Hydraulics

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

Module No. # 01
Introduction to open Channel Flow
Lecture No. # 03
Open Channel Hydraulics Part-2

Friends, in the last class, we did discuss some of the aspect of open channel flow, and today we will continue from that. Let us just recapitulate what we did in the last class. Well, first we did discuss, what are the differences between open channel flow and pipe flow; and that we would try to understand some of the details of open channel flow. And then, we studied some of the important geometric parameter that we normally used in various work of our open channel flow. Well, then we went to classification of open channel. Well, that was classification of open channel, and not the classification of open channel flow.

Well today, we will start with that is classification of open channel flow. Well, now when we say that classification of open channel flow that we can do on different basis in based of based on say different criteria, we can classify open channel flow. So, these are some of the criteria, you can see that say we can classify open channel flow based on variation of flow parameters with time variation of flow parameter with time. The,n we can classify each on the basis of variation of flow parameters with space.

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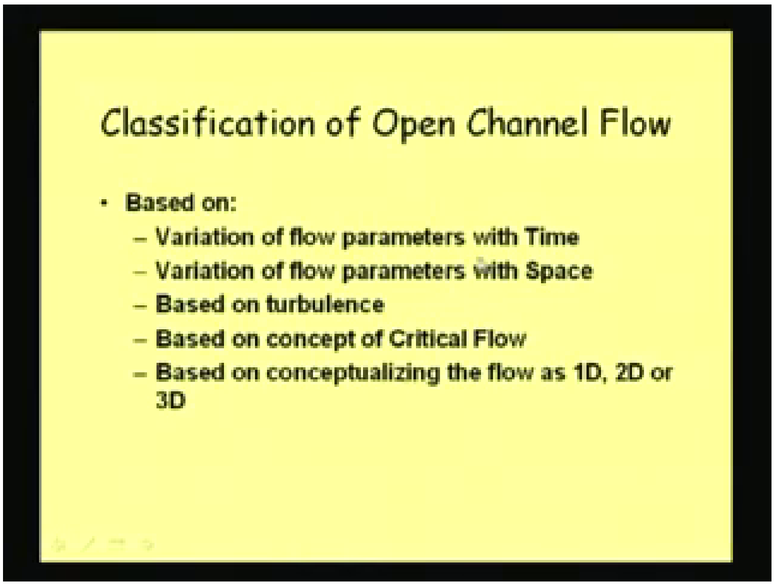

Well, by space here we mean that the flow parameter, well first let me go what is flow parameter; say when we say that variation of flow, then we need to just see that, what are the things basically, varying within the flow. And that is why, we decide or we talk about some parameter like that flow velocity or say flow depth or say flow discharge volume of flow that is moving through a channel. Now, how these things are changing with respect to time, and with respect to space. Well, by space we means, that distance say at a particular section, we have some velocity or depth; at a down sting section, we will be having some other velocity or depth and that we how it is changing. Well based on those things we classify open channel flow.

Well, then we talk about classification based on turbulence. Well, you can see that the flow in nature some time it moved in very turbulent way, and sometimes it is in a very smooth way that we did we we have already seen that in our very introductory class of our open channel, how the flow can in different forms are moving in a different way. So, based on how much turbulent or the strength of turbulence in the flow, we classify that open channel flow. Then, again based on concept of critical flow, well for understanding this particular point that is the critical flow, we need to discuss something more that we will be doing. But there is another classification, what I want to mean that which we do based on the critical flow.

Then again we classify flow based on conceptualizing the flow as 1D, 2D or 3D; well conceptualizing the flow means, for our various computational wall, we many a time just assume that the flow in the river is one-dimensional; by one dimensional mean it is moving in a particular direction; it is not it does not have any velocity in the lateral direction or in the vertical direction there is no change. So, like that when we consider then it is one-dimensional, sometimes you consider it is two dimensional. So, based on these one-dimensional, two-dimensional, three-dimensional also, we classify the open channel flow.

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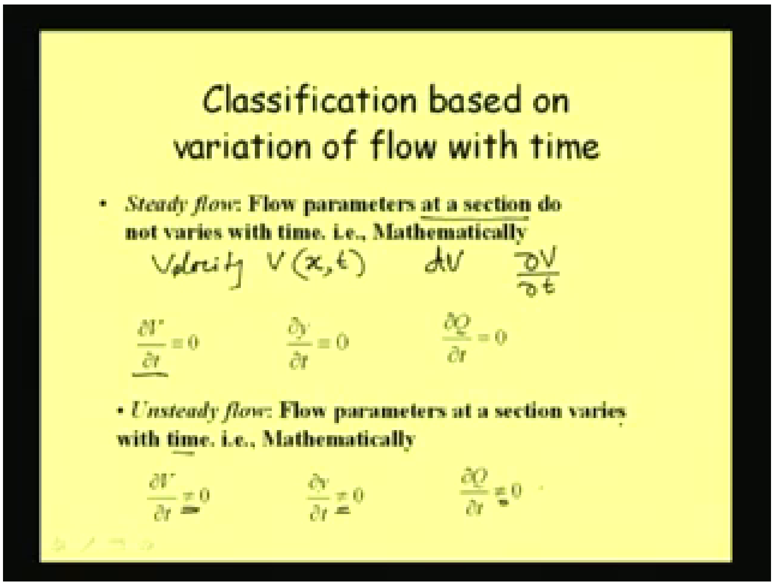

Now, let me go into each of this classification in a more detailed way, well. First we are talking about classification based on variation of flow with time. And that classification we do as steady flow and unsteady flow let me take the pen here, well. Say steady flow by steady flow what we mean that is when the flow parameters at a section do not varies with time, then we call this as a steady flow. So, this part is important, the flow parameter at a particular section at a particular section do not varies with time that we call as a steady flow. And then mathematically, we can represent that as say del V del t is equal to 0. Now why it is del V del t or say del y del t what is V? V stands for velocity; and y is say depth, Q is discharge, well.

Now, one of the flow parameter say velocity, when we say velocity, it can vary actually with respect to space that I am writing say x, and it can vary with respect to time. Now when we say the variation of velocity, then probably we would have written it as d V that is variation of velocity, well; this d V that is the total variation of velocity, when we say and this in fact, is varying with both space and time. Now when we say that it is very much space and time that means, total variation is partially with respect to time, and partially with respect to space.

So, when we say that variation of velocity with respect to time, then we write as say partial variation of velocity with respect to time. And then when we write the del V del t is equal to 0, say del V del t equal to 0 means, partial variation of velocity with respect to time is equal to 0 means, it is not varying at all, it is not varying at all with respect to time, but with respect to space it can varies.

Well, then similarly del y del t is equal to 0 means, the depth is not varying with time well, but it can varies with space, then it is not varying with picture. So, this is what we call as a steady flow. And then what is unsteady flow? So, unsteady flow is that when the flow parameters at a section varies with time that means, at a particular section, when we are observing a flow, then we find that at one time we have some depth, and the next time we might be having some other depth well. So, that mathematically we can write that del V del t equal to g is not equal to 0, and del y del t is not equal to 0 or del Q del t is not equal to 0 right.

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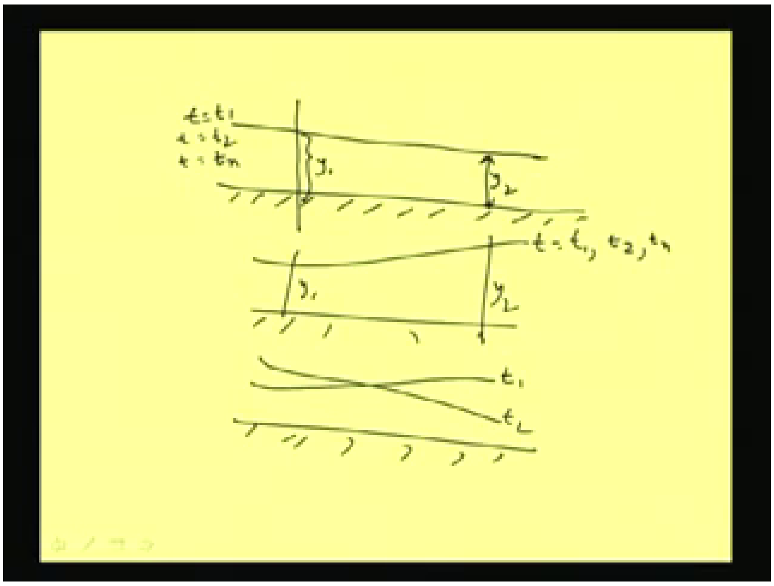

Well, say when we talk about steady flow, suppose this is the channel section sorry this is the bed of the channel, and then we have a flow like this. When we say it is steady, that means, at time equal to say t 1; at time equal to t 1, we are suppose to finding it like that; and that we talk about a particular section; in this section, suppose the depth at time equal to t 1 is this much y 1. This depth will continue or this depth will remain the same at time equal to t 2 or whatever maybe the time at time equal to anytime t n.

However suppose here the depth is y 1, here the depth can be something else say y 2 y 2; this not necessary that here it is y 1, here also it will have to be y 1, it is not like that. But this sort of flow, we will call as a steady flow. And it can be like this also that means, this is bed, so it can be like this also; there is no harm that we see if it is rise in changing here it is y 1, here it y 2, but with time at anytime that is t equal to t 1, t 2, t 3, t n at anytime it is remaining like that, then we call this as steady flow. Well, then what is unsteady flow say in the channel we are finding that at time equal to t 1, it is here; and time equal to t 2, say another time we are having that flow like this t 2, then this sort of flow we refer as unsteady flow well.

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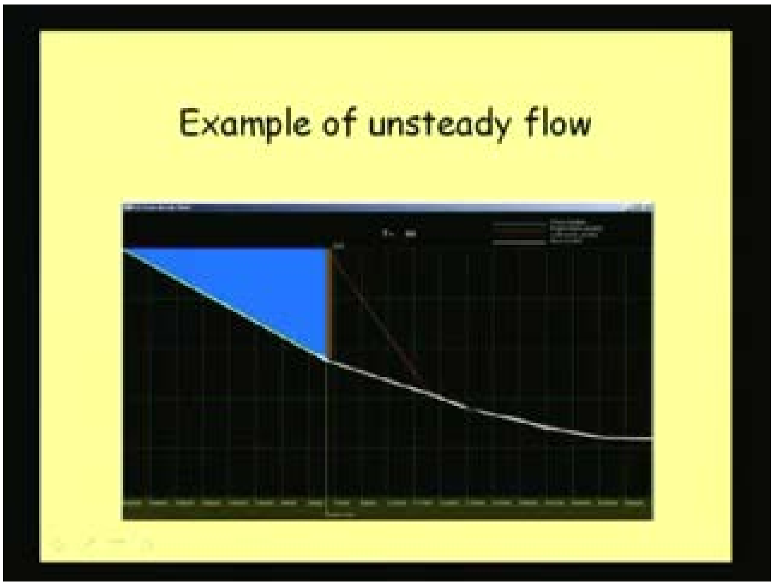

Let me give you one example, practical feel example. Suppose this you have a dam, say this is one dam, you can refer to the slide, this is a dam and you have some water stored behind the dam stored behind the dam, and this is the bed this is the bed. So, suppose due to some reasons, suddenly the dam has failed suddenly the dam has failed. Then the water will start flowing in this line water will start flowing in this line. Now you can see say at time equal to 0, the water is standing like this.

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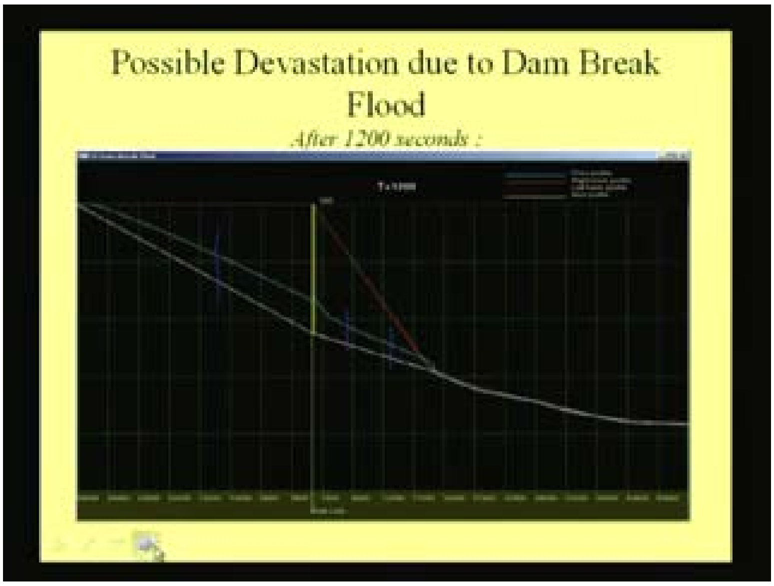

And at a time later period say, it is a 1200 seconds, suppose the dam has failed; so, it is no more there, water has got released like this, and it is in this point. So, if you take any section suppose, if I am taking any section here or here or even here, then you are finding that at time equal to 1200 second, we have depth here this much, but at you just see that in the next moment, this is changing like that; in the next moment, it is changing like that; in the next moment, it is changing. So, that way when these sorts of flow are changing in a practical situation, then we can call this as unsteady flow.

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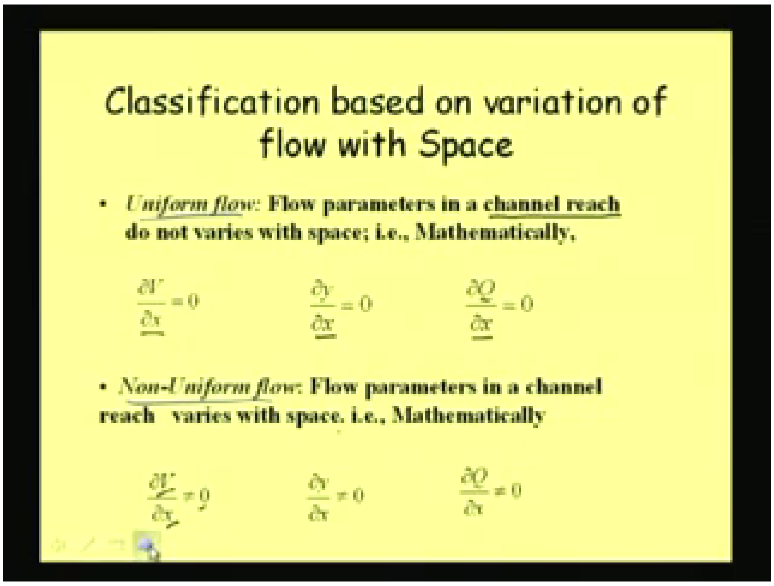

Then let me come to another classification that is classification based on variation of flow with space, and that we can classify in the form as uniform flow and non uniform flow. Well, what is mean by uniform flow what is mean by non uniform flow that we can see; with the uniform flow, when the flow parameters in a channel in a channel reach means in a portion of the channel, when the flow parameters in a channel reach do not varies with space. And again that is mathematically we can write say del V del x, del y del x or del Q del x is equal to 0.

So, here we are looking into the variation partial variation of velocity with respect to say distance or partial variation of depth with respect to this is say partial variation of all the flow parameter, we are looking in terms of distance; and that way we are just observing whether it is changing; and when it is not changing; that means, we are referring these as uniform flow. Then we can have when we have uniform flow, we can have non uniform flow as well, and here it is the flow parameters in a channel reach varies with space and mathematically, that we can write as del V del x is not equal to 0, del y del x is not equal to 0, and similarly del Q del x is not equal to 0.

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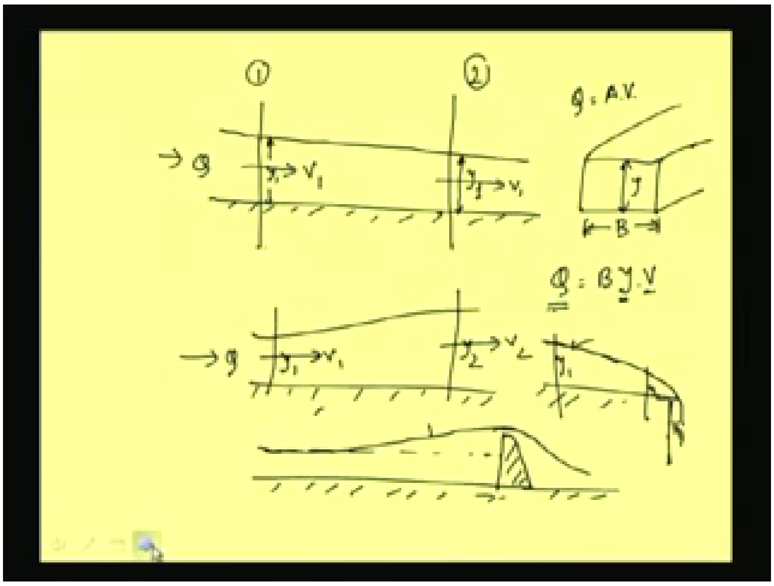

Well, now here again we need draw some figures to illustrate what we mean by del? Well, then say uniform flow means, if I consider this as the channel bed; well, depth of flow is say this one, and here in a section 1 suppose we have depth equal to y 1, then at the round stream section 2, our depth is not changing, this is also remaining as sorry this is also remaining as y 1 that means, the depth is not changing. Well, discharge what is coming is suppose Q, then we know that Q is equal to area into the velocity, this is a well known relation continuity condition we call.

So, suppose if Q is coming, if it a rectangular channel if it is rectangular channel or whatever maybe the channel say, suppose if it is a prismatic channel, everywhere the channel is remaining same all along this things. Then when we have depth y, then here velocity V if I say that this width is B, then we can write that Q is equal to area means, B into the y. So, Q is equal to B into y into V velocity. So, when our Q the same amount of discharge is coming, so discharge is not changing all through that channel or depth is not changing all through that channel it is here y 1, here also it is y 1. So B, if it is a prismatic channel B is also not changing, and then so V will not change; that means, here if it is V 1, here also it is going out with a velocity V 1. And this sort of flow we call as uniform flow that is the flow parameters are not changing with distance with space.

Now, if we can have a flow of this kind that say this is flow, here the flow parameters here is y 1 here it will be y 2. So, the flow parameters are changing, if the same amount of discharge is coming, then suppose no discharge are entering into this channel portion from this side or from laterally, then this will continue to move, and then velocity here will be V 1, but velocity here will be V 2, a different velocity we will be getting; because the depth is changing that is the sectional area is changing. So, you will be getting different flow velocity. So, this sort of flow we refer as say non uniform flow non uniform flow.

So, we have seen that we can have uniform flow as well as we can have non uniform flow. And in practical situation, where we can have this sort of non uniform flow, suppose we have a channel like this, and then you are putting some small dam or say varies like this, and you are abstracting the flow. So, earlier suppose the flow depth was in this level. Now, when we are putting abstraction here, then the flow depth will gradually rise like this. And then when it crosses this point, then it will be flowing this way, downstream something is happening we are not very much concerned about that right now. And well, so this flow, but it will continue like this, it will continue like this, and depth flow is changing with space, and that is why this sort of flow we refer as non uniform flow.

Similarly, a channel section is there, and suppose there is drop like this, and then flow is coming from this side it will be falling like this, it will be falling like this. And then this surface is also a non uniform flow, which is changing with space; here it is y 1, here it will be y 1 different. So, like that we can have uniform flow and non uniform flow well. Now, when we name these flow say, whether we can call a particular flow as steady flow, whether it will be sufficient or if we say that particular flow is a uniform flow will it really represent what the flow is definitely not, because when we are talking in terms of variation, we need to say how it is behaving so for its variation is concerned with respect to space as well as time. So, in that case we classify these by mentioning the combination of whether it is steady uniform, whether it is steady non uniform and like that, well.

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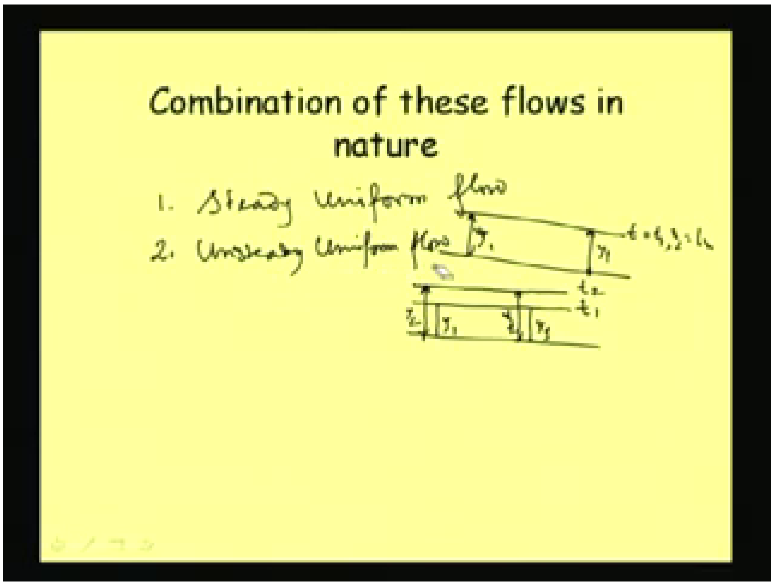

So, as combination what we can have say we can have a steady uniform a steady uniform flow, well. Then what we mean by steady uniform flow, that is say it is a uniform flow, it is a uniform flow that is the depth here as well as depth here is same, velocity is as well same, and this is continuing for any time say t 1, t 2 whatever it is, for any time t n for any time this is remaining like that. So, as such it is not changing with time nor it is changing with space. So, we call this as a steady uniform flow, well. Then we can have on in principle we can have unsteady uniform flow, but one point is true that in nature, we can hardly get a unsteady uniform flow, because if it is to be unsteady uniform flow, then what is that say you have uniform flow here at time equal to t 1, say here it is y 1 here it is y 1, that is it is not changing with it is y 1 again right. So, it is not changing with space in a particular time at any instant of time t 1 it is like that.

Then if it is to be unsteady that means, in the next moment time t 2, you will have to have another change that is with time it is changing say at t 2 you are having depth something else say y 2, at time two you are having something else y 2. But in reality or in real field, that sort of flow that is at this instant of time it is like this, and then it is jumping to t 2 like that it is not practically possible. So, we do not get this unsteady uniform flow in nature.

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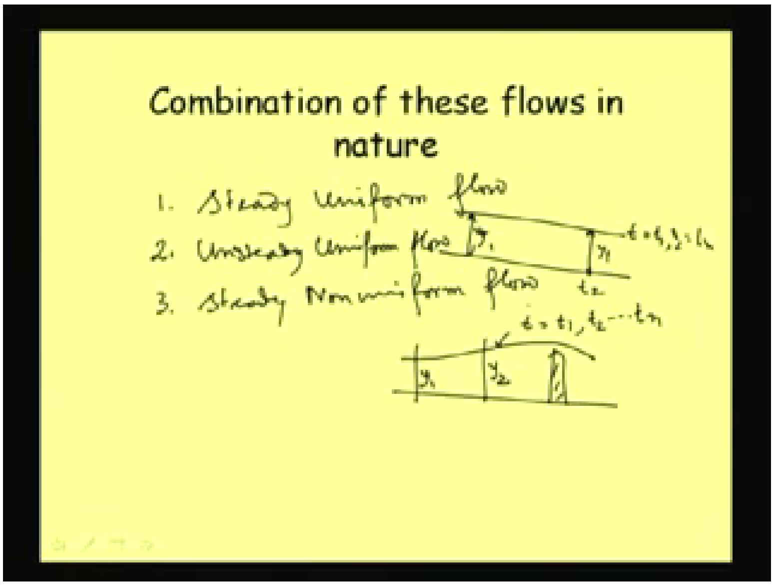

Well, then we can have say if we just see that is steady non uniform flow steady non uniform flow steady non uniform flow that already I have given one example that suppose you have the barrier here, then the flow is rising like this, and this is a non uniform flow this is a non uniform flow, and this is remaining like this for anytime at t equal to say t 1, t 2 anytime t n, this is not changing.

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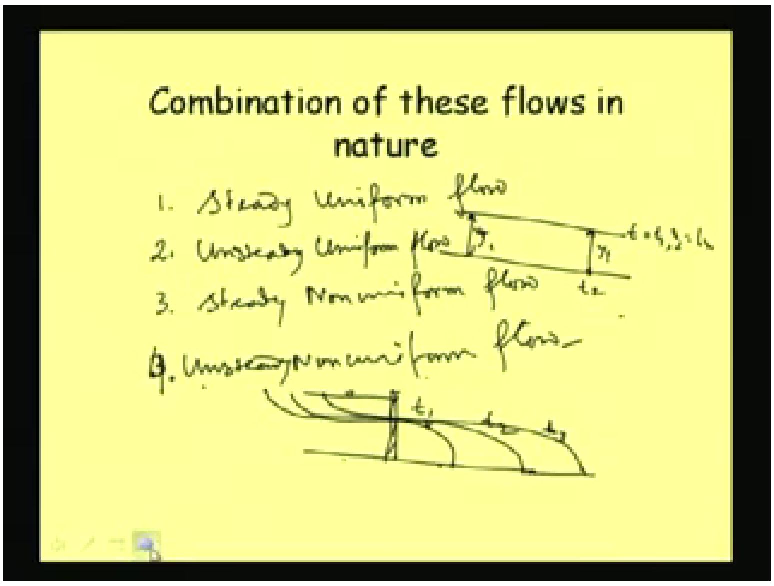

So, as such it is steady,, but it is changing with space it is changing with space here it is y 1 here it is y 2. So, it is all steady non uniform flow and say when we talk about unsteady non uniform flow unsteady non uniform flow that already one example I have given non uniform flow. Well, then we can see that suppose this is dam, what I give one example and somehow it has bridge. So, earlier the flow water level was like this, and then at time equal when it is failing. So, water is moving like this, so at time equal to t 1 it is at this level water level is like this, well. And it is also varying with space, with distance it is varying here depth is different, here depth is different. Then at the next moment at another time t 2 this is again changing; so, but depth is also changing, depth is also changing with distance as well as it is changing with time as well as it is changing with time.

So, when the flow are changing with time at t 3 it may be coming here, so with time as well as with space this is changing, then we call this as a unsteady non uniform flow well. So, when we name a particular flow, we need to specify it in terms of whether it is steady uniform, whether it is steady non uniform, whether it is unsteady uniform flow, well.

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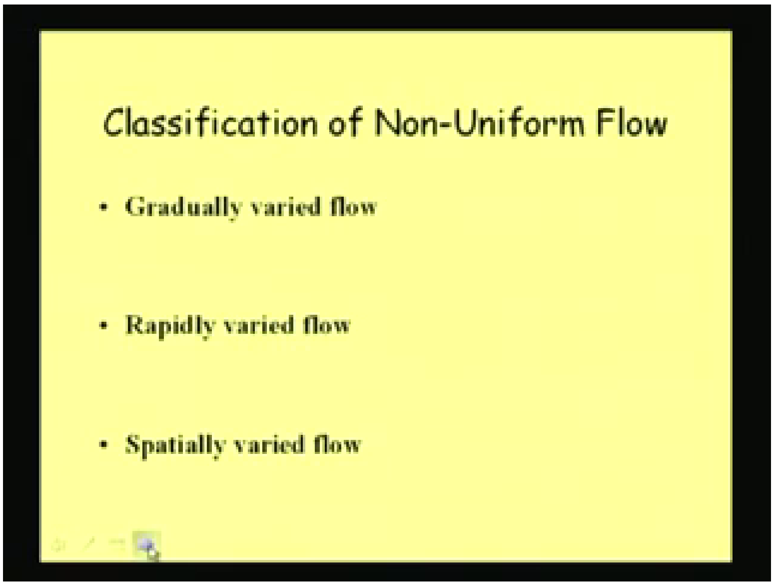

Then again when we say non uniform flow; well more details of this non uniform flow we will be discussing in a later chapter or in a later topic, but here I will just give brief about this that classification of non-uniform flow. This non uniform flow again you can classify in a way that it is gradually varied flow, then it can be rapidly varied flow, then it can be specially varied flow, well. By gradually varied flow what we mean; by rapidly varied flow what we mean, let us just see.

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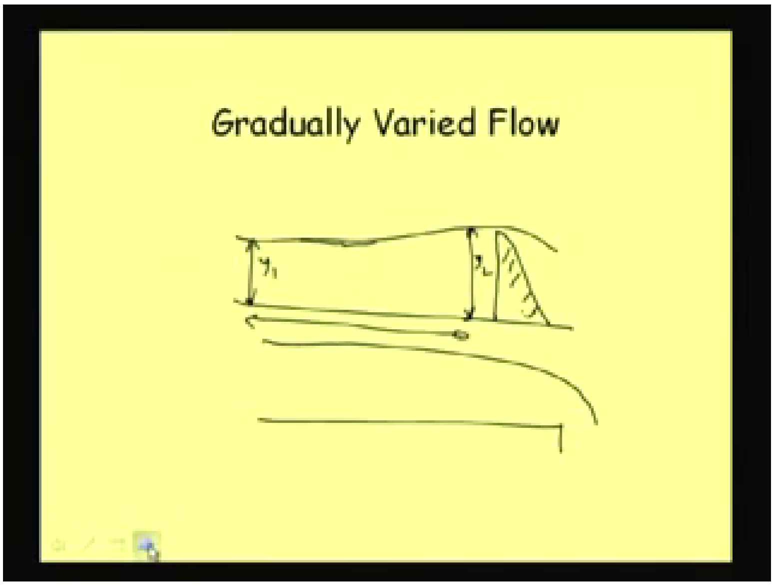

Gradually varied flow means, that flow is varying gradually, again I am taking the same example say, we are providing a barrier we are providing a barrier, and flow is varying like this. So, this variation this variation is gradual in a sense that this change in depth change in depth y 1 and y 2 change in depth y 1 and y 2 is taking place in a long reach this reach is very longer long, and then so slowly or gradually it is changing gradually it is changing, and this sort of flow we call as gradually varied flow. In fact, if you just in practical case, when you see these sort of flow, you will not be able to just realize by seeing by just seeing the flow that there is a change in the flow depth, you will not able to just realize, but the depth is changing.

Well, some more technical aspect of gradually varied flows are there and that will be coming when we will be discussing in the under the non-uniform flow chapter, well. Then well some example already I have given, when it is a drop like this, then also there can be non-uniform flow like this, and this is a curve which coming down, but this is a curve which is going up. So, there can be positive curve going up, then there can be drawdown curve like this. So, all these sort of different type of gradually varied flow we can have.

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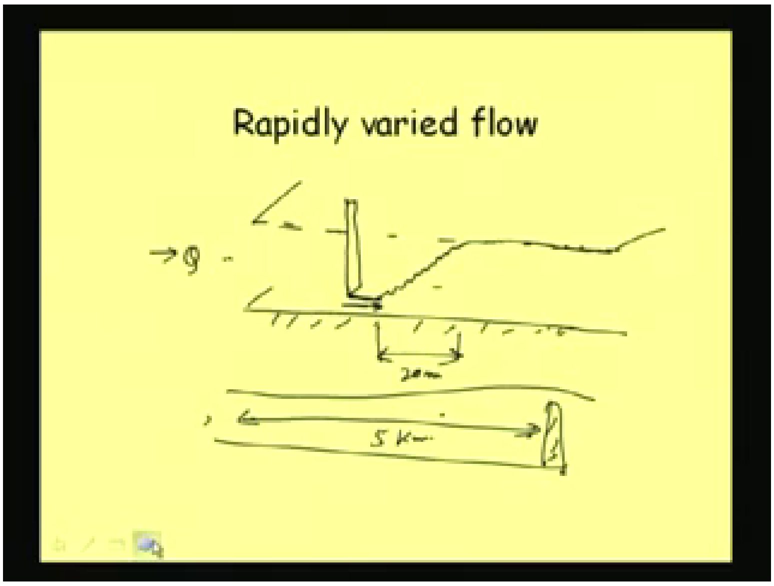

Then rapidly varied flow; well, then rapidly varied flow means, say we have a channel like this, and then in normal condition say the water depth if we allow to flow the water amount of the discharge Q in this channel in a normal condition suppose this is the flow depth this is the flow depth. Then if we put one gate if we put one gate here like this, and we make a small opening here, if we make a small opening here, then what will happen? This flow is immerging with a very high velocity at this point, because earlier it for moving this much of the discharge, it needs this much of height, depth of flow cross sectional area if you say in this term like that. But now, you are keeping a small opening here. So, it is moving with a high velocity.

And ultimately on the downstream side it would try flow in this level only. So, from here to here, there will be a just jump like this, water will be jumping from this level to that level, and that phenomenon is called hydraulic jump, this phenomenon is called hydraulic jump, well. Now this sort of changes or this sort of flow we termed as rapidly varied flow. Why rapidly, but rapidly does not mean that in a very short time, it is varying, this is basically not related to the time factor; what it mean that in a very short reach it is changing; this length of this portion is very small.

When we were talking about the gradually varied flow, the variation may say change of flow there from one value to another value maybe say in kilometers I mean distance. But here it will be in say meters, it it will it will be say 10 meter, 20 meter something like this, it will be say 20 meter, 10 meter like that. And when we talk about gradually varied flow, suppose you are giving a barrier, and then you are having this thing, in nature I am talking about in practical field say it can be of say 6 kilometer, 5 kilometer in that range.

Well, in laboratory channel, we can form these in a very small length also, and that will be of course, the dimension will be very small and of course, this distance what I am talking about this will depend upon what is the height of this barrier, what amount of flow is coming all these are dependent. But just a typical value I am just trying to give you, so that you can appreciate what is the difference between this rapidly varied flow and gradually varied flow. And of course, some other details are there. So, for energy conservation in this portion, what is happening to the energy what is happening to the energy in this gradually varied flow, what sort of equation we can write for this rapidly varied flow, what sort of equation we can write for this gradually varied flow, there are lot of differences. So, we need to handle these sorts of flow in a different way.

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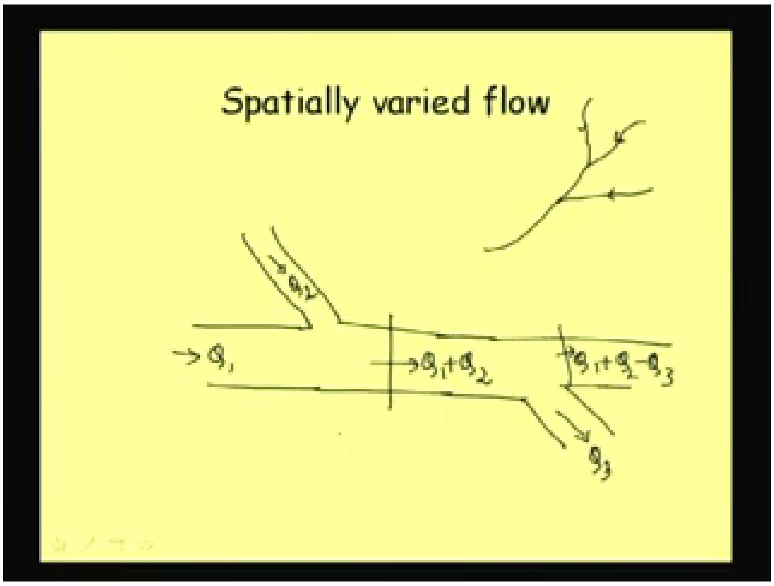

Then we talk about another type of variation that we call as a spatially varied flow spatially varied flow. Well, in a river system, we can always find or we see that a river is flowing like this, then some tributaries are joining, some branches are coming like this and that sort of things is very common, and this is what we normally depth. And then this sort of situation, suppose if I draw it like this a channel is moving like this, it is scaling a discharge Q 1. Well, then another channel from this side is joining this one, and it is carrying a discharge Q 2 and then this is moving like that. So, here in a in this section the discharge is Q 1, you have some depth, and then when going to this downstream section here, the discharge will be say Q 1 plus Q 2, discharge will be Q 1 plus Q 2.

So, that way the discharge, one of the flow parameter what we are just observing straight way here that is the Q 1 discharge, this is definitely changing with space. So, it is a non uniform flow. And then some discharge can go out also from this part say Q 3 is going out; then what will be the discharge here at this point? It will be say Q 1 if I see beyond this one; it will be Q 1 plus Q 2 minus Q 3. So, this sort of flow, we term as spatially varied flow, and then when we treat mathematically all these different type of flow gradually varied flow, rapidly varied flow, spatially varied flow we treat all these in a different way, some specialty are there. So, till now what we have seen or what we have discussed is that how we can classify open channel flow in terms of or on the basis of its variation with time and space.

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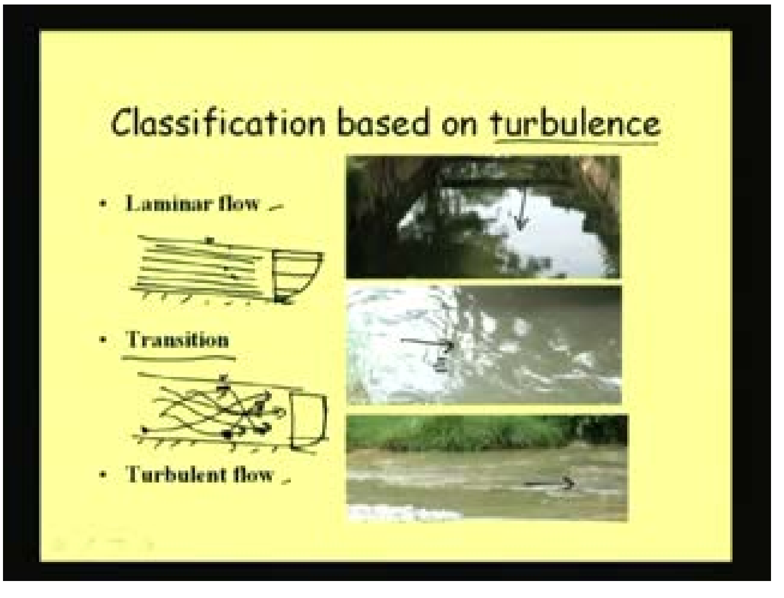

Well, but some more classification we can do based on some other criteria that is initially I told the turbulence turbulence, this is one of the important issues. There is the classification based on turbulence, you can see here I am keeping some of the figure picture under taken a different part; here the flow is moving in this direction and you can see that the flow is quite smooth; you do no find much undulation here. And then in this figure, you are finding that flow is moving in this direction, and flow has some undulation it has started I mean, the surface is becoming little bit undulated, and then it is moving in this direction.

When here you can see of course, it is I mean little you may not be that much visible, but from the terrain or from the entire geometry, you can see that there is lot of turbulence in this flow in this flow, because lot of undulations were there, and flow is moving in a much turbulent way. And so that turbulence level in this, in this, and this flow is different; and then based on this turbulence, we classify the flow in three classes that we call as a laminar flow, turbulent flow; and in between this laminar and turbulence, this is referred as transition flow, transition between turbulent and laminar.

Now, what we mean by laminar flow? what we mean by laminar flow? Well, basically when the water is flowing in a channel with a very low velocity, then for a ideal fluid we can see that it is moving; well, rather than let me draw a diagram here. Say this is the bed, then we can see that suppose total depth of flow is this much; and if it is flowing with a very low velocity, then we can see that or rather we can assume that the flow are moving in layer. Entire flow is definitely not moving entire flow is definitely not moving with the same velocity, there may be difference in velocity, there will be difference in velocity between this layer and that layer, and we assume that flow are moving in a in layers, in layers, different layers of flow are moving.

And one layer gliding over the other layer; and these stream lines if we say if you call this is a stream line you know, from basics of fluid mechanics that what is stream line. So, this stream lines are parallel. And then if I draw a velocity diagram, that is what I mean by velocity diagram if I draw a graph here, so what will be the velocity here? Say velocity here is this much, and what will be the velocity here, at the bed at the bed when it is just in touch with bed, it in the fluid, which is just in touch with the bed may not be moving at all. So, this part we can say that velocity is 0. And from here to here velocity is changing gradually.

Well, how this change in velocity occurred that we will be discussing in the next class. But here just I am trying to show you that the velocity variation is like that; you can find a high velocity here, and then low velocity here and gradually it is coming down and at the bed it is almost 0. So, that sort of velocity variation we get in case of laminar flow. Well, then in turbulent flow in turbulent flow what is happening? Well, let me draw here in turbulent flow, if this is the bed, then the streamlines or the flow layer are not moving smoothly like this; say one streamline is moving like that, another is moving like that, if the total depth is this much. Then in between these flow are getting mixed up, this flow are getting mixed up like this. So, increasing turbulence means, mixing up of flow say a particular water particle remaining here next moment it may reach this point.

Like that when we draw the velocity diagram what will happen to it? Now we cannot say that these are moving in layer. So, what you have you might be having some velocity here at this moment, the same particle is moving to lower side with a high velocity. So, there is mix up and this says, this was moving with a low velocity then this particle will be moving to upper side means, its velocity, it is gaining its velocity again. So, like that velocity becomes more or less uniform in the intersection, except the small portion near the bed small portion near the bed. And in other part, the velocity becomes almost uniform. So, that way in turbulent flow, the velocity variation along the depth becomes almost uniform like that.

Well, and then between these two laminar and turbulent flow, we call it as a transition flow. Well then as I am telling probably you might be thinking what is transition flow; laminar is this understood clearly, turbulent is this one, when there is mixing up of the flow, and then what is transition; that of course, to define very specifically we must need some, we must take some help of some index, and that index generally we used or it is used is Reynolds number, you know very well what is Reynolds number.

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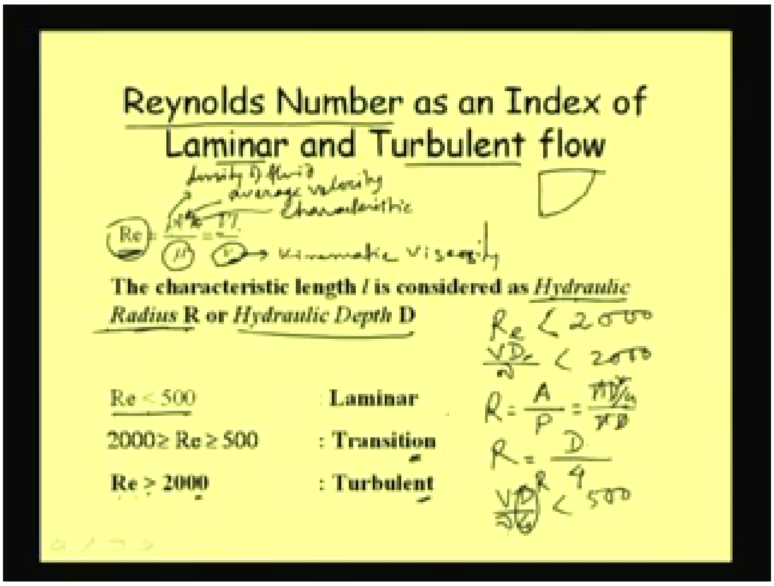

So, that Reynolds number we express as row V l by mu. So, row is the density of flow, this is the density of fluid density of fluid, then V is velocity velocity, now what is velocity that is again a confusing term, because already in that last slide itself I have shown that velocity is varying like this; here it is like that, and then here it is like this, then this velocity is what? Well, we are talking about, when we just put a velocity term here we are meaning that this is the average velocity. So, this velocity we call rather than writing it as velocity, we can write it as average velocity we can write it as average velocity. So, this a average velocity.

Then this l, l is characteristic length l is characteristic length. So, this l represents a length term, this l represent a length term, and based on the problem which length term is significant that way we take this length term. Say, for a pipe we consider this length term to be the diameter of the pipe, when we just talk about the Reynolds number of a pipe. And in open channel flow, we take this length term as either hydraulic radius R or hydraulic depth D. In the last class itself, we did discuss what is hydraulic radius, and what is hydraulic depth?

So, it is basically characteristic length that can be different. In fact, again for another problem or another study what we call as a boundary layer that length become different. So, this length can vary from case to case or depending on the problem, we take different characteristic length. And this mu is the dynamic viscosity of the flow. Well, that mu by row is nu what is kinematic viscosity. So, this is kinematic viscosity. So, ultimately this Reynolds number can be expressed as V l by mu V l by mu, and for pipe flow as I have explained, the this l can be diameter; and for open channel flow, this can be radius hydraulic radius or hydraulic depth.

Now, this term is used to express how much turbulent the flow is; why, because you can see that suppose you just consider that in a channel, water is flowing with a velocity V. Now in the same channel, and then water is getting becoming turbulent there water is becoming turbulent now in the same channel with the same velocity, if you allow a oil to flow, if you allow a oil, which is having say higher viscosity, and that with higher viscosity, a higher viscosity fluid, if you allow to flow, then we find that turbulence may not occur in that particular fluid. So, this turbulence is inversely proportional to we can call that it is to the viscosity term.

And then similarly, if you allow it to flow with a very small channel, the same velocity, same fluid in a smaller channel, then your I mean, with a small hydraulic radius what I mean or with small hydraulic depth if you allow it to flow, then there may not be that much of turbulence. But the same velocity, but if it is flowing with a higher hydraulic depth, then you can find that the turbulence is increasing. So, again velocity is; obviously, if water other things remaining same if the flow velocity is more, you can have more turbulence. So, that is why considering all these aspect the Reynolds number is used as the index for indicating whether the flow is laminar or the flow is turbulent.

And well this expression, we can get for pipe flow, for pipe flow it is found that Reynolds number; if it the Reynolds number up to 2000 up to 2000 when it is less than 2000, then the flow remain laminar; this was in a pipe, it was lot of studies were conducted, and we can have these things, and we can visualize these things very well in Reynolds apparatus in fact, you can see these things. Well, in our lab class, we shall try to demonstrate that part also.

Now that say Reynolds number less than equal to 2000, and in pipe, what is that? We can write it is V D by nu V D by nu. So, this should be less than equal to 2000. But this in case of open channel flow, we use hydraulic radius. So, it should be represented by hydraulic radius, this D should be represented by hydraulic radius. Now in case of pipe, if we write a hydraulic radius R, and if we just consider that it is a pi hydraulic delta is equal to A by P, just to refresh your memory. So, it is is equal to area by perimeter and in case of pi, if we write this things, then it become say pi D square by 4 is the area, and then pi D is the perimeter of a pipe, when it is flowing full.

So, that we can see that R is equal to, we can just see that this is going out, and then it is becoming D by 4. So, hydraulic radius, if I just put the same expression of hydraulic radius in case of pi, then we get an expression of D by 4. And you know that in pipe flow, it is less than 2000. So, if I make it just V, then in place of D if I write V by 4 let me put a 4, and nu is here. So, this will be if I divide it by 4, this is becoming again if I divide this 2000 by 4, then it is becoming 500. So, then D by 4 is something that we can replace this as R. So, what we can write that well let me write here; well this part we can represent as R. So, V R by nu which is the Reynolds number expression for the channel. So, V R by nu is less than 500.

And from this, just analytical concept also we can say that when Reynolds number less than 500 in case of open channel flow, the flow remain laminar. However, experimental study has shown there up to about 600 value, this flow remain laminar of course, it depends on some other factors also like that in fact, the viscosity will vary with temperature and all other factors, like that this is laminar. And then when the Reynolds number goes beyond 2000, then the flow become turbulent in case of open channel flow. Well, then when the Reynolds number is between 2000 and 500, then the flow is called in transition from laminar to turbulent. So, that way also we can classify the flow based on each turbulence level. Well, then let me go to another classification that is classification based on the concept of critical flow.

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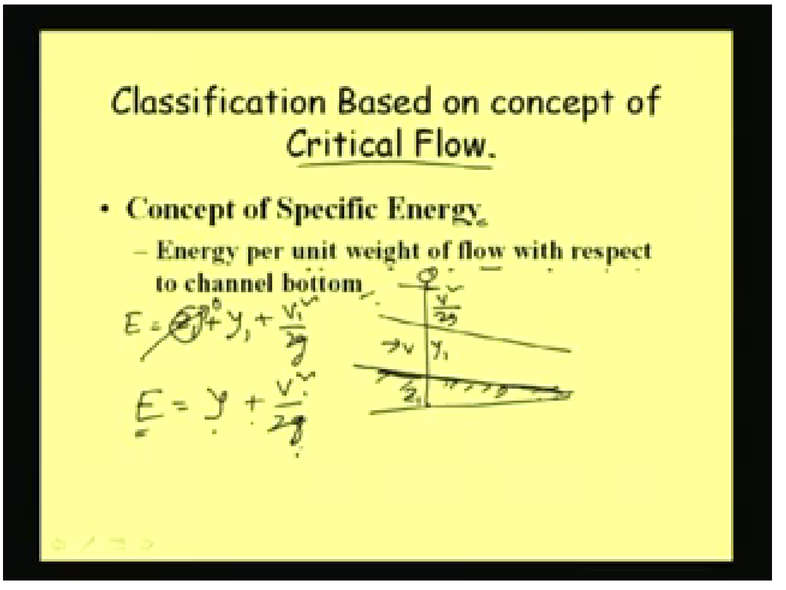

Well, again this, what is critical flow and all that, we will be discussing in more details about critical flow in our later part. But but to start with, what is critical flow? To give you a brief idea, we need to have the concept of specific energy; we need to have the concept of specific energy. So, what is specific energy? In our last class we did discussed that energy head at any section, we write as say if it is channel bed, then we can call this is as a depth y, and then say this is datum, we call z 1, y 1, then if it flowing with velocity V, then there will be energy V square by twice g. So, up to this much, it is the energy. So, we can write that energy at any level is equal to say z 1 plus y 1 plus V 1 square by twice g, 1 represent a at the section one.

So, this energy is per unit weight of fluid that is why we will call it as a energy head. And then if we measure this energy with respect to channel bed that means, our datum itself is becoming the channel bed. So, we are talking about the energy per unit weight of flow with respect to channel bottom. So, when we say it is respect to channel bottom that means, this z term is becoming 0. So, our energy is becoming y 1 plus V 1 square by twice g of course, as we are saying about general without referring to a section. So, we can write that y plus V square by twice g. And that energy we call as a specific energy. So, when we say definition of specific energy, we call it the energy per unit weight of flow with respect to channel bottom, and this is nothing but E is equal to y plus V square by twice g.

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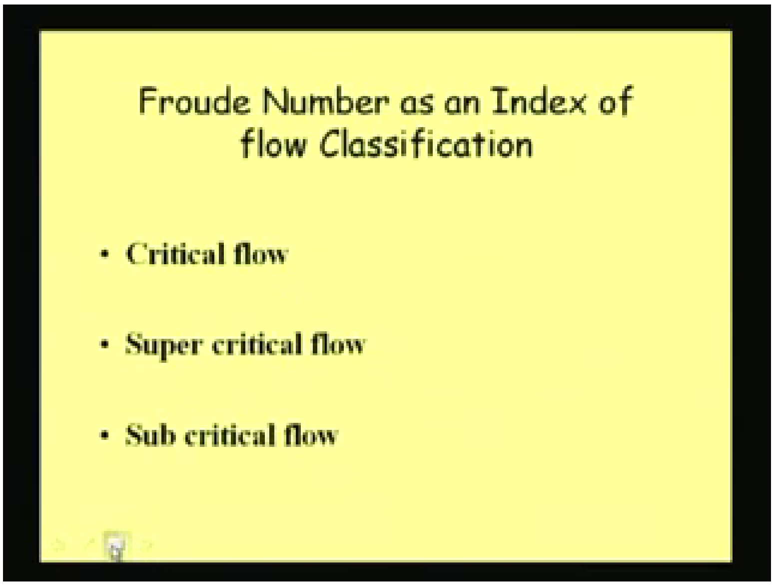

Well, now let me try to give you another concept say a water, some amount of water is flowing in a channel. Now let me just keep this expression that E is equal to y 1 plus y plus V square by twice g; and in this channel amount of discharge Q is flowing. And what is discharge? Suppose in normal condition, you have this much of depth y, and then it is flowing with a velocity V.

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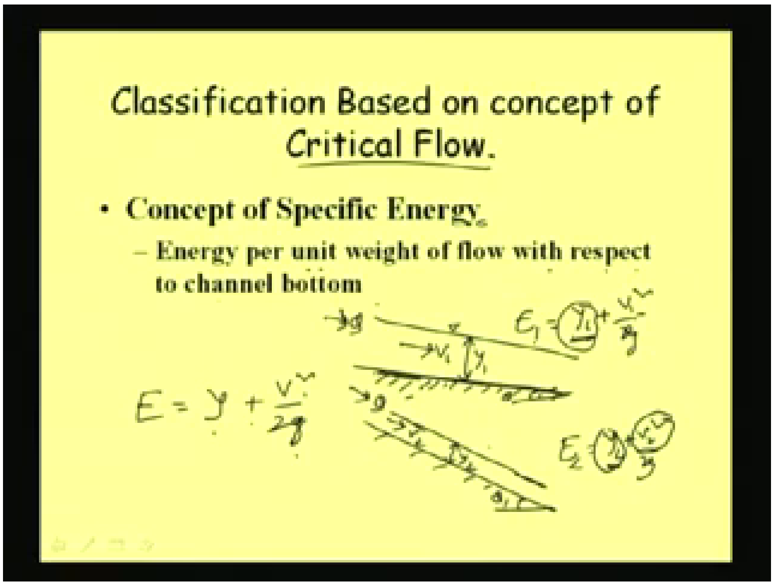

So, it will have some energy that will be y plus V square by twice g. Now suppose the same amount of discharge Q is flowing, and I have increased this channel slope this channel slope here is suppose theta, and I have increased this channel slope like that; say this is theta 1, I have increased the channel slope. Now what will happen to the flow the same amount of discharge is flowing, Q is same. So, definitely when you are increasing the slope the flow velocity will increase; and when the water is moving fast then same amount of discharge is moving faster. So, depth will become placed, depth will come down depth will come down.

So, now if I say it is y 2, now I can again use index; suppose in this case, it is y 1 V 1 and here it is y 1 and it is flowing with a velocity V 2. So, for the same amount of discharge, if I increase the slope here the velocity become V 2 and depth become y 2; and for these it has energy say E 2 is equal to y 2 plus V 2 square by twice g; and for these E has energy E 1 is equal to y 1 plus V 1 square by twice g. Now is it possible to say just concentrate on these two equation, and these two relative value; now is it possible to say that whether E 1 is more larger than E 2 or say E 2 is larger than E 1 is it possible, because it is definitely not possible just by observing, because here this two terms are there one is y 1, y. Depth another is velocity. Now, in this E 1 your this term is more than that is y 1 is more than y 2; but the V 1 is less than the V 1 is less than V 2; and here again V 2 is more, V 2 is larger, but y 1 is less. So, we cannot definitely say that which one will be more, which one will be less, and then if we just change this slope this energy level is changing.

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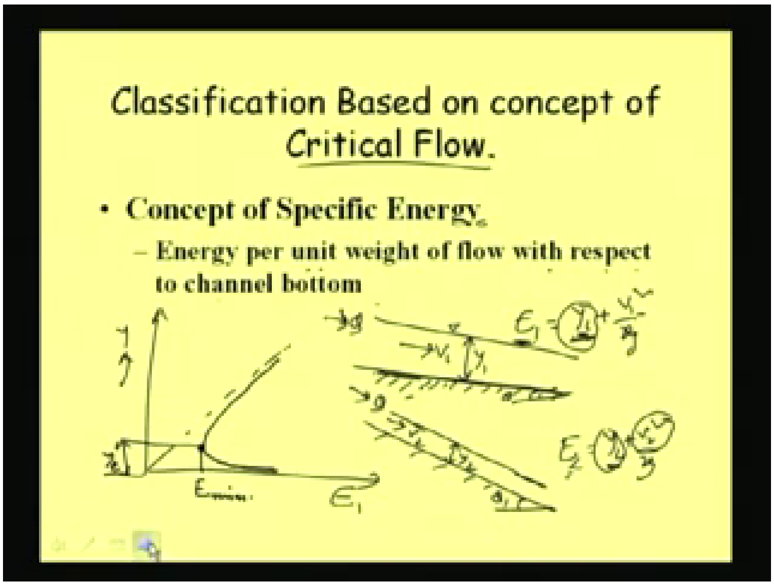

And for a particular slope, we may have a situation for which we can have the minimum specific energy that means, if I draw a graph if I draw a graph, it will be like that say energy if I plot in this side, and say depth I am changing for the same discharge, I am changing the depth; then this is a line, then I am plotting E versus Y, and then again one point that as I am writing this energy versus Y plotting this one energy versus Y. So, this is plus something energy versus Y plus V square by twice g.

So, if I plot E versus Y, a line then so this is a 45 degree line, and it is always we have that positive term, V square will always the positive term. So, total energy will always be on the right side of this 45 degree line, because this line represent E equal to Y. So, something more than that means, E is something more than this means, it will be always on the right side, and then if you draw a line it will be like this. And you will find that with change of say with change of depth, this energy is changing; and then for a particular value of Y you will be having a minimum energy, you will be having a minimum energy and this particular depth is called critical depth this particular depth is called critical depth.

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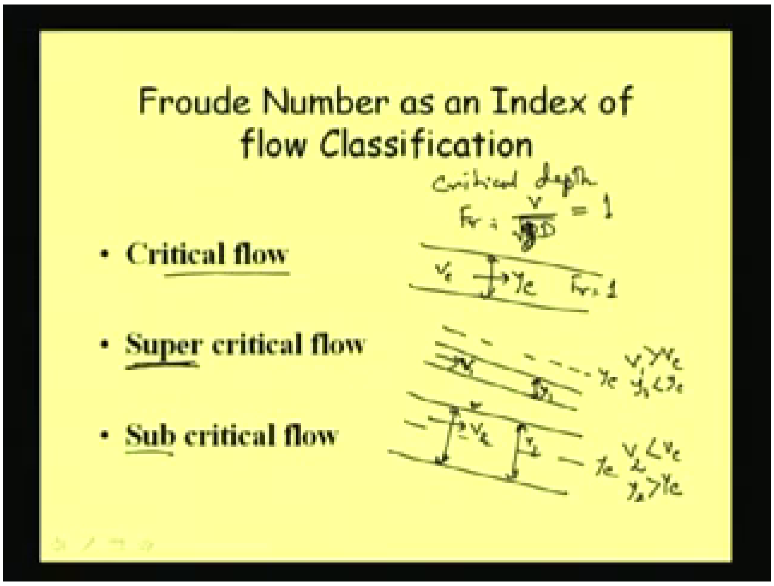

And then another important point; for the critical depth for the critical depth, the Froude number, (( )) also you know what is Froude number. So, Froude number is equal to so V by velocity by root over g D, g into D g from this side to D and D and this is equal to 1. So, for critical condition this Froude number becomes equal to 1. And so this Froude number can be used as a index for classifying this sort of proof. So, when the flow depth is critical, then it is called as a critical flow. And when the flow depth is suppose, this is critical depth that means, when the water is flowing with this, I am writing Y c critical depth, then your V square by g D term become 1 that is Froude number is equal to 1.

Then when the depth of flow is less than this one, when the depth of flow is less than this one say this is our critical flow depth, Y c if the depth of flow is less than this one, then we call this as a super critical flow. Now in fact, a generally the super terms comes when something more, but here when depth of flow is becoming less than critical depth, we are saying super why? Because basically, we are naming it in terms of the velocity here the velocity is more than the velocity of the critical flow say if I write it as velocity in critical flow, then this velocity will be more than that. So, that is why it is called super critical flow.

And then, when we talk about sub critical flow, this depth will be suppose it is critical depth Y c, and this depth will be more than the critical depth. So, then it is called as a subcritical flow. And here again the velocity basically the flow velocity is less than the critical velocity if I write this as V 1, this is V 2, then what I can say that V 1 is V 1 is greater than V c here, and if here the V 2 is less than V c; and of course, depth in a in terms of depth, if I write it as y 1, this is say y 1, then we can call here say y 1 is less than Y c critical depth, and here it is y 1 is greater than Y c. But thus many a time it get confused which one is sub, because sub generally refers to lower value that is why suppose you may confused that when it is y 1 is less than Y c, then it is sub, but it is not basically, we are referring it this suffix are coming, the prefix are coming, because of this velocity concept. So, that way we again classify the flow as critical flow, super critical flow and sub critical flow.

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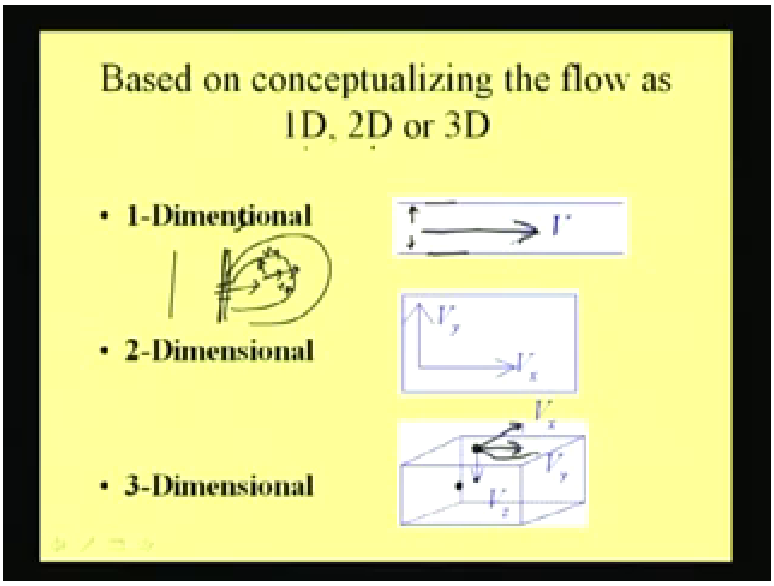

Well, then another classification we have that we make in terms of whether we are visualizing the flow as 1-dimensional, 2-dimensional or 3-dimensional, this is particularly for analyzing the flow. So, for some case for some case, we can analyze the flow as 1-dimensional suppose in a very narrow channel in a very narrow channel flow is occurring, and then velocity in the lateral direction velocity in the lateral direction say, it is a very narrow channel; you can refer to the slide this say velocity in the in this narrow channel say we are having this velocity flowing like this. And say component of this velocity or suppose velocity in the lateral direction is very insignificant neither in this direction that direction; and maybe in the in in the vertical direction also, the change of velocity is not that significant, then we can call this as a 1-dimensional flow.

So, what we will consider that flow is moving in 1-dimensional, in in one direction that is called 1-dimensional flow. Now in some case suppose a flow is occurring in a wide valley, in a wide valley, say in that case the there may be significant component of velocity in both the direction, let me give you one example suppose this is one river, and the another sub channel is there, which is also suppose a wider or suppose there is embankment, and this has fail somehow, and the river from water from this side has flown into that side. This also we can consider as open channel as it is flowing over the surface, and then here it will be moving like this; and in that case, the flow direction V in this direction and other direction V y, suppose these are also significant say if we call this is V x, V y these are significant.

So, we cannot neglect the flow in the other direction, lateral direction. So, that we call as a 2-dimensional flow. And similarly in some cases, the flow in the vertical direction, there may be some component of flow, a fluid we are considering here suppose this this I am considering here. So, it can it is moving suppose in this direction. So, there can be a vertical component of velocity, and a component of velocity in this direction, and in this all the three direction it may have significant component of its velocity. So, in that case we refer this particular flow as 3-dimensional.

And based on this consideration that is basically we are visualizing in real situation always the flow will be 3-dimensional. But considering the significance of the velocity in other direction or in all the dimensions directions, we can just classify it as 1-imensional, 2-dimensional and 3-dimensional flow. Well, so what we could see that we have classified the flow based on different criteria based on different criteria. And of course, we have just tried to see that how we can combine these classifications to give a name to a particular type of flow.

And in the next class, we will move to another aspect that here we have seen to some extent; the flow velocity is not a single value, when the flow is occurring through a channel it is not a single value; it is basically, the flow value velocity can be different at different part of the channel. Then in our competition work, how we will tackle this problem; how we make this sort of correction, if we consider this as a single flow velocity, so that we will be discussing in the next class. Thank you very much. We hope we will be going in a better way in the next class.