Fluid Mechanics
Prof. Subashisa Dutta
Department of Civil Engineering
Indian Institute of Technology-Guwahati

Lec 35: Open Channel Flow II

Good morning all of you as we discussed in the last class introduction to open channel flow. Today I will continue open channel flow going slight bit more in depth about the open channel looking that I have been following now the best books for open channel flow which is the books on Hanif Choudhury books but it is a higher level book but I can suggest you to read either FM White book or the Senral Simbala book. So most of the derivations we have taken from the Sinzel-Simbala book. So we can really the correlated the discussions what we are doing it if you follow Sinzel-Simbala book. Let us discuss today what the contents we will go through for lectures. One very interesting things we will discuss about flow-proud numbers and the wave split which is new concept what we will introduce it.

No doubt we already discussed about these mass conservation equations, linear momentum equations, energy conservation equations. These equations will apply for a control volume. So it is a control volume concept what we discussed more with RTT, Reynolds transport theorems. So that the thing concepts are used for the open channel flow to solve the flow depth, energy losses, the discharge flow depth, energy losses, energy loss.

and also we discuss about the discharge all the variabilities things we discuss it in a open channel flow maybe natural channels maybe the manmade channels. One of the manmade channels we India is a country we are very much leader in constructing the canals if you look at the history of the Ganga canals you always can google or look in the wikipedia's what is a Ganga canals. The canal was constructed way back 1842 to 1854 so it is about 12 years the constructions what had happened the Ganga Canal. Today this canal is also functions the almost 170 years old canals also it is a functions having the 33 megawatt power generations 33 megawatt not only that today's the our capital of the country the Delhi is getting about 240 million MLD okay. liter per day for Delhi city.

So you can just understand it how we are the leader in open channel flow, how we are the best in the world constructing the canals. The one of the reputed institutes which earlier named as University of Roorkee now IIT Roorkee, they were the leader the world related to construction of the canals. So we have an inherently this knowledge about how to construct the canals to understand about the rivers. So the basic concept what I will talk about it is not a new concept. So that means if you look it the way back 1842 to 1854 we constructed the canals 170 years still is running it and supplying it about 240 million MLD waters to portable waters to the Delhi city that is what is happening it.

So if you look at that we are leaders in the open channel flow as this is what was constructed for the as a navigations canals okay that is what is as navigation scanners. So, I am not going to move details how we were really the world leaders in these fields because it is a very limited for you the open channel flow. I just want to tell you that when you constructed the Ganga canal there was no computers, there is no hi-fi computing systems. The basic the conceptual idea used to design canal systems even if the alluvial canal systems okay that is I am not going detail. So if you look at that that is all the experience what we have and now what is the lifeline for Delhi city is the upper Ganga canals water feeding systems.

So looking that I am not going to more details because as you know it we have just a few lectures remain for the concept of open channel flow. So more details is there if you have interested in next levels is the river engineering course and other courses are there. Now if you look at that just to think it that when you have let me have the river is flowing like this okay river is flowing and this is what you have the bed level or the canals this is the bed level. this is what you have the free surface. That is what you have the free surface okay having the flow depth of H.

If you have these things and if you create any disturbance okay let me there is a one big stone is there. okay or just dump a stones here. It create a disturbance to these flow systems okay or you throw a stone to a river. So it creates the disturbance. Once it creates the disturbance, how does it propagates it because there is a off streams and the down streams okay.

because of these disturbance what is the wave speed the speed of speed of of surface water wave okay surface water wave. So that means if I put it a very simple way this is what hypothetically we are creating a disturbance wave okay. If you consider is that there is a open channel flow is going on and we create a disturbance because by putting a stone as you create a disturbance that is what will be reflected on the surface that means we are talking about the surface disturbance what is happening it. Does that disturbance propagates of streams? or it propagates both the direction in up streams and down streams or it just propagate through down streams. That is what is indicates are the flow behaviors between different conditions flow regimes.

That is what we look at in terms of speed of the surface water wave surface water wave. That is what is a create by natural processes like the flood occurrence, lifting a gate, having any stones or bed roughness all create the disturbance to that. When you create the disturbance of that then we try to look it how that disturbance is propagated. What is the speed of the propagations of this surface wave let be designated as C0. So, what that speed? See if you look at that as we discussed earlier we talk about 3 types of the flow subcritical, critical and supercritical.

In terms of the flow crowd numbers we define as if a lesser than 1 that means the gravity force is more than the inertia forces with this the case we define as subcritical flow okay. When you have a very rare occurs it that you will have a the inertia force is equal to the gravity forces of the flow systems that we call the critical flow. if a flow crowd numbers is greater than 1 we call supercritical flow. As the equations is a part of inertia forces in y gravity forces you can can just rewrite this okay from you can find out the flow Froude numbers is a functions of v by square root of gy. Here the characteristic length is the flow depth okay.

So now if you look at that the flow proud numbers what we define it as an inertia force by the gravity forces and when you do this inertia forces gravity forces we are getting the flow proud numbers is a functions of the speed of water okay. That is what again I have to write it this that what I am getting it this flow proud numbers okay as the speed of waters divide by g by y. Many they define it or I will also derive it. This is the speed of water divide by the speed of water wave or any liquid we can consider it is a water wave. That means this is one speed which is is equal to the C0 is equal to the C0 that is what we are going to derive it.

So we will talk about at the low velocity the flow crowd number lesser than that small disturbance travels off streams affects the off streams conditions at the high velocity when flow crowd number get small difference cannot travel the off streams thus the off stream conditions cannot be influenced by the downstream conditions. That is what I try to explain you looking these figures and with a disturbance why does happens it between the flow parts the dominancy part of the inertia forces or the gravity force components. So definitions of the flow crowd numbers the speed of the velocity by the speed of the water wave. So velocity by velocity by the speed of water wave okay. So now the point is coming it how to derive the speed of water wave okay.

How do you derive the speed of water wave which is a functions of the flow depth. It is a very simple things. as I will talk about as another disturbance you consider it that you have the I am just rescheduling these figures you have the river and you have a gate okay. So you have gate and you are just lowering the gate and after that you keep it the gate positions here. So definitely in off streams you will have a flow like this then there will be a energy dissipations like this.

So these the reasons will have a flow proud numbers lesser than 1 is the subcritical flow. Here you will have a supercritical flow. then you will have a subcritical flow. So if you look at that same thing is a subcritical flow supercritical channel. In between whenever a convergence of flow happens from the supercritical to subcritical flow there will be a formations of the eddies and there are a lot of energy dissipations will happen it their energy loss will happen it.

turbulence formations you can see it just downstream of a dam structures you can see the turbulence because of the formations of hydraulic jump okay. This is what called its hydraulic jump and we try to design a hydraulic jump because at these hydraulic jumps the mixing process the aeration process happens very dominantly no doubt there is energy losses happens it which is required for the some of the cases. But the hydraulic jumps which is created from the supercritical flow to subcritical flow at the transition zones which makes a the sound noise it is makes the turbulent structures a because of that you can have the a significant energy losses and those reasons there is jump formations are happening it that is the reasons we define as a hydraulic jumps. Some of the times we believe it we need a hydraulic jumps for mixing this chemical process chemical things or erosions process all we need a hydraulic jumps for the formation. So we will discuss more about the hydraulic jumps Now if you commit that the speed of the surface wave as I take it very simple way that let here have a flat channels okay and I have the depth of the flow is there and I just make a piston here.

okay. So there is a piston here and this piston is moving it let be del V and this is the fluid at the rest having let be y depth and this is what the surface wave having a depth of delta y and it is moving with velocity C0. that is the speed of water wave, that is the speed of water wave, okay. So as equivalent one piston says moving it to creating a surface wave of height of delta y, it is a smaller and the speed will be the C0 value. need to quantify it how much the C0 values. So what we can do it we can have the same concept we can use of control volume the same concept and the certain assumptions okay no doubt about that.

So we will have the assumptions we will have a make this the control volume. So basically I am making this is my control volume. If this is my control volume if I just zoom it the control volume part I have the control volumes like this the bottom shear stress acting is could be much much lesser than other force component. okay much much lesser than other force components. The because of the bottom shear stress what is acting on this play on this channel that should be much much less as compared to the force acting one is pressure force.

So here we can assume it that pressure distribution is hydrostatic pressure distributions okay. hydrostatic pressure distributions. You can assume it and that is quite this assumption is quite valid to have this is the y depth as it is a and this is the depth of y flush delta y and this is what is moving with c0 okay. This is moving with or the C0 as it is moving with the C0 we can always have a the velocity just you can see it as a moving control volume concept okay as the shear stress is there. So you can see that it is just a reverse like you know it this will be moving with C0 but this is what we will be having this moving with just C0 delta V.

okay this is the the velocity okay and we can assume it because this fluid at the rest and this is the zones which are moving in the delta v. So if you look at that if this is the control volume moving it at the free surface it looks like that it is a negative direction it will act it as you can see this part and these two velocity distributions help us to crossing the mass fluxes as well as the momentum fluxes. What are the force components are there? If I am looking it, this is the x directions and the y directions. So I have the two equations with me. One is mass conservation equations for this control volume.

Another is I will apply the linear momentum equations. in y direction because I do not bother about the x sorry x directions sorry will apply not in the y directions because that is not necessary for me. So I am looking the x director momentum equations from this I can find out what would be the relationship between the speed of water wave and the flow depth that is what we are looking at. Now if you look it as it has given it of the first component assumptions is very nearly constants okay that is what is assumptions we many of the times we did it and beta and beta 2 is closer to unit which is the momentum flux correction factors. distance of across the wave is a short the frictions at the bottom surface or air direct at the top surface will be negligible quantity.

That is what I discussed it here okay. The force due to the frictions at the bottoms will be much much lesser than the hydrotactic pressure distribution force what we are getting it. and the pressure distributions can consider it as a fluid at the rest we can estimate it what is the pressures at this point the rho g average of height that is what will be the rho g to y the average will be the half of this and same way this average pressures you will get it in y plus delta so this is y plus delta. the pressure at this will be rho g y that is what you know it okay. And what is the mass flux are coming it okay we can put it the mass flux what is coming it as a rho c0 yb that is what is mass flux is coming it and if I looking the horizontal directions equations and you are equating it okay.

The first is the steady mass balance equations for this control volume again we have sketch it okay. So if you look at that the control volumes and as we are telling it as I explained it the same concepts are there with how the velocity becomes negative components and all. So if I apply this mass conservation equations I will get a relationship with this control the velocity c0 delta y y flush delta y. This is very simple concept what we discuss as a integral approach. The same way in the x directions I will apply the sum of the force is equal to out beta times of momentum flux.

which is going out from this is equal minus of beta in okay. This is what we discussed much earlier but just we substitute the force component as we did it here. As we did it if we substitute it we will get a long expressions like this. and the finally we get a relationship between again I can write it the C0 the speed of surface waves is square of gy 1 plus just some rearranging the terms and 1 plus 2 y sorry 2y. Now if you look at these terms since we are consider it okay most of the times we will have this surface wave height which much much lesser than the depth of the water.

So in that case these terms is become close to the one value. That means the C0 the speed of surface wave is equal to g times of y square root of that. So it can have a positive and negative more details I am not going it but again we are coming back to this the flow proud numbers is again I am writing it not only inertia forces by gravity forces it is also the velocity divided by the speed of surface wave okay. That is the definitions the new definitions for flow crowd numbers. So if I have a velocity speed of surface wave larger than the velocity.

So we will have the subcritical flow. If the velocity is larger than the speed of surface wave then we will have a supercritical flow. So just like we talk about subsonic, supersonic, sonic speed. So same way here in case of incompressible flow the free surface flow we talk about speed of surface wave with respect to the velocity of flow. If the velocity flow is larger than this then your flow proud numbers will be greater than 1 the flow behaviors will be the supercritical flow. So if you create any sort of disturbance it will not propagate to upstream it will go to downstream.

If the conditions when this velocity is a lesser than speed of the surface water wave which we have derived is a functions of the flow depth square root of the flow depth that times we have subcritical flow. The critical flow is the condition there is very special conditions where the velocity is equal to the speed of surface wave. So that way you try to understand it there is a physics behind that to classify the flow accept very simple way to define the inertia force by gravity forces. But in terms of the open channel flow where the speed of the surface wave is matters to us we try to look at the ratio between the velocity and the speed of the surface wave. More detailed derivations you can look it here in Sindhal Simbala books or you can look it FM White book I am not doing the line by derivations but try to understand this physics of these problems.

Now if you look it as I said it we follow the basic the integral approach concept the average conditions okay. We are not looking at detailed flow field like as we discussed for differential analysis part. So when you talk about because when you design the open channel flow we may neglected the velocity distributions how it is happening it how these turbulent structures are creating it. So those if are not considering it and if I know it what is average velocity what is the energy losses and what the flow depth then I think this one-dimensional equations okay which we already derived which is Bernoulli's equations for that what we can use it which talks about the total head is equal to you know it okay b square by 2g the velocity head. the depth okay which is talking about your pressure head that is what is the pressure head and this is the elevations head that is the pressure head we make it as rho gh.

So that is the reasons we can get it the pressure head components. So this is what the total energy as I discussed many times that when you talk about the rivers we take it river the lines whatever is this, this is the x directions and this is what we consider the data. that means we are considering very flat terrains okay very very flat terrain that is what it happens when you construct a canals you cannot the slopes are very very negligible. So it is order of 1 is to 10,000 1 is to 50,000 so that way the scale that is the z variations we can consider is next we will use that. So if is that we introduce for very specific cases of open channel flow we can solve with a two heads one is the pressure head which is we define as y and other is the velocity head.

okay and this energy as we have with a certain assumptions we have commit to this we define this energy of specific energy. which considers the head as we discussed about that energy per unit weight. So this is the pressure head, this is the velocity head. So we are not considering the potential head or the head above the datums. So if you have you can consider the in new simple way we can analyze the flow field using a specific energy concept which is having a two component of velocity head and the pressure head.

Now if you look it as we did it for the in case of the pipe flow we can apply the same concept like I have a channel and I have this three surface which is the hydraulic gradient line I have this energy gradient lines ok. So if is that conditions if I consider the two sections section 1 and sections 2 ok and if I draw a lines here this is what my energy loss. this is what the energy loss hL as you define in the pipe flow. We did it the same things. So we can have right for the two sections as similar to that the z1 plus h1 v1 square 2g is equal to z2 y2 v2 square 2g plus energy loss in terms of head in terms of head which is reflected here in the diagram this is the part what we have the energy loss.

So if you draw the energy gradient line the free surface line is hydrogradient lines you can get it this component. So if this Z1 and Z2 is very close or by so you can write it the specific energy of E1 is equal to specific energy E2 plus energy loss. So very simple things. It is very simple things as we learn from the Bernoulli's equations as we learn from the pipe flow the same concept we are putting it with a assumptions is that these are no doubt as I said it very very flat conditions when you construct a canal when you constructed the natural rivers are very flats okay except in some of the waterfalls and all. So you will have either energy losses specific energy of E1 and specific energy E2 they have the relationship between is that E1 at the sections 1 is equal to which is the upstream sections is will be the energy specific energy E2 plus energy loss okay in terms of this.

So please have the same concept what we discussed in pipe flow, we discussed about Bernoulli's equations. Now if you look it as I said it when we constructed way back almost 200 years back Ganga canals and all we did have opportunity like Now we have a computing facilities and all. The people used to the specific energy curves to understand how the flow happens, how much of energy losses happen. It is very simple the graphic way, graphically understands how the flow happens in a channel flow. So people used to today we have a so much computing facilities and we have empire.

So they used to have a very simple graphic techniques to solve the open channel flow or design the open channel flow. How they do it? Then let me I go for as I said it we are talking about open channel flow where a channel when I am designing it so my Q is more less a constant like for example is very close to the 300 meter cube per second as a design discharge for the Ganga Canal. So you can google okay you can watch look at the Wikipedia. So that is discharge which is in a canal is going it is more less constant. if it is that so when the canal is moving at 300 meter cube per seconds then how they are having the relationship with energy versus the flow depth okay.

It is a very simple graphical technique but this graphical techniques gives a lot of knowledge about this open channel flow. So if you draw as you know it the e is equal to y floss v square by 2g and for a rectangle channels having the b is the width, y is the depth. So you can have a v will be the q by a that means it will be the q by b into y. So you just substitute that much. if you just substitute it what I will get it I will get it E will be the Y is a Q is a constants here so Q square is a constant is a for a constant flow if I have a 2G b square is width of channels into the y square b is let b constants.

So it is a e is a functions of y and the y square. If you just plot it this is the e equal to y line it is a 1 is to 1 line and if you draw this curve okay please practice this curve okay. you will get like this. This is the nature of the curve okay. Nowadays you have a lot of tools, mathematical tools are there for a particular discharge of q, the q constant. If I draw the relationship between varying the y and the e, I will get this curve.

That is what here. This curve what is indicate for us? That for a particular discharge q, There is a minimum energy and with that is a representing a depth which is actually the critical depth that derivations we can always do it. This is the minimum beyond that the flow is not possible. It is a really impossible flow can happen for a q equal to the same constant discharge because that is the minimum energy is necessary to have the flow. Minimum energy is necessary to have a flow minimum specific energy is there for these constant discharge. So if you look at that and just you can see that This is the critical zone.

This is what the critical zone and it divides into two zones. One is supercritical and other is subcritical zone and the line will be representing the critical flow zones with a different discharge we will get it that. So you have a supercritical and subcritical. You divide the zones and you have a E minimum. The e minimum represents as the critical depth and this line is y, this line is v square by 2g okay. At the critical depth whatever the velocity we also call the critical velocity okay.

That is the equations when you have a flow proud numbers is equal to 1, inertia force is equal to the gravity force. The second definitions what we are derive it the velocity of the flow is equal to the speed of the surface wave or if their locations if I throw a stone it will not move any directions. The waves whatever created it will not move it to any directions. So if you look it that way this critical zones what I get it it has it the two components divided is one is a subcritical another is supercritical. But very interestingly if you look at that if I take a particular specific energy and take a line that means I am getting a two depth y1 and y2.

One depth which is the higher depth where the velocity will go that is the subcritical zones the depth is less, velocity is high, the velocity head is higher that is the supercritical flow. So you can understand it drawing this specific energy curve that how the patterns of this curve, how a particular discharge for a constant discharge, how the variations between flow depth and the specific energy. that way we try to look it now we are looking in very mathematical way that we know it to estimate the E is a specific energy is a functions of flow depth. and the constant discharge is a constant. So we can find out the minimum of these functions which is very easy to do it.

That is what the same things as I explaining you the channel width b you can have a discharge per unit width. and you can derive these equations which is already I have done it or you can make it like this okay. So it will be the constants for a particular distance okay that is what is given it here but more interestingly so if I look it at which point we will have this E minimum this point if you look it so there is a two sections and you can have a subcritical flow and also we can have a supercritical flow, we can have the critical depth okay and this is a line 1 is to 1 lines where the specific energy is equal to the flow depth. So you have the two depths that is what is called the alternate depth. So the river or the upper channels it has a freedoms with the same energy specific energy it can flow through either a subcritical or the supercriticals.

Let us try to understand it with the same specific energy the channel can flow either subcritical or the supercritical. It will have a two different depth two different velocity. So two different depth we call alternative depths okay alternate depths okay so alternate depths. Now if you have to talk about how specific energy components are there and again we are revisiting it I think that is not a big issue that specific energy curve.

This is E minimum and you have a E value, you have a Y value. So what you needed to get it this? You just differentiated specific energy with respect to Y. The point is 0 that what we give a relationship between Yc and these values okay that is a critical depth. See if I just dispensate it making is derivative is equal to the 0 I will get it again same things is a critical velocity and it will be satisfied it the flow proud numbers is equal to 1 the critical or the point of minimum specific energy is indeed the critical point where the flow becomes critical the specific energy reaches to the minimum value. So with this let I conclude today lectures.