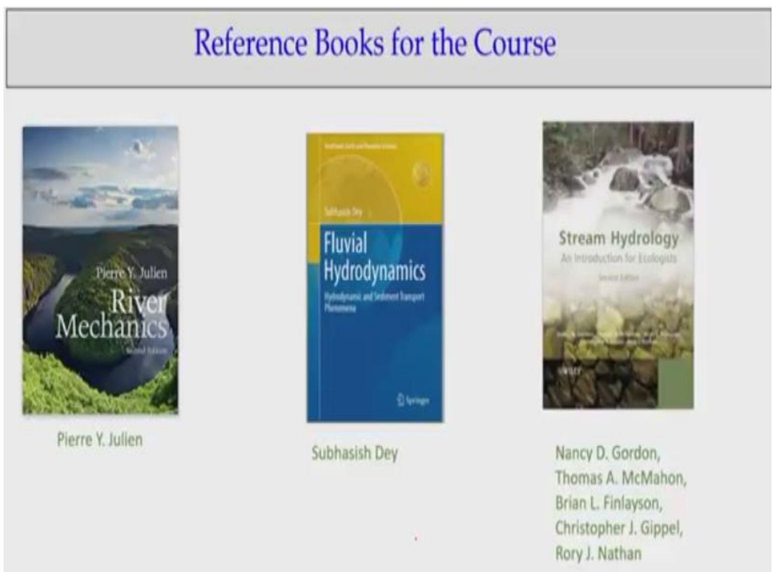

We are following these books which is having a chapter on river engineering that part what we are following it here as well as you know it those are the books also we have a lot of reference on that.

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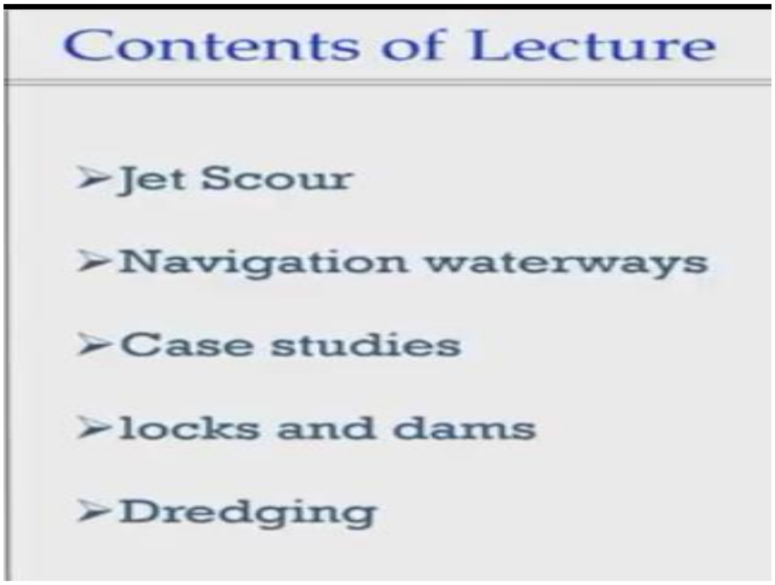

Now if you look at that today what we will cover it, jet scour. We will cover about waterways. We will talk about some of the very relevant case studies and we also will talk about the locks and dams and also you know the dredging. So those are the concepts. Today, we will discuss that how we can do the dredging to maintain a river channels for navigations point of view or other utility point of view. We can also look for option for dredging. Those things we will discuss today more detail.

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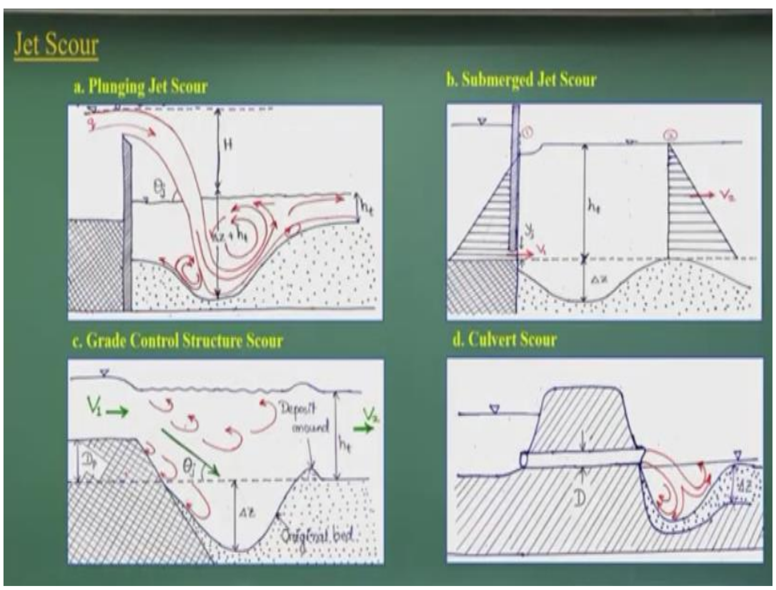

Looking for the first part, jet scours. Let us look at these four figures which gives very interesting things that what type of scour can happens it, like if you have the dam structures and you have the water jet here. Because of the water jet, initially whatever the soil part that what will be scour it and you can see there is a vortex patterns, what will be created in and that vortex will be dissipated as go up.

So if you look at that it also depends upon Θj, the angle of jet water jet what is impeding on the waters. It also depends upon the tail water depth, how much of the water depth at the tail water levels. It also depends upon the bed materials, what type of bed materials are there. So this is the scour happens it, just the downstream of a dam or the waste where you have a water jet impeding on a tail waters.

We need to find out what is the scour depth Δz, the scour depth and you can see the process. Mostly again, we go for the physical model and establish the relationship with this Δz with the flow with the water depth at the tail end, the bed material characteristics, all we do it with function of h. We try to establish the relationship with the Δz with the functions of all this part, that is what we look at when you talk about this.

As we discuss for the scouring bridge pier, the same concept also followed it the plunging jet scours. That part was also follow it. Same way if you look at mini gap case, you can have the dam structures and you can have a sluice gate. As you have the sluice gate and that the sluice gate will have a V1 velocity and Yj depth and you can understand it how the scour mechanism is going to form it here and there will be a scour depositions.

And because of that, we try to know it, what will be the scour depth Δz. What is the scour depth? It is a functions of V1, V2, Yj and the bed material at the bed material. Again the similar way, conducting a series of physical experiments scaled down models and try to establish the empirical relationship between the flow characteristics with the scour depth. That is what the basic idea is there, but many of the times you can have a great control structure scours.

That means you may have a higher level of, then you may have the low level of scouring materials. It can happen in the rivers. You may have regions where you have a stones followed by you may have the sand. Because of that if this stone and sand or if you have a weir and the riverbed, we can have great control structure scour. So you will have the scour, because as the flow the vortex sense generates in it and this is what that scour it and here you will have a deposit mode.

That means whatever the scour materials also deposit here and then you have the tail end depth, this to velocity and V1. So just try to understand the conceptually how the processes are happens it. How the scour depths are happening and most of the times we conduct the series of physical experiments and then we establish the relationship between Δz with the hydrodynamic parameters like the velocity, Θj, the ht, the tail end depth as well as the flow velocities.

Those empirical equations are really necessary for us to know it, how we can effectively design a hydraulic structure like a weir or having a gate with a sluice gate or you have a graded control structures or you can talk about the culvert. So many of the times, we do not bother about culvert scours, but culverts also have the scour during extreme flood events. During extreme flood events, you can have the scour depth.

That is the things I used to say that you have to understand it there will be the scour, when you have the culvert, like if you look it, the culvert can make a water jet when you have a very high flow the Q amount of this size is going into that. It can create the jet and that jet can impede it and create the bed scours. So just downstream of the culvert, we can have the scouring and whenever we design the culvert, we should take care of how we have to protect the scour or what should be the strategy for scour counter measures; that we should do it.

So if you look at this culvert scours which depends upon the diameters, the discharge and the flow patterns, what is happen that is the Δz is the scour depth and you have the flow. So in summary, I can say that the jets scour happens in case of plunging case, that means you are impacting plunging it inside a tail end or it can have a submerged jet scours. It can have a culvert scours or great control structure. So now let us come to the empirical equations, which are derived by conducting a series of lab experiment or the physical experiment, the scaled down experiment setups.

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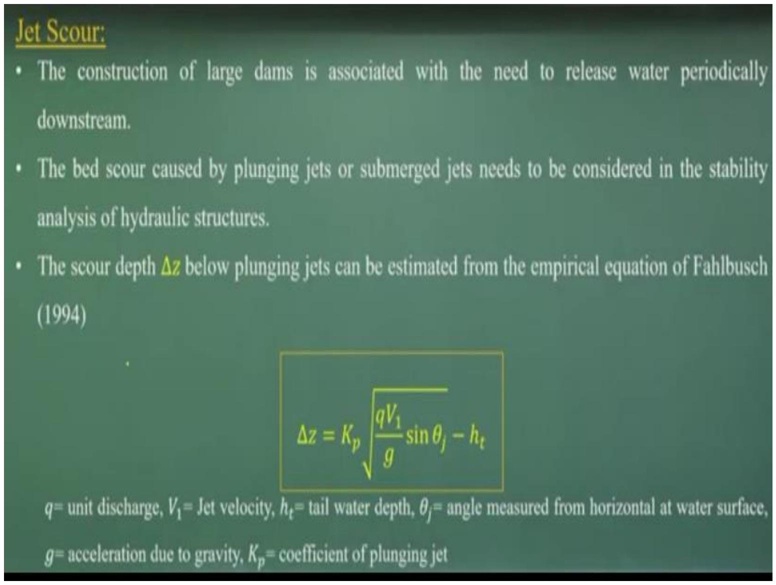

Now if you look it, first once that is what basically we release the water periodically in the down streams and the plunging jets or submerged jets needs to be considered to look at the stability analysis of hydraulic structures and if you look at that, the Fahlbusch 1994, he established the relations with the scour depth with V1 velocity of z velocity, Ɵj stands for the angle measured to horizontal at the water surface, the jet angles which is measured from horizontally at the water surface.

Then you have it the depth, the tail end water depth and you have a Kp stands for here the coefficients for plunging jet. So that is the reason if you look it, it depends upon jet characteristics in terms of the jet velocity theta z. It depends upon tail water depth that is what is if you have higher the tail water depth, you will have a delta z is less. That is what is most of the times is there that they create a stilling basins or can have another control structure, such a way that we can increase the tail water depth and we can reduce the scouring depth.

That is what is being followed many of the downstream of a bridge or the downstream of weir, when you measure that we try to have the tail water depth. So if you have a tail water depth is sufficient, you can know the scour depth will be that and this Kp depends upon the bed material characteristics and you can look it, these are what it all depends upon the sin Ɵj, q is the flow rate per unit width.

So what I want to say it, if you look at the empirical equations always we try to understand it and that understanding will give us a guiding principle how to manage that hydraulic structures during the scour formation, extreme flow conditions. That is the biggest idea that if you have very extreme flow conditions are coming it, we need to have either tail end water depth at the major bridge dam locations or the weir locations, such a way that we can reduce the scour depth. Next one is that we can look it, how we can have a Kp value variations.

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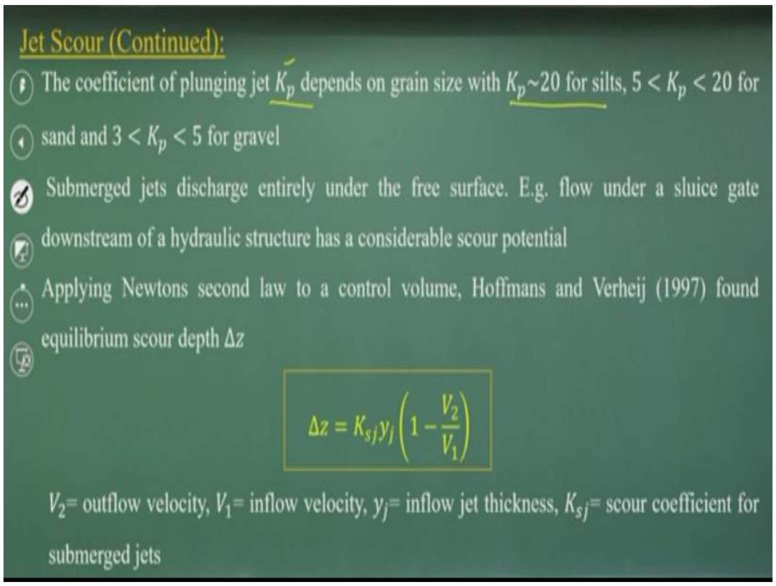

If you look at that the Kp is a plunging coefficients is a multiplication factors, that is what you try to understand it which is a 20 for the silt. So in the downstream you have the silt, this factor is 20. 5 - 20 the range for the sand and you have gravels is 3-5. So we just interpreted it that if you have the silt, the scouring depth will be 20 times or the almost 10 times, close to the 10 times as compared to the gravels. So what it indicates? From this experiment data, so we can know it what type of downstream bed materials.

We can either armoring it or we can put it such a way that we can reduce the scour depth. That is what is here. So you can see that you have a gravel, so this coefficients is just range from 3 – 5, but in case of the silt, it is as high as the 20. So that is almost 8 – 9 times higher. That is what it happens it in case of the silt and the gravels, because the more the scour depth it will be dangerous to the hydraulic structures, because that the depth it will go.

Again I have to repeat it, the extreme scours happen during the extreme floods. So we do not know it what type of flood is going to come and that period how do we manage it or what could be the our strategy to look at the safety of the dam and the weir structures, because we have to protect the scouring mechanisms, protect the scour holes. To protect the scour holes, we should have this knowledge of the scouring that how we can manage it with gravels or tail water depth.

So that is the reasons the submerge jets entirely under the free surface flow under the sluice gate. So you have the sluice gate, you would also have the considerable scouring potentials. That is what the Hoffmans and Verheij 1997 established the equilibrium scour depth. It followed the Newton's second law. We have been discussing about applying the linear momentum equations in a control volume, exactly same concept with using a coefficients.

It has to find out that Δz is a functions of yj, y is a inflow, z thickness depth, Ksj is a scouring coefficients. Again it depends upon the bed material characteristics and V1, V2 inflow and outflow velocity respectively.

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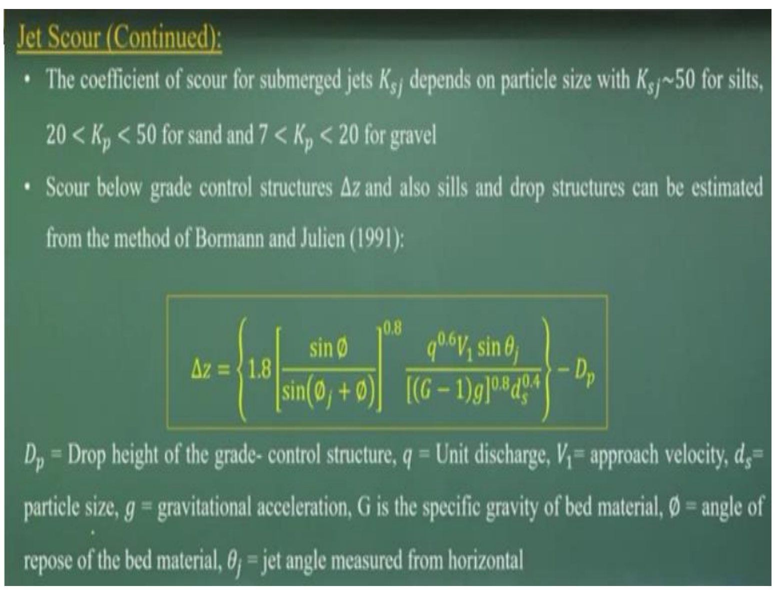

So again if you look at that Ksj it varies from the 50 to again this range of values for the gravels and for the sand and for the silts. So you can see that you have a bed materials in different, like a silt, sand or the gravels the scouring you can know it what is happening. Now let us come in to the scour below the great control structures. There is a drop structures. That is what we are talking about that. They have a great structures below that I have the materials.

As z happens it how we can estimate the scour depth, how we can estimate the Δz, the scour depth. So if you look at that again the same experimental works, but the equations looks bit lengthy, but if you look at that Δz is a function of sin ϕ ϕj, G is specific gravity of the bed materials. You have a q V1 and the Dp. So it is a complex equations, but it is not that complex todays world. If you look at that the Dp is a drop height of the grade-control structures.

If you look at the figures here, so Dp stands from this part θj is the impinging angles, you have a V1 the velocity, V2 velocity you have a tail water depth, then you have a original bed. So looking this you can understand it that we can have a relationship between the scour depth with a functions of Dp. The ds that is what particle size distributions d50 most of the times you consider it, then you have a theta z V1 and q. V1 is a unity discharge per unit width.

V1 is approach velocity, ds is a particle size and G is a specific gravity of bed materials and ϕ is angle of repose of the bed materials. θj is angle measured from the horizontals. So if you look it, these are all the experimental studies plus the dimensional analysis to establish these empirical equations, but these relationships tell us that what type of the dependencies of the scour hole depth in terms of the flow characteristics, in terms of the drop height, in terms of the bed material characteristics. That is what how are these things.

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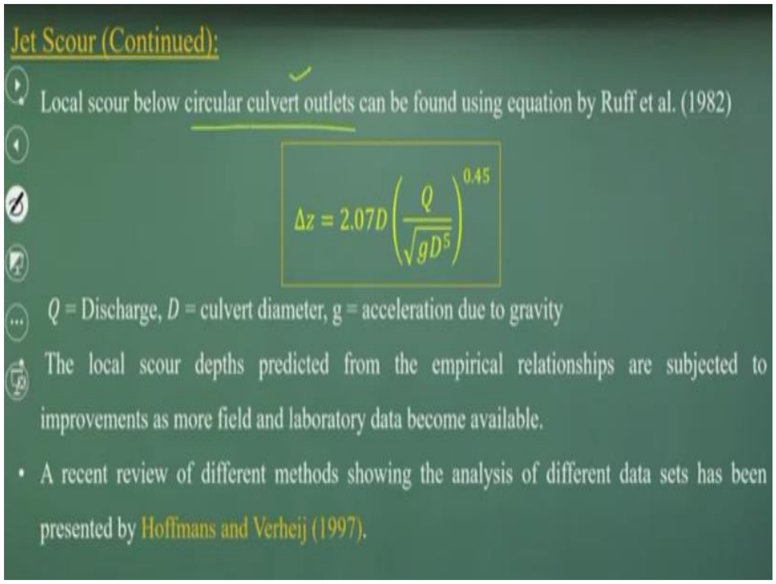

Now if you look it that scour below the circular culverts outlets. Many of the times, we generally avoid it. We do not bother about the scouring mechanisms for a culvert, but I do believe it many of the time, whenever you have a 10 years or 20 years floods most of the time the culvert fails it and that is what is a lifeline of the road networks and during the flood when it fails, all sort of the problems we face it, because of the floods, not because of the waters, because of failure of the culverts.

So whenever you design the culvert designing, at that time we should consider what amount of the scouring happens it during the extreme floods. That is the basic idea. So if you look at this Q is the discharge, D is the diameters for the circular outlets. This is the scouring depth. So as D is the culvert diameters, Q is the discharge. So basically we always have this empirical equations to estimate the scour hole depth.

But whenever you go for major structures, we conduct separately the physical modeling studies followed by the dimensional analysis from case to case, because that is what gives us the more the field data and the laboratory data we combine it and we try to modify these equations or try to locate whether these equations are enough for designing scour holes, how to protect the scour holes in major structures like a dam, like culvert, like you have a sluice gate or the grade controls. That is the things. So let us go for a very simple examples, what is there.

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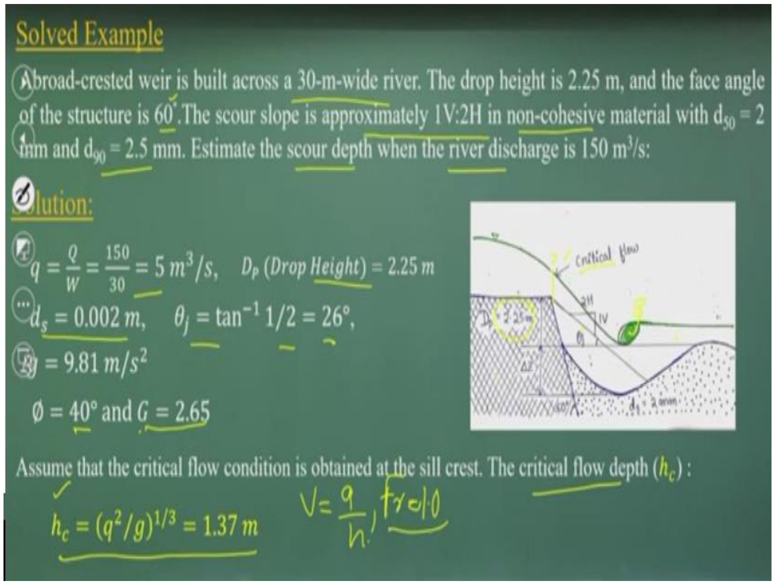

Let us say you have a broad-crested weir which is built across a 30 meter wide river. It has a drop height is 2.25 and the phase angles of the structure is 60 degrees. That is what is given it here the 60 degrees and the scour hole approximately 1V:2H non-cohesive materials. It is a non cohesive materials having D50 2 mm D90 2.5 mm, estimate the scour depth when the river discharge is 150 m^3/s. This is very simple problem.

Only we have to give it the basic things. So as you have this weir, it will have a critical flow depth is here. So that you know from the critical flow concept. So you will have the critical flow here, so that we need to compute what is the critical flow at this and there will be some sort of hydraulic jump formations, then followed by this. So we need to compute the Q, discharge per unit width. We have the drop height ds is given to us.

Ɵj we compute it as the impedance that we have a ϕ value 40 degrees and we have a G equal to the 2.65 and we try to compute first the critical depth. That is what comes as the critical depth. That is what we discussed earlier, how to estimate the critical flow in terms of flow Froude number is equal to 1 and we can substitute this is V=q/h. So you can compute it these equations at the critical flow, which will come it with a flow Froude number is equal to 1. So you can compute it easily just to remember these things. We can compute it.

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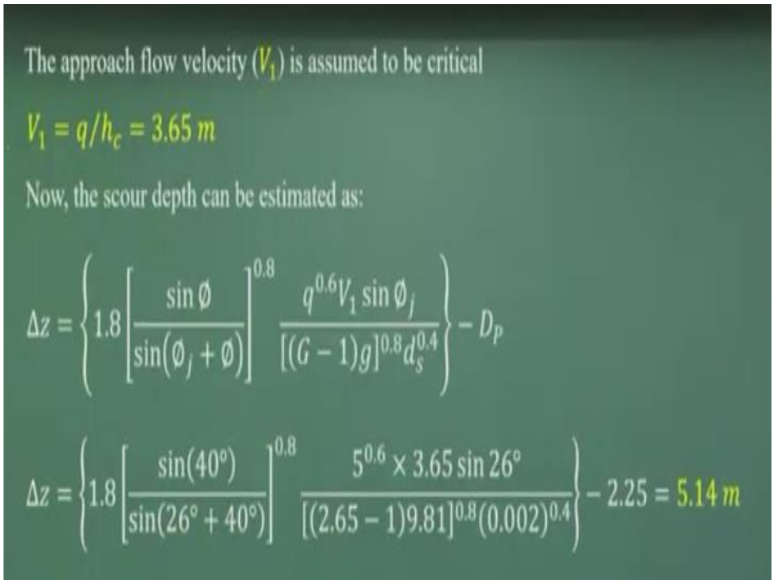

Now if you look it, if you go for, so V1 is we are getting the V1 for the critical depth, then we are just substituting these values. As it is given it to estimate it what will be the Δz. So here it comes out to be 5.14 meters and this is for the drop height. This is what the drop height is there and we are computing it, what will be the scour depth.

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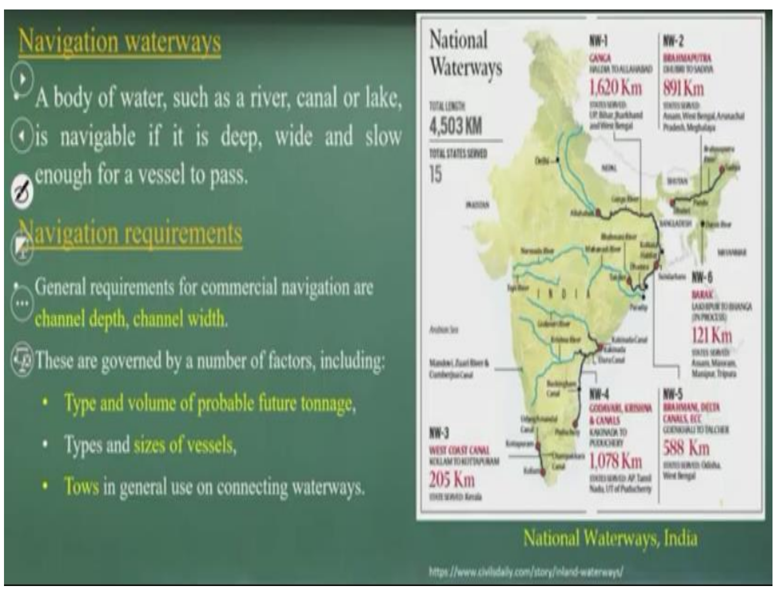

Let us come in to very interesting topics what we are talking about that is national waterways. You all know about national highways. So similar way we have national waterways. It starts from national waterways one, the Ganga rivers from Haldia to Allahabad, we have the river systems where we can use it. We have been using it as a national waterways one to transport the good from Haldia to the Allahabad and that is what covers the state like UP, Bihar, Jharkhand and the West Bengal.

Same way, we have a national waterways 2, that is what is the Brahmaputra rivers from Dhubri to Sadiya, which is about 891 kilometer length. So that is the national waterways starting from Sadiya to Dhubri. We also have a national waterway 6 which is connecting for the Barak rivers 121 kilometers. We have a national waterway 5, which are Brahmani projects, that is what we all we demonstrate you as mathematical modeling of Brahmani river is a part of this national waterways 5 projects, where we have a Brahmani and the deltatic regions.

That is what is the national waterways 5, then we have a national waterways 4, which is in the Andhra Pradesh, Godavari, Krishna and the canal systems. That is a combined systems of connecting from Pondicherry, Kakinada all these are connectivity with the Godavari, Krishna and this. That is what is 1000 kilometers and it covers the state like Andhra Pradesh, Tamil Nadu and also Puducherry. So if you look at that this is what the national waterways 4.

Then similar way, we have a national waterways 3, which is the West Coast canals, which is around 205 kilometers. See if you look at this national waterways systems what we needed that to have navigable, we need to know always have the waters at least a minimum water depth; that is a minimum water depth should be there the river should be navigable. That is not always possible to have that and what way we can maintain this national waterways.

Such as the way that all throughout the seasons throughout the years, we can have the ship, the vessels can go through these channels, goes through this national waterways. These are very challenging tasks for us, because as you know this river morphology changes it and the river is quite dynamics and maintaining the water depth and all the bigger issues.

So looking that let me talk about the contest that to navigate the river to have enough water to maintain as a national waterways, you need to require for the commercial navigations for the goods from one point to other points. For example, from Haldia to Allahabad, we need to have a channel depth and the channel width. The sufficient depth should be there; sufficient width should be there such a way that the ship, the vessels can start from Haldia and can go to Allahabad or can start from the Dhubri can go to the Sadiya.

So we need to have a minimum the standard channel depth and the width, such a way that river will be the navigable or the commercial navigations can be done. So that what we look at that it also depends upon the factors like the type of volume of the tonnage, what the goods is carrying is there from one point to others. It is just a transport processes. We should know it how much goods we need to carry from a point to b point and b point to a point through national waterways.

We should know this what type of vessels we are using and what is the size of vessels and tows in generally used to connecting these waterways. So the basically let us try to understand it how this national waterways we have and how we need to make all the national waterways are the commercially navigable and that is the reasons we should know it what is required channel width should be required and channel depth is required throughout the years and that all depends upon what type of goods we are having and what is the volume of that, the type and size of vessels and tools connecting the waterways.

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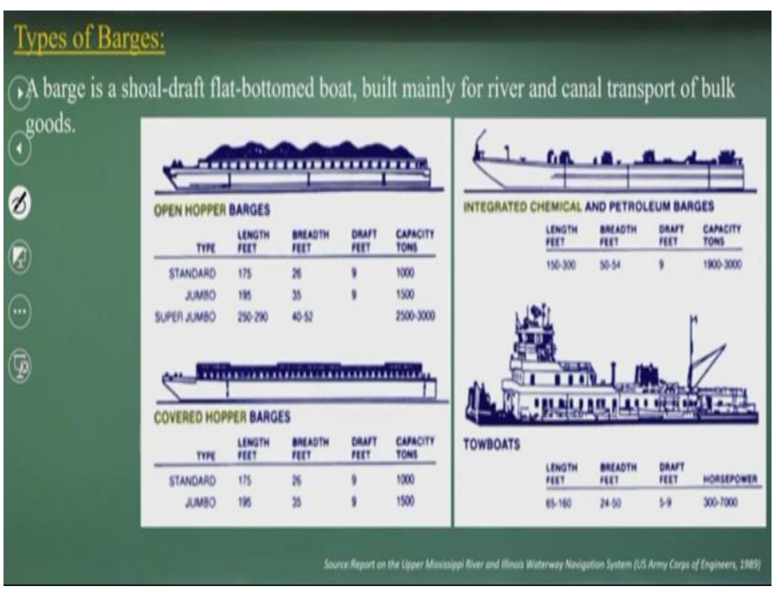

Now if you look at the next point. There are the barge are there which is carrying the goods from one point to other point in rivers or the canal transports for the transporting the bulk goods. One is open hopper barges. So if you can see that this type of barges can be good for the carrying openly, that mean upon deck it can have a mineral, it can have the coal. So the length is 175 feet, breadth will be 26 feet, the draft the depth of the water requirement to carry to have the shipping through this river, it is needed 9 feet.

So you can understand it needs a 9 feet depth and its carrying capacity is 1000 tons. Same way, it can have a super jumbo which is 250 to 290 length is more, the width or the breadth will be 40-90 and it can carry as many as 3000 tons. So you can compare with a particular truck. It carries about 6 ton to 12 ton. So as equivalent you can compute it, how much of goods we can carry in a barges, open hopper barge, which can carry from 1000 – 3000 ton.

And as you know it, it is more fuel efficient, no environmental pollution systems, but there are the issues. So if you look at that way, you can see that as equivalent how much ton of materials we can carry it having a standard or the super jumbo which will carry as high as 3000 tons, but nowadays you have this integrated chemical and petroleum parts. So here the basic idea to carry the chemicals and the petroleum things which can have a length 150 – 300, width will be 50 feet, draft need is 9 feet and the capacity can vary from 1900 tons to 3000 tons.

Same way, if you look it covered hopper barge, the standard one is 175 length, 26 width, draft feet is 9. It can carry the 1000 and there are the two barges, which will have either you would have a length, breadth, depth and horsepower you needed. So the basically what I am to do that there are different type of inland vessels are there and depending upon our requirements whether you need an open or covered hoppers or integrated chemicals and petroleum, it can have it.

And you know it is much well efficient, environment friendly inland transport mechanisms, but that is the way that we can carry as one as the 3000 tons, so that and it goes to 3000 tons of goods we can carry from point a to point b through the rivers, which happens in many of the developed country like United States. In Europe countries, they extensively use the inland navigations to carry the goods from a to b using the river navigations or the inland navigations.

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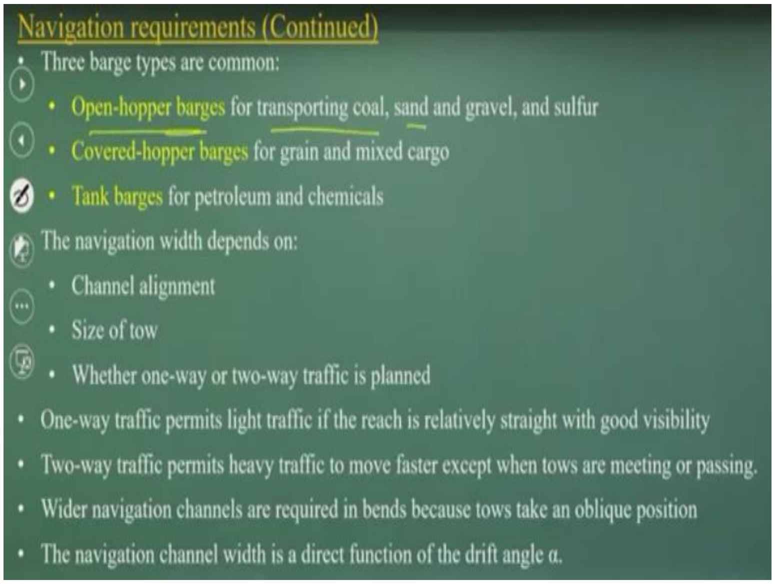

Now if you look at that that is what you have discussed is that open hopper barges transporting the coal, sand, the gravel and the sulfur. You can covered hopper base because it could be a grain and mixed cargo in it and the tank barges for the petroleum and the chemicals. It needs channel alignment whether it is a straight channel river or it is a mandarin channels, we cannot have the straight channels. We need to know how you have to do it.

So for the straight channels what is the alignment is there, what type of is a straight channel; that you know it for a river. If it is a canal, it can have a straight channels; for rivers we will have some degree of the meandering and that is the reasons we should have the strategy for that. Size of the tow whether one way traffic or the two-way traffic you can plan it. As you plan for national highways, we can think it that whether you have a one-way traffics or the two-way traffics.

That what you can plan it. So one way traffic basically we can have the signaling systems. You can also look at the good visibilities and all the things. So one way traffic you have to know it how much visibility we are happening it. The two way traffic, it heavy traffic to move fast, but tows are meeting are the passing points. So basically you try to know it, as when you are going through this thing how these two spacing and its giving it in case of the river meanders, river bends.

The wider navigation channels, we required it for bends which takes the oblique positions in river. In a bend, the navigations vessels will have oblique positions for that we need a wider channels as compared to the straight channel, navigation channel is width is a direct proportional with drift angles. We will show it and we will discuss more. Look at the next figures.

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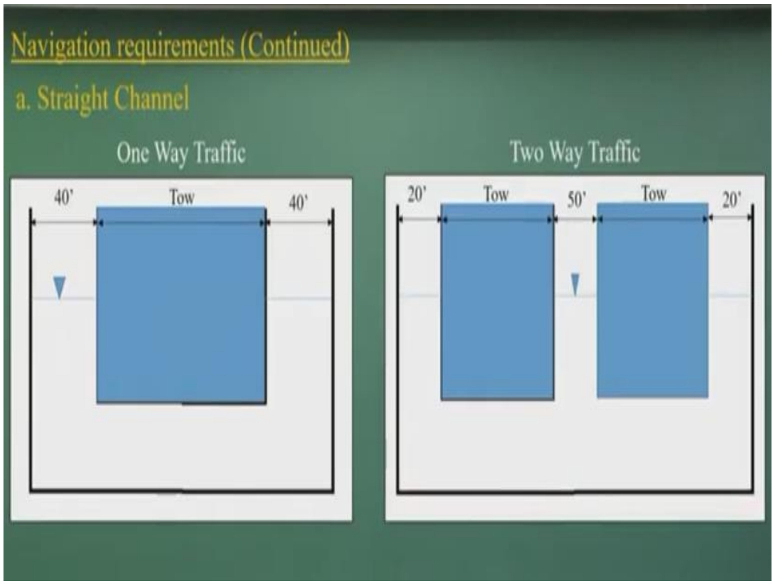

What is the width is necessary? It is very simple figures. If you look it one way traffic, it is a tow then you need to have a 40 feet, 40 feet both left and right side, but if you have a two way traffics, you need to have a 20-20 and 50 feet, then you will have the both the tows. So this is for the straight channels. As I said it the straight channel is possible for only the man made canals, but the rivers we may not have the straight reaches. So we always have a bend.

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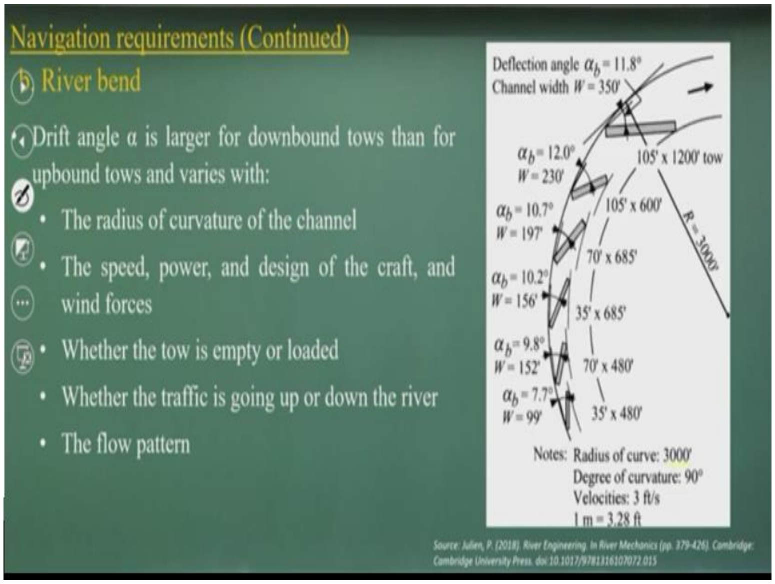

So if you look at this figure, you can understand it that when you have a radius of curvature with 3000 feet, degree of curvature is 90, the velocity is 3 ft/s and if you have that, so it is from the P. J. Julien books. If you look at that how the deflections angles are changing it and the channel width requirement. So you have a two arrangement. You can see that as the vessels goes and how these deflections angles are changing it and how the channel width requirements are changing it.

That is what is showing to you. So that is the compositions it is showing from difference width requirement for different angles and we also have a difference to width and the length that is what is showing it that the drift angle is larger in down bound tows than the off bound tows that varies it. The radius of curvatures, it depends upon the speed, power and design of the craft, wind force, the tow is empty or the loaded, the traffic is going off or down.

All we do it and the flow patterns. Many of the times, we do a physical models try to know it if the ship vessels are coming with it to that how things are happens it, whether it can smoothly pass it without having any impact on the river banks, that is the canal bank so that is how we do a physical models, try to know it the scale model, try to know it whether it will be navigables with a particular river bank and what could be the width requirement and the deflections angles.

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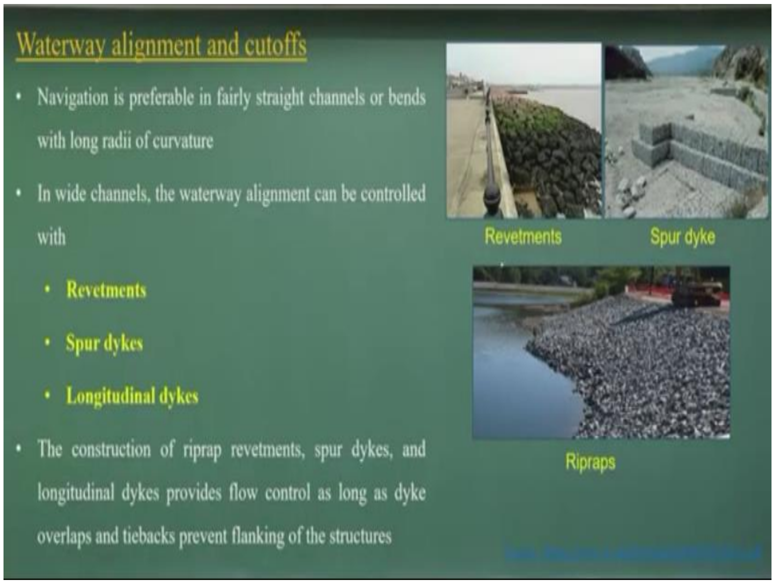

Now if you look at the next part, the many of the times we have to make a river its alignment, either as mild river bend or we can have the straight channels. The river as you know does not follow exactly straight path. We have to confine the rivers. We have to make it fairly straight channels or the bend with a larger radius of curvatures. That is our idea for a channel to make navigable. So wider channel waterway alignment can be controlled through revetment.

You can see this revetment. You can have many places you can see the revetment, the structure protecting the riverbank and as we discussed earlier. So you can have the revetment, you can have a spur dykes to divert the flow. You can have the spur dykes. You can see this figure. You can have the spur dykes to divert the flow from the bank and confining the flow or you can have a stone riprap.

You can see these figures and if you visit any rivers, which is a navigable river, you can see that stone riprap the revetment nowadays. You can have a longitudinal dykes. The construction revetments for dykes, as you know it we discussed earlier you can have a different structures. So that we can make the river or the canals is navigable maintaining its alignment.

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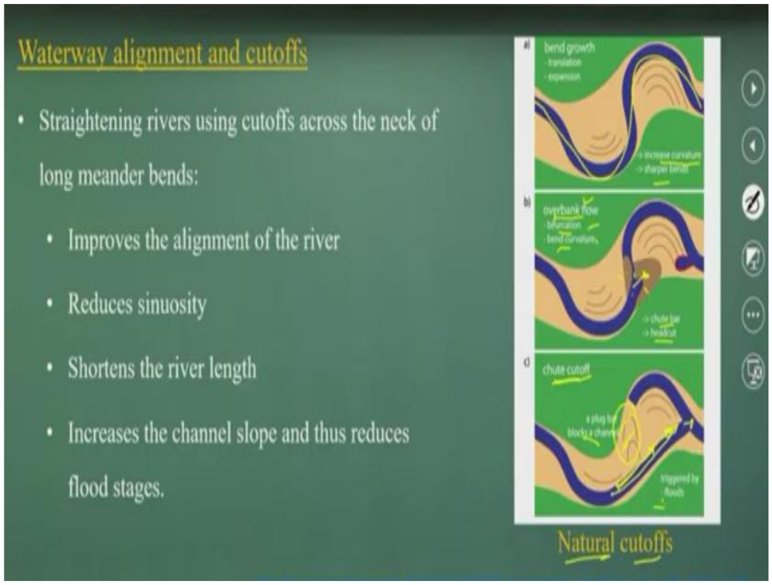

Now you talk about the basic way, the cut off. So you know from natural cases that when you have a river bend, so river has bend like this, it increases the curvature, sharpens the bends. After certain times, it cannot maintain more sharpening of bend, because overflow happens. If the flow overflow happens like this, the bifurcation bend covered. So it form a headcut, chute bar. So it start depositing here, then start making a chute bar and the headcut here.

And after that it blocks the path, then it can take up this channel, chute cutoff followed by the triggered by the flood, then you can have this. This is what naturally cut offs happens. Most of times when you design national waterways, we should understand this process what it happens naturally. That means when you have the river bend, it bends grows it. After certain the bend cannot grow it, at that time the overflow bifurcations happens it.

Followed by chute cutoffs are happening it with the trigger by the flood that is what will carry the waters. So then this part remains as a cutoff, because this knowledge we need it as you know it, sometime we have to man-made triggering this cut off process. That is what we try to do it whether you can trigger the cutoff process, because natural cutoffs it takes lot of times. It depends upon to have a major flood events to have a natural cutoffs.

We cannot wait till that, so we try to make the as resemble to as the natural cognitions. We try to make artificial cutoffs following the behavior of natural cutoffs. So the basic ideas we learn from the river systems, we try to understand the morphology of the river systems of that particular river and how the natural cut-off process happen. The same cut-off process mechanisms, we artificially or man-made, we try to introduce to the rivers, then river will be safe.

That is the idea always we should have a morphology studies to try to understand it, how this cut off process happening in a particular river or particular river reaches from the first historical satellite imagery or any data set. That understanding is necessary to design artificial cutoff. That is what my point to say that and we have to understand the river behaviors. If you understand the river behavior, we can trigger that mechanisms same behaviors with some artificial cut off process.

So that is the reasons, we do the cutoffs improve the alignment of the river, reduce the sinusity, shorten the river length as it shortens the river length, it increases the slopes and reduce the flood stages. It has other effects but let me have this things to that.

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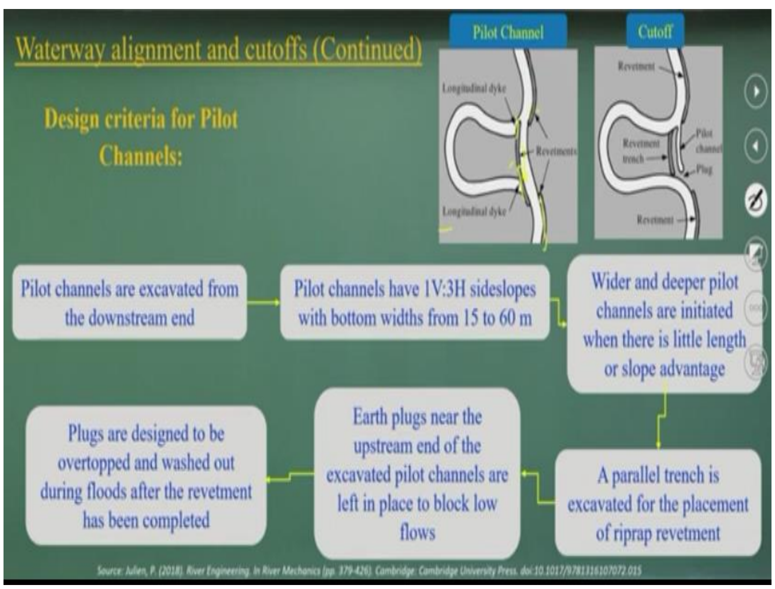

Now if you look it, how it happens. Like if you look at this pilot channels, so you want to cut off this river bend. You can consider the revetment and you can make a channel here, the pilot channel and you can have a longitudinal dykes here and followed by you can have cutoffs, revetments. So we can constrict that or you can have a cutoff like this. If you look at that you have a revetment, you have a revetment trench, then you construct a pilot channel.

You have a plug, then you have a revetment here. Now if you look at that, what are the structures we put it to make a cutoff channels. One is pilot channels and the cut off process what you are there. First what you do it. We exhibit the pilot channels. That is what we do it from the downstream end and we just excavate it the channels, then what we have? Then we have to make it a side slope, which is stable side slope of 1 vertical 3 horizontals.

And keeping the width of channels depending upon our navigation requirements 50 meter to 60 meters. Wider deeper pilot channels are initiated with their little length and the slope advantages. As once you make it the pilot channels, it slowly it can initiate it as the flow passes it. A parallel trench you make it with the placement of riprap revetments. We make a trench and with that trench we put the riprap stone revetment, we just put it.

We have earth plug near to the upstreams, this is the flow directions near to the upstreams, you have the earth plug and end of these excavated pilot channels are left in place in block the flow. So we try to look it as soon as the flood comes it, it plugs a design to what top it and washed out and the revetment have been completed by the times. So if you look at what I am telling that in when you do for any river training work to make a cut off channels, we follow the two ways.

We modified something and some of the part we leave it to river to do it. That is the reasons we have the plugin. So as it is naturally over tops it, that is the reason the river can take care of widening the channel or deepening the channels depending of the flow behaviors during the extreme floods. That is the periods we will have the over topping of the blocks and that is the conditions once it is established, then the flow will maintain it.

The basic idea from this cut off channel design, you can know it we do some part of artificial thing and some part of the work we intentionally left to the river to do it, so that it can make a regime channel or a stable channels. That is the idea is there like if you look at that, we make the pilot channels but we do not link the finite channels to the upstreams. We leave it with a plugs, so that it is designed such a way, it will over top it, washed out.

As soon as it is washed out and over top it, that flow will make it this pilot channels configurations in terms of bed slope, in terms of width, in terms of depth it will change it and that after certain days or in a seasons it will come up active channels with a modified width, depth, the slope which is the stable things what we do it and that is what we look at and we wait till the plugs to do that part. So the idea is, I said it again and to repeat it that it is two ways.

We do some part and some part of the things we leave it to the river to do and many of the time we should try to understand it how do the river behave during the flood at that particular states of river systems. So our understanding of the river is foremost requirement to have a stable channels or to make a river navigable.

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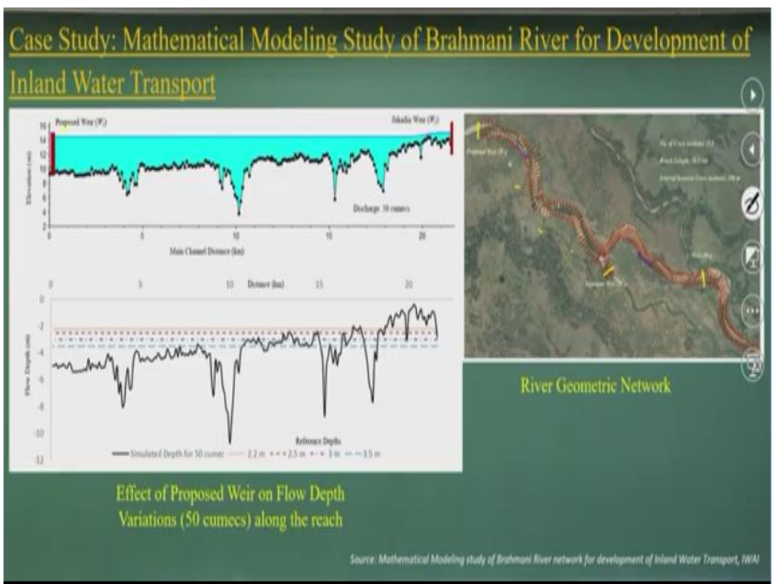

Now if you look at the similar studies, we conducted is a case studies. We conducted for the Brahmani river. If you look at the rivers, you can look at these cross sections which is set up through the HECRAS models and these are the weir, proposed weirs. You can see that before weir and after weir and you can see the channel depth requirement and you can see the longitudinal profiles. This is part of national waterways 5.

This is a study we did it as group of hydro fluvial groups, we conducted this study and we tried to look what is the design proposed weirs, dimensions where the locations, all we have done it with help of HECRAS model, very detailed mathematical data and the bed material data, all we integrate it and the solved this one. So it is possible nowadays with help of the mathematical models, we can know it, how we can make this river navigable with a series of them or the weir structures. That is the things what we have done in this case.

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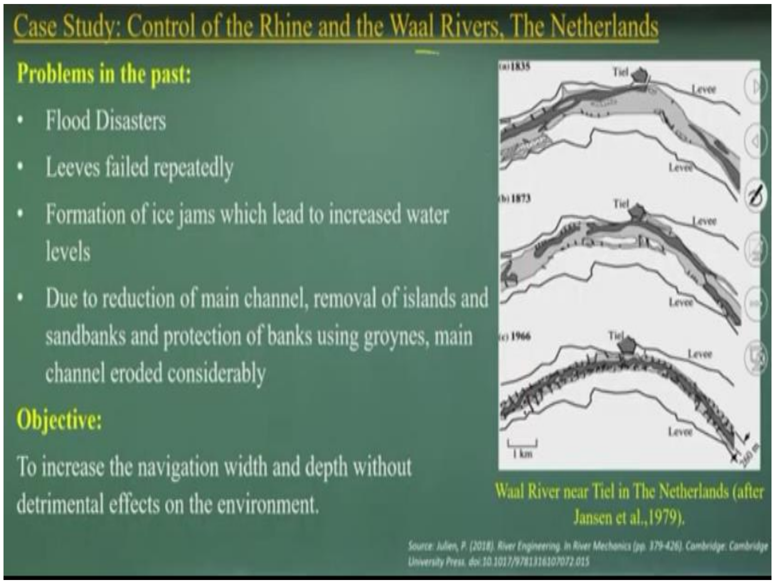

Let us have another case study; that is what very interesting case studies Rhine and the Waal rivers in Netherlands. So you can see the figures 1835, 1873, 1966 and looking these figures, these are the water and this is the levee, the embankments and you can see the river width is much larger, the depth of the water is very shallow. Some of the portions, the depth of water is not there.

To avoid that, there are the structures, if you can see the structures are there; minor structures are there to confine the rivers. You can see these minor structures to confine the river in terms of the spur, in terms of the structures what you put it to confine the rivers. By 1873, you can look at that almost 50 years still river is confining it with the help of with a spur and also the parallel levee. It is a parallel levee with these ones.

For the 1996 you can see the jacketing of the rivers happening it with both the sides, putting it all the structures, the spurs bend, weir both the sides such a way that we confine the river. This is what the history of river training works in Rhine and the Waal rivers in the Netherlands. If you look at that 1835, it took almost 130 years to come in to a river which will be navigable. So what

I am telling you that when you try to make a river to stabilize and river to navigable having a flow depth, it is not a matter of the few years.

It can take decades; it can take the century to establish the rivers. That is the idea, that is what the experience Waal rivers near the Tiel in Netherlands. So if you look at that how much time did that, how the step wise they confined the rivers. If you look at that 1835, 1873 and 1966, it is more than 120 years and they try to do it confining the river in the step by step and this is a major levee and they want to put the levee in the structures in between and they can find the jacketing the river in the both the sites after 1960s.

Only 260 meter width of the rivers, which is necessary for the navigables with the depth of waters they got it. So that is what I am telling it when you do any river training engineering works, it is not the canal, we try to understand the river morphology, how does the river responds to this the man made river training structures. Based on that the step wise, we should proceed it. It may take few years, few decades to stabilize the rivers.

Because all the times river as we know from experience that each river to respond a particular river training works are the different. It is not the same even that is the reasons we should do a series of physical modeling studies, series of mathematical modeling studies, still we should acquire the knowledge about the rivers, try to understand what is the response of the rivers, the morphological response of the rivers for the extreme flood events, the average flow events, how the morphology is changing it.

That is what can take it very huge time. So that is what we can take it in terms of years, in terms of decade or sometimes like a century to reach it a river, which is stabilized river, navigable rivers. That is what the case studies by Netherlands. It is okay. It is a smaller river, which is having 260 meter wide, but you see that how much of land the stabilizing river becomes navigable as well as the depth is increases and could have increased the aquatic life.

The river health could have been better, also they have reclaimed the lands. So it has advantage. It has a significant advantage to stabilize the rivers as it may take the decades or made it century, but ultimately we get the benefits in terms of river health, in terms of aquatic life, in terms of getting the land reclamations can be done it and you can understand it is a rich land what we get it and you can have the levee things. It is possible.

That is what is this case study is showing from the Netherland. It took it 120 years. It can have a bank using groynes, can have main channel eroded considerably and there are the removal of the aisle. So there are all sort of the problems what we in generally talk about, levee failure, the flood disasters used to happen it almost one decade before, but that is what is not there, because that what it controls it with a navigations width and depth without detrimental effect on the environments. That is what is possible and more detail you can go it the structure wise what type of the structures, what are the things are there.

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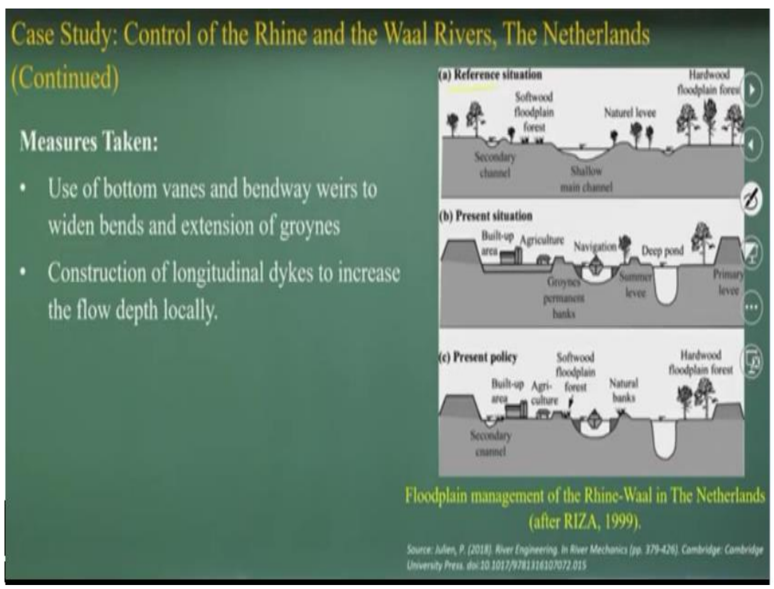

Now if you look at the next ones is very interesting. Again this when you try to look at the rivers, river corridors, we try to talk about not the river; river with the corridors. It has a flood plain. It has its own space. So idea is considered that in a natural the reference sections we can have this. There will be a shallow main channel. It could have a natural levee. It can have a flood plain forest, which could be a before the civilizations there are not much agriculture development.

You can have the secondary channels and you can have a pilot channels. If you try to understand the rivers in this way, but what it happens in present conditions as the economy growth it, which we have the built up area, we have the agricultures, also we have to need it to protect that part we need to put a permanent bank with a groynes or the spur. We put the summer levee embankment. The channel which is a smaller channels, it becomes a deeper channels.

We put the primary levees, bigger levee we put it in the both the sides. We have to protect beyond of that, so we put the primary levee, we put a summer levee. We have a groyne and permanent bank supporting agriculture and built up areas and then you have the banks beyond river corridors, which you protect other part of area not to affect by the floods. So if you look at that, we transform this reference to present conditions. This happens in many part of the worlds.

It is not that we leave it as a reference situations. We cannot leave it. We need a space for agriculture. We need a space for build-up area. We need to have the river with navigables to make it economically prosperous. So to look at that means we always convert from reference to present situation. What could be the present policy, how we can convert to go as natural as close to the reference sections? That is what any river engineering should try to look at that.

So that whether he can bring as close as to natural conditions as to the reference sections. What he will look it? Again he has to break it, because this part he can take a risk. So the location when it was there natural levee, now they have a natural banks. The bank with some vegetation, so that it will act like a natural banks. The banks can be collapsing but it can have a natural banks with a banks with the vegetation structure.

You can have at a small forest area, which can also give a resistance to the flow. To maintain this, this is a deeper channels now, deeper pond. The secondary channel is also activated. The idea is here, because you again have come back to that, you can give it the river to space. So the secondary channels what we close it, that is what can be activated. Whenever you have the flood that what you can take a risk to this ones.

But you want to make a natural system, because you need to have this agriculture needs a nutrient supply through the secondary channels. So if you look at that, if it is a river it does not carry the water only this carries the water, the sediment and nutrient and it has a space or the river corridors, as we go from the reference to the present situations, with a economical development like agriculture activities, deforestations and the built-up areas.

We can again mix up with increase this forest part, target the natural levee to the natural banks. You can activate the secondary channels with all these control systems. We can make it the natural channels and this way we can go back to as natural as possible to back, because that is the basic idea happens to any river engineering specialist that he will try to make it go to as natural as possible.

That is the reasons, we need to know it river corridor management; not the river management where you can talk about these things in a sustainable way to manage the rivers. That is what the concept and that is what I am just focusing on this. If you maintain that no doubt you can have navigations, you can have agriculture, you can have built-up area, you can also have the forest. All these compositions will be there and we are managing the built-up area.

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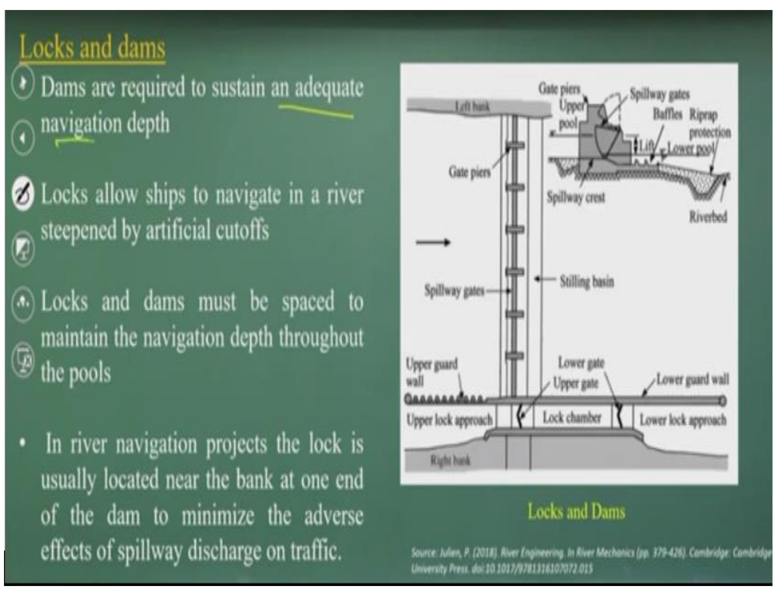

Now look at how we can have a locks and the dam. So whenever you have the density is required to sustain the appropriate navigable depth, what you need it as 9 feet about 2 meters and the locks allow the ship to navigate in a river stiffened by the artificial cut offs.

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So we will discuss other part in more details like locks and the dams. Let me complete these lectures again thanking my group of students and more interesting quote by Rabindranath Tagore ji that you cannot cross the sea barely by standing or staring at the waters. The same thing is what I am to talk about. We cannot manage the rivers without we go into the river systems. That is the idea of this course. We should understand the rivers with all this advanced knowledge, so that we can manage our river space, river corridors in a sustainable way. With this, let us conclude this lecture.