River Engineering
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Lecture – 15
Bridge Scour: Processes and Estimation

Good morning all of you. For today lectures on scours and most focused I will do on bridge scours

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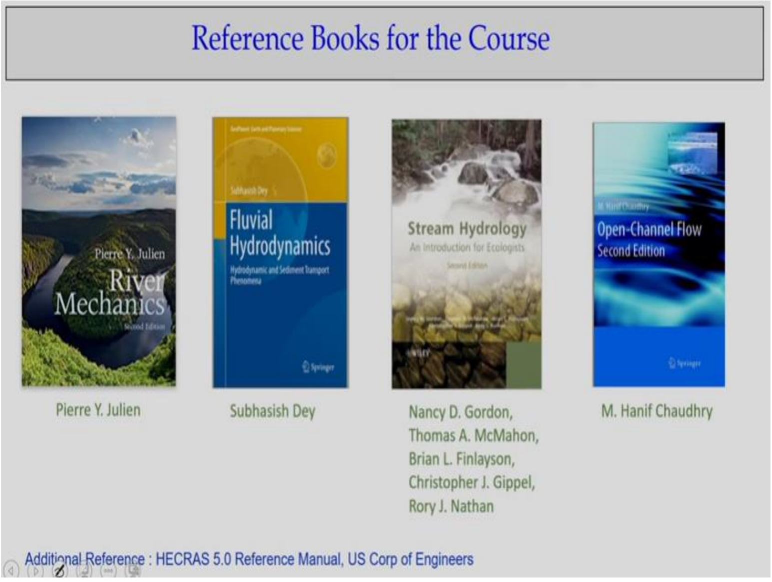

Whenever we design a bridge over the rivers the major challenging task caused for us to do a hydraulic design of the bridge. Today we will discuss how we do the hydraulic design of the bridge and mostly its standard guidelines are which is available from HECRAS reference manuals as HECRAS models and also, we will talk about the partly with fluvial hydrodynamics book that is what we are partly following it. Combining these two books, I will summarize it how we do hydraulic design of a bridge. Before going to hydraulic design of a bridge.

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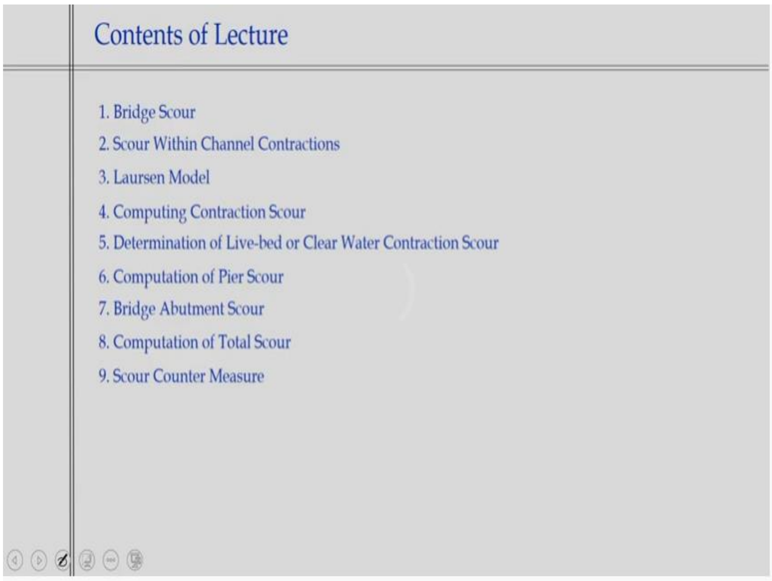

This is what we talk about contractions scour then we will talk about Laursen models how to compute the contraction scours and about the abutment scours this is what today I will cover it about the pier scours and total scours and counter measures we will discuss in the next class.

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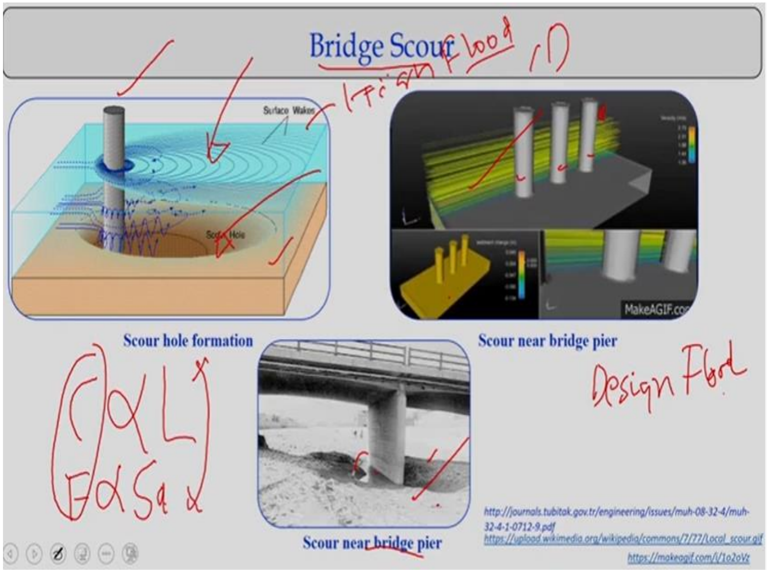

So if you look it when you talk about a bridge and if you look the figures like this the scour hole formation will happens that means the erosion of the river bed materials that is what the scour and you can see the scour holes and you can see this the flow properties in terms of vortex formations, in terms of changing the velocity field. So, whenever you have a scour formations exactly that is during high flood, we have the scour mechanisms around the bridge pier.

To protect a bridge pier you should estimate the scour depth and we should have a foundation below the scour depth then the bridge is protected from the scour hole formations. So, this high flood in case of the bridge, we consider a design flood. For the design flood, we have to estimate what is the scour hole depth? What is the extent of the scour holes? Like if you look at these cases, if we look at this field photographs with a bridge pier, you can see the scour holes.

If you look at the bridge scours is a very important for us and that is what we design for design flood and we need to estimate the scour holes. And if you look at these ones it depends upon the flow characteristics, depends upon bridge pier characteristics, it also depends upon the bed materials. The same way you can see the scour hole formations when you go for any bridge site you can see the scour hole formations.

Nowadays, also it is possible to do the mathematical modelling, CFD modelling to know it how this scour hole formations happens when you have a three piers or conjugate piers are there. It is a quite challenging tasks to do hydraulic design of a bridge because if we look at the construction, the cost of bridge if it is considered that is what is proportional to the length of the bridge and more the length of the bridge more the cost to create it.

But same way though; if you look at the foundation cost that is what have a proportional to the scour depth. So, foundation cost it also the proportional more the depth you go part the foundations that depends upon the scour depth. The cost of the foundation it increases and so that way we need to have a balancing on these two. So, if we reduce the length the scour depth is going to increase it the cost of the foundations is going to increase it if you do not reduce the length the cost of the bridge the span of the bridge will increase it.

So that is the reasons the hydraulic design of the bridge is not a single way to design it is its iterative way to design it. You design something try to find out the cost effective then again you design it so it is iterative way judging either hit and trial methods and finding optimized solutions where the total cost of the bridge is minimum. So that is what a hydraulically worked to try to look at the safety of the dam during the high extreme floods where at that period you will have data, high scour depth formations here the bridge piers. Same way other component we will talk about.

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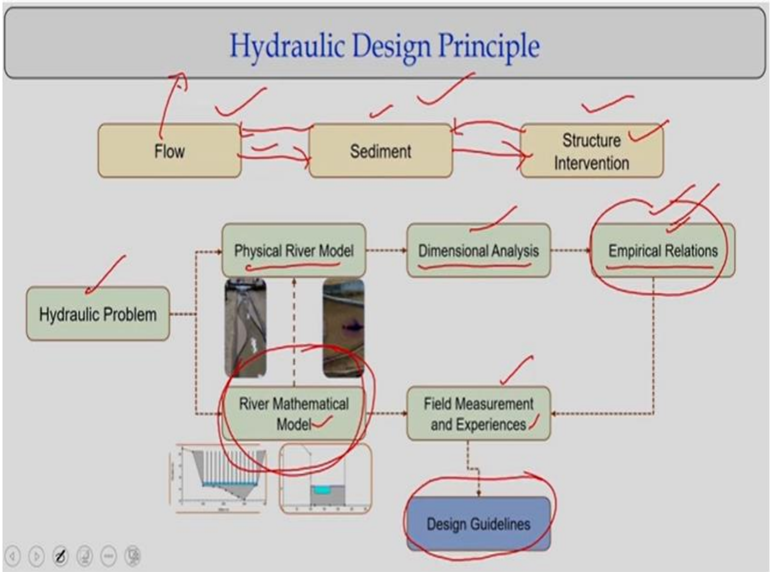

So the basically the hydraulic design of the bridge is a very interesting fact and that is the reasons mostly we do the hydraulic designs of bridge if you look it depends upon the flow characteristics, it depends upon the sediment characteristic also structure intervention they all are interacting each other's that is what it happens it with the flow, sediment and the design structure relative to it.

The flow when you talk about the flow characteristics, we talk about during the extreme flood event, the design flood event it could have a frequency of 1000 years or return periods or it could have a 10000 return periods or 100 years return period. That type of floods what the flow characteristics at the river locations that interact with the sediment, the bed material sediments formation of scour hole happens it that depends upon the structures what type of piers we have, size of the piers, what is the dimensions of the pier or the abutment all we interacting each other's to find out what will the hydraulic design of this.

That is the reason it is not an easy task that is the way to do it if we have a hydraulic problems we that problems we try to solve by physical river models we have the flow, we try to put these the piers in scaled down models and run different characteristics flow characteristics and the sediment characteristics and try to do dimensional analysis and i start with the empirical relations with a scour depth, flow characteristics, sediment characteristics and the structure characteristics like what will be the pier dimensions , the type of the piers all will decides that is what we establish a empirical equations.

But nowadays river mathematical models also come to pictures taking care of a three-dimensional river models are there, two dimensional models are there with the sediment transport we can also locate how it performs well. But many of the times these are complimenting to each other’s we get physical river models all over the world that people do the physical river models to do a hydraulic design of the river because you know it hydraulic design of bridge is a very much cost expensive.

So, each bridge we have a unique design that is the reasons we go for the physical river models but nowadays also the mathematical models are complementary each other’s. So if we will look at that way we can have a physical river models dimensions analysis, empirical relationship that is what these give is parallelly also we conduct field measurement the scour depth, the scour extent and also the engineering experience all these things are integrated finally create a design guidelines for designing the bridge components the hydraulic designing of bridge components that is what is there.

In summary what I am say that whenever you have the bridge problems or any hydraulic problems we go for a physical river models or the mathematical river models do a dimensional analysis and particularly empirical relationships integrated with the field measurement and the experience if you have the design guidelines these are not as the technology improved this these design guidelines changes it. This is the basic philosophy of hydraulic design of bridge or the river training works.

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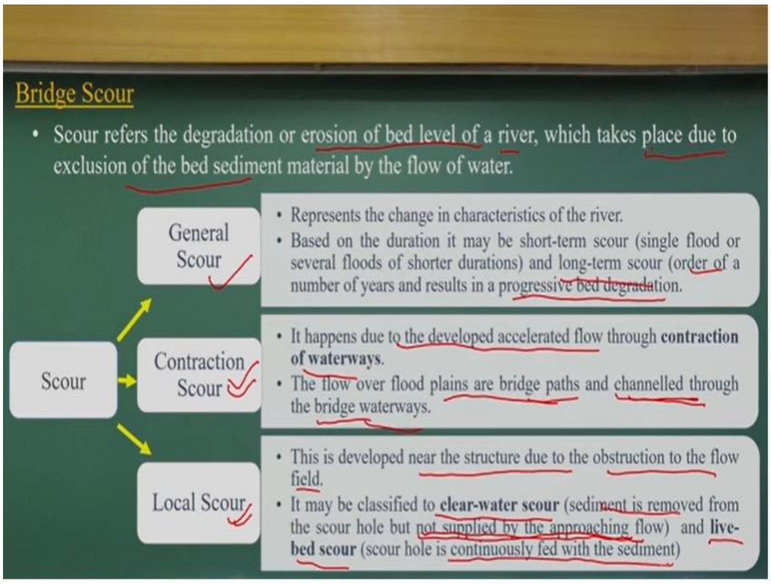

Now if you go to the scours what do you mean by the scours? Okay as I have shown you figuratively that is what is erosion of the bed level of a river because it takes place due to the exclusions of river bed materials, the removal of the bed materials, by the flow of the water, that is very basic definitions what type of scours happens it one is general scour, contraction scour and the local scours.

Whenever you construct the bridge, we contract the flood plain or the river or the both. So, the basically what to try to do it that we contract in the flood plain otherwise we cannot have affordable to give a river space. So, because of the contraction there will be the scour mechanism that is more detail will go it because of the contractions you can try to understand there will be the accelerated zone because reducing the width the velocity is going to increase it there will be accelerated zone and during these bridge path and the channel flow through the bridge flow over the flood plain are the bridge path and channel through the bridge waterways.

So you can see that we contracting the channels but general scour is that any river if you know it the bed materials does not remains fixed it changes with the times that depending upon the basin characteristics that depending upon the changing of the rainfall patterns changing the land use land covers though the long term the change of the bed levels that is what we call the general scour the long terms aggradation of the rivers that is what we do it if we have a last 100 years of bed level data.

We can find out whether river is in aggradation stage or the degradation stage and based on that if we know these on average aggradation rate or the degradations rate and we can quantify it what could be the long-term scour which will be progressive bed degradations will be there. For example, it may be 5 centimetre per year that is a degradation rate so bed levels are lowering down at their rate of 5 centimetre per years.

So if our designing the bridge pier for100 years then you can compute it what could be the total general scours happens in the next 100 years so we can have just a simple multiplications but that needs to have a last historical bed level data to quantify the general scours where that part we are not going detailed here but contraction scours and the local scours. Contraction scours because of contracting the river space in the flood plain as well as in the channel.

The local scour is developed near the structures due to the obstruction of the flow that is what it happens is when you construct a bridge pier when you construct an abutment it is because of that locally it changes the velocity field changes the flow patterns the vortex patterns and all. Because of that what is the scour happens? That is what the local scours here we divide the scour into part is one is Clearwater scour and other is live bed scour.

The Clearwater scours in that regions that there is not supplied by the approaching flow sediment is removed from the scour hole but not supplied by the approaching flow. That means approaching flow is not carrying any sediment to the scour holes. All these scour materials are going out from the bed near to the local zones there is no bed sediments that are moving it along with the rivers if moves with along with the rivers that means live river conditions that is the condition is live bed scours.

There are the bed load is moving it in that conditions whenever we have with a scour and that is a continuously fed with the sediment and that what is make a live bed scours. So clearly understand what is Clearwater scour and live bed scour.

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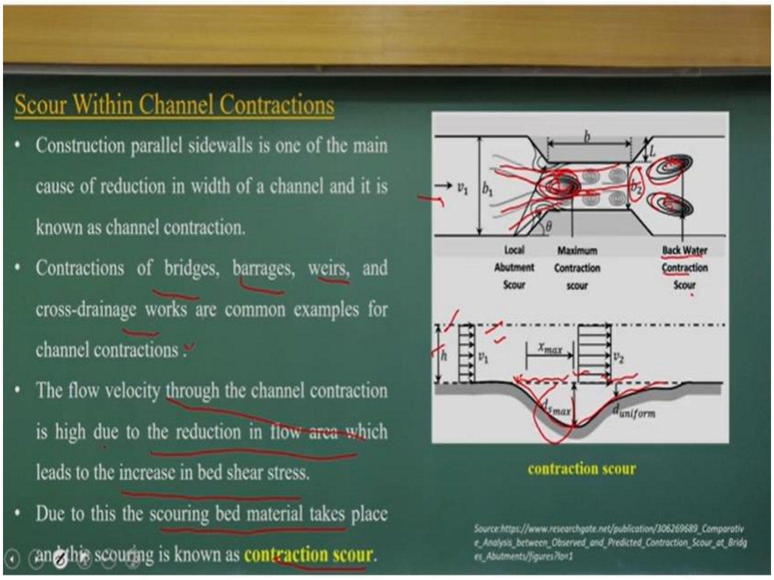

Now let us go for next one what it actually happens it if you look at this river coming with the velocity v1 width is b1. But because of this bridge constructions we confine the river we contract the river. So as we contract the rivers we make a width of the river is b2 okay and if we look at that if you draw the streamlines it will like this there it will be accelerated zone there will be scour hole formations here, there will be back water contraction scour will be there and there will be vortex specimens.

So if you look at that the maximum scours will happen to these points and there will be contraction scour and if we look at the if I take a section and this is the h depth of the water this coming v1 is velocity feet and this is all original bed levels and because of these contractions the scour depth is d max and this is what our scour hole the cross section of the scour hole formations.

So, the v1 velocity is coming it h is depth and here d max scour hole is happening here in showing it where the scour hole formations happen it and where other two scour hole backwater contraction scour happens at this. This is the structure of the flow phenomena we can get it just conduct a lab experiment with a flow just have a contraction points and have the flow you can easily see these contraction zones. Easily see the scouring zones where the scour happens it.

So, the flow velocity through the channel contraction is high due to the reduction in flow area was a basic thing and that increases the bed shear stress. Okay that is the reasons as the flow velocity increases the bed shear stress increases due to this scouring of bed materials takes place that is what we call contraction scours this is what it happens in bridges, barrages, weirs and cross-drainage work many places we can have a contraction scours okay not only the bridge you can have in barrage location you can have in the where are the cross-drainage work.

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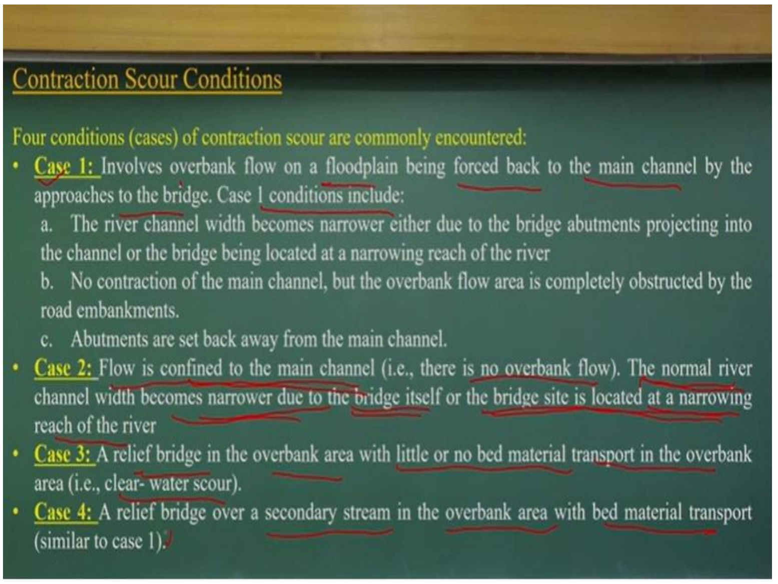

So, if you look at that point what happens in a river? When you construct a bridge. As I said that river has one space and we are designing the river for design flood may be 100 years return flood may be 500 return period flood that means the exceeds the channels okay flow exceeds the channel capacity very rough idea is that the bank flow discharge of a river is about 2-year return period discharge.

So when you have a 100 year return period discharge definitely this is a discharge is carried in channel as well as in flood plain that is the reasons what type of constraint we are doing it the case one the conditions of the contraction scour where it involves the overbank flow on a flood plain being pushed back to the main channel by the approaching the bridge that is what this case one conditions.

Case 2 is a flow is confined to the main channel flow there is no overbank flow there is no flood plain overbank flow. So, the normal river channel width becomes narrower due to the bridge itself or the bridge site is located at a narrowing reach. Most of the times we choose the bridge locations which are narrowing part that is that is what I discussed earlier the cost of the bridge project is a proportional to the length of the bridge.

So that is the reasons the site selection of the bridge locations will take care of that should have a narrowing locations the narrowest part of the river we can construct a bridge that is because of that there will be there the case 2 is the flow is confined to the main channel but the main normal river channel becomes narrow due to the bridge itself or bridge site is located at the narrow reach.

Case 3 is a relief bridge in the overbank area with little and no bed materials transport in the bank that is basically clearwater scours is there are the bridge piers will be there abutment will be there on the flood plain area there will be no bed material transport mechanisms to will there and that is the case 3 which relief bridge conditions where we have a only clearwater scours.

But the relief bridge over the secondary streams as you know it cannot have only one main channel it can have either multiple channels there could be secondary streams on the over bank area with a bed material transport as the similar to the case 1. So, you can have a different case of the estimating the scour hole depth because these are different conditions like a case 1, case 2, case 3, case 4. So that is the bridge design conditions we consider it.

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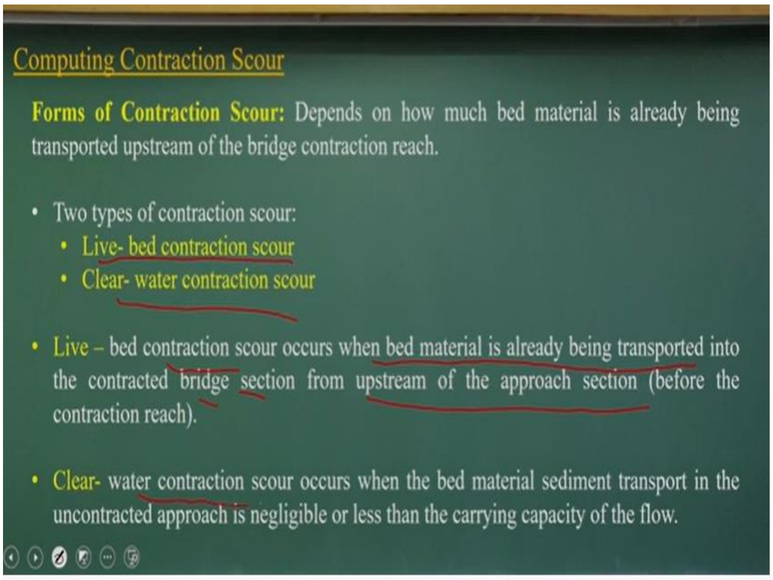

So now we will look at the contraction scour as I discussed earlier so we will have a live bed contraction scour, clear water contraction scour, the bed contraction scours occurs when bed material is already being transported into contracted bridge sections from upstream of the approach sections. That is what I earlier I try to explain you water contractions scour that is a Clearwater contraction scour is a bed material sediment transport in uncontracted approach is a negligible less than the carrying capacity of the flow okay? So, these is again we are defining it what is live bed contraction scour and the clear water contraction scour.

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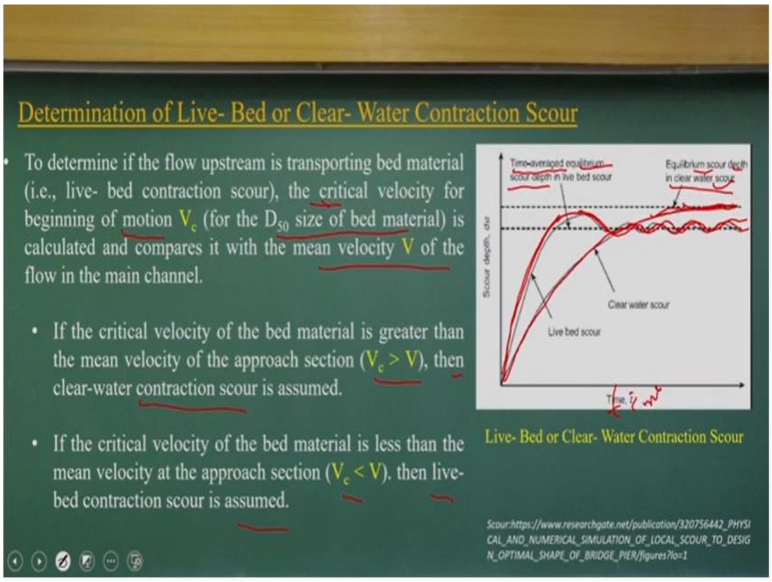

Now if you look at what will you define it, is it a live bed contraction scour or the clear water contraction we define in terms of critical velocity in terms of a critical velocity. The critical velocity being of motions okay sediment particles is Vc for the D50 sides of the bed materials is calculated and compared with the main velocity of the field. If the Vc is greater than V then you will have the clearwater contraction scour if it is less than these the critical velocity bed material is less than the main velocity of the flow then we have a live bed contraction scour.

But now try to look at that if I have the live bed and clear water contractions scour how do they vary with time? So, you brought the time said the scour depth if you look at the y-axis scour depth the clear water scours will follow these scours okay and then it reaches the equilibrium scour depth. So, with time it will be increases as a power functions and it can reach us a steady level equilibrium level that is what the equilibrium scour depth formations will be there.

But in case of live bed there are the bed sediment materials are coming to the scour holes again transporting like that what will happen to scour will accelerate it very fast as compared to the clear water scour after that it will have the steadiness it is a fluctuating over that as you can understand it as the sediment particles are coming upstream of these scour holes that spreading mechanisms out there so we cannot get a steady equilibrium there will be plus the positive and negative side the storage and reduction part will happen in it.

That is the reasons you will have a scour depth of increase it will be there and there will be the fluctuations. So that way the time average equilibrium of scour depth we have to get time average we do a scour. So as this figure indicates for us that the Clearwater scour is larger than the live bed scours, clearwater scour is larger than the live bed scours and we define the scour within that.

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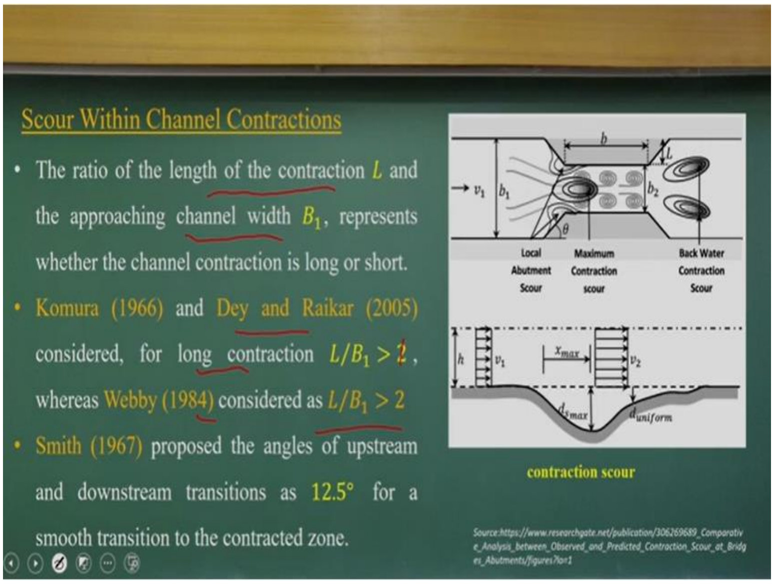

Now let us complete that the scour contraction scour also depends upon what is the dimensions in terms of length of contractions and approaching channel length. So, we define it within it is a long and the short. Dey and Raikar has defined it that L1/B1 ratio that it is greater than 1 it is long contractions and Webby 1984 considered L1/B1 greater than 2 will be considered as long contractions otherwise short contractions.

So, if you look at that it also depend upon the length L and the B, L and B1 the length of the contractions and the B1 that is will be give us that whether the contractions are long or the short because the hydrodynamic behaviours or sediment scour hole formation behaviours are changes it as we go for long contraction scour or the short contraction.

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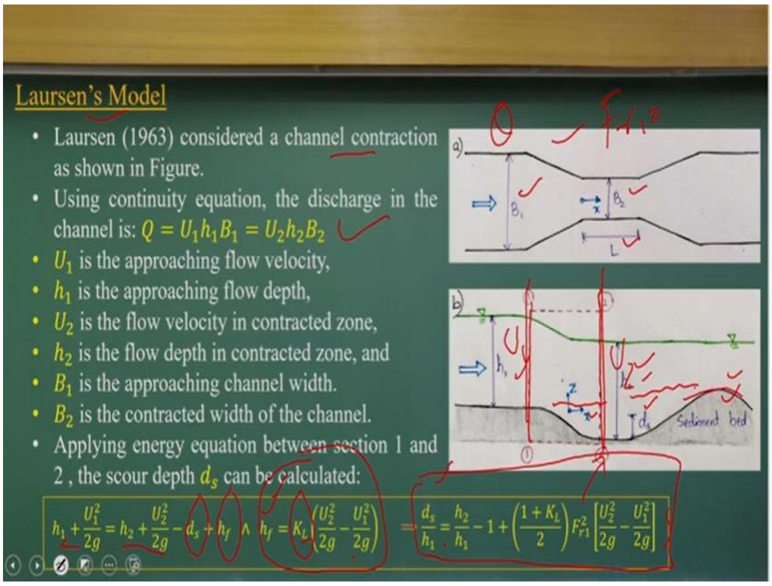

Now if you look it, we have just a simple theoretical model which is a Laursen models okay which established a channel contraction as shown as in the figures in a very simplified cases that B1 you have width it contracted to B2 it is having L length. As it is a constant discharge Q is going it flow depth is h1 is a at the scour hole we have the h2 and we have the ds is the scour depth and these scour hole can have the deposition of material at this point.

It is scour remove these materials also have a deposition those we are not interested where it is deposited but this has soon as you have the scour role there will be the sediment deposition will be there the downstream of the scour holes. So, if you look at the geometry of the channel geometry of the contraction scours okay you can have a continuity equation you can have an energy equation.

So, we are applying this energy equations at the two sections okay that is what you know it and here we are considered the specific energy with reduction factors also we have considered because of the scour hole formations there will be the energy losses which will be the functions of upstream the u1 velocity and the u2 velocity. So, velocity head the difference between these two that is what we take with a multiplication factors we will get it what will be the head losses?

The energy losses is happens it because of these contraction there only be formation of vortex, there will be high turbulence structures we will create it and that what we will have with the energy losses here we just quantified as a pipe flow is proportional to the velocity had difference okay velocity head difference that what will cause us the energy losses. So, if I rearrange this equation, I can write in this form which is very simple form and here Fr1 here stands for the flow Fr1 stands for the flow froude numbers at the upstream locations at the section A1.

So, know this flow numbers if I know the velocities at the two points at the velocity at the upstream at the scour holes, we can compute it what will be the ds/h1. So, if you know h2/h1 then we can compute it what will be there.

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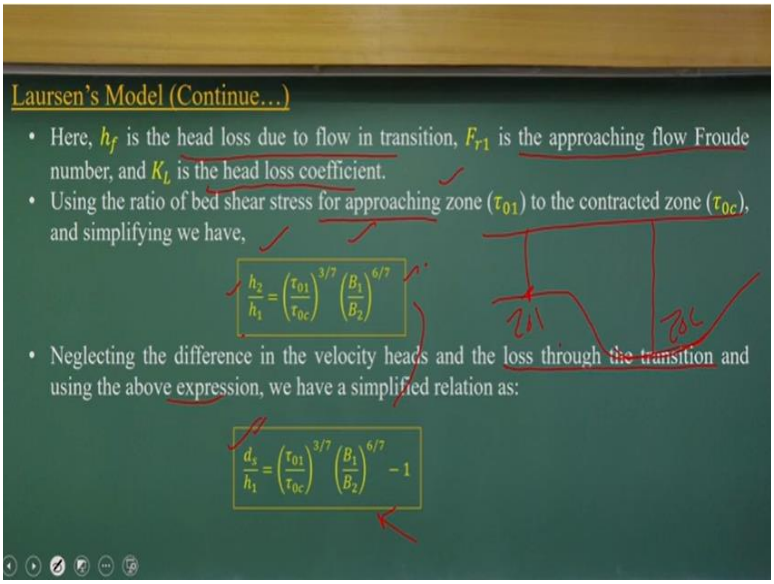

But if we look at this not that when you look at the scour hole formations hf is the head loss do the flood transitions. Fr1 is the approaching flow Froude number and KL stands for a head loss coefficient. Mostly we try to look at what is the estimation to h2/h1 which is not known to us more detailed derivations I am not giving to here but if we look at that I can compute it the approaching shear stress at the channels.

I can compute the τ_{o1} will be indicating me approaching the shear stress the bed shear stress approaching zone and the bed shear stress at the contracting zones because if I assuming it comes to equilibrium points that I can need the critical shields numbers the shear stress will achieve the critical shear stress will achieve when you have the scour hole formations.

After the equilibrium conditions is achieved when the bed shear stress is equal to the critical shear stress that is the conditions if I use it and take care of h2 h1 and all the things I will have a relationship to h2, h1 and that what if I substitute it and neglecting the loss the component that means then we will have a simple relationship between the B1, B2 and shear stress of upstream and critical shear stress which we can compute from the bed material, distributions and we can compute it what will be the scour depth. So, this is the data what we are computing just a theoretically considering it is an equilibrium phase.

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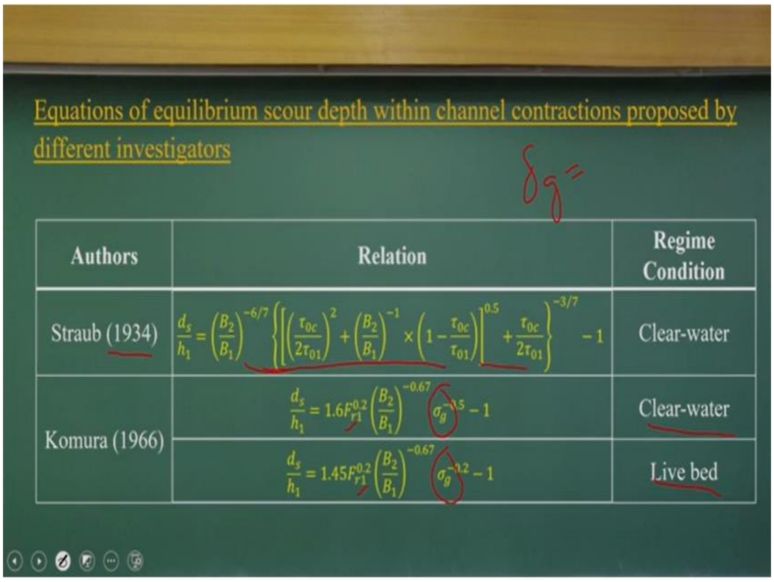

But if you look many others did similar type of experiment and tried to modify it. Like for example Straub 1932 he has similar equations from the experimental data and try to find out what could be the values combined. Komura 1966 he has included the particle size distributions this is for the clear waters and the live bed scour.

So σ_g stands for geometric standard deviations of particle size distribution that is the reasons these Komura it consider the as you know it this when you go to a river bed materials are not uniform size you can have a particular size distribution of bed materials from that you can compute the geometric standard deviation of bed materials and if you know these flow froude numbers and you will know the B2 and B1 you can easily compute the ds values.

That is very easy things that to compute that means in this Komura 1966 not going more details it considers it the mixed distribution of particle size bed material particle sizes to estimate the scour hole depth in a contracted zone.

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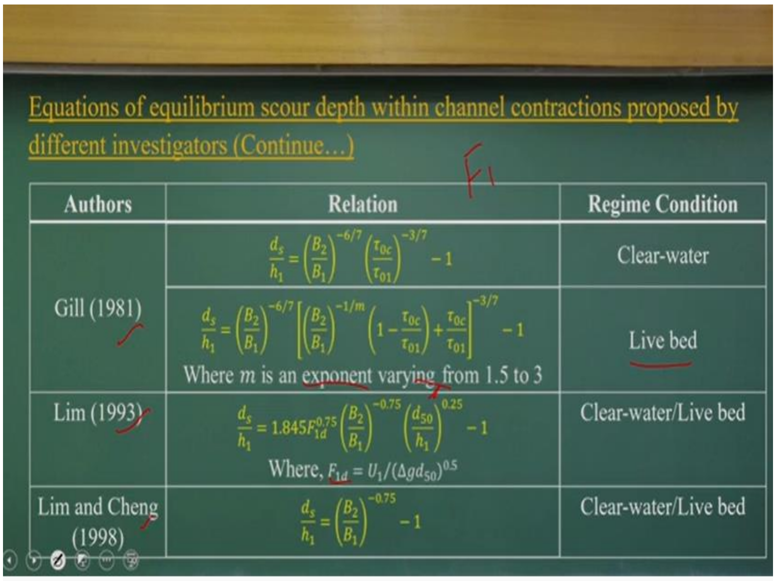

So same way there are lot of studies has been done it if you look at the Gill 1981 Lim 1993,1998 more the derivations are more or less same but there are the exponent components is raising for a live bed scours and if you look at in this case there is a d50 is here the bed material part is there and you will have the B1, B2 and you have here F1d stands for not the flow Froude numbers that is you try to understand it is not a flow Froude numbers because it is in terms of d50 it is not in terms of g.

So, that is why it is different than the upstream so it considers the particle size distribution that is what in 93 and in 1998 Cheng also develop it this simple equation only if you know the B1, B2 and h1 you can know it what could we do scour holes. So, that is all these clear waters the regime conditions like Clearwater live bed Clearwater or the live bed.

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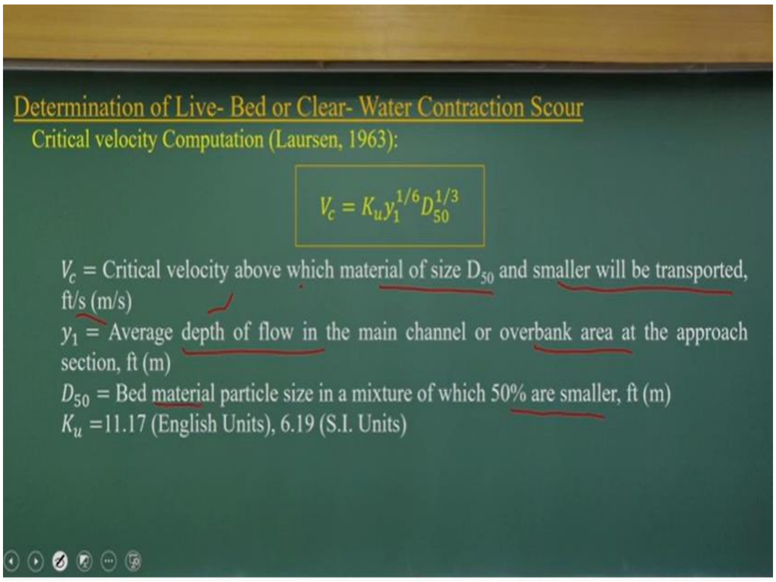

Looking that always point is coming it how to estimate the critical flow that is a Laursen models if a critical velocity above which material of size D50 and smaller then will be transported that is the in spin motions okay that is all so that I need to have a average flow depth in the main channel or overbank area. D50 is 50 % finest D50 bed material value Ku value we can compute the Vc is the critical velocity above which material size of D50 and smaller will be transported. So, these are experimental finding with D50 values and the coefficients.

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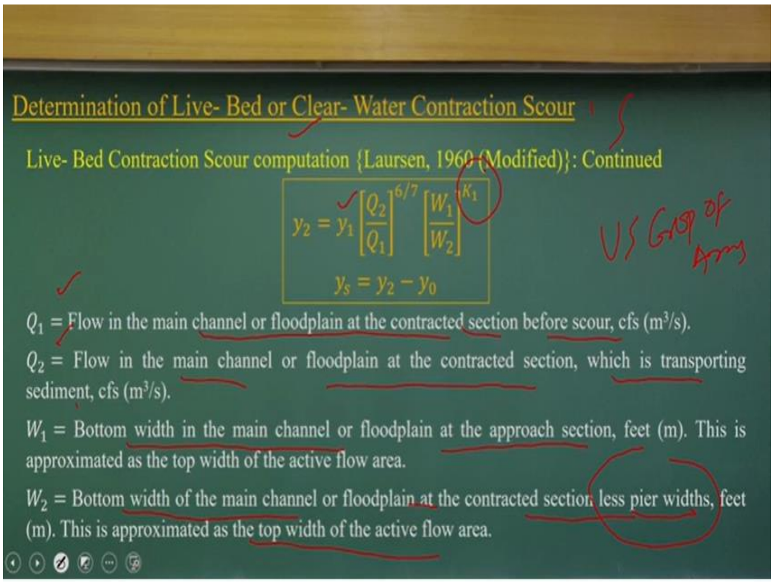

Now we will look at that, there are equations which is adopted by U.S Corp of Army they established in the live bed scours with a very simple formula is in terms of Q1, Q2, Q1 starts for a flow in main channel or floodplain in contracted sections before scour. Q2 is flow in the main channel or floodplain at the contracted section which is a transporting the sediment. And W1 is a Bottom width of this main channel the floodplain approaching section. W2 is the bottom width of the main channel or floodplain at the contracted section the less the piers widths which is approximated as the top width of the active channel.

So, that way if we look at that there are simple equations are there in terms of y1 in terms of Q2, Q1 and W1 W2 only in the K1 constants are there the power exponent is there otherwise we can compute what will be the these simple Laursen models as is given with a ratio. If we look at these are all are non-dimensional ratios and they are exponent is we are estimating from experimental dataset.

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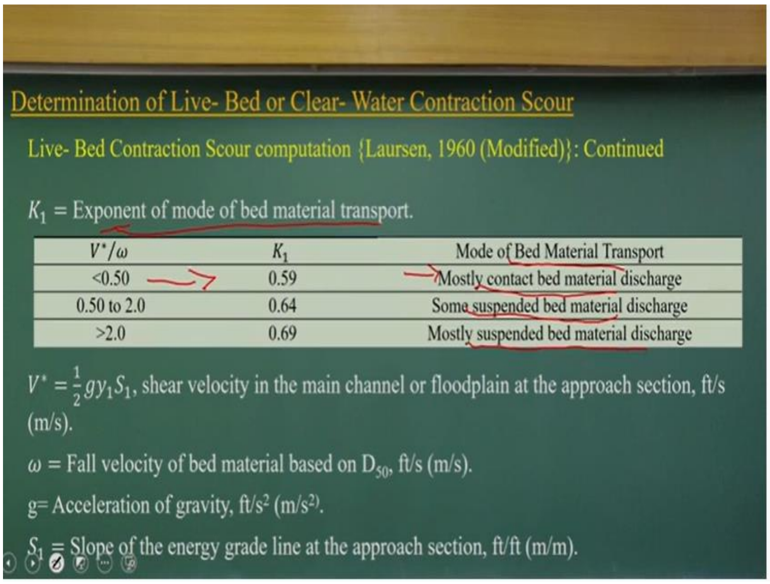

Now how to get the K1 values okay if you look at this K1 is exponent of the mode of the bed materials bed can have a material mostly contacted bed materials some suspended bed materials discharges mostly suspended bed material. So, as we go for this ratio okay increases the bed materials and the suspended material behaviour are changes okay like when you have this value the lesser than 0.5 if you look at the K1 is 0.59 it is a mostly a contacted bed material.

The river will have the bed sediment what to transport as a bed load it will transport it, but when you in the transitions of 0.5 to 2.0 will have the K value this. This is the suspended bed material discharge. Then we have mostly suspended bed material the V* we can compute it which is a shear velocity in the main channel or the floodplain that is what will be the function of the slope of the energy gradient acceleration due to gravity and the fall velocity.

These are all experimental findings we do not have a much a physical concept to define it but you try to always understand it when you talk about the scouring mechanisms it is flow, interact with the sediment transport and the structures the three combinations three interacts between flow, sediment and structures. That is the reasons after conducting a series of the experiment, we get to empirical equations.

We may not have a physical justification for this equation but we can try to interpret it and make it a design guideline or design skill. So, what type of transport mechanisms should be there in the river and what type of value should go it beside the numerical value. That is the reason whenever you design a bridge field visit is a necessary to understand the rivers not only the numerical value.

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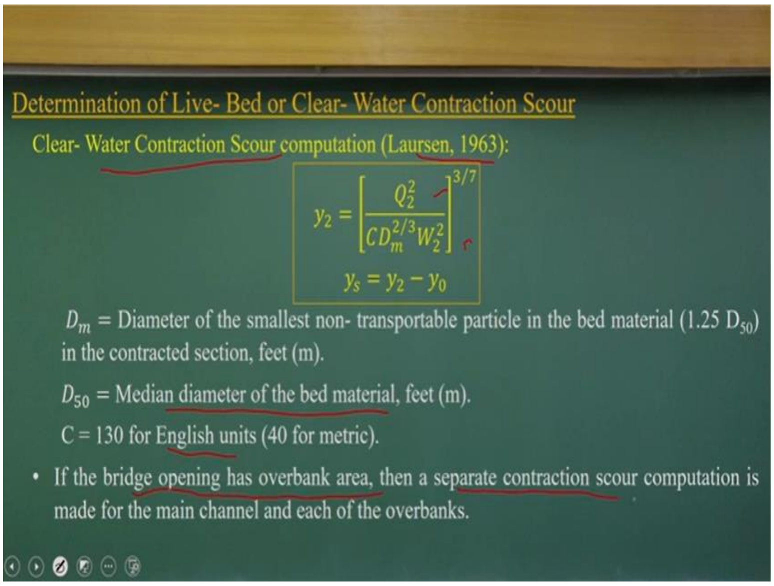

Okay that is the more points to that when you have Clear-Water Contraction scours, Laursen in 1963 which gives in terms of median diameter of the bed materials C is a constants which is 40 for Metric units and you know those Q values and W2 values and see if a bridge opening have the overbank area then a separate contraction scour is computed for main channel each of the overbank. So, you can understand it you can have the abutment either in the main channel overbank or the floodplain area that the understanding we should have.

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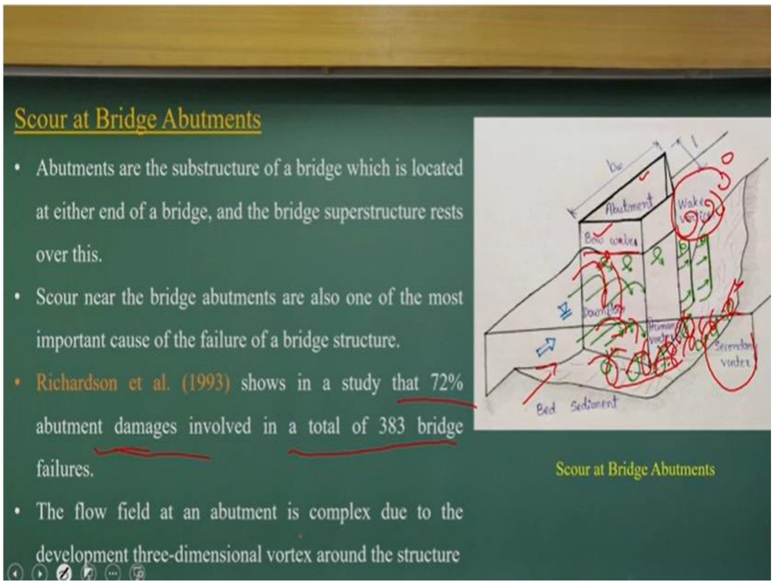

Let us come back to the scour at the bridge abutments you know it the abutment we will be there in a bridge and what are the scour happens in the bridge abutment locations. If you try to try to understand the flow behaviours if I have the left bank or the right bank abutment as the flow is coming from this distance and there will be the stagnation point will be there and because of that there will be change of the velocity as the upstream flow is having the higher velocity at the free surface as it reaches to the abutment that velocity reaches to 0.

Okay so that is the reasons there will be the downflow okay that will be downflow and these downflow will start eroding the bed materials as the start bed material eroding it and it will make a scour hole formation starts. As the scour hole formation starts because of the scour hole formations the horse shoe vortex formation are also there which is called primary vortex And parallelly also the secondary vortex will formations and just above behind of this abutment you can have a wake vortex formations will be there at the surface you can have a bow vortex.

If you look at how the flow structures are changes when you have the flow near to a abutment. How the flow structures are changing it is there will be downflow there will be a formation of horse shoe vortex, there will be secondary vortex, the wake vortex formation, bow vortex formation and the scour holes. Now the same approach will go it discuss it that conducting a series of experimental studies or the field measurements established the empirical equations and that what is validated for the bridge which is already constructed they validated the scour depth.

So, the basically that is what the again have 72% damage abutment damage involved in 383 bridge failures. So, bridge failures it so often happens because of damage at the abutment. So, you need to design the flow field which abutment is too complex due to the there is a three-dimensional vortex around the structure that is what I tried to show you three-dimensional vortex structure what it happens it.

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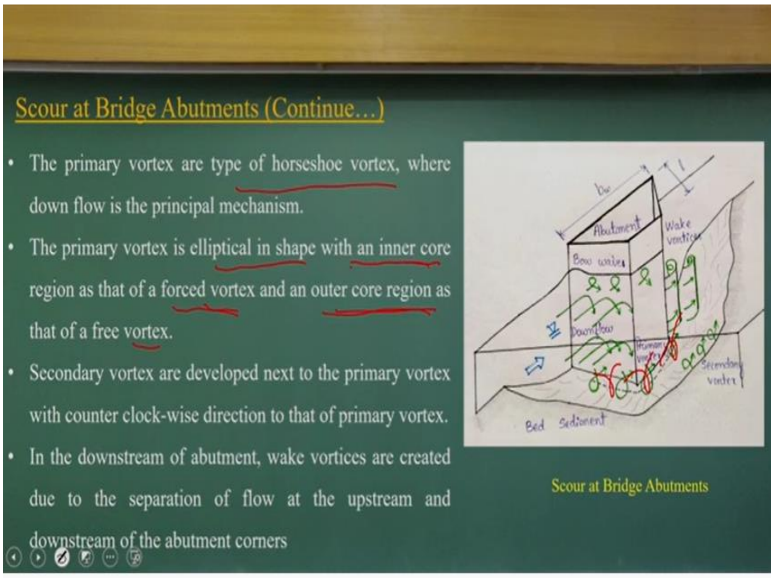

Now if you look at that this is a primary vortex, this is horse shoe type of vortex this happens which is the where is the downflow mechanisms happens that is what it is that primary vortex it will be there is elliptical in shape with the inner core regions as that of a forced vortex and an outer core region as that of a free vortex you can try to understand it how this vortex is complex that elliptical shape with the inner core region this will be forced vortex the outer core region will be the free vortex as you know from the fluid mechanics book.

The secondary vortex will be developed at the next to the primary vortex which is the counter clock directions to the primary vortex if you look at the secondary vortex. At the downstream of abutment; the wake vortices that create the flow separations at the up streams and the downstream of so you can have a wake vortices. So, this is a three dimensional very complex flow structures happen near to the abutment.

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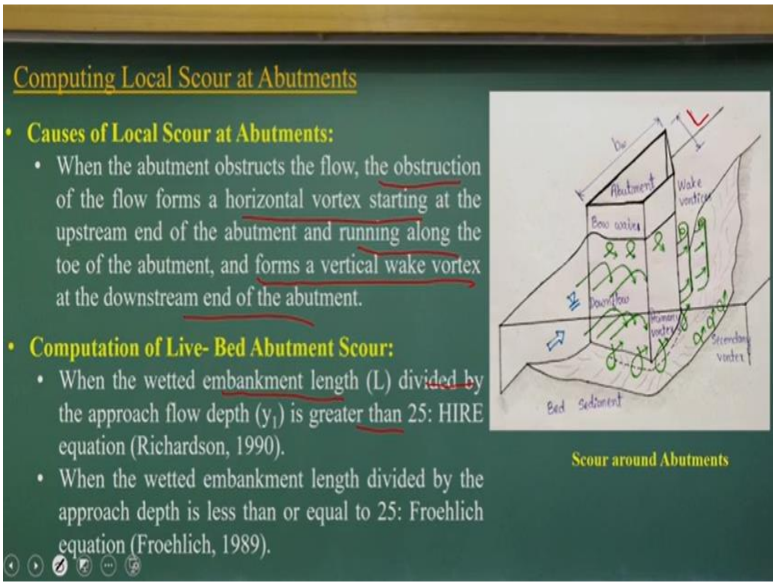

So, looking that we can compute the scour mechanisms as a live bed scour the scouring mechanisms at the an abutment it also depends upon the obstruction of the flow forms horizontal vortex okay and the running along these two of the abutment forms a vertical wake vortex at the downstream that is what we are talking about how the vortex formation happens and the wetted embankment length this L is greater than 25 divided by the approach length or the abutment wetted abutment length is 25 times than the approaching flow depth.

Then, we use a HIRE equation. When the wetted embankment length is lesser than then we use the Froehlich equations we use Froehlich equations which is 90 Richardson equation and all.

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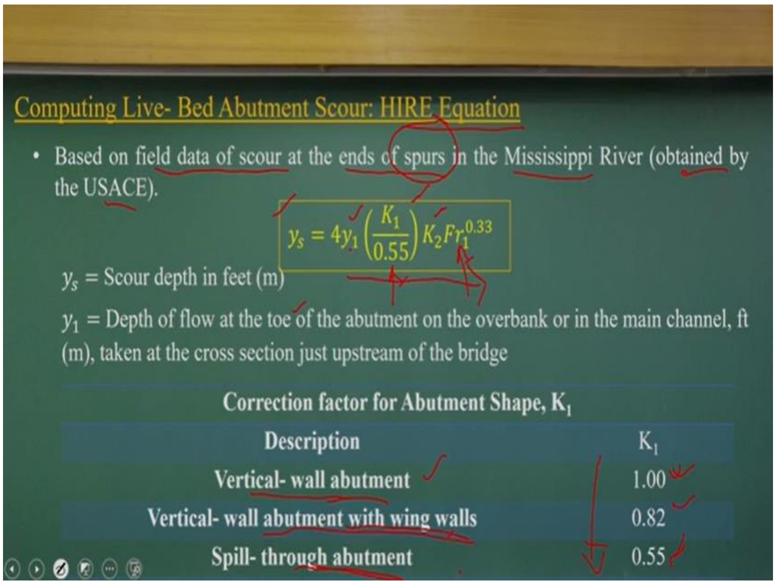

So, these are if you look it basic way this is what the HIRE equation which is developed from field data scour at the end of the spurs and the abutment is more or less same for the Mississippi river by US association of civil engineering that is what it developed from the field data the scour data the scour depth in a feet winds upstream flow will have the functions of upstream , flow Froude numbers K1 is a correction factor, K2 is a correction y1 this is what is developed in the HIER equations.

And the K1 is if you look at that K1 depends upon the type of abutment is it a vertical wall abutment to vertical wall abutment with wing wall or spill through the abutment. This is it depends upon what is the abutment type if it is a vertical abutment the value is 1 that means it is more and when you go for a spill through abutment you will have a 0.55 that is what this value becomes 1.

So, in case of same abutment it will change from spill through abutment to vertical abutment the more lesser two times the scour hole depth will be there because of abutment. So, that is the engineering scale where we try to understand it how the K1 K2 changes it. Because we know the flow depth which we cannot change it we know though upstream flow depth for a design flood that is what we can change it we can change it as a hydraulic designer.

The K1 value or the K2 value that is what we look it by understanding from these tables like what type of structure we should construct what type of abutment we should construct whether the vertical abutment or the spill through abutment. The spill through abutment will be less scour almost half of the scour of vertical wall abutment or we will have a vertical wall abutment with the wing walls with zero quantity.

So what am I pointing to highlight is here is that when you look the scour equations that is what is the knowledge for us and that the gives a hints for us how should we design a abutment with minimum scours that is the way because right to look at that the scour depth should be minimum otherwise the foundation cost will going to increase it.

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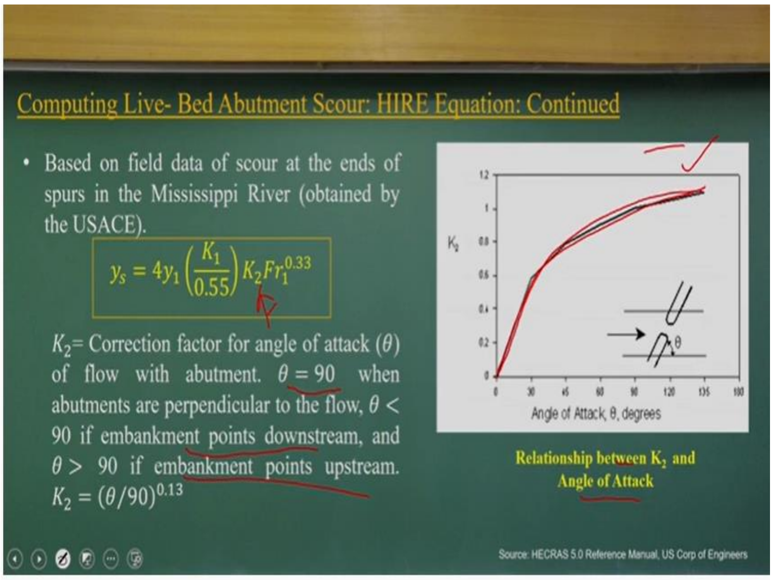

That is what I mean if you look at this K2 variations the K2 is dependent upon most of the times we tried the abutments should have the perpendicular to the river flow but it does not happen that is the reason ϴ= 90 degrees so you will have abutment many of the cases you will have a theta angles okay the embankment pointing towards downwards or the upwards K2 is a function of the ϴ /90 and if you plot the K2 value becomes like that.

That is the reason the angle between ϴ is better slot which is the angle between the attack and the flow between the attack whether the point is towards downstream or upstream your K2 value is changes it and that is what is value is increases from as close to 0 to 1.1. So, we tried to look at that how the alignment of the abutment we should consider it. Please be noted it. We are looking for extreme floods or design flood conditions that is the reason, we need to have a physical model.

Try to understand it what would be the hydraulic conditions at design flood conditions? As you know it, it is rarest to rare event and we cannot observe that data. So, that is the reason we follow physical models or the mathematical models to estimate the hydrodynamic figures and then we try to locate how what could be the scour hole formations. So that what we do it, it is a combination of physical modelling mathematical modelling and these empirical equations. All these have to develop a model or develop a design a bridge component which will have a minimum scour depth. With this, let I conclude this lecture.