

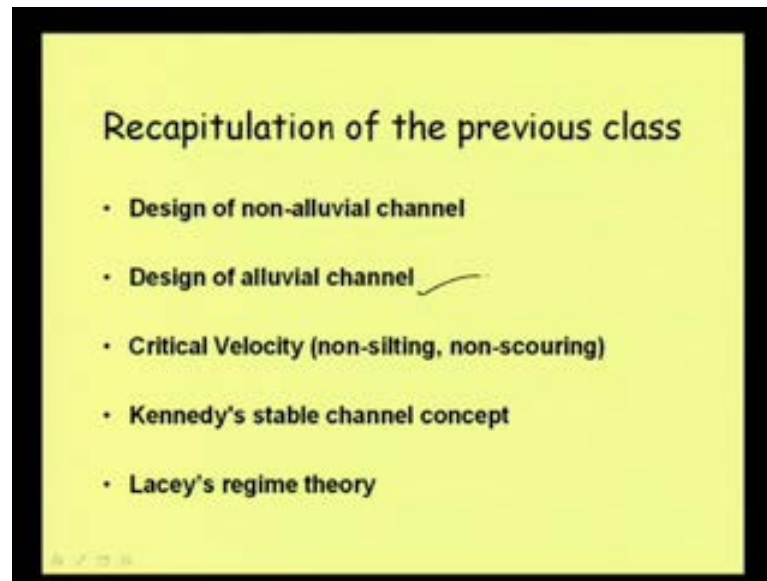
Hydraulics
Prof. Dr. Arup Kumar Sarma
Department of Civil Engineering
Indian Institute of Technology, Guwahati

Module No. # 06
Canal Design
Lecture No. # 02
Design of Alluvial Channel

Then, because the erosion question is not coming, but here in the Design of unlined canal, this erosion is coming very much. And of course, in case of non-alluvial channel, where erosion is not that much significant, it can be significant or it becomes significant when the velocity exceed a particular limit, and that we call as a maximum permissible velocity. So, in non-alluvial channel, our design principle is that our velocity should not exceed a maximum permissible velocity and then of course, if it carries some sediment, which is not a regular problem of non-alluvial channel, but still if it carries some sediment, in that case, the velocity also must exceed a very minimum velocity, which will not allow sedimentation, if that water carries sediment or if sediment let in water come through the channel.

That was a the discussion about non-alluvial channel and today we shall be discussing on Alluvial channel and of course, we started discussion on Alluvial channel earlier and on Alluvial channel, our main criteria the design criteria is the concept of Critical velocity, that we did discuss in last class.

(Refer Slide Time: 02:08)



The Critical velocity, we mean here, it is the non silting non scouring velocity. That means, we need to have a velocity, we need to have our size of the channel, in such a way that the dimension of that canal should be such that, the flow velocity will be of the type, that it will neither cause scouring of the channel nor it will allow deposition of the silt, that is flowing through the canal. And that sort of velocity achieving that sort of velocity is of course, very difficult that we discussed in detail in the last class.

But, still people are trying and then the person who tried this design first is the Kennedy. And then, he was doing this by observing several Stable Channel in the region of upper Bari doab, which is located in Punjab. Of course, Punjab means now it is in Pakistan, in that part and then by observing some Stable Channel he gave it and then of course, then this theory had lot of limitations and then Lacey's theories came up and that way, we are now working on Alluvial channel. Of course, now a days and all these channel Formula like Kennedys Formula, Lacey's Formula all these are basically empirical Formula, that is based on observed data, these were Derived based on observed data and, but after that people started working on possibility of having some analytical solution or at least to have some analytical basis, although the things may be designed or some parameter may be coming up from some observed value, but still there should be some analytical basis, that way some semi analytical approaches can be adopted and attractive force method is one of such method. So, we will discussing all those.

(Refer Slide Time: 04:23)

Kennedy's Silt Theory

- Gave this theory based on his observation of several stable reaches of Upper Bari Doab canal system of Punjab (Now in Pakistan)
- He measured the Flow Velocity (V_0) and Depth (D) and plotted these data to give his well known theory

$$V_0 = 0.55 D^{0.64}$$

V_0 in m/s, D in m

- He considered bed width to have no effect on the critical velocity
- To introduce the effect of silt size, later he introduced a factor m (Critical Velocity Ratio)

Let us just start with some of those important issues of Kennedy's Silt Theory, that we did discuss in the last class, but still we will be just starting from that aspect. So, you can concentrate in the slide, because we will be showing the Formula here basically, that it gave this theory, he gave this theory based on his observation of several stable reach. I am under lining this one, several stable reach of upper Bari Doab canal system of Punjab and now in Pakistan. Then he measured the Flow Velocity actually after getting those stable reach, he measured the Flow Velocity and he named this as V_0 .

So, this V_0 he measured and of course, he considered that this V_0 velocity will be having a relationship with that Depth of flow. That means, if the Flow Velocity and Depth, we observe, then we find that the stable remain and the channel remain stable for a velocity and at that velocity, if the Depth is having a particular value. So, that way he tried to relate this Depth and the velocity, and at that point he considered that the width of the channel has nothing to do with this relation, and then relating this V_0 and the Depth D , he plotted this data in a curve and then after plotting these things, he derived this particular relation, that is V_0 , velocity V_0 is equal to $0.55 D^{0.64}$.

Then D means Depth to the power 0.64 , means suppose, if we plot the V_0 in this direction, I am just giving one example, V_0 for all those stable channel, suppose several stable channels are there in the upper Bari Doab canal portion, then he observed, then he found that some D_0 , he D he is measuring Depth and then at the same time, for that

particular portion what is the Flow Velocity, that he is observing. And for several years, that he found that for several years, this particular channel is stable. And that is why he took those channel portion and then say putting this V_0 and this D say he is getting a curve like this. Exactly what sort of curve he got that is not a question here but suppose he got several points and say for example I am giving suppose the points can be plotted like this and the equation of this particular curve may give us one relation or a equation.

So, that equation is say this one V_0 is equal to $0.5 D$ to the power 0.64 where this V_0 is in meter per second, this V_0 is in meter per second and D is in meter. So, this was the popular and famous Formula of Kennedy and then he as I said that, he did not consider the effect of, I mean this width of channel on Critical velocity and then in fact, to introduce the effect of silt size, here as we can observe in this Formula, this velocity, he is saying that this velocity is the Critical velocity, where no erosion, no deposition will take place. And this Depth is only the parameter on which he is deriving this velocity, but from our general concept, we know one thing that, at a particular velocity whether there will be erosion or whether there will be deposition, that will definitely depend on the silt size. If the bed material, that is consisting of very fine silt, then at a very low velocity also, this can be eroded, if it is suppose a larger size silt, then it may not be eroded.

So, that way, the silt will definitely have some influence on the entire relationship and when he initially observed, he did not consider those effect of silt, because the very reason is there, he was observing this value only in the region that is the upper Bari Doab, the canal system, and for that canal system the sediment size or the silt size of the canal are same, I mean identical in all the channel reach, he considered these were same. So, what he observed, then he got the same value, he got that this relation is valid, but if we put a different kind of silt, then definitely the relation what we obtain will not be valid and that he could realize later when this formula was attempted applying in different area having different silt grade, by silt grade we are meaning silt size, what is the proportion of silt size in a particular silt sample and what is the average size? we call it as a D_{50} average size.

So, that way this effect came later and so to introduce the effect of silt size, later he introduced a factor m and this factor is called Critical velocity Ratio, he named this as Critical Velocity Ratio.

(Refer Slide Time: 09:58)

Kennedy's Silt Theory

- After introducing the effect of sediment size the formula became

$$V_0 = 0.55(m) D^{0.64}$$

Where, $m = V/V_0 = \frac{\text{critical velocity place under consideration}}{\text{critical velocity of VBD channel}}$

$m > 1$ for silt coarser than Upper Bari Doab
 $m < 1$ for silt finer than Upper Bari Doab

So, what is this Ratio is Critical velocity Ratio? That if we see that this m was introduced, which is called Critical velocity Ratio well. So, m means it is V by V_0 . Now, what this V_0 ? V_0 is the velocity or Critical velocity, we can write it as Critical velocity of upper Bari Doab channel region, Critical velocity of upper Bari Doab canal region canal system upper Bari Doab canal system. And, then this V is the Critical velocity. Somewhere else means, the place under consideration. By this what we mean that if we know the Critical velocity for the upper Bari Doab canal region, then we can find the Critical velocity in other place or indirectly, if we know the m value for a particular region or a particular type of sediment, then we can find the Critical velocity for that particular place. So, when m is greater than 1, then it is greater than 1 for silt coarser than the upper Bari Doab canal region.

So, that means, for suppose upper Bari Doab canal region, we have a V_0 value, then if the silt size for a different region is, greater than or the size is larger than the upper Bari Doab channel region, then definitely the Critical velocity will be larger. It will be say erosion, that means, the larger size larger velocity will be required for eroding the channel. So, that way it will be larger and that is why this m value will be greater than 1. And if your silt is finer, then the upper Bari Doab canal region, then this m value will be smaller and so, then people are investigating and different other followers are walking on that line and they have given some value for m also, for different part of the country and then definitely for using this equation, we cannot, we should not use directly in a

particular region. Once we are sure about this m value, say this equation was developed in the region of Punjab, now if we want to which is on the west western part of our country, and then if we try to apply that equation in the suppose eastern part of the country. Then we should conduct some experiment then only we will be knowing that this will be the m value for this particular region and then only we should apply this formula of course, this Kennedy's Formula has some of the limitation.

(Refer Slide Time: 13:07)

Basic Equations required for Design by Kennedy's Theory

- Basic equations used for design are
 - Continuity Equation $Q = A.V.$
 - Uniform Flow Equation $V = 48.3 R^{2/3} S^{1/2}$
 - Kennedy's Equation $V = 0.55 R^{2/3} S^{1/2}$
- There were no suggestions for slope.
- Later Kennedy recognized the need of providing a B/D ratio. Using B/D ratio one can compute slope

And then, what is the procedure, how we basically use Kennedy Formula for designing our canal. So, the basic equations, that are used for the design are continuity equation that will be the required. That means, along with the Kennedy's Equations, we will be requiring some of the fundamental equation for Design of the canal and continuity Equation as we know that this is equal to Q is equal to A into V . And then we should use the Uniform Flow Equation, because this canal, we design for Uniform Flow condition always.

So, Uniform Flow Equation again, there are several Uniform Flow Equation as we know, that Manning's Equation, Chezy's Equation, then Cutters Equation, Bazin's Equation different equations are there. And now in while designing this canal, people generally prefer the Cutter's Equation, they use the Cutter's Equation, but of course, we can try with Manning's Equation also basically, this we need one relationship, that is to know that. So, that we can express V in terms of the other parameter R , that is hydraulic radius,

roughness parameter, now I am writing as $1/n$ and the slope and based on all those parameter, if I write Manning's Equation it will be $S^{1/2}$. So, $S^{1/2} B^{2/3} R^{1/3}$, R is the Ratio of Area by Perimeter as we all know and that means, R is a function of what is your B value, what is your y value that means, what is your width and what is our depth. So, based on that we can express the velocity.

So, this is 1 relation that we know and then of course, our main equation for Design of the canal, that is the Kennedys Equation, that will be required, that is V_0 , as we are writing this 1 is equal to 0.55 m and D to the power 0.64 and this is in matrix unit that is the D is in meter, V_0 is in meter per second, but in this entire computational process, for designing that channel, there is no mention about the slope. That means, if we do it, if we calculate our size of the canal, here we are not considering the Bed Slope, particularly when we were using the Kennedys Equation, we are finding that this is the V_0 , if we Assume a Depth D . And then we are calculating the Critical velocity, then once we get the Critical velocity, we can get the Area of the canal. Then from the Area of the canal, Area is again a function of B and y , so, y means the depth I am talking about and here of course, we are using the symbol D . So, in this place also I can write D in place of y .

So, depth, so, depth is already known. So, B we can calculate and then calculating the b , so, once we get D and B , then using this D and B , we can calculate R , then of course, Bed Slope will be known to us. So, for that Bed Slope, we can now calculate our Uniform Flow Velocity V , we can use Cutters Equations also, as it is very lengthy, I am just writing the Manning Equations here V we can use. Now, So, far our requirement is concern, that we are considering this is to be Critical velocity, but when we calculate by using Uniform Flow Formula, after getting B and D from this Continuity Equation and this Kennedys Equation, we will be getting another Uniform Flow velocity, but if these 2 velocity are not matching, that means, our design is not correct, we are considering something to be Critical velocity, but in reality, we are getting something else, because the Flow Velocity, what we are getting by using Uniform Flow Formula is actually the velocity, what will be getting in the field.

So, it is not matching. That means, the D , what we assume, initially we assume a D value, rather we took, we take a trial value of D . So, that trial value of D , that we did take is not correct. So, what we will have to do, we will have to change the D value. That means, for that D value, we are not arriving into a position that our Uniform Flow

velocity, what we are getting is not matching with the or it is not becoming the critical velocity. So, that D will not survive proper.

So, we will take another D and then we will again calculate our V_0 and then with that V, we will be finding area then again we will be getting B and D, that is the Depth and width and we are again trying what actually we are getting in the field by using the Uniform Flow formula. So, that trial and error procedure is required here and once we find that both the V is matching, then we are getting that, I mean, the channel what we are proposing, the design what we are suggesting for B and D are of course, acceptable. So, that is what the basic procedure is, but in this formula we are not talking about anything about the slope in the Kennedys Formula.

And then later and of course, we are calculating the B and D based on this continuity equation, then later Kennedy, he realized that, no, there is a need of putting some relationship or some proportion of B also, because when he is equating, when he is trying to find this Critical velocity with respect to D and at the same time he found that a B by D ratio can be given. That if this is the D, then this should be the B, that this then only the channel will become stable. So, based on that, some experimentation were carried out and so, departments of Punjab area that time also, they conducted experiment and they gave some B by D Ratio. Now, what is the advantage of having this B by D ratio? Because, earlier also we could calculate our ultimate size of the channel, because where which match with this V, that is the Kennedys velocity and the Uniform Flow velocity. So, that we could do.

But, as it was stated, I have also mentioned, that slope was not considered at that point. We are considering a slope, which we are getting from the natural terrain, that is from the topography of the channel, rather topography of the area, we are considering that this is the slope we can provide, but always there remain a scope of adjusting the slope to some extent. That is, I was explaining that part earlier also. Let me take some space, say this is the area and there suppose to carry the water from this point to that point, point A to point B, we under construct a canal. Now, we can make the canal, suppose we are starting digging here and then we can make the canal like this or one can feel that no he will go like this, he will go like this. And then, another may think that we will carry, we will do some of that, in this case he is cutting this much, depositing this much, in this case, he is cutting here lot, but no deposition and he is going like that. So, that way there

is a scope of adjusting the slope to some extent and that we cannot achieve when we use, when we do not use rather B by D Ratio, then we do not have the scope of adjusting the slope.

And when we use B by D Ratio, then what we can do? We can use this B by D Ratio to find, once we can find, we are assuming a D. So, now, considering that B by. So, from that we are getting a V and then from the B by D Ratio, we will be getting a B also. And using that B, we can directly put it using that B, now we can just try to see that if we adjust the slope with that B and D value, can we get this velocity. So, we will try adjusting this, as B and with some adjustment of this as B, we will try that if we can have this, because once we get this once we assume this D value, that as we have a B by D ratio. So, both B and D are with us. Now, putting this B by D, we can get this relation and then we can try to see that whether we can adjust this value or not. Of course, this Q is our primary requirement, because we are trying to put that much of discharge. So, this Q is equal A into V we have to be satisfied.

(Refer Slide Time: 22:35)

Steps in Kennedy's Theory

- Assume a depth D ✓
- Compute Velocity by Kennedy's method ✓
- Compute Area $A=Q/V$ ✓
- From Known A and D compute Width B ✓
- Compute flow velocity using Uniform Flow Formula ✓
- Compare the computed velocity with Kennedy's Velocity ✓
- Adopt iterative procedure have the correct value of D, so the both the computed velocity become almost equal ✓
- If B/D Ratio is given, one can adjust the slope to have commensurate value of velocities ✓

So, let us see step by step, what we should follow. I have explained it briefly and now in step by step way, what we can do, that first we need to assume the Depth D. So, Depth D, we are assuming then using the Kennedys method, we are computing the velocity V, that is the Critical velocity we are computing. Then, we are computing the Area from the continuity equation. Then from known area and D, that is the depth D, then we need to

compute the width D , that is the bed width D , of course, when we are using this Q and this our shape can be trapezoidal, shape can be rectangular, anything it can be, that we will have to decide, again we did discuss about that part also how we decide this slope, that we will have to do. Then, next step is that Compute Flow Velocity using Uniform Flow Formula, this Uniform Flow Formula can be Cutters or Manning's, but basically Cutters Equation is preferred here.

Then we should compare the computed velocity with Kennedys velocity, computed velocity means this Uniform Flow Formula what velocity we are getting, then from this step, we should go for iterative procedure. So, adopt iterative procedure and have that correct value of D . So, that both the computed velocity by the Kennedy method and by the Uniform Flow method that become almost equal of course, we can go for almost equal, exact value may not be matching. So, this is what the procedure is and if B by D Ratio is given, one can adjust the slope to have commensurate value of velocity.

So, commensurate value of velocity means again, these two velocity should be almost equal. So, that is what the steps, that we follow in Kennedys theory. After Kennedy's theory, the next theory that came is Lacey's Regime Theory. We just gave the name earlier in the last class and then we discuss the originally, when it was developed and all those things. So, we are not going to that part, but his principal is the Regime Channel, his principal is the Regime Channel and of course, it is similar to having a Critical velocity, but what he suggesting that for a particular size of the channel, the channel can be regarded to be in regime condition and naturally, if we allow, what is Regime condition, the naturally if we allow the water to flow in a channel, then depending on the Flow Velocity and the size of the channel, it may happen that, if it has the erosion power, the water will have erosive power if the Flow Velocity is high.

Then, it will start eroding the channel in Alluvial channel I am talking about. So, it will start eroding the channel. And, just the reverse if we think that, if it is the size of the channel is very large and the Flow Velocity is very low as such, that means, we are talking always about all this fact, when we are talking about a particular discharge. So, for that discharge, if our Flow Velocity is very less, then as it will be carrying some sediment with it, because it is in a Alluvial channel. So, sediment is a must, I mean, sediment will have to flow through the water. So, that is why then those sediment will start depositing in the pair and then so, ultimately what we can see that, if we allow a

channel to run for a long time, it will adjust its own size, the width may increase, the depth may increase or due to sedimentation width may decrease and depth may decrease. So, that process will continue and after continuing this process for a very long period, it will come to a stage, that it will not change its width or depth further and that condition is referred as Regime condition, that condition is basically referred as Regime condition.

(Refer Slide Time: 27:21)

Lacey's Regime Theory

- **Regime Channel (Stable Channel):**
Alluvial Channel carrying a certain discharge undergoes changes in bed width, depth and slope until an equilibrium is reached and become a stable channel (Regime condition).
- Understanding following terms are important.
- True regime condition
 - Discharge is constant
 - Silt grade and silt charge are constant
 - Flow occurs in an incoherent alluvium of unlimited extent carrying silt grade same as that of the formation.

The slide includes a diagram of a channel cross-section on the right side, showing a central flow area with a dashed line representing the bed profile and a solid line representing the channel banks. The diagram is labeled with 'D₅₀' and 'D₁₀' indicating different sediment sizes or depths.

So, as a definition of Regime condition, we can state like that. Alluvial channel carrying a certain discharge and that part is very important, that when we are talking that this channel is in Regime condition, we are always talking about that, it is in a Regime condition for this particular discharge, that is very important. So, it is carrying a certain discharge. Alluvial channel carrying a certain discharge undergoes changes in bed width, depth and slope of course, in when I was saying, I was not mentioning about the slope, the slope will also get adjusted, when discharge is when the velocity is more, it will be eroding and slope may that way get increase, when discharge is for that particular discharge when velocity is less, sedimentation will be there and if the sediments start from downstream, then discharge slope can reduce of course, if the sedimentation takes place at the upstream itself, then downstream is so, all sediments are getting deposited at the upstream then when all sediments are depositing at the upstream and downstream is getting free of sediment then again that water may start eroding and that way slope can increases also.

So, that way this change of slope will continue. So, this slope is also getting adjusted and until an equilibrium is reached. So, finally, it will reach an equilibrium, until an equilibrium is reached and become a Stable Channel and that Stable Channel is called the channel is in Regime condition. And for using Lacey's Theory or before going to Lacey's Theory some of the term we should have very clear idea, that is we say that Lacey's principle will give us 1 channel, which will be in Regime condition, but what is Regime condition we have explained, but then we should know what is True regime condition. So, understanding following terms are important. That is first, we let us see what we mean by True regime condition, because many a time, we say that this is in Regime condition, but True regime conditions are very special and of course, we must know that in practical field, getting a True regime condition is very difficult, but still we go with that assumption.

Now, for True regime condition, discharge is constant. Now, if we think about a natural channel, then definitely for a region like India, where our rain fall is fluctuating a lot, I mean, seasonal variation of rainfall is quite high and there we cannot imagine of having a fixed discharge through any natural channel. So, though we see that this channel is in Regime condition many a time, but it is not exactly true. Of course, there we find that for the dominant discharge this can considered to be in Regime condition, but when discharge increases, again a channel may get eroded and again that there may be deposition in the channel.

And that is why, for the river of India, where the rainfall is more, suppose rainfall is in the more again in the north eastern part of the India, if we talk about where rainfall is very high, then in those area, the discharge is fluctuating a lot and that is why the channel to have a perfect Regime condition is not possible, it always keep on changing. And that is why we are getting braided channel, then channel meandering is taking place channel, because at some point the sediment get deposited at certain point and in other part, it is getting and in another season it is getting eroded. So, that sort of things keeps on going, but when we talk about manmade channel, because when we are talking about design of channel we are basically talking about manmade channel.

Then suppose manmade channel means, it can be irrigation canal, if it is a irrigation canal then of course, we can think to some extent about a constant discharge. If we feel that for the irrigation will be supplying a constant discharge, but again here also, that

point comes, because if our agricultural field is in a region like India, this will require irrigation only when it is not raining or when the crop is facing water stress.

So, we are not always allowing the same amount of water to the, I mean, canal because again if it is control by a reservoir on upstream, we need to store water when the rain is coming and then we need to release water, when there will be lien period and that is why we cannot afford to have constant discharge, but still there can be the variation we can minimize and we can think of having some constant discharge and of course, in if the canal, that we are designing is a drainage canal of a city, then definitely this condition cannot be satisfied, but still we need to design with some assumption in this part, with some discharge considering as the dominant discharge.

(Refer Slide Time: 27:21)

Lacey's Regime Theory

- **Regime Channel (Stable Channel):**
Alluvial Channel carrying a certain discharge undergoes changes in bed width, depth and slope until an equilibrium is reached and become a stable channel (Regime condition).
- Understanding following terms are important.
- **True regime condition**
 - Discharge is constant
 - Silt grade and silt charge are constant
 - Flow occurs in an incoherent alluvium of unlimited extent carrying silt grade same as that of the formation.

The slide includes a diagram of silt particles on the right side, represented by several overlapping circles of varying sizes. There are also some handwritten scribbles and arrows on the slide.

Then next point is that, that means, for 2 reason condition this must be satisfied the first point, then Silt grade and silt charge are constant. What we mean by Silt grade and silt charge? Silt grade means, the size and distribution of the silt size rather, we sometimes we call well graded silt, sometimes we call poorly graded silt or uniformly graded silt means poorly if in a silt portion, if we find that all silt are of uniform size then it is uniformly graded silt. And when it is uniformly graded silt means all are of almost uniform size. This is not good rather it is bad, because if we have smaller size, bigger size, then all will get say smaller size particle will go inside the bigger size particle like that, these are bigger size and then these are suppose some smaller size. So, this smaller

size will go inside and then the inter locking will be better so, but if it is a poorly graded, that is why it is a uniformly graded, all are of the same size, then there will be lot of gap in between, lot of gap in between and that is why these are call poorly graded. So, and well graded means, when there are smaller and bigger mix different size.

So, like that, this is basically the gradation of the silt we call like that, but to represent this, we need a value. So, generally the average particle size is given to use the gradation and in this case, of course, when we talk about grade, our emphasis is to see that, whether if the silt are of bigger size, then it will not be eroded easily, if they are smaller size, it will be eroded easily. Of course, if it become very fine then of course, it is not coming under Alluvial formation, then if it become clay, that is not erodible, that is a different thing.

It is a basic property or its cohesive property is very strong and that creates some other sort of bonding, but when we are talking about Alluvial formation, then if the silt is of finer size it will be eroded quickly and so, the average size of the particle is significant and that is why, this by Silt grade we mean that what is the size of the silt and that can be represent as D 50 means, that if we use sieve analysis and then suppose we are sieving the entire silt and then we are finding that how much percentage of the silt is passing through the, I mean 50 percent of this is finer than that particular size and then that we refer as, that particular size we refer as D 50, that is 50 percent of the silt will be finer than that particular size, when 50 percent is finer definitely 50 percent will be coarser than that. So, that particular definition, we use for representing the silt size and then what is silt charge?

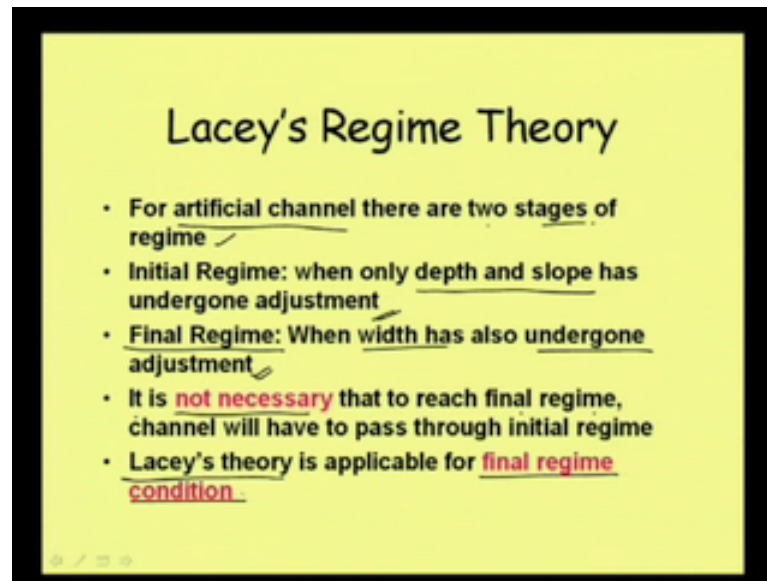
Silt charge means the volume of silt volume of silt that is coming into this channel and then suppose not only the size of the particle, what is the total silt concentration, sediment concentration in the water? So, sediment concentration is flowing means, it can be in the suspended form, it may be moving through the bed. So, how much total sediment over the bed as we are discussing that, but earlier also, that is the bed load and suspended load. So, that way what is our, I mean say when we were discussing mobile boundary channel I recall. So, when we were discussing mobile boundary channel, then this part we were discussing, Uniform Flow in mobile boundary channel.

So, in that case, we were discussing that sediment can be moving along the bed by jumping or rolling or it can move in getting mixed up with the water. So, entire things total concentration of bed load and suspended load, we call as a silt charge. So, how much silt charge is coming, that is important. But the point is that in Kennedy's theory or in Lacey's theory, we are not using any parameter to take care of this silt charge. We are just considering that, it will be in Regime condition that when silt charge that is flowing through the channel and the Silt grade is constant. Then, next point this is more important that Flow occurs in an incoherent alluvium, that is cohesiveness is less incoherent Alluvial that is a Alluvial soil, incoherent Alluvial of unlimited extent carrying silt grade same as that of the formation.

So, this sentence what it means that for True regime condition, to have True regime condition, our channel should be of infinite extent. That means, infinite extent of incoherent alluvium is there and through that our channel is moving and then it is carrying silt grade, same as that of the formation. So, in the bed through which the channel is going, suppose for a through a particular alluvium the channel is moving. So, the sediment size of that alluvium, silt size of that alluvium, we will be getting some value, if we take some sample and if we see what is the D 50 of that, that we are getting there and then what sediment it is coming from upstream, that is coming from far upstream and that is coming as silt charge and in that silt charge, the value what we are getting the dimension or D 50 of that what we are getting, there D 50 may not be the index, we can use some other index also in case, but whatever index we use, the size of or the grade of silt charge, that is coming from the upstream and the grade of silt size that is remaining in the bed, this must be same and that entire alluvium should be of infinite extent and then only we can have True regime condition.

Now, when we go into these three point and when we think about this three point, then 1 point is very clear that when we are talking about application of Lacey's Theory, then we know that True regime condition, if it is to be achieved, that is very difficult in the field and that way, there will be definitely some error in the design or limitation of the design.

(Refer Slide Time: 39:45)



Then, some other important point, when we are talking about artificial channel, that artificial channel there are two stages of Regime, we are now till this point, we are talking about Regime condition, then we are talking about True regime condition. What are the condition that we should have? But in artificial channel, when we are making an artificial channel, then there are two stage of regime. So, that is called two stage of Regime, one is called Initial Regime and the other is called Final Regime, and of course, some more points are there that we need to know, but still as the beginner, we should know that what we mean by Initial Regime, when only Depth and slope has undergone adjustment.

So, initially when water will be flowing through a channel, then the depth of the channel and the width of the channel, finally, we know width will also get adjusted, but initially the depth of the channel will be adjusted means, if the velocity is high it will be scouring in the depth in the depth wise direction. So, depth will be adjusted and the slope of the bed will also be adjusted. So, initially the depth and slope get adjusted and when this two are getting adjusted and we are getting more or less a stable channel for some intermediate period and this is called Initial Regime condition. And then of course, after some time, it will start eroding from the side and then its width will start increasing or if it may get decreased also if deposition start, means width will start adjusting. So, when both, I mean, when these three parameter, that is depth, slope and width gets finally,

adjusted, then this is called Final Regime condition. So, once we get Initial Regime, then we call this as a Final Regime condition, when width has also undergone adjustment.

And in the entire process, the side slope is also getting adjusted. When we are talking about Regime condition, we say that side slope will have its own value based on the erosion and deposition. So, that way we are not providing a side slope directly here, that we will assume that for the Regime Channel, this is the side slope. Of course, in Kennedy's theory, we were not talking about the side slope and based on the sediment characteristics, we can have some side slope there, but here we are saying that in Lacey's Theory, side slope will get adjusted. In fact, he suggested some value for the side slope or from observation, it can be taken that side slope can be taken as 0.5 is to 1, that is for 1 depth 0.5 width.

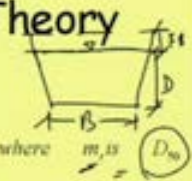
So, that way the side slope can be considered, but one more important point that I am putting in red here is, you can concentrate in the slide, that it is not necessary that to reach the Final Regime, the channel will have to pass through Initial regime. So, the channel need not pass through Initial Regime to reach the Final Regime in all cases. Normally of course, normally it goes first to Initial Regime, then it achieve its final regime, but sometimes without passing through the Initial Regime, it can reach its Final Regime. For example, suppose Final Regime width of the channel should be 5 meter for example, and we have made a 6 meter wide channel and then the flow is flowing through that, so, what will happen, the depth wise it is adjusting and then width is also getting deposited, I mean channel sediment, that is carried by the channel may be depositing on the side, because width is larger and that way by depositing finally, it is coming to the width of 5 meter, which should be in the Regime condition and that way we may get a Regime Channel, without passing through the Initial adjustment of only bed and slope.

So, I mean, that way this is not the necessary criteria and then more importantly Lacey's Theory, what he studied and based on his study, what are the Formula he has given those are applicable for Final Regime condition. So, once we are designing a channel, we should know that this channel, we are basically designing, considering that, this is the Final Regime size and so, those Formula will be giving us this value.

(Refer Slide Time: 44:47)

Equation of Lacey's Theory

- Side slope is considered as 0.5:1
- Equation of silt factor $f = 1.76 \sqrt{m}$, where m is D_{50}
- Mean Velocity V and R $V = \frac{4.75}{f} R^{1/2}$
- Area A and Velocity V $A = \frac{Q}{V}$
- Flow Equation $Q = \frac{148.6}{f} R^{2/3} S^{1/2}$
- Free Board $FB = 0.20 + 0.15 Q^{1/3}$



Then, he gave series of Formula, series of Formula, initially of course, he gave four Formula. These are the four Formula that were given by, I mean Lacey, first is that, this is not exactly a Formula, that it was found or it was rather observed in many cases, that side slope, it can be considered as 0.5 is to 1 for when we are designing by Lacey's Formula, the side slope we can put like that, and of course, the next Formula or the other this four Formula, what he gave is that unlike Kennedy's Formula where the silt factor was not given at all importance, later on only they introduced a term called m , the critically velocity Ratio, which was used to take care about the silt factor, but unlike that Lacey first gave the Formula for silt factor, silt factor F he gave this Formula as $1.76 \sqrt{m}$ over m I, where this m R that is which is basically representing the particle size and that m R is considered as D_{50} .

So, for the Design of Lacey's channel or Lacey's Theory, application of Lacey's Theory, if we go to the field, first we should collect the sample, that through which the channel will be made. Then after collecting the sample, we should carry out Sieve analysis and then after carrying this sieve analysis, then we should see that the size of the sieve through which 50 percent finer we are getting, that we should consider as the D_{50} and that D_{50} value, we should put here and then that we should consider as a representative value of silt factor F . Otherwise silt will be of different size definitely and we need a definite value. So, that definite value we are getting by this approach.

Then, we should calculate the Mean Velocity and then he gave some relationship between, in fact, he gave four relationship, one relationship is between the Mean Velocity V and this R , R is nothing but hydraulic radius and that is what this a by P R is equal to a by P . We know that in Manning's Formula or in our Uniform Flow Formula also, we relate this velocity to the hydraulic radius R and then we take care of the slope, but here this is the velocity, which we try to achieve and then this velocity is equal to is given as 2 by 5 rather root over 2 by 5 $F R$. Again silt factor is playing a role here. And in fact, in all those formula, in most of the Formula that he has given the silt factor has a vital role. So, the determination of the silt factor is very important. And then the V , we can have 2 by 5 F into R to the power half. So, that relation he gave, then he gave another relation. So, here also one relation for V and another relation he gave between the area, that is the cross sectional area of flow and the velocity V .

So, between these velocity V and cross sectional area A again gave this relationship, that a and F square, again the silt factor is coming here is equal to 140 into V to the power 5 . Now, this you can see very well, just I will show later this is one relationship. Then another relationship he gave that is the Flow Equation. Normally, in Kennedy's Formula or in our Design of Uniform Flow channel also, we were using the Uniform Flow Equation, that is V is equal to say 1 by n R to the power 2 by 3 and S to the power half basis on Manning's Formula. And there, we took that n value that can take different value based on the material and when we are going into the field and we are seeing the material, then what will be the n value taking a decision about, that is very difficult of course, unless, we have a lot of experience on having seeing different type of material and then experiencing how the depth of flow will be or whether the depth of flow, the Uniform Flow Depth, we can have by using a particular numerical value for this n , but here in Lacey's Formula rather than giving 1 by n the other part is remaining same R to the power 2 by 3 , S to the power half, this part is remaining same as Manning's formula.

But, he gave a value 10.8 by experimenting, by collecting data from different sources from several portion he collected data, several stable section he observed and collected data and he gave this formula, that velocity can be computed by using this direct formula, where we need not be worried for the n value, rather we can take a definite value of 10.8 . So, that way when we try to compute, this computation become easy, but of course, the limitations those are there, as we are considering a definite value, that is

having definitely some limitation and of course, this formula was not given directly and, but still for freeboard in Lacey's Formula, we can use this relation, it is actually not for the channel design, but what he gave, that if the channel need to carry higher discharge, freeboard means, if we have a channel like this, then say by design we are getting that this much is the depth D and this is the bed width b .

So, we have got this design, but the channel, when we are putting in field, we cannot put exactly equal to D , because due to many reason this depth can increase beyond that or may be the wave are coming through this channel and that way also it can exceed this limit. So, always it is necessary to provide a freeboard, suppose channel we are constructing up to this much, our water depth is here, but we are always providing a freeboard and he suggested that this freeboard should be more when discharge is more and that way he gave a relationship, that is $0.2 + 0.5 Q$ to the power $1/3$. So, that relationship was given by him. And now, just we want to discuss about this formula. Another aspect, that is a F square is equal to, suppose $140 V$ to the power 5 . This formula if we multiply by V , then what will be getting, suppose if we multiply by V , then it will become area into velocity.

And from the continuity condition, we know that continuity relation, we know that area into velocity is nothing, but Q . And for Design of channel always. Well, in all this formula, we are not talking about Q except the free board, but in all these formula, we are not about q , but channel we need to design for a given discharge, for a given discharge and as such we should be careful about or we should be concerned about what the Q value use. So, you can concentrate on the slide, that if we write here Q , just multiplying by V , this formula will become $Q F^2$ and this is equal to 140 and V to the power 6 . Now, from this relation, just by multiplying V we can have another equation, which is relating Q and V .

So, now we can write as V is equal to say $Q F^2$ by 140 to the power $1/6$. So, that way we can write, V is equal to $Q F^2$ by 140 into $1/6$. So, this way; that means, from 1 formula, suppose we want to say Q is given, then in practical field as I have already explained, that taking the silt data we can find the F . Our target is to design the channel for a particular discharge. So, rather Q is our required things it is given, F we have obtained, then we can find what should be the velocity, then this V we can find out,

Q^2 by 140 to the power 1.6. So, this equation can be manipulated to have different relationship.

And, then we can try to see, if this V is to be achieved and say V is equal to from this formula we can see what will be the relation between a and b **sorry** between V and y , because R is a function of B and y , from here we are getting some value. And then here we are or we can go by other way also. So, here it is R and if you put R here again slope term is here and what will be the slope we should take or once we get the V value, then we can go back to this formula, first formula, this one. In this Formula as we have got the V , we put the V here by putting the V here, we can get what the value of R is because F is already known. Getting that R , we can now put here R and we can get what slope should be or that way we can indirectly calculate the advisable slope in that channel. In fact, in some channel suppose of course, we say that natural terrain will govern the flow, but we have a scope of adjusting the slope also in sometimes.

Suppose our terrain is having a particular slope, but if we increase, if we try to increase the slope, we can align the slope in a curvilinear way like this and then we can have a slope, different slope. So, like that we can adjust it to some extent. So, what I want to emphasize from this point, that by manipulating these equation, we can have some derived equation which were perhaps were not given by Lacey's, but we can derive some relation from these equation itself.

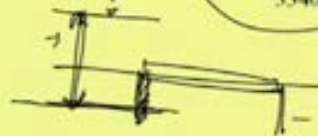
(Refer Slide Time: 56:33)

Lacey's Derived Equations

Perimeter $P = 4.75 \sqrt{Q}$

Normal Scour Depth $R = 0.47 (Q/f)^{1/3}$ $R = 1.35 (Q/f)^{1/3}$

Bed Slope $S = \frac{f^{3/2}}{3340 Q^{1/6}}$ $S = \frac{f^{3/2}}{4980 R^{1/2}}$



And one of those equations are, I mean some of those equations are very important and we can directly use, one is the Perimeter p . So, as I have already explained that, we can have from here, we are getting Q and then perimeter is equal to say R is equal to area by perimeter that we are getting and area we can calculate from this continuity equation also knowing the V and putting those value, we can then indirectly calculate P also. So, P in terms of Q we can calculate and that Formula is $4.75 \sqrt{Q}$.

So, if Q is given or Q is our required thing, from there we can calculate the perimeter and this perimeter in many a time is used for considering, suppose in a breeze, we are considering and with 1 to reduce the water way, because the breeze will be smaller than the actual width of the river. We narrow down the breeze portion for economy purpose. Then P will indicate what should be the minimum width of the breeze. Otherwise our perimeter will further reduce and then it will not be in Regime condition in nature. So, to have the channel in Regime condition or to not to violate the Regime condition in a much way, this P is used for that purpose also, finding the minimum water way in breeze and different purpose also we use.

Similarly, the scour depth, this is also used for design of many hydraulic structure, that what will be the R . That R means, we are calculating by indirectly from these formula, that is $Q f$ and these are coming, this is in terms of total discharge, this is in terms of unit discharge, and by using these things we are getting R , because this is in Regime condition this will be. Suppose, in a channel we are having this much of depth, but we know that it will get eroded and then it will be depositing, it may deposit or it may erode if the depth is less, suppose it will be flowing in this depth, then suppose its Regime condition depth is much higher, then it will be eroding and the ultimate depth may come up to this portion and then if we are constructing a hydraulic structure here, then if this water eroded up to this much depth this hydraulic structure will not remain, it will be washed away.

So, we have to provide some provision. So, we are putting some barrier here. So, that this erosion even if it comes to this much of depth, it will not take this hydraulic structure away and this is called cut of sort of things, and for designing those things, we use this scour Depth, that is why it is called scour Depth, because this is the depth in Regime condition and of course, this is the Normal Scour depth, but in again, depending on some other criteria, that is bend, if it is straight, then we need to for design purpose, we need to

take some safe curve. So, we get the actual scour Depth we can multiply it by some factor and similarly Bed Slope we can calculate using this friction factor, I mean silt factor and this discharge and of course, by two different way, if we calculate we get two different formula and these two different formula will of course, not give identical value, one is relating R, one is relating Q, but both the way we can go and it will gives us some tentative value for this Q for this bed slope.

So, all these formula, we can apply for Design of channel by using Lacey's Formula. And as discussed, there are some limitation and practical knowledge of the practical field of a particular region is very important to apply this equation in more confident way. Then some other methods are there as we explain, attractive force method and those will be discussing in our next class.