River Engineering
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Lecture - 16
Bridge Scour-II

Welcome all of you for this interesting class on Bridge Scour and the Jet Scours. In the last class, we discussed about how to estimate the scour because of contractions and because of abutment positions. Today, we will further discuss about abutment scours, then we will discuss about the scour due to the pier. That is the bridge scour part we will complete it with examples.

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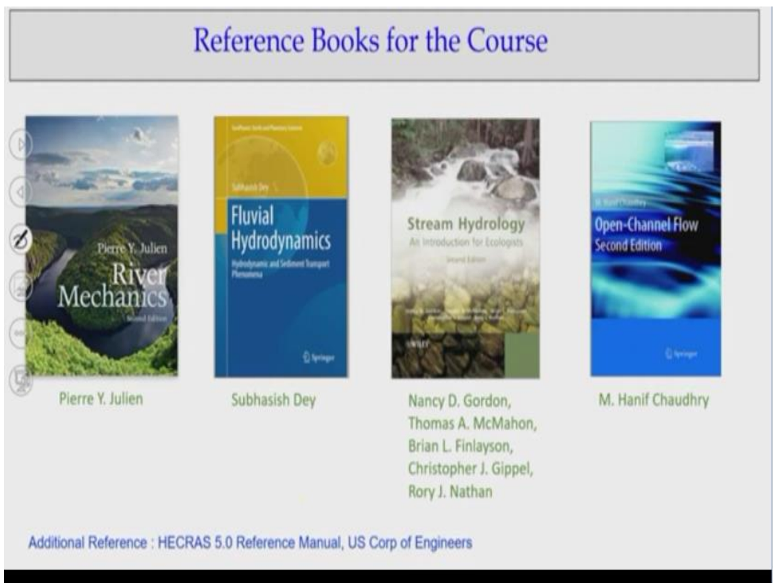

And with the standard guidelines what is available for scour estimations. As you know it, we have been following basically the HECRAS 5.0. This is HECRAS models. Reference manual is part of US Corp of Engineers and also we are following partly from the books of fluvial hydrodynamics, and also this partly we are following this river mechanics of P. Y. Julian's book. So, basic idea is now to compute the scour depths in bridge locations.

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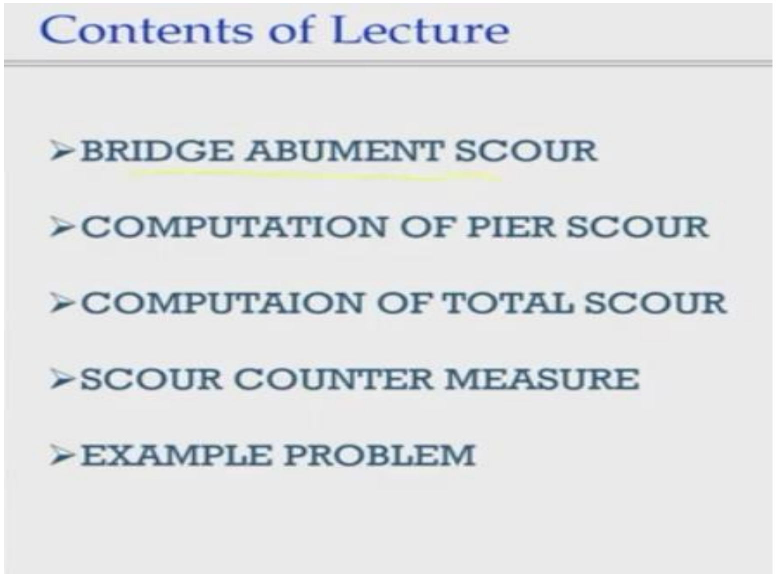

That is what today we will talk about bridge abutment scour. Yesterday in the last class, we discussed about that but further we will discuss how to estimate the bridge abutment scour. We will talk about computations of pier scours. We also will talk from computations of total scours which is there in HECRAS models or you can say it is there from HEC-18 models. So basic concept what we will follow it, HECRAS or HEC-18 manuals, that is what how to compute total scours.

Then also we talk about scour counter measures, how to reduce the scour depth in a particular pier locations or abutment locations that what is scour counter measures, then you will have a simple example problems. That is what today lectures content.

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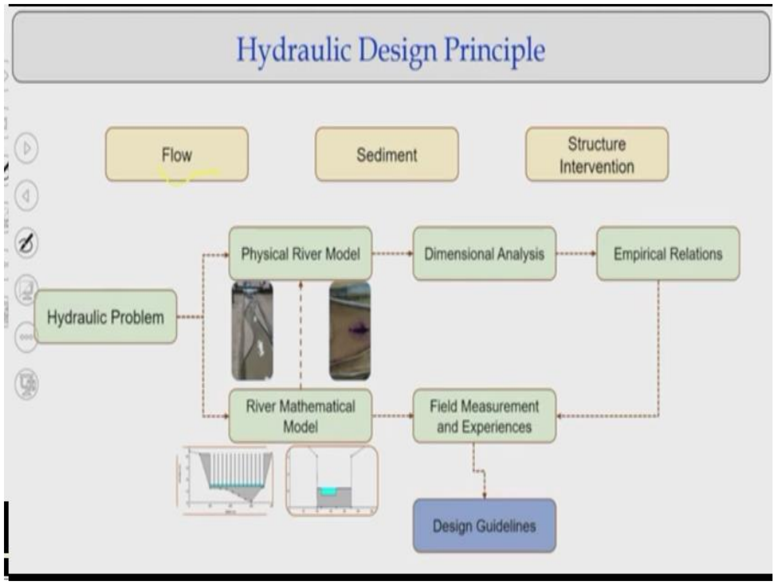

If you look at the scour part, it is having a computational, the sediment and the flow structures, maybe abutment, maybe you have bridge piers or you have any structures. That is the reasons it is having the 3 interactions are happening in both the way. All are linked to each others; the flow behaviors, sediment behaviors and the structural interferences. That is the complex process. Most of the times, we do physical models like the scale models what you have seen this.

The scale models what we conduct in the laboratory and followed by we do a dimensional analysis and we develop empirical equations. That is what I have been presenting you empirical relationship and that relationship when you implement in the field, we do the field measurements as well engineering experience that if you do this type of design how much failures are happening, what are the problems are encountered during implementations of the bridge.

Those experiences we consider it and along with the some field measurement, we develop a design guidelines and many of the times nowadays also river mathematical models we use it and maybe this is the one dimensional or 2 dimensional or the 3 dimensional models. We try to use it again further refinement of this field measurement experiments and the empirical relations and further we modify the design guidelines. That is the concept what we follow it and we will have talking about the same concept when you talk about abutment designing.

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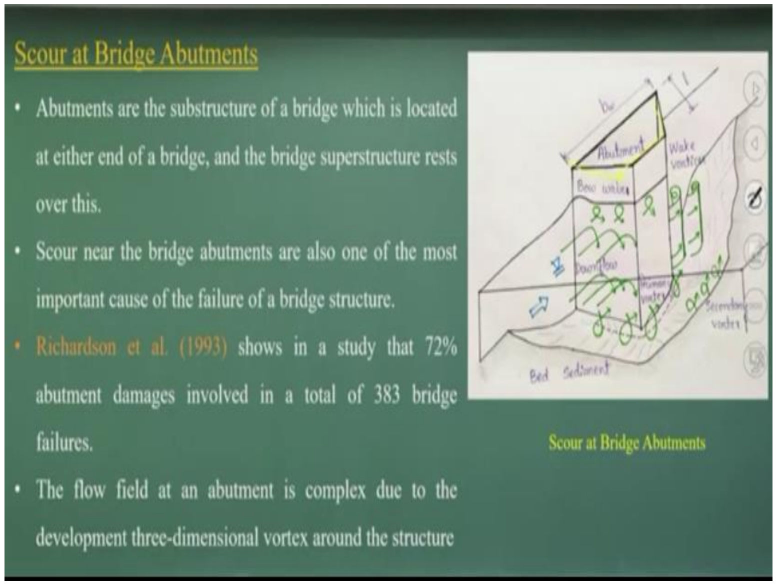

Now if you look at this abutment locations, the abutment structures like these and if you have a flow from these directions, very easily you can understand it. There will be a down flow and there will be the vortex formations, primary vortex formation, which is the vortex formations happens and that the vortex formations what we reference it as we call is the horseshoe vortex. As we call it is a horseshoe vortex patterns.

Then you will have a secondary vortex and followed by we can have a weak vortex. This is the hydrodynamic behavior. Because of that, the sediment is removed from this back, the scour hole formations will be there and there will be extend of the material. So if you look at that the scour at the bridge abutment, it depends upon the flow characteristics in terms of vortex formations, downflow, wake vortex formations, bed sediment materials, what type of bed materials are there and what is the shape, size of abutments.

That is the reasons we try to have with the equations which we try to develop it having a functions of the abutment characteristics in terms of shape, size, length, flow characteristics. That is what we can measure it like in upstream flow Froude numbers, the velocity and the depth, also we try to know it the bed material characteristics in terms of D50, D90 or D95. So this is quite complex flow, as this discussed is a 3 dimensional vortex around the structure.

That is what it is complex but today we have a lot of literatures to do this type of work. It is not that difficult now. I just tend to remind it, the 72 percent of abutment damage involved 383 bridge failures, okay most of the bridge failures because of abutment in not appropriate design of abutment can have the failure consequently you can have the bridge failures.

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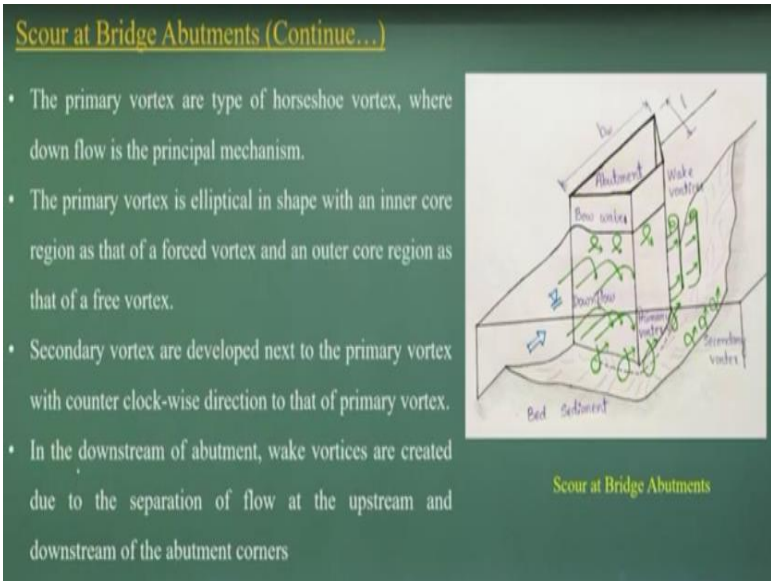

This is the concept what we discussed in last class that how the vortex formations happen and how it creates in a wake vortex, the horseshoe vortex and the secondary vortex. That is the processes, which happens in it.

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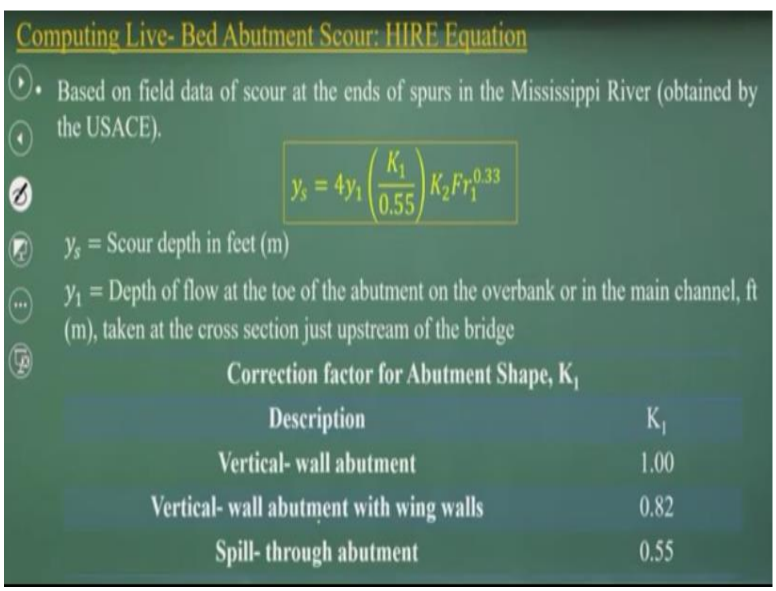

And now if you look at in the last class, we call it HIRE equation which is developed from the end of the scour, as similar to the abutments. So if you have the spur data is collected from the Mississippi rivers and that Mississippi rivers data when they do a non-dimensional analysis and try to find the scour depth is as functions of upstream flow depth, that is what is the option and this is the correction factor because of the abutment shape.

This is the correction factor related to angle and this is the upstream flow Froude number. See if you look at that, it depends upon the upstream flow depth, upstream flow Froude numbers which is indirectly representing us the strength of the vortex for flow what it happens it and the shape and the K2 is talking about the what type of abutment shape and the angle of attack. That is the thing what we will discuss it.

Now if you look at that if I have the river you can construct a vertical wall abutment. So, you can have the flow and you can have a vertical abutment like this as vertical structures, vertical wall structures. In that case the coefficient is equal to 1, but some of the cases that is what is the vertical wall, but some other cases what if you look at the conditions that we do not design like a vertical wall unless this is smaller bridge, generally have to construct the width having the side flank.

So we always design the spill through the abutment conditions or the abutment with wing walls. So when you constructed that, as you can understand it the flow stream lines, the vortex strength will be much lesser than the vertical walls. That is the reason the scour depth will be the lesser; that means if you look at the abutment shape, if it is a vertical wall and the spill through abutment, they are almost 45% reductions in the scour depth.

This is the multiplications constant. That is what is the multiples constant 0.55 to the K1 is it. So, most of the times unless otherwise we have a small river we have a vertical wall abutment or most of the times we create embankment which will be spilled through abutment. That is the reasons there is a reduction of the scour depth. That is the advantage what we get it when you design a spill through abutment.

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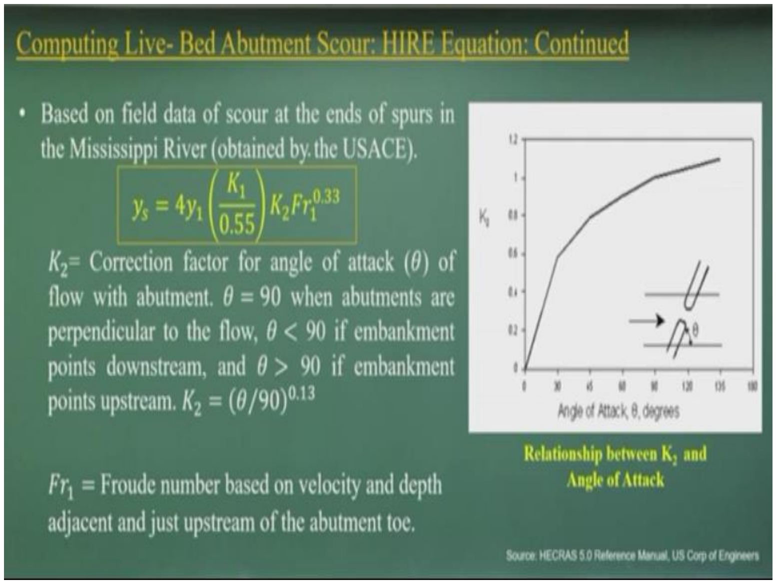

Now if you talk about the angles, so if you look it, this is a flow passing through like this and this is the abutment is making the angle theta. As when the theta becomes 90 degree, it is just perpendicular to the flow, when theta equal to 90 degree, so angle of attack will be abutments or perpendicular to the flow. So that the; conditions we generally accept it, but we do not know the flow behaviors.

Most of the times we cannot have the perpendicular, but as a designer we try to make it as close to the perpendiculars. If you have 90 degree, then your K2 value comes to close to the 1. That means this equation is normalized to the conditions when you have a perpendicular to the angle of attack is equal to 90 degree and flow is perpendicular to these conditions, but if you have a theta equal to beyond to 90 degree, that is the conditions you will have more the scour.

The less 90 degree you will have the less scour. That is what you can look it. Just try to understand that as we are changing the angle of attack and how the scour is having a multiplications factor, which is plotted here. So, beyond 90 degree, this factor is more than one values other than it is a less than one value. That is always the reductions of the scour depth. That is what it happens. So you can see it, how to compute the K2 value.

When theta is greater than 90, you can apply these equations and you can get the K2 value or from the graph you can get the K2 value. So we know this K1, you know this K2 and y1, Fr1, I can easily compute it, what will be the scour depth, but try to understand it these are data driven methods. Considering the Mississippi river data, they establish a non-dimensional number relationship and that non-dimensional relationship having a functions with upstream flow depth, upstream flow Froude numbers and the K1 K2, which depends upon angle of attack and the shape of abutment. You try to understand these empirical equations, which is very interesting to know it, how those scour phase happens it.

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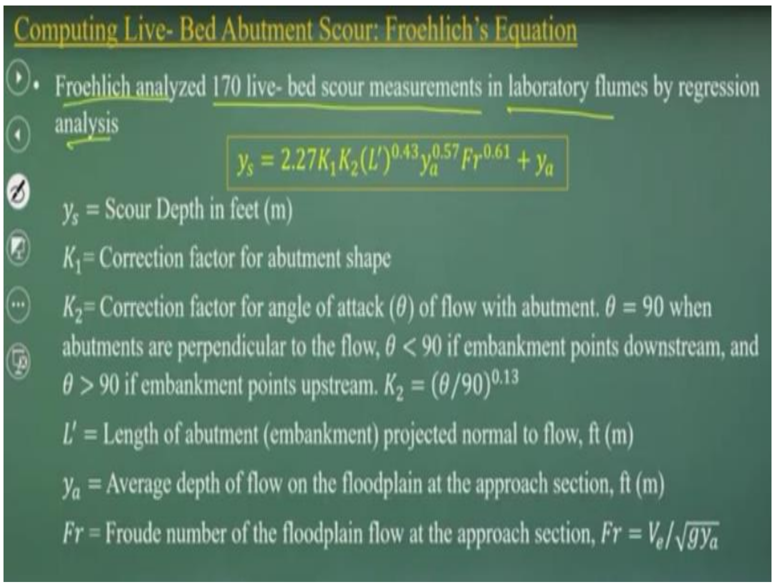

Now if you look at the live bed scour measurements, that means the river at the live condition the sediments transports are happening it, in that case the 170 live bed scour measurements is done in the laboratory flumes, which with regressions analysis, analyzed it and established the relationship between the scour depth, upstream flow depth and ya and K1 K2. So for the live bed scour measurement, which is obtained from the laboratory from analysis followed by the regressions analysis, it establish the scour depth is a relationship with K1 K2.

Already we have discussed what is the K1 and K2 and it is L', y1 and the flow Froude numbers. So the corresponding factor of angle of attack, already we discussed about that. The length of abutment this L' stands for, which is projected normal to the flow. It can have a unit of feet or the meter. Average y_a is average the flow depth on the flood plain at the approaching section.

Froude numbers flood plain at the approach structure, so that is what is you can look it the flow velocities and all. So, if you look at the strength of these equations, again it is a laboratory flume experimental data established by dimensional analysis, but it is not a non-dimensional equation, but its looks like non-dimensional form also. It can be done it. So it looks like a non-dimensional form of regressions and that is what we give it.

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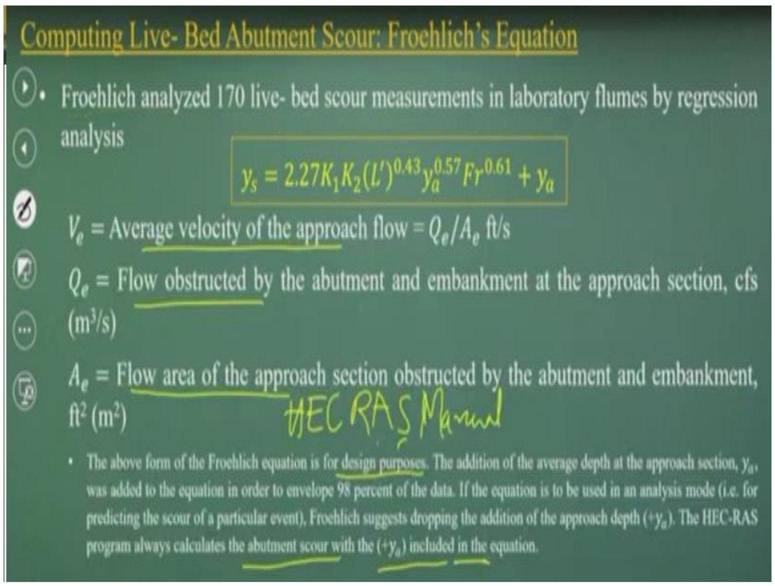

And this is what like how to compute the average and the flow approach and there are the notations is that what we should do it, when you have to use for the design purpose, which is there in HECRAS manual 5. So that is what we will give it that it calculate the abutment scours with including ya. That is what HECRAS manual says that when you interpreted the scour depth using the HECRAS models, you can know it what does it compute?

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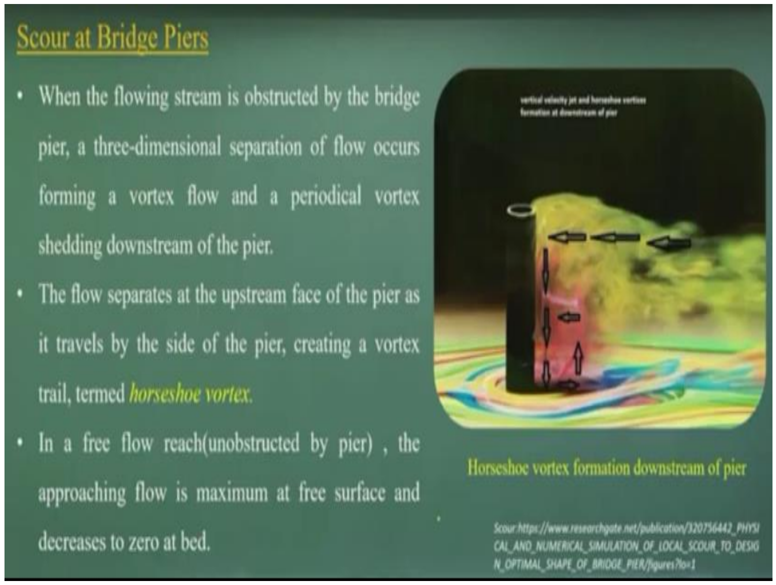

That is what is representing here and let me come into the next part very interesting to look at what the flow behaviors at bridge piers. So if you look at that part, it is quite interesting now. That is nowadays is possible to do with a very, very precise experiments in the fluid mechanics. Try to know this flow structures what it happens, when you have a bridge pier. That is what if you have a bridge pier and if you look at that downward flow things are happening, creating the vortex patterns.

See you can know it how this the scouring patterns and all the things very interesting experiment nowadays can be done at very advanced level of fluid mechanics experiment. To know it very, very microscopic scale, how this turbulence happening it, how the vortex formations are happening as a horseshoe vortex as the wake part is permitted. That is what, today it is possible to do this type of high end experiment to know the velocity, vertical velocity jet.

That is what is happening it here and the formations of horseshoe vortex. That is the recent publications what you are showing it. So if you look at that, again I talk about the horseshoe vortex and it is a three dimensional flow separations happen and forming a vortex flow there will be a periodical vortex shedding happens. It is vortex shedding also process happenings. So flow separations, vortex flow as well as the periodically vortex shedding downstream happens.

So that is the reasons it is very complex. Now as we discussed in flow through the abutment, the same conditions happens in when you have a flow and try to look at the hydrodynamic behaviors, which indicates for us 3 dimensional flow separations, vortex flow and also the periodically vortex downstream. That is what it happens it. It is very complex process and as I said it nowadays we can do quantification. It is not a big issue.

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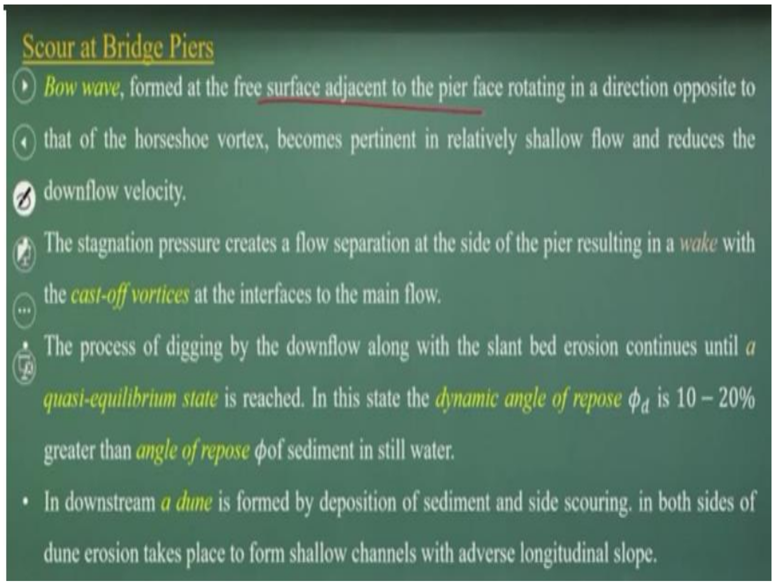

When you have this bow wave formations happens at the free surface adjacent to the pier surface is rotating in a directions opposite that to horseshoe vortex. It is pertinent in a relatively shallow flow reduce the downward velocity. So you can have a bow wave. Similar way, you will have a stagnation pressure that is what will happen flow separate the site of the pier and the wake what is formations happen is cast off the vortices at the interface of the main flow.

Because of that, digging process start, the removal of the bed material started and it continues till a quasi-equilibrium state it happens. The strength of the vortex is or the bed shear states acting after the scour, it will not have that much of strength to take out the bed materials and that is the position we will have the quasi bed equilibrium state. That means during this state, the dynamic angle of repose we call about dynamic angle of repose, which is almost 10 to 20% higher than the angle of repose.

So that means, when you have this horseshoe vortex formations and all the things, it creates a dynamic angle of repose, which is 10 to 20% higher than the angle of repose. You try to understand it that when there is a formations of vortex and that what is the supplement the additional forces, so that the dynamic angle of repose is 10 to 20% higher than the angle of repose of the sediment in still water.

Downstream, there will be dune formations will appear, which is your depositions of a sediment material and side scouring whatever the sedimentary material is covered at the local of the bridge pier, that is what will be deposited as a dune formations and side scoring some performances and that what in very interesting figures what we will show to you.

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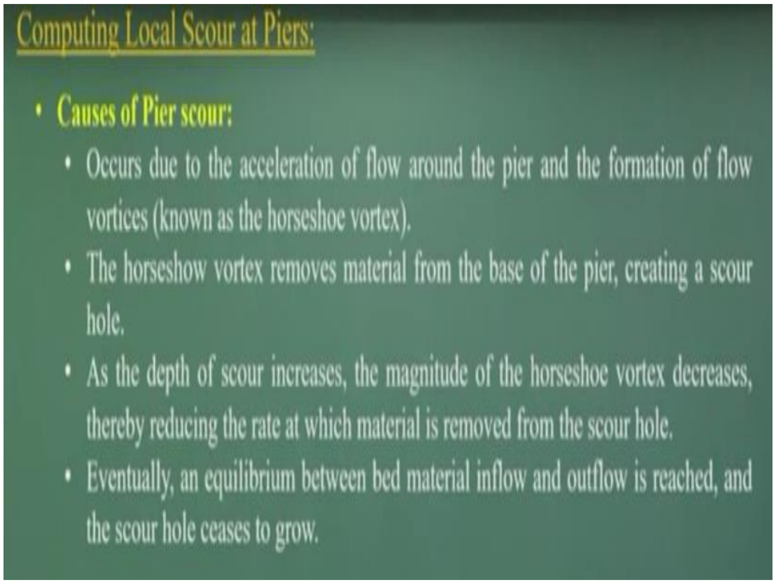

Later on we will show you to that and if you look at that.

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The basic concept if you look it, if this experiment setups which is the part of IIT Guwahati experiment setup, if you look at the snap shot of bridge pier just instead. This is what the bridge pier is and if you look at the scour depth, you can see these scour depth formations and also you can see the deposition formations, formations of dune. Also we can see that from the downstream and the upstream view, we can see that the flume you can see this experiment before scour formations and after scour formations.

If you can look it, the scour formations, how it happened, if this is considered a circular bridge pier and try to do it and look at the scour hole and the depositions pattern. More interestingly you just look it, 3 dimensional plot.

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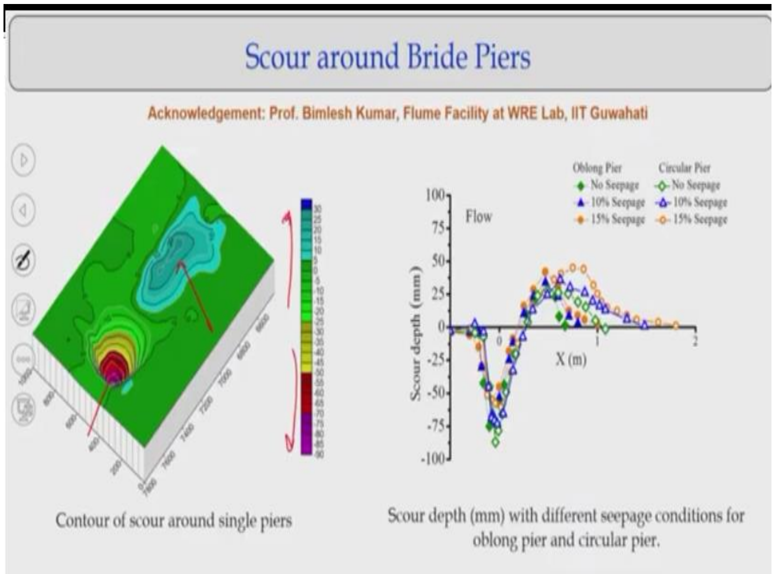

The scour depth, you can see it the scour depth formations and the depositions. It is a contour lines. It is a clear cut indicating that the negative is indicating the scour depth formations and positive is indicating is a depositions and if you take a profiles, so it will have a profile like this. It is very interesting; a profile like this. There are the conditions of seepage and no seepage. We are not discussing that, but mostly it will have a scour depth and followed by the depositions.

That is what is showing it, the scour depth and the depositions because of bridge piers, which we conducted the experiment as a part of the PhD thesis and we can try to know it, how does the scour depth is happening, how the deposition is happening it.

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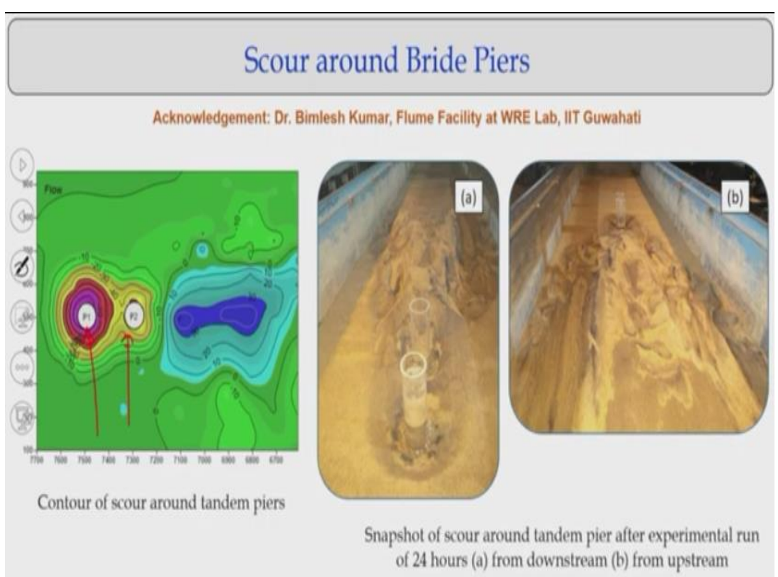

Now the same experiment, if you look at more details with two piers, P1 and P2. So many of the times you have the highway constructions which is much more two lane roads or the more than two lane roads. So we cannot have a one pier. You can have a consecutively two piers. So if you have a consecutively two piers, because two piers will have the distance apart from that. How do they affect it and if you look at this two pier conditions and the scour hole, the first one is generated, second two are also nearby.

If you look at the scour part and also the depositions because of these two conjugative piers are there and how it is affecting both the upstream and the downstream looks. So what I need to tell it that many things we can study if you have the laboratory setups, conduct a simple scour experiment with the bridge piers and you can try to know it how the scour depth formations happens because of one pier or the multiple piers. That is what we can do it.

It is not that difficult task. We can always do it and know it the scour hole formations and all. So basically what I want to try to do it that when you talk about the affecting depth of the local scour at the bridge piers.

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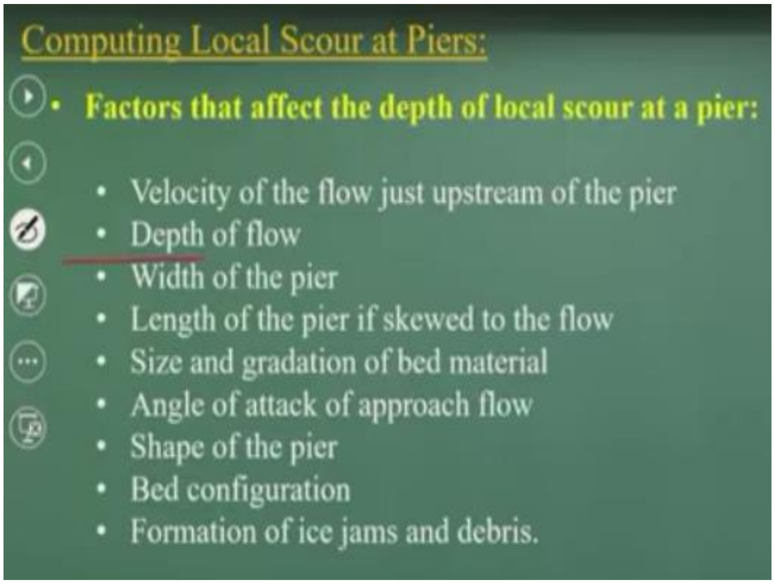

It depends upon the velocity, flow depth which indirectly represents of the horseshoe vortex, strength and wake vortex strength. So indirectly from the flow Froude numbers, the velocity depth, this is the information about the width and the sides and these are all depends upon the shape of bridge piers, bed configurations, whether the dune or this and nowadays also we talk about that because of presence of debris. This is what partly the research is going on.

So if you look at that, these are the controlling factors of those locals scours. Flow characteristics, the bridge pier characteristics and the bed material characteristics, that is what are bed configurations is. What types of beds are there?

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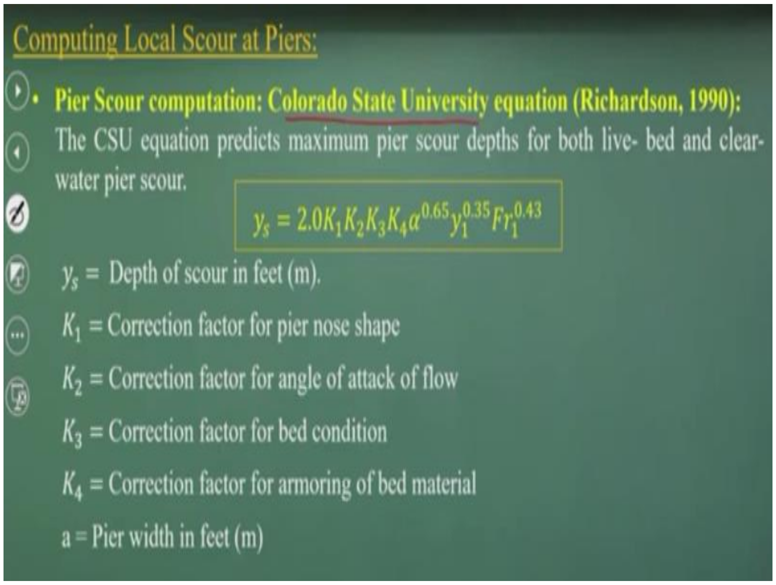

So if you look it that way and that is what is the equations developed by Colorado State University equations, which is Richardson 1990, which developed the maximum scour depth for both live bed, clear water pier scour. This is all experimental. Now if you look at these interesting scour depth equations, maximum scour depth equations which is functions of 2. K1 K2 K3 K4 a to the power 0.65 upstream flow depth, upstream flow Froude number.

Now we can locate this non-dimensional form of equations are giving a correction factors, because of like K1 start for pier nose shape, K2 stands for angle of attack. These are correction factors. It can have 1 or more than 1 or less than 1. That is what we do it. If you consider the pier nose shape, it can be more than one or less than one value. Similarly, correction factor for bed conditions, correction factor for armoring of bed materials, we will discuss more.

So how much of scour reductions are happening in it, because of the bed material as you know that it is always a mixed bed materials. It will have a different size of bed material mixture will be there. There will be formations of armoring. Because of that, the scour reduction is what had happened and then you have to have a bridge pier width, what we have.

As we discussed that the Colorado State University equations establish the scour depth in terms of flow upstream depth, flow Froude numbers, the width of the bridge pier plus there are four correction factors. First correction factor for the pier nose, K2 correction factor for angle of attack, K3 correction factor for bed conditions, K4 correction factor for the bed materials, that is what is indicate for us that how we can compute it the scour depth for bridge parts, which is a functions of flow depth, the bridge pier.

If you look at the scour depth equations is quite interesting equations as a non-dimensional equations formations after conducting a series of experiment in live bed conditions, clear water pier scour conditions and this equation if you look at that, it depends upon the flow characteristics as upstream flow and flow Froude numbers followed by the pier characteristics like the width of the piers, pier nose shape, angle of attack, layout of the piers and the riverbed conditions, armoring of bed materials.

These are the correction factors. As I said it, the correction factor can be more than one or the less than one or equal to one. So these are all K1, K2, K3, K4 are the correction factors and the y1, Fr1 is the flow characteristics and the pier width conditions.

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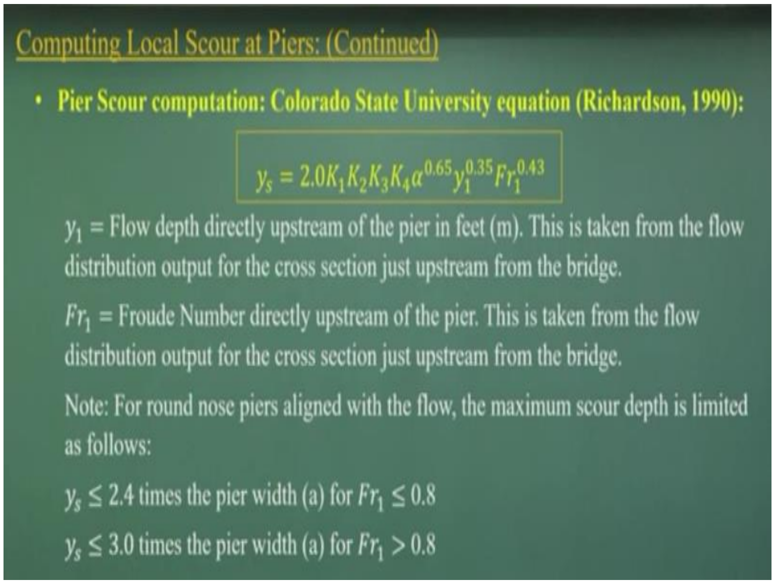

Now if you look at that more details which if you look at that y is the flow depth directly upstream of the piers and Fr1 is the flow Froude numbers upstream of the piers, but there is a limit of the maximum scour depth. That is what we have to consider it. When the flow Froude number less than equal to 0.8, it will be the scour depth will be 2.4 times of pier width. That means if you consider the pier width is 0.5 meter, so pier width is 0.5 meters, then you will have a 2.4 times of 0.5; that is maximum what will happen it as the maximum depth, when you have a flow that is subcritical and less than 1.8, but if you look at this 3 times happening when the flow is more than 8.

So that means if you flow Froude number is more than 0.8 that means coming closer to the flow Froude super critical flow. In that case, you will have the 3 times of the scour depth. See ys will be the 1.5 meters. So it is just an example what I am telling it. So you can see that what is the bridge pier width, it is not in terms of 0.5 meters, some bigger reverse you can have a 10 meter or 15 meters or more than that.

So if you look at that you can have a thumb rules to know it what could be the maximum scour depth. That is what we try to look it and maximum scour depth is the relationship from the data analysis they found it, it has a condition in terms of upstream flow Froude numbers is divided into 2 zones. The first zone is a scour depth is 2.4 times of the pier width; more than 0.8, it will have a 3 times of the pier width. That is the maximum scour depth what we get it.

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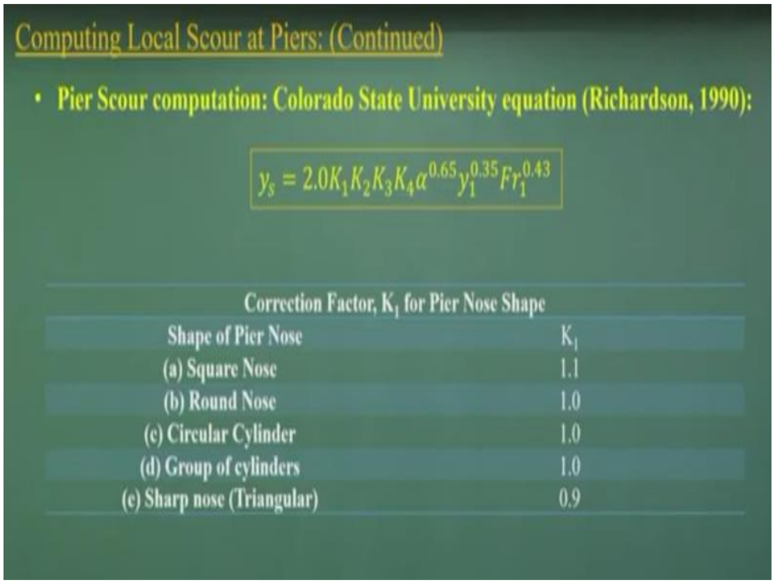

Now if you look at the corresponding factors, because of pier nose shape; so if you look at this pier nose shape means, very small channel of the rivers we have the circular pier, but many of the times you can have piers with nose shape, different nose shape. So you can have a square nose, which will have more scouring, but if I have a round nose circular cylinders or group of cylinders it is equal to one if you have a sharp nose of triangular, which is very difficult to construct it.

In that case, you will have a less than 10% scour depth. So this is the correction factors as I said it earlier is because of pier nose shape, what type of nose we have and what is the corresponding factor for that. That is what you can look it and basic common sense of the fluid properties, the streamlines behaviors we can understand it which will have a more, which one will you have a lesser scour depth.

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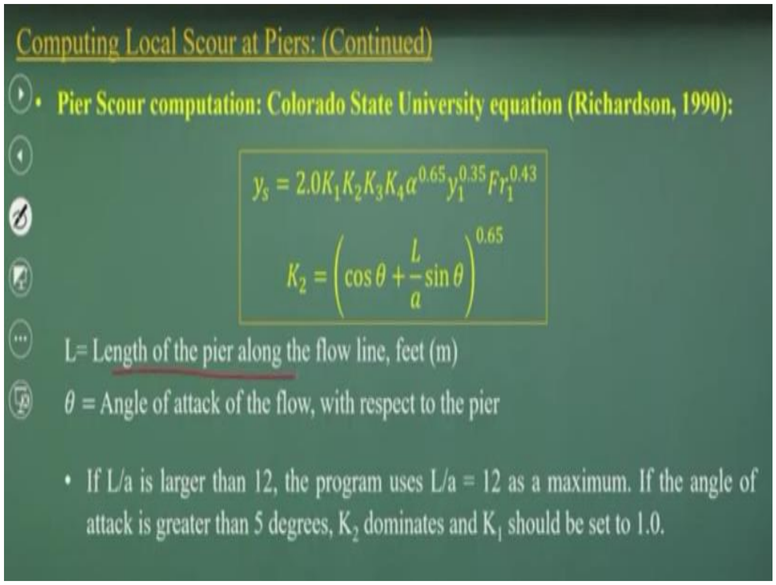

The same way if I look at the K2, the L stands the length of piers along the flow lines, theta is angle of attack and that is what is a sinΘ and cosΘ, L/a is bridge pier. Whenever L/a is a lesser than 12, it is HECRAS models is L/a is a maximum and that the conditions it said it and if the K2 dominates it, K1 must be said to be 1 that the relationship between the K2 and K1 happens it when you have the different L and y conditions.

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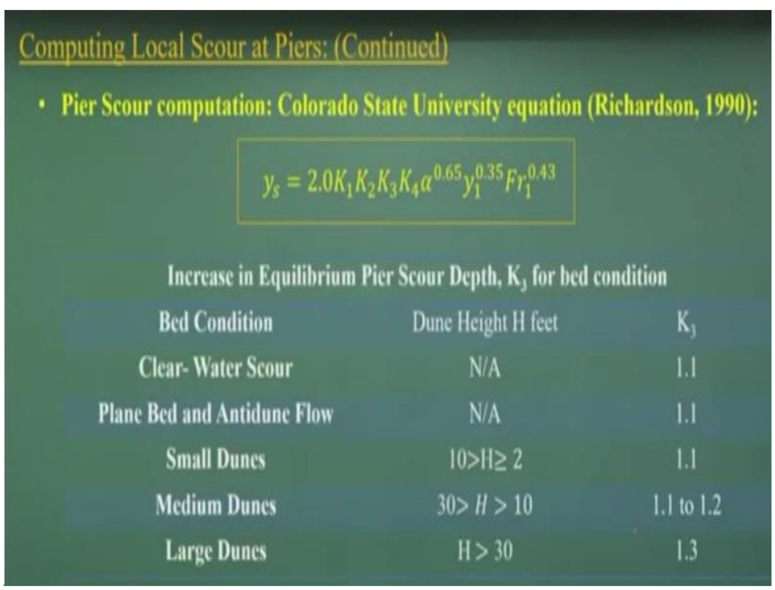

Now if you look it, next part is bed conditions. Bed can have different conditions. For example, it can have a clear water, that means bed is not like mobile conditions. You can have plane bed or anti-dune formations, you have a dune formation. The bed can have a dune formation. When you have the small dunes and all, so you have the correction factor 1.1 goes to the 1.3. So the correction factors will go as 1.1 to 1.3 depending upon the river bed conditions.

As you know it, the river can have the dunes formations, can have a smaller dunes and larger dunes. If I have a larger dune height is more than 30 feet, then you will have a correction factor is 1.3. If it is a 30 to 10 and that the conditions you have a correction to 1.1 to 1.2 and less than 10 to 2, you will have a 1.1. So if you look at that when you have the river bed, the river bed dune formations as we discussed earlier it can make as a correction factors for river having more morphologically active, where the larger dune formations happens it. The scour depth can increase by 30%. That is the dune formations, the scour depth increase what we have to consider it.

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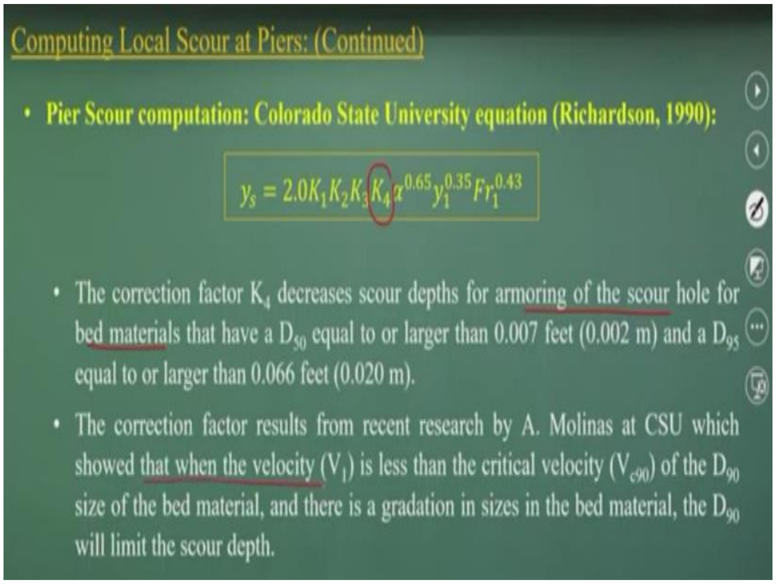

Now if you look it very interestingly if you look at another coefficients what is a K4 that because of armoring of the scour depth, scour holes. That is what we consider when you have the most of the rivers bed materials are not uniform. They are mixtures. There are the bigger size. There are the smaller size. They are the medium size. That is the reasons we have a particle size distribution curve.

Because of that armoring processes happens it and we should try to look it because of the armoring process you will have the reductions of the scour depth, that we will look it. Let me just sketch it more details.

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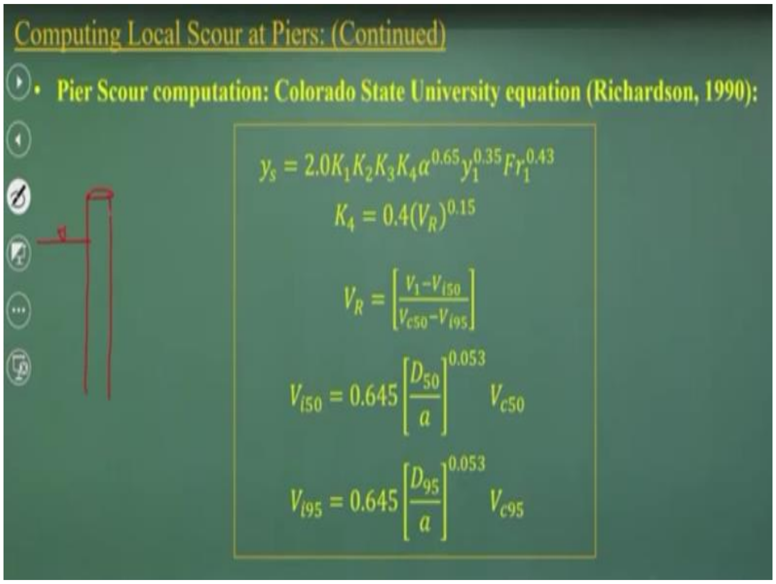

that you have a bridge pier and you have the flow and this is the bridge piers and initially when you have a bed you can have a bed materials of bigger size and also the smaller size, could be bigger size and could have the smaller size and if that is the conditions before scouring, before local scour formations, you can have a bed materials with composition of bigger size, mixed size, smaller size and medium size.

As you know that when you start the armoring process; starting off armoring process that means the smaller particles will be washed out or moved from this bed. As you know it, the smaller particles can easily be removed by the flow, because of higher bed space first, it will remove the smaller particles. The bigger particles which are having the gravity force is more, that is what will go over.

So what it actually happens is, as the flow process starts in a reverse, at first the finer materials are washed out. The bigger materials remain on the bed. This is the process we call this armoring. The same things also happen in case of scour formations. When you have the scour formations, if you look at, you will have a scour formation like this. This is the initial bed. So, you can see that bigger mud particle, the armoring particles will be here.

Because of that, there will be reductions of the scouring depth as compared to the uniform size. So we try to look the armoring things. These are also again it is experimental work. Try to look it how to consider the particle size distributions curve and try to know it, how can the effect of armoring we can consider during the scour formations. That is the idea. If you look at that, here all as empirical equations but it is a non-dimensional form of empirical equations.

The K4 depends upon the VR is a normalized velocities in terms of upstream velocity Vi50, Vc50, Vi90. You just look at the subscript. We will discuss more. The Vi50 and Vi95 have an empirical relationship with D50 from the particle size distribution curve, D95 from the particle size distribution curve, we can get it and they have the empirical equations like this. From this, we can find a non-dimensional VR value and that what will be used here to compute the K4. So now let us discuss what are they? If you look at these figures and try to understand it.

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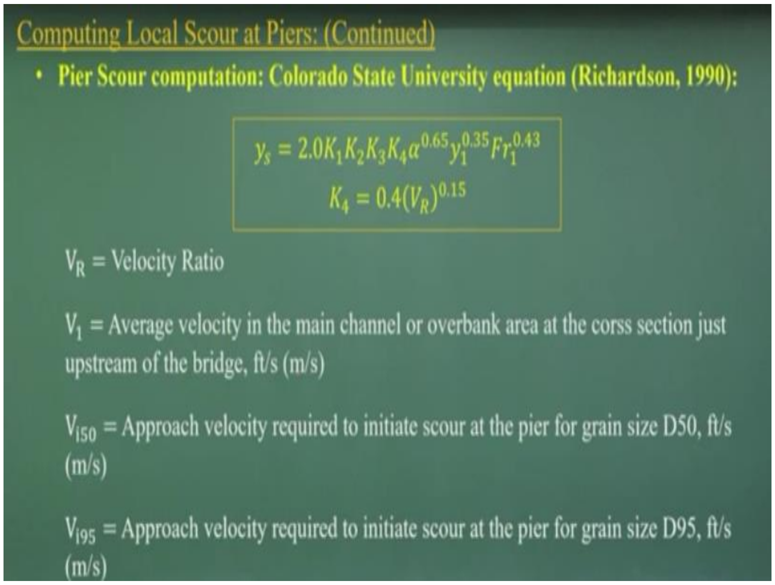

VR is a velocity ratio, as if you look at that. What is V1 is average velocity in the main channel or the overbank area depending upon the piers where it is the upstream of these bridge locations. That is what we can get it using the HECRAS models or you can do physical models. Vi90, 50 it is approach velocity required to initiate the scour at the grain size of D50. Again I want to repeat it. Vi50 is approach velocity required to initiate the scour at the pier for grain size D50.

Same way I can define Vi95 is an approach velocity, which is required to initiate the scour at the grain size of D95, so it consider the armoring process in terms of two representing grains, bed material characteristics; one is D50 another is D95. For that respective what could be the approach velocity to initiate the scour.

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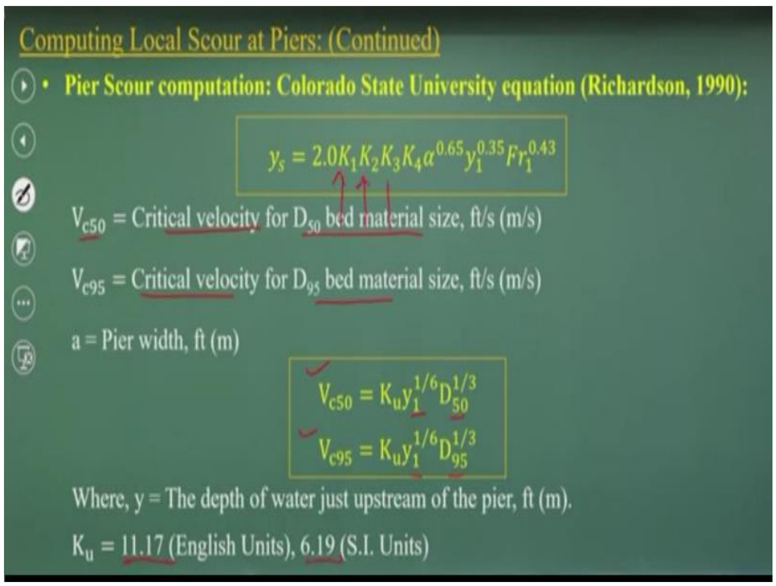

Same way, if you look at that Vc50 is a critical velocity from the sealed numbers or the relationship here. We can find out for D50 materials, you can have this and they have a relations with the D50 D90 upstream flow depth. So we can have a critical velocity, which is a function of D50 and D95 and it has a coefficient. Now if you try to understand it this equation is developed from Colorado State University equations.

There are a lot of experiment conducted and lot of data is analyzed it and mostly it is a data mining concept and to develop empirical equations or non-dimensional equations, taking care of all these flow characteristics, the armoring characteristics and the bed material characteristics. All they have considered as a correction factors to develop this scour depth. So that is a combination of experiment and the data mining concept to bring it empirical equations which can be used for designing the bridge pier. That is what it happens all over world, we use these equations to design the bridge piers.

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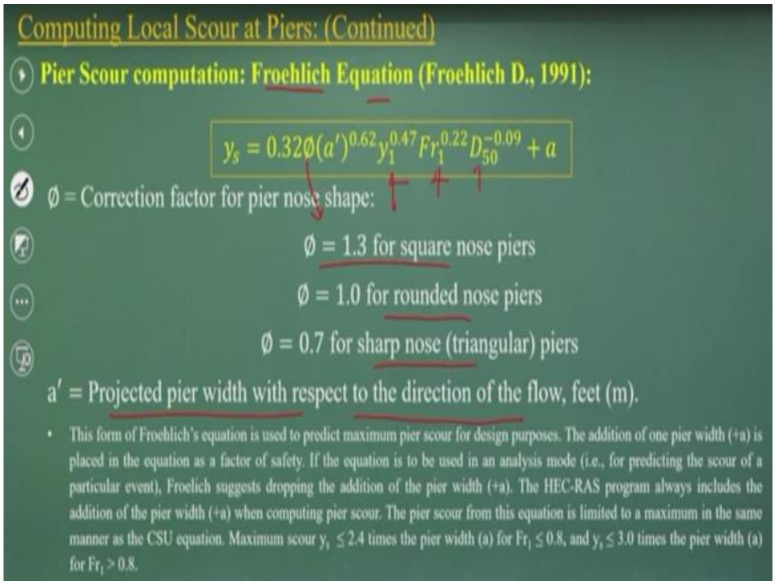

The same way Froehlich equation also developed in 1991. He has considered the ϕ value, which is a function of type of the nose of the bridge piers, which is a triangular, rounded or the square nose. That is the correction factor for that. Here this projector pier width with respect to dimension of feet and others you know it. This is again equations we got it from Froehlich D. developed thing scour depth. So that is the HECRAS program also allows you to do these things.

We can compute both the equations and try to find out which one is the maximum as it is a form of empirical equations, we also should have always a strategy to look it that which one predicting the maximum. As a hydraulic designer, we try to look at which protect the bridge you have to consider the maximum scour depth and try to correlate it with the field conditions.

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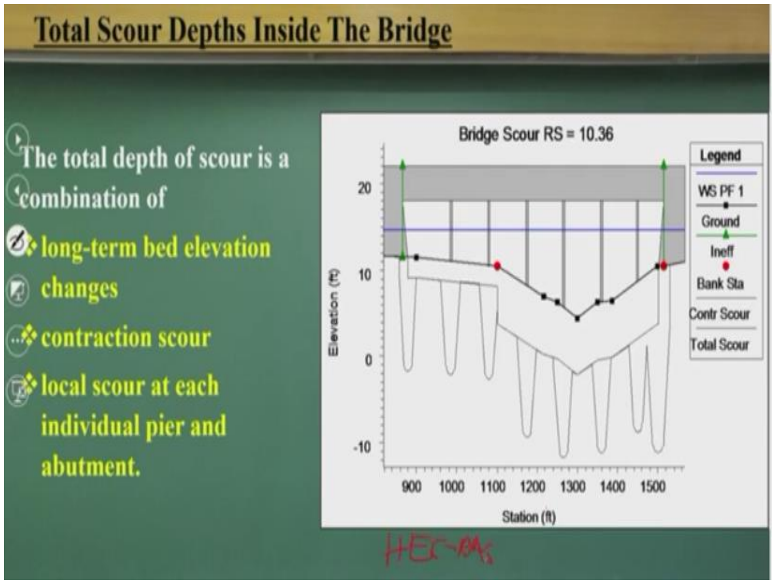

Now if you coming back to the bridge which is there in a HECRAS manual, if you look at that we need to compute total scour. So if you have a HECRAS model setups, you can see the scour depth. These are pier scour. This is because of piers. You have this abutments scour. This is the contraction scours and we can have also long terms bed level scours. So you can graphically, when you set up the HECRAS models, you can see the scour up due to the breeze, pier scour, abutment scours and the long term score.

This total will show us the total scours. These are combinations of contraction scour, the local scours and the long term scours. So if you look at these combinations and the graphically in a HECRAS model setups, you can look at what will be the scour depth and that is possible nowadays to model the bridge scour in HECRAS models, which is given very detailed in HECRAS 5 manual. You can go through it and it can have the scour compositions like this.

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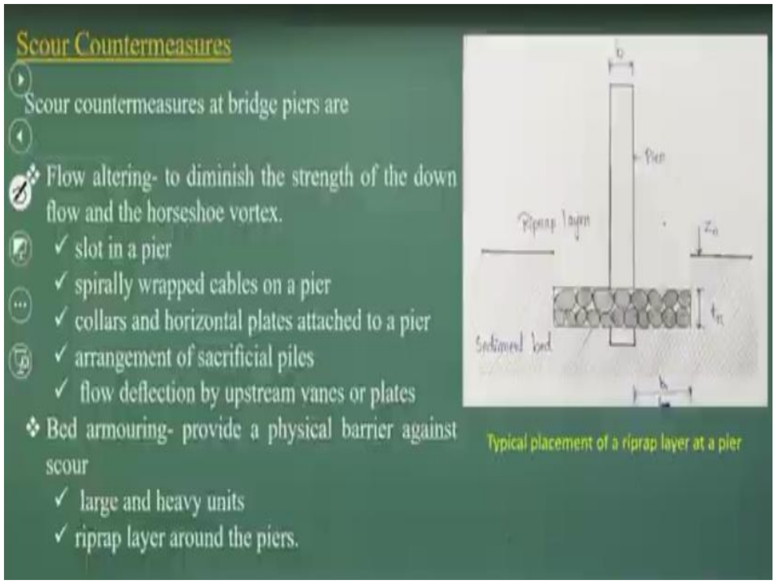

We also try to have an engineering skill to reduce the scour depth. That is what is called scour counter measures. That is what we can do it in two ways. The first one is reduce the strength of the vortex, the horseshoe vortex and the secondary vortex concept. If I can reduce the strength of the vortex, then it will have a scour depth recession or way to locate the strengthening the bed or armoring the bed. So we can have two ways. One is reduce the strength of the vortex.

That is what altering the flow mechanism near the bridge piers or we can locate the having a bed armoring or considering the riprap foundations we can reduce it. That is what we can do it, if you look at this case, you can have a bridge piers, you can have a riprap layers. As detailed design, they consider if is b is the width of the piers, br what could be the width of the riprap layers, t as the thickness and what could be the depth, we can put it this one.

In general, you are conducting experiments and the same conditions we look it when you consider the scour counter measures at the field levels. So there are the design guidelines to do this the riprap layers, how we have to do it as a design layers. To reduce the flow altering, we look it, we can have a slot on the piers; in generally we do not do it much. You can have a spirally wrapped cable.

That means many of the times they put in the cable formations, which can reduce the scour depth or you can have a flow reflections of upstream vanes or the plates. These are quite costly and many of the times, we do not follow these. Mostly, we follow bed armoring concept. That means we put the physical barrier against it. We put the heavy stones on the bed. I put the heavy stones and riprap layers around the piers and now the point is how to design it? As the US Corp of Army design guidelines mostly is a HEC-18.

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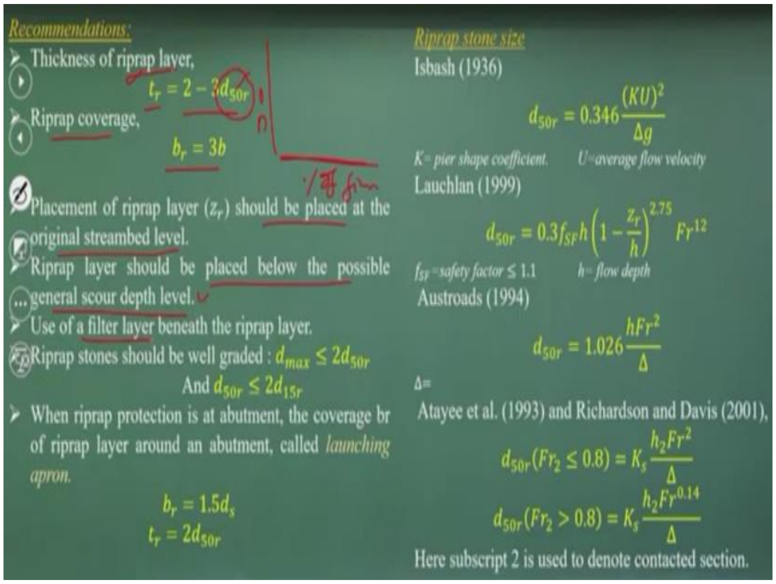

I have given the desired guideline in terms of computing thickness of riprap layer, which will be a function of d50 2-3 times of d50 value. So as particle size distributions scour, percentage of finer and the d size you can find the d50 or that is the d50, we consider it to find out what will be the tr, thickness of the riprap layers. Riprap coverage what could be the distance, into three times of width of the piers. So we have to provide three times width of the piers and the Zr to be placed at the original steam bed levels.

Ripraps should be placed below the possible, general scour depth so we should allow the riprap to have a general scour depth and many of the times, we use filter layers below the riprap layers as a geosynthetic materials. You can have the filter layers and should have a well graded, that means is the definition is given it the size of d_{max} and d50 with relations of other d50 value and all. The riprap protection also we do at the abutment as the launching approach.

Later I will show it more detail how the launching approach are there, which will be the br, the length of the launching approach and thickness of launching the apron in terms of the scour depth. This is in terms of d50 of bed material size and how to compute the d50, so that here is a relationship between the d50. If you look at that d50 will be functions of K is a pier shape coefficient, u stands for average flow and delta is the difference between the specific gravity – 1.

So most of the times, we use the stone as a riprap foundations. The specific gravity is assumed to be 2.65 and g is acceleration due to gravity. So we can compute it. The same way we can have a slightly difference by different methods, we can compute it what will be the d50r value with a different empirical equations or the design equations are available to compute the d50 values and once you know the D50 values, you can easily compute the thickness of the riprap, riprap coverage and the well grade conditions and the abutment conditions. These are the design guidelines, which is partly it is experimental data as well as it is data from the field levels.

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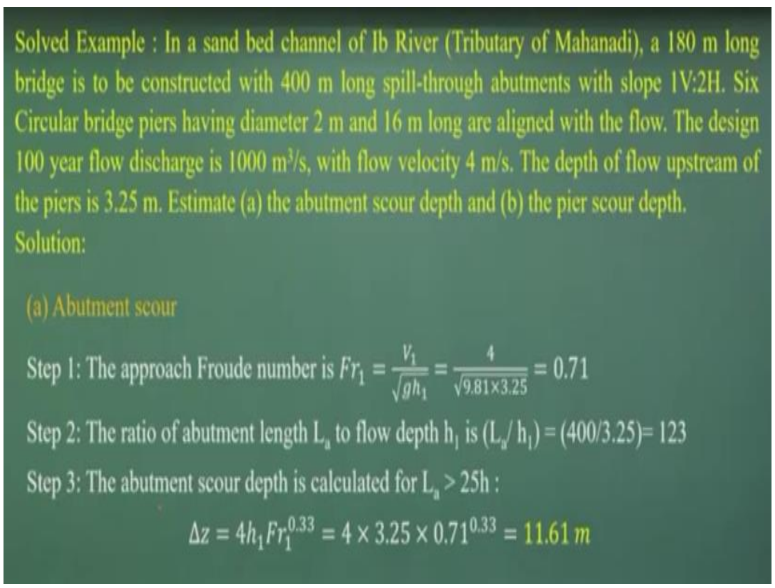

Now let us do a very simple problem to solve this. It is example problems. In a sand bed channel of river part of a tributary of Mahanadi rivers 180 meter long and 400 meters spill through abutment with a slope of one vertical two horizontal, 6 circular bridge piers having diameter of 2 meters, 16 meter long and the design flow of 100 years distance is 1000 meter cube per second, the flow velocity 4 meter per second and 3.2 meters depth of the flow of upstream.

Compute the abutments scour depth, pier scour depth. It is nothing else just compute the flow Froude numbers, apply the equations which is appropriate for us. So i do not want to take much time. So we can compute the upstream flow depth. You can find out the relationship between the abutment length and the flow depth and you can use the appropriate equations to compute it. The abutments scour depth will be 11.61 meters.

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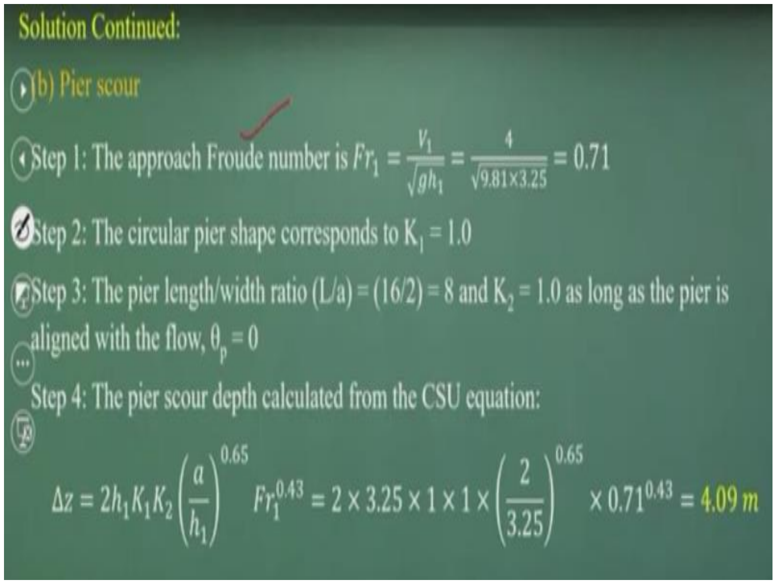

Next is the pier, similar way we can compute it approach flow Froude numbers, circular pairs, K1 consider it here. You can have L/a ratio. You can find out the K2 values and then you use the Colorado State of order equations and to finally compute it. It comes out to be 4 meters. So similar type of examples problems, we will give in the assignment you to solve or estimate the scour depth, because of contractions, because of abutment or because of bridge pier. These are the numerical examples.

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And this lecture I want to complete with a thanks to my student groups, whom we have been working continuously to prepare these PPTS compiling the data and end of the day you will say that very good quotation is that Do not treat a river as an amenity, it is a treasure and you should value for that. That is what Oliver Wendell Holmes states. With this, I would like to complete this lecture. Thank you.