River Engineering

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Lecture No -19
Riverbank Stabilization

Very good morning all of you for this course, river engineering and we are going to talk very interesting topic; river stabilizations looking this river erosion problems in Ganges, Brahmaputra and alluvial rivers. The bank erosions is a major problem in our country and looking that I will talk today how we can stabilize the river bank, that is the very interesting topic which is a part of my research study.

I will show some of the research study along with these lectures but let us try to understand it. What is a contributions of US army corps of engineers in the last 50 years in their experience on river stabilizations. That what today I will discuss it and I will try to make it to as much as possible to understand the mechanics behind them also there is a design guideline which is a partly embedded from the field experience.

There are the design guideline are there so I will talk about basic physics and basic river mechanics as well as I will talk about the design guidelines for river bank protections that were my objective today.

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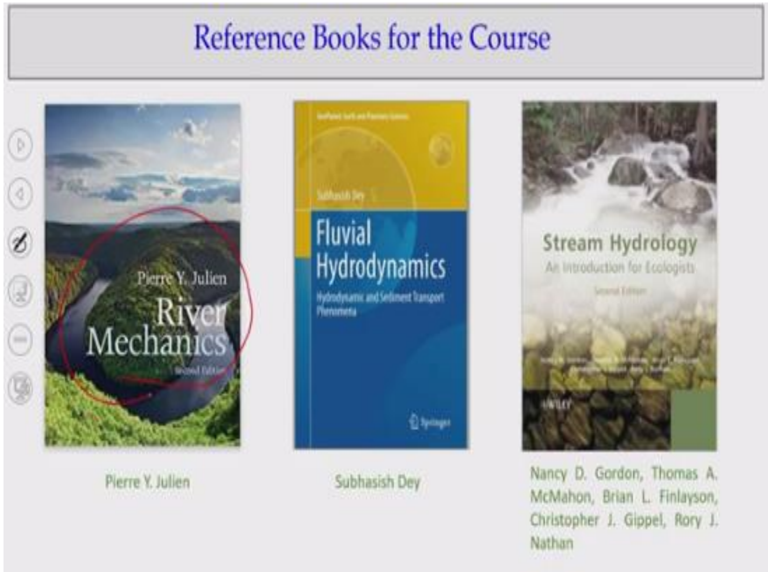

And if you look it this way and mostly we are following this book the river mechanics Pierre Julien books which is a very concise book on the river stabilization status and not only that other books are there just for the more reference for this.

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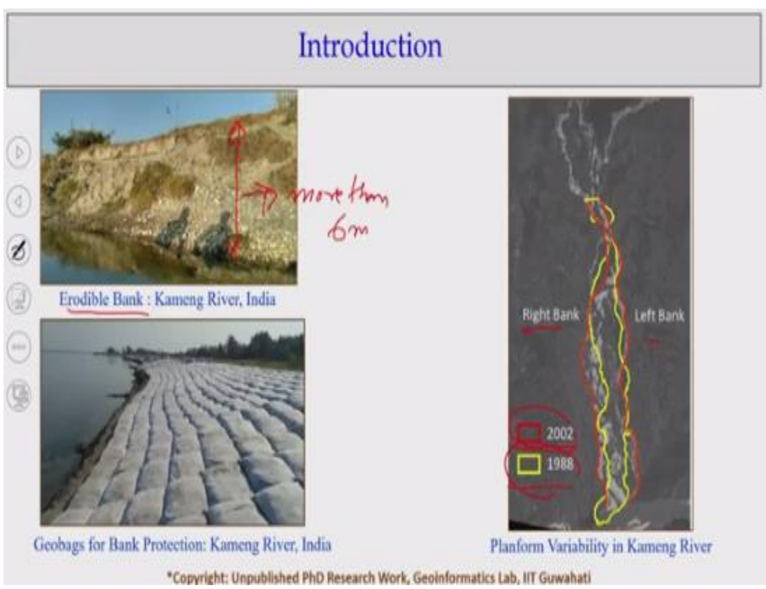

Look at the next part just if I give an introduction, see that how the plan form of the river varies it? It is quite confusing that you nowadays it is a quite easy to make the plan for availability of a river with different time span because you have we can get a satellite imageries which is almost free of cost. So if you look at the satellite imagery analysis of the Kameng river one of the tributary of Brahmaputra rivers.

And if you look at that how these bank lines migrations are happening it is the right bank, this is the left bank and you can see this 88 and 2002, how the bank line migrations are happening it? How the bank erosion process are happening it? Which is quite significant order; as compared to the worth level or so. And why it is happening it that if you look at the bank materials erodible bank materials, look at this the height of the river bank which could be a range of more than 6 meter. This is the height of bank, so we can see it that and some river protections like a geobags we have been doing it to protect the river banks.

So we have a lot of experience in the last 1 or 2 decades, how to protect the river banks of Brahmaputra rivers, Ganges and other alluvial rivers. So we try to have a understand it how we have to design the riverbank protections work as technical as possible. That is the idea today we will have a more discussions.

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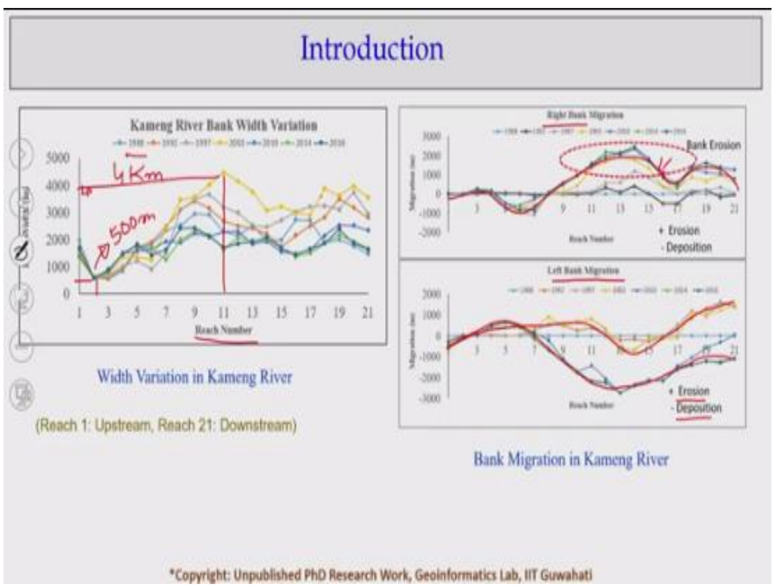

And if you look at the next slides it is a showing about in different year from 88 to 2016 is almost 18 years, how this river width is varies with reach numbers along the length? How it is varies it? You can see it, so each year there is variability in terms of width of the river. The width from the left bank to right banks, if you look at that width is considering some of the locations as high as it goes about 4 kilometers.

That is that is quite interesting if you look it and some of the cases it goes as lesser than 500 meters and this is what 4 kilometers, just try to understand it how river has so dynamic terms in terms of manifestations in terms of plan form variability. And if I look at the left bank and the right bank you can see the figures it is quite interesting shows the erosions and the depositions. The positive part is erosions the negative part is depositions.

If you look at the trend what is happening it there are the trends like this and there is a trend like this two process are happening it and that is what is reflecting on this. Where is if you look at the right bank most of the time this process goes like this. Why does it happen this? How can you protect the rivers bank? It is a quite challenging task to protect the river bank when you have a looking the satellite imagery just do the satellite data imagery analysis, you can see that how the erosions depositions patterns are changing it?

How this with a temporal domain, with a temporal domain how the erosions depositions are changing it and it is quite interesting for us can we protect the river banks for this type of so dynamic river bank erosion process are happening. It is a really a big technical challenge.

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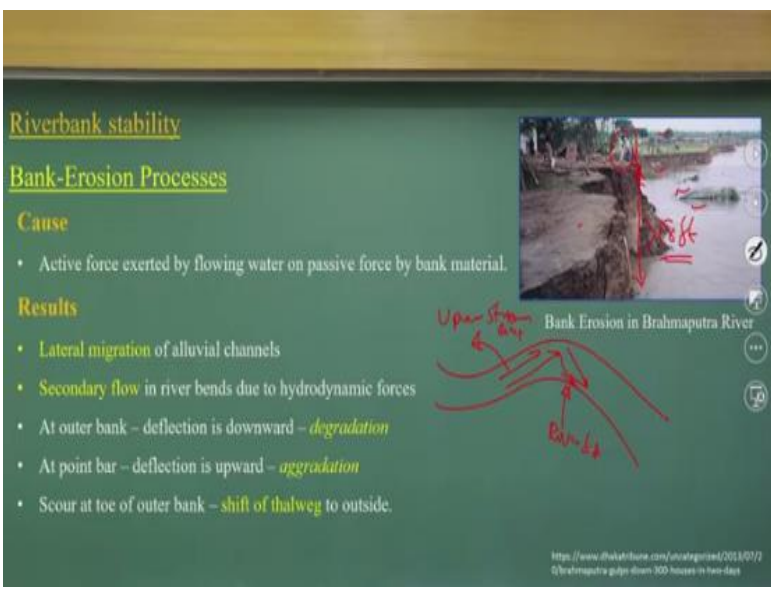

But let our knowledge can help us to make it appropriate riverbank. If you talk about bank erosions process, how it affects it if you look at any of the during the monsoon periods or the flood periods the bank erosions losing the land mass is a quite evitable like a river like

Brahmaputra river like Alluvial rivers these are quite every years we heard about that. But if you look at this bank erosion process which is a part of Brahmaputra river.

If you can see this height of these, if you just compare with this height of the man which will be about 6 feet and you can understand it this may be more than 18 feet. This height of the river bank is collapsing it you can see the collapsing river you can this. See, look this figures; it tells many story to us, how bank erosions process happens it? Just look it so it is will be more than 18 feet.

And that is what is under cutting of the rivers are happening it and this mass cantilever failures crackings even the trees are falling down its and if you look at this habitats these are quite, this is similar figures photographs you can see in many part of Brahmaputra basins and the Barack basins having the so high erosion threats happen it during the flood periods or the receding other flood periods.

Let us understand the process what is the process happen? See if you look at that the when you talk about a straight channels simplified as a rectangular channels and if h is a depth of the flow, we know it the average bed stress what is again working is ΩRS or ΩhS, S stands for here we can consider is a bed slope. So the mostly the Sh varies each the shear stress is increases. So that is what is a proportionality.

So we can say the shear stress acting on the bed is a proportional to the flow depth. Higher the flow depth more the shear stress acting on the bed or average shear stress. But if you look it try to look at how the shear stress distributions happens it you can get it the shear stress distribution, something like this, similar to this. That is what is the shear stress distribution ? So there are the shear stress acting because of the flow.

Because of turbulence behaviors we know it what will be the average applied forces per unit area that is what the shear stress acting it which is having proportional to the flow depth. As the higher return period about the flood comes it there is a more like to have a more shear stress there are more applied force per unit area acting on this. That what will try to erode the bed material and as well as bank material, that is very basic things.

So very basic things concept if you try to understand it as you would have a higher depth of the flow higher the applied shear stress acting on river bed and the river bank then it is going to erode the bed materials and also the bank materials that is what is happens it. But if you look at that one is the process is that how the bed shear stress and the bank shear stress acting on a straight rivers?

But many of the times you know it the river meanders it that means river have a the curvatures that is what it. So you have the river curvatures as you know it there will be the secondary current generations will happen it and because of that you can see that upper stream lines will act like this, where each the bottom stream lines will act like this. This is the upper stream lines and the bottom stream lines.

So that the process is happening it this is the upper stream line, this is bed river bed stream line. See, try to understand it, that is what it happens the secondary current formations. How does it affects to in terms of erosions? The outer banks is more vulnerable because of the this process what it happens it the secondary current.

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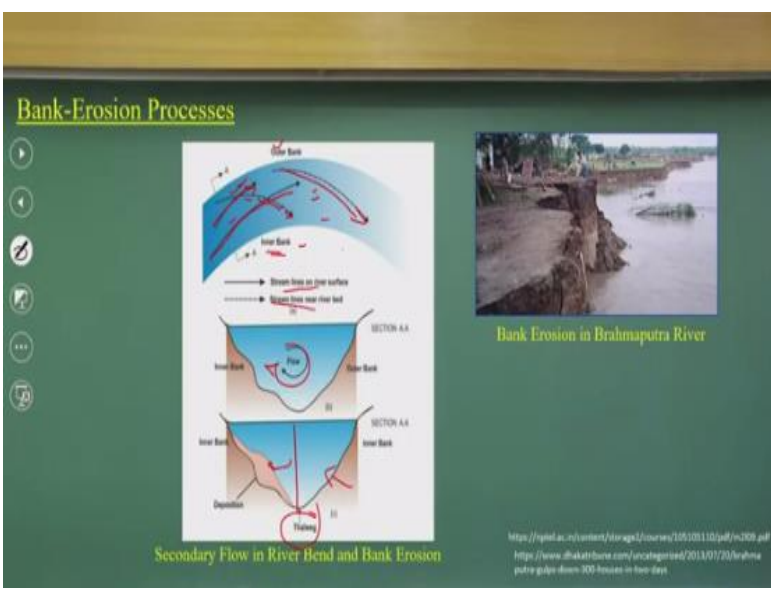

That is what you can look it from these figures, what it happens it? If you look at the outer stream lines, free surface stream lines and bed stream lines. So one is attacking this outer bank another is lowers the stream lines which are bringing the bed materials from outer bank to the inner bank, just try to understand it how it happens it. So if you look at this free stream lines are behaving like this and you have the bed line stream line which is working like this.

Because of that, there will be outer bank erosions and the inner bank depositions process that is what you can see in terms of the process what it happens it and the depositions here and erosions here. So you will have a outer bank and this is a line which called the Thalweg lines this is the line we call the Thalweg lines, how this depositions patterns are happening it and how this Thalweg lines shiftings are happening, because of this process.

So river banks are accelerated the bank erosions, at the outer bank also its facilitates to have a deposition in an inner bank. That is the reasons the point bar formations happens at the inner bank. So the strength of the secondary current the geometry of river bank in terms of radius of curvature, in terms of the flow depth, in terms of the width. Those are critical points for us to know it what is the strength of secondary current.

And because of that what is the patterns or the flow strength in terms of flow stream lines at the surface at the river bed level and how the erosions deposition process happens. So in case of river bend it matters for us to know it what is the strength of secondary current and what is the geometry of this river bank in terms of radius of curvatures in terms of width of the flow, in terms of the depth of the flow that is the matter us.

Because that is what initiate the bank erosion process the and erosions and deposits both the process are initiated because of this secondary current besides these applied shear stress acting on this bank.

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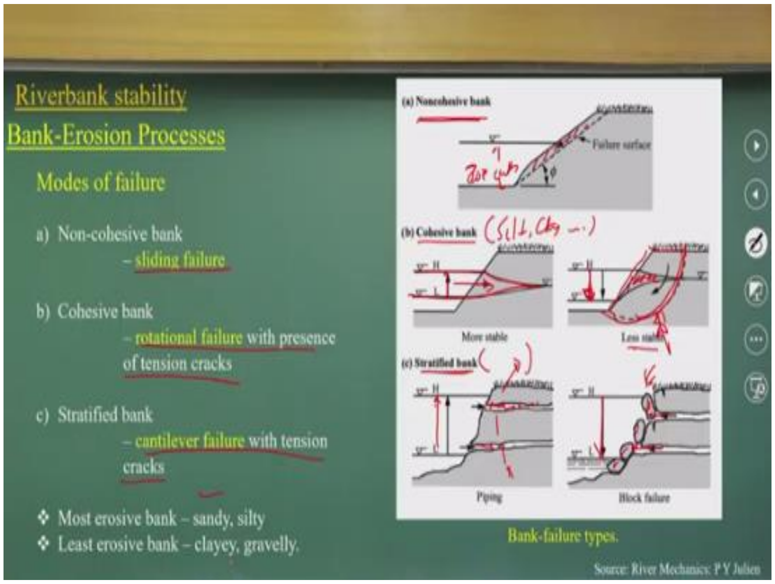

No doubt, let me go for the next level how the bank erosion process happens it is not the same things happens everywhere like some of the case you consider this non cohesive bank means there is not significant the cohesive strength on the bank materials that means as close to a sand materials, there is no cohesive strength. In that case if you have an angle of repose and because of higher the stress there will be toe cutting will be there.

Toe Cutting will be there, so the toe part you will be cutting and this will be as a slice it will slide down it because as soon as the angle is more than the angle of the repose than of the bank materials that is what the sliding will happen it for non cohesive banks. But please remember it in generally the river bank is not a non-cohesive nature, it is a combinations of the both that is the stratified bank.

Or you have the cohesive bank means you have a silt and the clay compositions along with the sand that is most of the times we see the rivers which will have a non cohesive natures where you will have a silt clay and some part of sand mixings that is what whenever you go to the river bank you can see like that. So if you look at that what it actually happens here when you have a low flow if you look at these figures, if you have a low flow like this.

As its goes to the high flow your ground waters tables will increase. The water will be go from the river to the bank; water will be shift to in to the river bank. But what it actually happens it when the plot receded when it goes back from high flow to the low flow this saturated mass additional mass strength is comes here as compared to the low flow earlier, so this is a saturated mass the soil mass.

Because of that it makes failure cycles and it has a rotational failures like landslide problems. So you try to now understand it bank and fail like landslide problems and that what is during the receding phase of the flood not the rising phase of the flood. Because when the flow depth is decreases in that period this process happens the saturated mass gives additional weight to this block and we have other as we know it for in landslide failure mechanisms exactly same things happens the less stables and the rotational failures happens.

You can do a geotechnical analysis to know it with how what type of geotechnical failure cycles, failure surface and all the things you can understand it. But some of the cases like alluvial rivers as we studied more detail for the Brahmaputra rivers will have a stratified layers. That means what we have you will have a compositions of clay sand, clay sand like this. So you will have some permeable may be sand filled with the clay layers then clay layers and then will be sand and clay layers.

These are general depositions of the alluvial rivers it can have a stratifications of the sand and the clay layers, if you have that case. That is what is in generally in alluvial rivers in our country we see this type of bank stratifications. There will be bank stratifications will be there, where do it happen it when the river plot comes it or the monsoonal flow increases the water shifts into inside these permeable layers.

Waters shifts into this permeable layer, as it shifts into the permeable layers as it recede it the waters comes back it because of that the you will have a the top surface cracking and you will have a the cantilever type of failure mechanisms will happen it and you will have a mass wasting like this. So try to understand it, there are 3 the bank characteristics how it controls the bank erosion process like non-cohesive banks which generally does not happen it.

Except some cases where the under cuttings will happen it and the non cohesive material like a sand there will have a failures surface the slicing failures will happen it. If you have a cohesive bank you will have the rotational cycle failures slip failures. That is what it happens in the as you do a embankment design and all you look at that the same concept what we have to look at how the failure mechanism happens it.

But we have to consider how the flow those variations are there from low flow to high flow high flow to the low flow. Similar way if you look at the stratified bank which more common in alluvial rivers like Ganga and Brahmaputra and that is what it happens it how the block failures are happens it. These are the process understanding we need to know it cantilever failures with a tension cracks, you will have a rotational failures with a pressure and tension cracks you will have a sliding failure.

That is what the basic failure mechanisms are happens and we should try to understand the failure mechanisms. Go to the field observe the bank erosion process and try to understand what type of mechanisms are happening at the field that is more important before stabilizing the rivers bank. That means you are strengthening the river bank by revetment or any process or you are modifying the hydrodynamic characteristic near the bank.

These are two process what you try to do it, but before implementing any river bank protection work we should visit the field try to understand what type of bank erosions process are happening it, which is more important before designing any river protection work.

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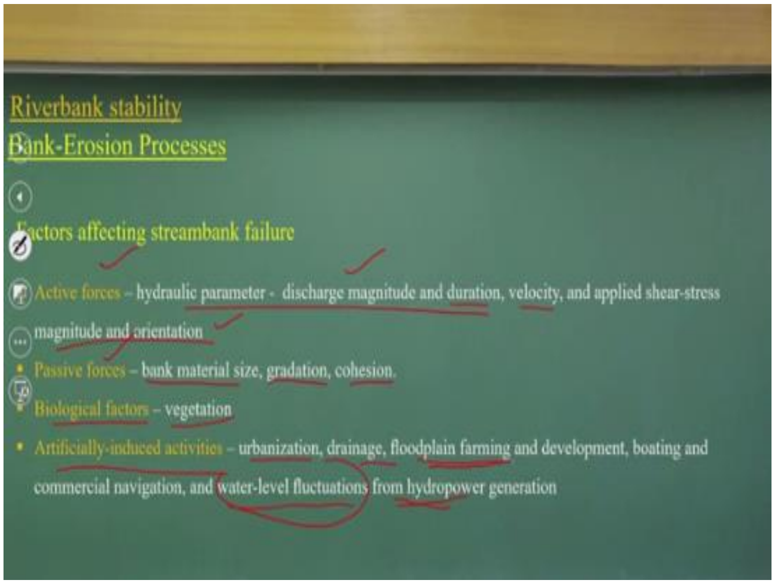

Now if you look it, the basically you can understand it what are the forces is acting it is very simple things; it is a flow parameters in terms of discharge magnitudes durations the velocity applies shear stress magnitudes and also orientation. Similar way we need to know it what type of bank materials are there; there are gradations, there are cohesions and biological factor like vegetations and artificials like urbanization, drainage floodplain farming development, water level fluctuations for the hydropower projects.

All we should try to understand it and try to incorporate it, why the bank erosion process has is accelerating. What are the reasons behind that? That is the needed to understand all these active forces, passive forces, biological factors and man-made or artificially induced activities like the water level fluctuations due to hydropower generations floodplain farming also. It happens it even if commercial navigations also play the roles for bank erosion process that all we try to understand it.

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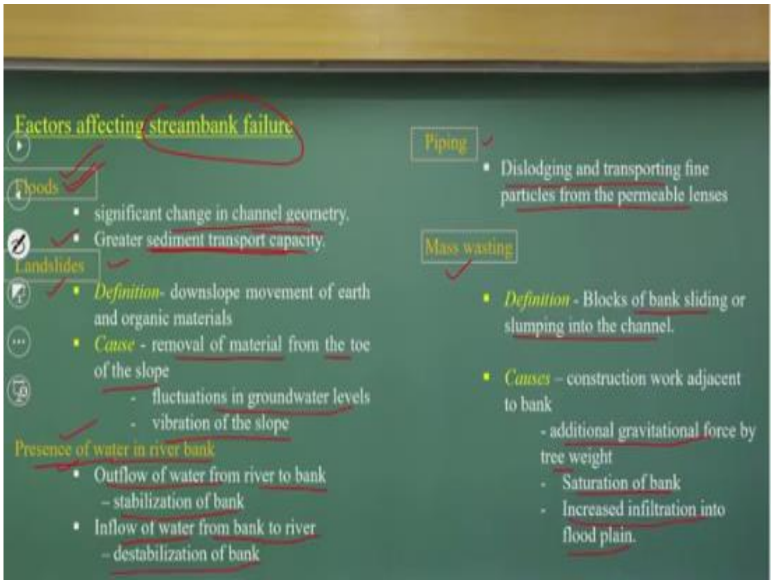

Now if you look it what are the factors affecting the streambank failure, as I discuss on the bank river bank processes is that significantly we should understand the floods, how significantly changing the channel geometry. We should understand the sediment transport capacity during the high flow events, that is the period will have the bank erosion rate will be much more higher rate.

So that is the reasons we should try to understand the flood characteristics which affects the channel geometry also make a edge higher order of sediment transport capacity. Then we should try to understand this landslide cases that small land clash type of failure mechanisms happen it on the river bank because of fluctuations of groundwater levels. The slope variations that may be the causes.

Because of earthquakes also can play the major role to triggers the landslides process at the river bank you can also understand the presence of water bank; water in the bank, that is what is outflow of water from the river to bank stabilization of the river. In flow of water from bank to the river that is what it destabilization of the bank. Just try to understand it as I explained earlier. And if you have a stratified bank there will be piping process which you will have remove the particles or dislodging and transporting the fine particles from the permeable lens.

That is what it happened the piping process, then you will have a mass wasting that means there will be a block of the banks sliding slumping into the rivers that is what it happens is and you also look at that additional structure the saturation process infiltrations all you try to understand it to know it how the bank erosion process are accelerated or dis-accelerated. Because of floods, landslide process, presence of water in river bank, piping, mass wasting. That the process and how we have a intervene all these things we should understand it.

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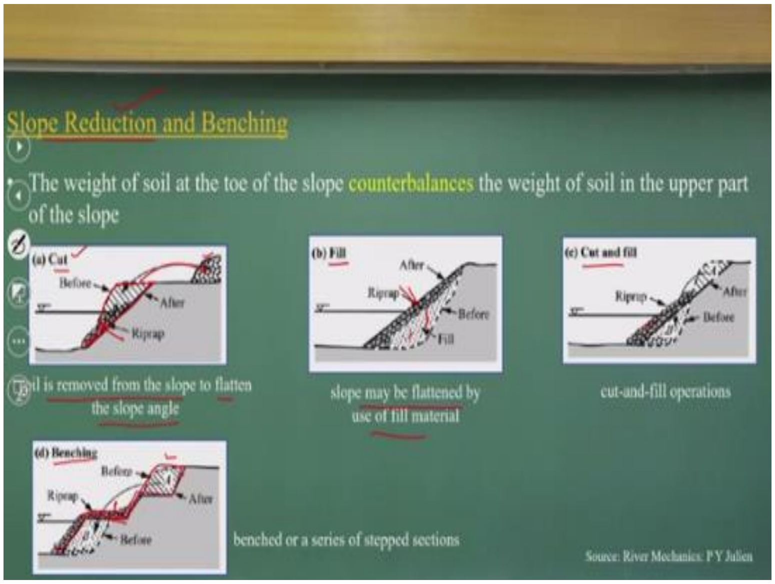

Now if you look at what very basic engineering things we can do it, the basically concept is saying that you change the slope. So make it the best slope, the reduce the slope. So that is what is called slope reductions benching process. It is very simple things like for example you can have the soil is removed from the soil slope flatten the slope angles. Basically you try to make a slope reduction method.

The bank slope you want to reduct it, so what you do it you just cut these materials and fill it here. This is earlier bank after cutting you reduce the slope. This bank material you cut it and dumped it here and you put the stone riprap or gabion mattress on this so that is what the cut is a very simple things. So same way you can reduce the slope of the bank flatting of the slope use of fill materials you are filling these materials after that top of that we have a stone riprap or you have a cut and fill.

So you can understand from before and after there will be partly cut partly fill up then you will have a stone ripraps or the Gabion mattress or any riprap concept we will see that nowadays geotextile riprap also we are doing for the smaller rivers. So basically to reduce the slope of the river bank which will be stable slope or you can have a benching process if you have a river is very wide or the depth of the flow is much larger you cannot do it cut and fill or the fill you can have a benching.

So that is will be the bench will be there, the cut and fill will be there before and after. After that the final shape of the rivers will come like this. This is a before and you are making this after concept like this. See if you look at that then you also have a stone riprap. So very basic things we can do slope reductions of the river bank using cut, fill, cut and fill or the benching process. You can visit any of the river bank you can see where river draining are there the most properly they use up only use this slop reductions methods which are very simple things to do it.

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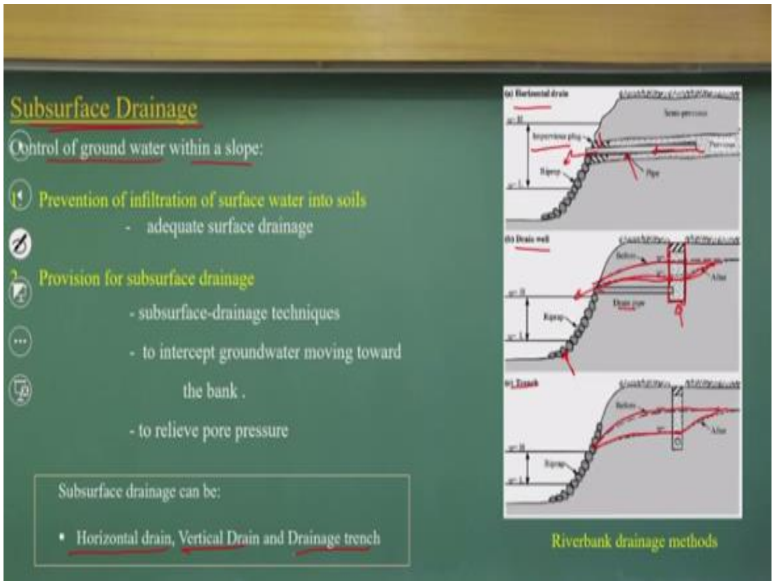

Now when you will do it as you know these groundwater fluctuations play the major roles for the two failures or the rotational failures. How we have to reduce the fluctuations of the groundwater tables that what we do it, you provide subsurface drainage; control the groundwater within this slope that is what we try to do. How do you to do it? If you look this figure you can understand it, is horizontal drain.

So we can have a drain will have a horizontal drains and we have a pervious materials, the permeable materials or maybe the sand and all and you can have a pipe arrangement and you will have a impervious plug here so that way water will shift through these ones and that what will reduce the fluctuations of groundwater tables. So this is the subsurface drainage systems with a horizontal drains.

So needs to do it, otherwise the groundwater fluctuations will be there or you can have a drain well. So we can have a drain well, so you can have this and you can see before ground water level like this because of this drain well the ground water tables decreases like this. Nowadays it can be done it many numerical software's are there, you can see that how much of effectiveness of this subsurface drainage that is what we can do it.

But, theoretically you can know it; it will happen like this. So we can have a drain pipe we can have a well to collect all these materials and that part will be water to put it and you will have a stone riprap or the gabion mattress. Same way, you can have a trench and you can see this ground water tables earlier and because of the trench the groundwater tables like this. So it has lot of change and basic your idea to protect it too with a riprap.

And, also reduce the rotational failures control the ground water table fluctuations or in the river bank, to do that we should provide the subsurface drainage; subsurface drainage along with river bank protections along with river break protections with having a horizontal drain, vertical drains or drain trench all the combinations we can look it which is a suitable for proper appropriate river locations and what is the ground water fluctuations are happening it.

And, we can geo-technically and hydraulically we should design it how the groundwater fluctuations will live there how we can have a two protections that is what we can do it.

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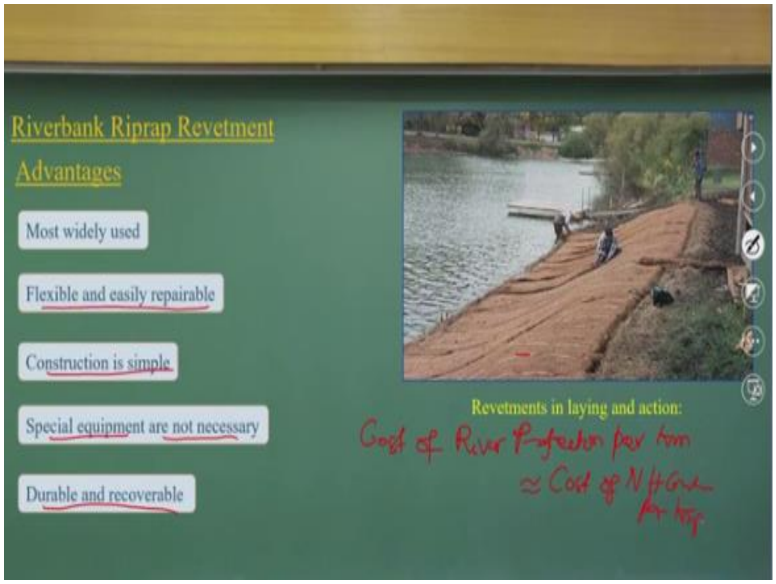

Now, if you look it at that when you talk about the river bank protections if you look at this is a simple textile based river mattress, textile mattress they are just this is small river they can put a textiles jute type of materials and can have a just protect over the bank with the filters and all. So there is not a single solution for the same river same type of river protection for all the rivers that is the reasons.

We should look at what are the advantage and disadvantage because it should be flexible, construction should be simple, special equipment are not necessary and durable and recoverable. It is basically any civil engineering concept we locate that we should have a locally available materials and constructions should be simple it is not be so expensive because we do in a very remote type non accessible point where the riverbank erosions are happening it.

So that is the basic idea should look it how the riverbank protections we can do it that is the point we should try to understand it because the cost of cost of river bank protections per kilometre is close to the cost of national highway construction per kilometres. So, please try to understand it the cost of product sense of the river banks is as much expensive of constructing a highways national highway per kilometres they are more or less same or many of the cases is much higher order of that.

So when you are trying to protect the river bank we should try to optimize everything in terms of material, in terms of constructions cost, in terms of this, otherwise cost of riverbank protections per kilometer is close to the cost of the national highway constructions per kilometre that is the point I want to highlight you that we should not take so lightly just dump the stones on the river bank and you feel that river will be protected by just dumping the stones that is not.

Because, U.S army corps of engineers they have done a very significant studies and remarkable success stories in rivers in the USA as particular to the Mississippi river. So, we should take the knowledge from them it is not that we are just to dumping the stones on the river bank to protect the bank that is not be the idea should to be a river engineers because it is a very expensive work because cost of the river protections per kilometre as is as close as to the cost of the highway constructions, national highway construction per kilometres.

That is the reasons, we should take the knowledge what we have from US army corps of engineers and because that successful stories and the local knowledge both we should in build it to make it a successful story for river bank protections or river stabilizations.

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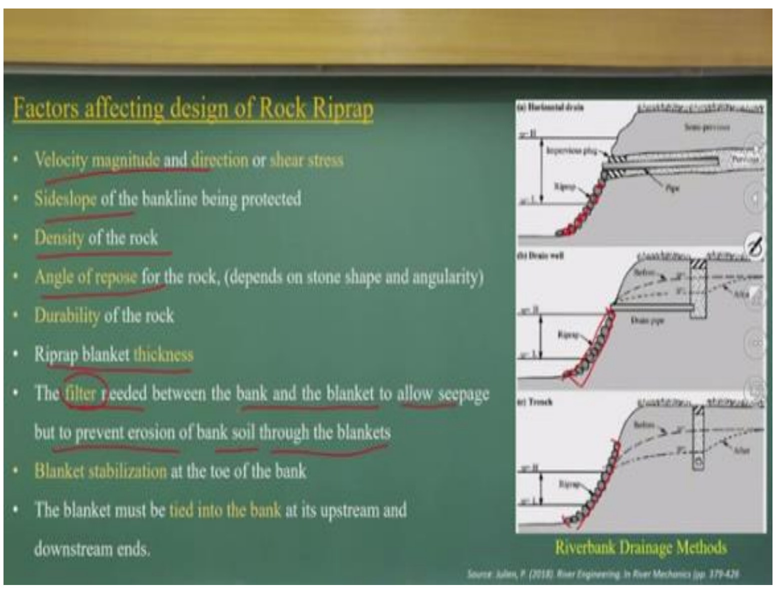

So, if you look at that there are points for the rock riprap type design, we all talk about protect the rock riprap or you put the stone gabions you put the any geo-textile mattresses, we should know it that what type of stone ripraps are coming it. It all depends upon velocity, side slope, density of the rock, angle of repose, riprap blanket thickness, you can know it you can have the geo or you can have the thickness they providing that this thickness those things you can consider it as a gabion mattress.

Filters should be provided between the bank and blanket to allow the seepage to prevent the erosion of bank soil through the bank blankets. River can this river plan can have a consider as a blankets with gabion mattress and all in that case we should provide the filters between the bank and blanket to allow the seepage go through that so it can reduce the seepage forces. Blanket must be tied into the bank add it in upstreams and downstream and I will show the photographs in the end of this presentations.

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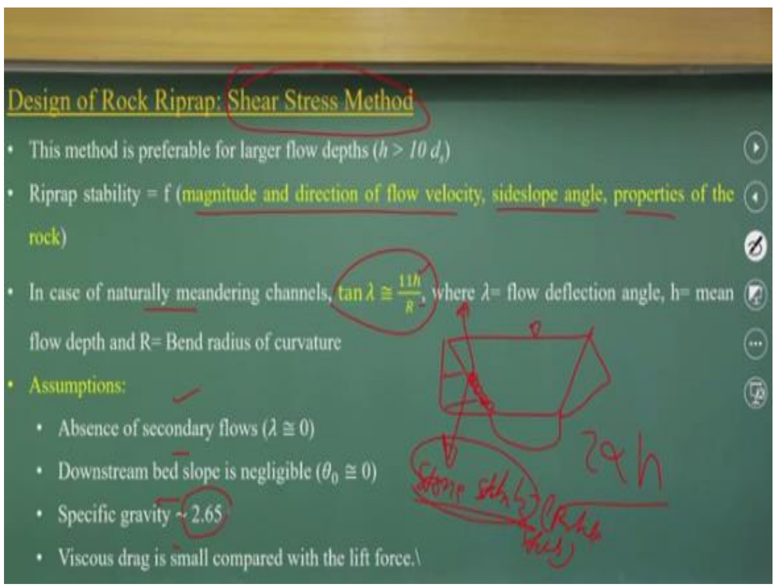

So, if you look at this what is actually happen see that how to design the rock stone riprap as I said it please do not put it the stone just on the river bank and it will have a without any engineering knowledge. Stone dumping on the river bank does not suffer stabilize the rivers or protect the river bank because we have to understand the physics behind that. That is what we should look at the shear stress methods.

We should look at the shear stress methods, again I am to sketch it if I have a river you have a flow depth if you are not considering this any bank of the river there will be shear stress distributions along this and this shear stress is a proportional to flow depth. So, we need to compute it if I am putting this river bank materials a stone riprap, I have to do particle stability analysis for this stone.

Whether these stones are stable with respect to the flow shear stress acting on this turbulent structures acting on these whether these particles stability or the stone stability we should look it. That is what is there the riprap stability depends upon the direction magnitude of the flow velocity, side slope angle, the properties of the rock, all the properties depends that is what the shear stress test methods gives us.

And, if you have a meander if you know it there will be deflections angles which is a function of 11 h by R h is the flow depth, R is a radius of curvatures for a natural meander you can additionally consider because of meandering what are the stability of these stone. Stone stability which earlier we define as a particle stability we should try to look it as a stone we have when you are dumping over these rivers during the extreme steam flow plot situation whether these stones are stables at that positions.

So we should do stone stability analysis as close as the particle stability analysis what we discussed earlier. So, if you look it that you can have a certain assumptions; the specific gravity of the stone 2.65 and you can show it downstream bed slope is negligible, absence of the secondary flow.

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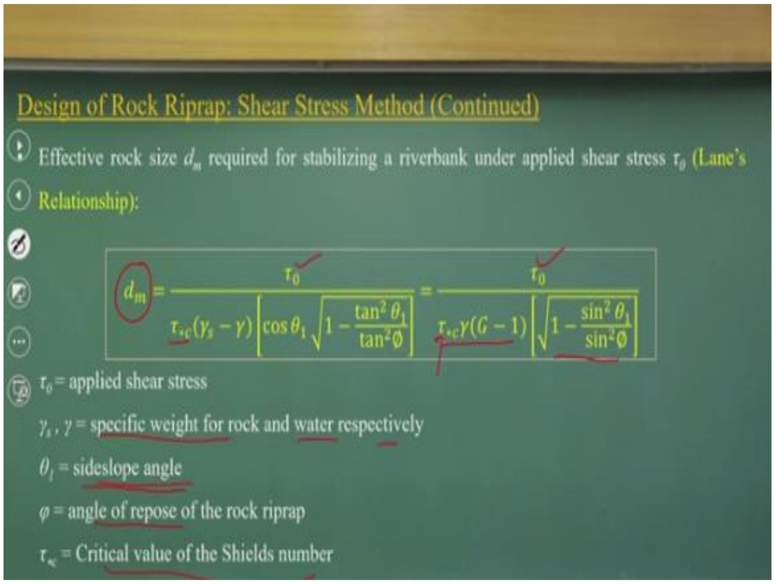

Now, if you look at the design of shear stress methods as I said it you can consider is a particle stability analysis as you are dumping the stones, as equivalent to bed material particle stability or bank material particle stability we can analyze it and find out the relationship between size of the bed particles or the bank particles in terms of a functions of theta y apply shear stress I discussed earlier you will have a shield shear stress that is what the critical value of the shield shear stress.

You have specific weight of the rock and water respectively and you have a angle of repose and side slope angles, these are functions already we derive in a particle stability analysis the same concept we can use it to compute what will be the dm size for that. That is what coming to a functions with a applied shear stress versus a functions of theta one is a side slope angles and the phi is the angle of repose and you also have critical value for shear stress for the shield numbers, that is what you already we discussed earlier.

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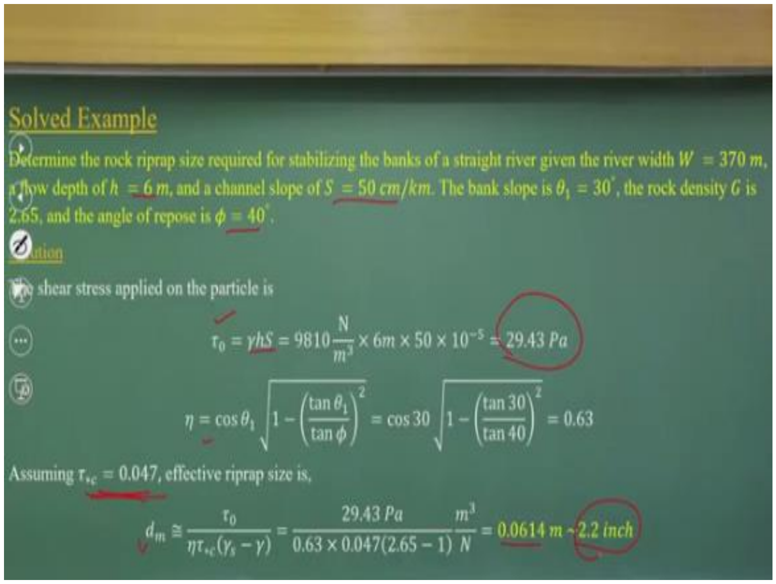

Now, if you look it with a very simple problems that determine the rock riprap size required for stabilizing the banks of a straight river given the river wheat is W is 370 meters, the flow depth is 6 meters, channel slope is 50 centimetre per kilometre, bank angle is 30 degree then density G is 2.65, angle repose is 40 degree. So simple cases you just use this compute the applied shear stress which is a functions of flow depth and the slope is given.

So, we can find out the shear stress what acting is close to the 30 Pascal and you can also compute it basically that component and finally you can compute it you can assume the critical shear stress value we already earlier discussed that we can consider critical shear stress is 0.047 and for that respectively you can substitute this value then you can compute it. It is necessary to have a 3 inch it is very smaller close to 2.2 inch depth of river bank protections what you need it.

And, that is what is a simple calculations we can do in Microsoft excel or anything you can try to understand it how what is the thickness of the bank materials stone riprap size is necessary, knowing this flow characteristics, bank slopes rock characteristics in terms of density the critical shear stress we can make it get it the value of what will be the thickness for stone riprap.

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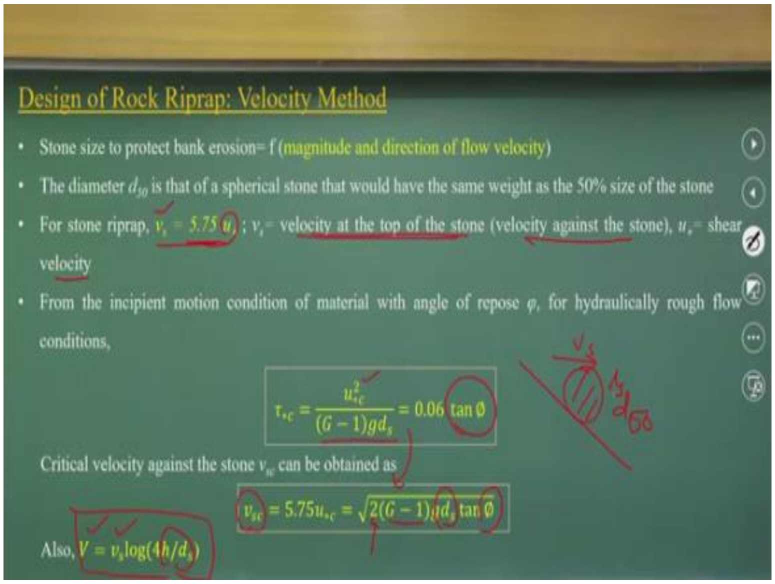

Now, if you look it there is another methods which call the velocity methods which is depends upon if I know the velocity of the flow we can know it or we could design you consider the design flow velocity then you can find out what could be the size of the deep amps of a stone riprap size. See, if you look it the concept is come in same way that if you consider a d50 value, so this having a d50, 50% finer particle size distributions.

If I know it diameter of that and if I consider if you look at that the velocity against the stone at the top of this, if I what should be the top of the velocity v s on the top that what can be written as a functions of shear velocity. We can write it this is empirically conducting a series of experiment it found that the for a stone riprap the velocity at the top of the stones is a simple functions of shear velocity.

Since, it is a shear velocity functions we know the relationship within the shear velocity and d s with the tanϕ we know it earlier, in terms of critical shear stress numbers. So we just substitute that then you can find out what will be velocity at top of the stone riprap in terms of functions of (2G – 1) d s and tanϕ, thus substituting these values we can understand it.

Now, we cannot compute is the v s value because we can know average velocity for a or we can design velocity maybe 3 m/s, may be 5 m/s, maybe 2 me/s or 10 m/s. So, we can have a design velocity but we cannot have a the exact value of the velocity at the top of the stone but again there is empirical relation the logarithmic relationship with flow velocity with respect to the velocity at the top of the stones and relative submergence h/ds, h_f, d_s values, so that the empirical relation.

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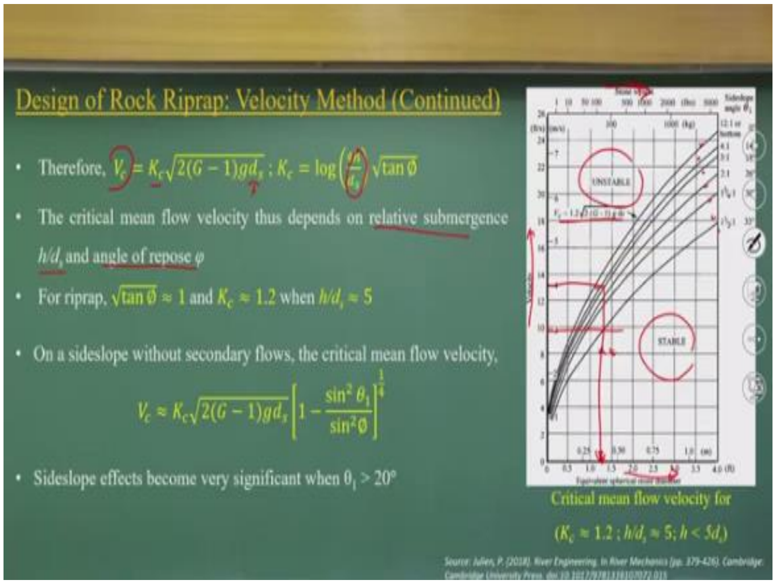

So, we can again substituting this two relationship empirical relationship the finally we can get it the v_c the critical velocity or design velocity what we consider it is a functions of k_c, k_c is a with a function of h/d_x this is the relative submergence h/d_s, you can understand it and angle of repose that is what and you have a d_s value. So that means if you look at this graphic is a design chart is provided by U.S corps of army's sorry U.S army corps of engineers.

So, if you look at that very interesting design chart has been provided in this axis the diameters equivalent spherical stone diameters this is a stone weight because you know the specific gravity you can find the stone weights this side you have the velocity and there is a curve of v_c equal to this ones there is a region are stable and the unstable and these are this curve for different slope 3 is to 1, 2 is to 1, we have a different slope this is called design charts.

You do not have to remember these equations you just to have a design chart that means if I consider my flow is 3 m/s and I am designing for this case slope we can find out what will be the equivalent spherical diameters just opposite of that what will be the stone weight that is what also I can find out. So same way I should consider in stable regions not the unstable regions.

So, we can consider is a 4 m/s is the velocity the slope is 2.1 for that what will be this case, so we can always look it what will be the stable dimensions of the stone riprap from this design charts these the design charts are come with by extensive experiments as well as empirical relationship and the field experience they create a they have prepared a design chart which we can use it just to know the design velocity, know the slope what you have to maintain it for that what could be the appropriate the representative size d 50 size of stone riprap that is the design chart.

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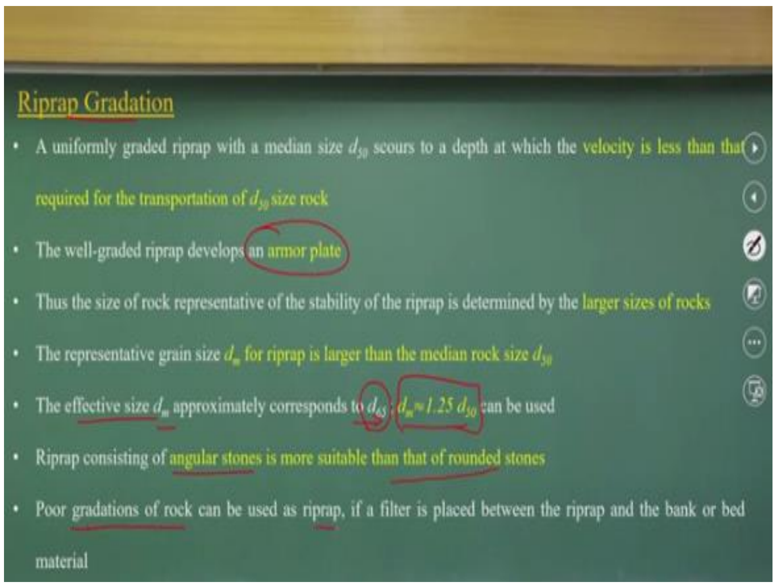

And, that what we can use it to design the riprap part. If you look at that more detail things that you need to have a gradations because a single side uniform stone will not get it from the natural cases you will have always a gradations of the stones what you will get it and most of the times in the river when you have the scouring process the turbulence process are there because of well graded river of bed materials and we can take advantage of armouring the layers.

The smaller and bigger size they can prepare an armouring plate. So that is what advantage we can take it, so that is the reasons we should have the gradations it is not having the same size and we should have a dm the effective size is a d65 which will be 1.25 because we are so prone show upon. We use a d 50 value but when you talk about the rock size and well gradations part if I talk about then we should represent a d65 which is representing that which also we know which is closer to 1.25 times of d50.

And, should have a angular stones which is suitable than the rounded stones and poor gradation of the rock can be used for riprap then we should have a proper design of the filters. The filter materials otherwise bank and bed materials can collapse it.

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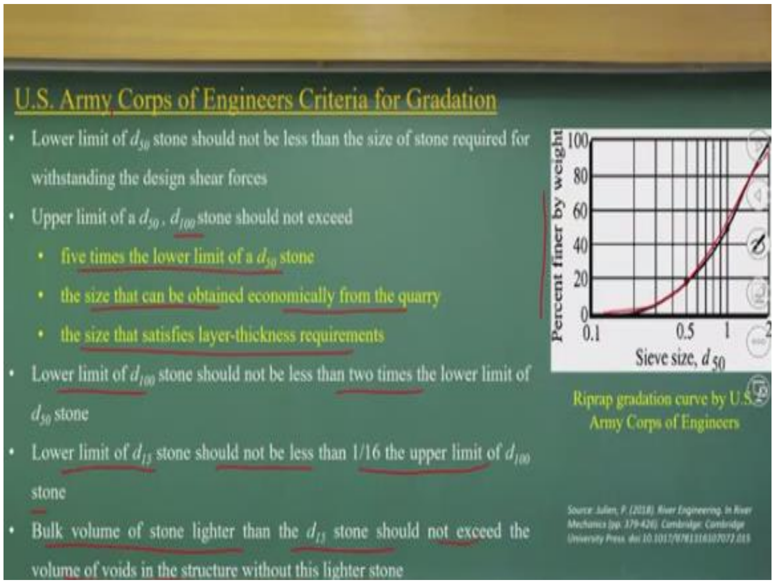

Now, if you look at some of the design guidelines is given by this, this is particle size distributions of the riprap gradations you have a d50 riprap size percentage of weight. So, if you look it that you need to do a geotechnical investigations to know the stone materials what you have and the US army corps of engineers they have given from their field experience all these design guidelines is a very interesting thing.

These are all their field experiments they say that there should be a upper d 100 should not exceed the five times of lower limit of d50. Size that can be obtained economically from the queries because the stones with a different size cannot get it these all are natural sense stones, so that is the reasons we should have a target to bring the stones from natural quary which is nearby one and size that satisfy the layer thickness requirements.

And, the lower limit of d 100 stones should be less than the two times of lower limit of d 50 and similarly lower limit of d 15 should not be less than 1/16 of up to upper limit of d 100 bulk volume of the stone lighter than d 15 should not be exceeds the volume of the voids in structure without these lighter stones. This see look the design guidelines what they have prepared it looking having lot of experience in the stability of stone riprap.

The U.S army corps of engineers they have followed these guidelines, just follow the guidelines because that is what is advantage for the stability of stone riprap that is what the upper limits the lower limits and design guidelines what they have been prepare it.

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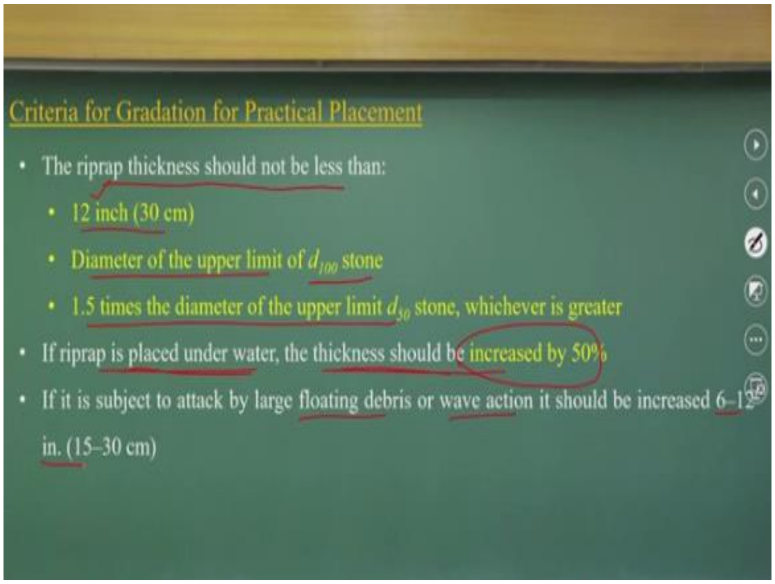

So, if you look it that way also they have a gradations riprap thickness should not be less than 30 centimeters that is what the minimum that means 12 inch should be, the diameter of upper limit 1.5 times of diameter upper limit of d 50 whichever we get us the riprap is placed under water, the thickness would be increased by 50% because many of the times to protect the scours the torch scours we apply lay this riprap under the waters.

So thickness has to be increased by 50% and is also looking that if there is a floating debris wave actions in that case you have to have a increase by 6 to 12 inch additional things to be put it which is 15 to 30 centimetres. So if you look at that these are all design guidelines considering that because of debris because of underwater stone repose you are doing it which we can increase by the 50%.

So all you look it, the US army corps of engineers based on their field experience they have given these guidelines which is already has been applied for many of the river in US and they have been successful in terms of designing this part. So with this let me I conclude today lectures and in the next class we will also further we will discuss on this more details how to design the filters and other parts, thank you very much.