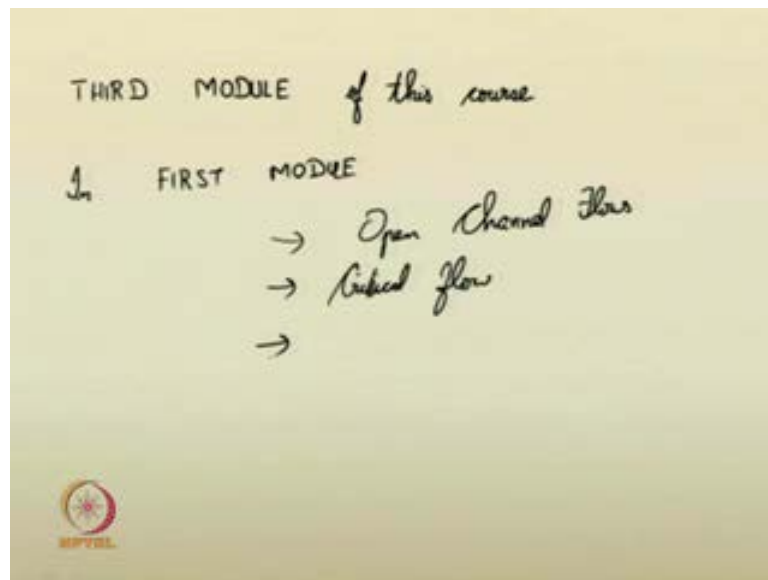


Advanced Hydraulics
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Indian Institute of Technology, Guwahati

Module - 3
Varied Flows
Lecture - 1
Introduction to Gradually Varied Flows

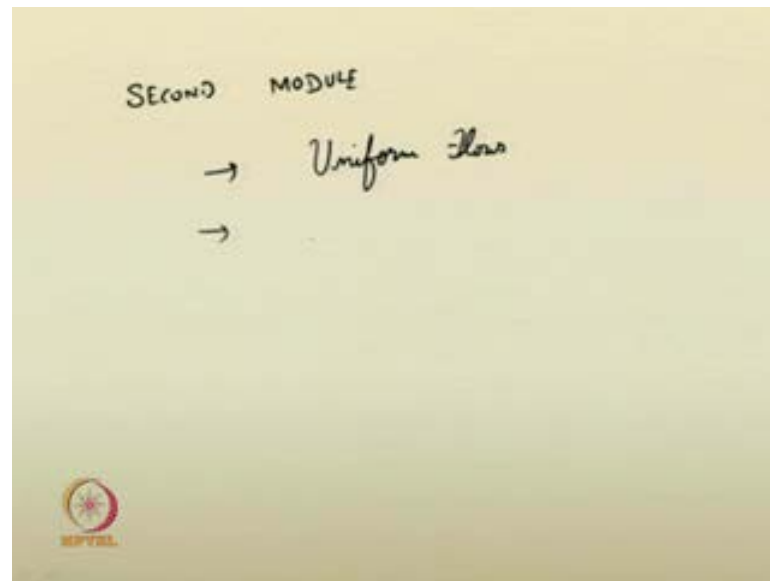
We are back into our lecture series on Advanced Hydraulics. Today, we will start the module three. The module three is on varied flows.

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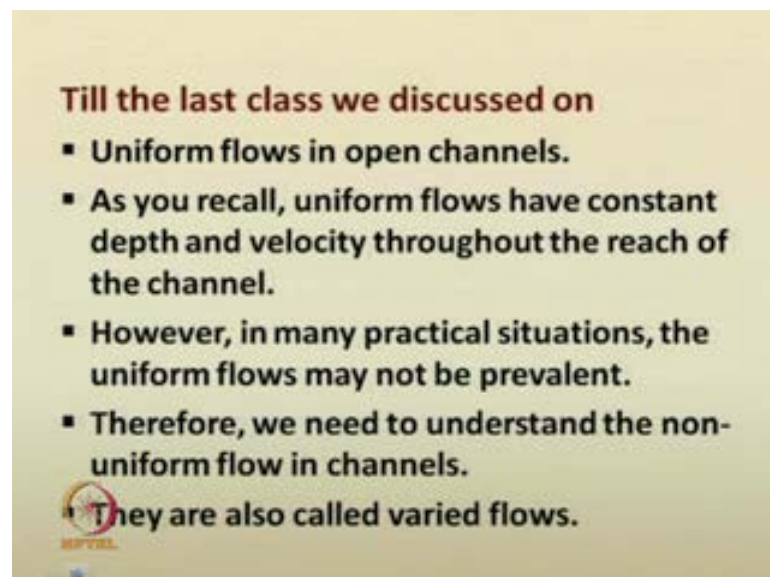
So, if you recall that as we mentioned, we are today going to start on the third module. If you recall back the first and second modules, the first module you had, in the first module you had briefly gone through the open channel flows, what are the various open channel flows; you have also, we have also described about the critical flow, we have also described about the sub critical flow and super critical flow, various aspects on the general open channel flows; these things we are described in the first module.

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In the second module, we discussed on uniform flows; what is uniform flow assumption; how we can assume uniform flow in various natural conditions; what are the process to analyze uniform flow; all those things we had discussed. We have discussed about the design, aspects of uniform flow also, in some of the thing.

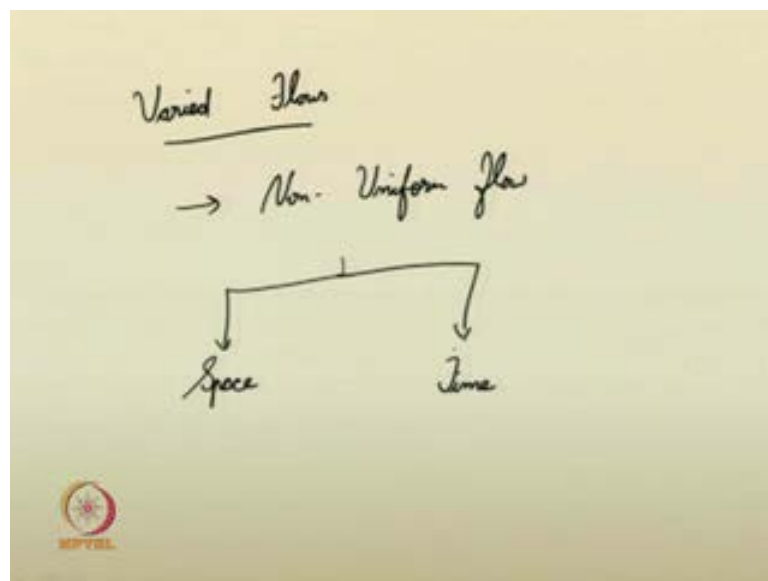
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If you recall, especially in the last class, till the last class we discussed on the uniform flows in open channels; the, they have constant depth and velocity throughout the reach of the channel, that is what is meant by uniform flow.

So, but now if you look into the aspect now seriously as we covered two modules, and now you have gone through various feel condition, you might have gone already gone through the feel conditions you might have gone already gone through the feel conditions and all. You may see that the uniform flow approximations are not that suitable for many of the natural process. So, what should be done? We need to understand the non uniform flow mechanisms. So, many of the non uniform flow, they are called varied flows. So, this module deals on the varied flows. So, what are the various types of varied flows, or what is meant by varied flow and all?

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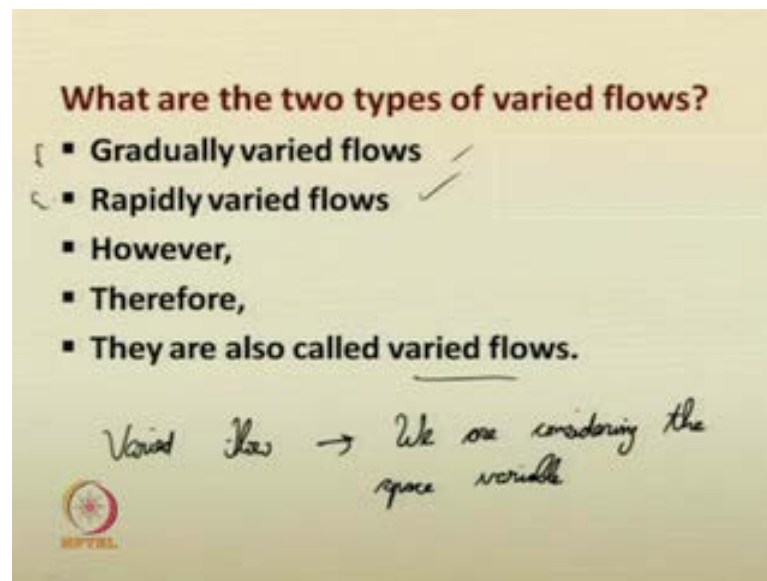
So, that is generally, the non uniform flow in open channel, they are called varied flow. You may encounter several type of non uniform flow. Some of the cases, you may, you might have seen how if you construct a dam, from the spill way the water splashes out to the downstream. This is the particular type of non uniform flow. We will discuss on what is that category of non uniform flow called, that lecture, in the later part of this lecture, in this lecture series we will discuss on those things. You will see that if there is any block in the flow path, the water in the upstream gets rise, a way may get generated; these things are also non uniform flow.

So, we will deal all those things. So, non uniform flow mainly based on how the uniform key of the flow condition varies with respect to space as well as time, that is the way we consider non uniform flow; especially, if the flow varies with respect to time, you know

that it is called unsteady flow. And if it is, if it varies with respect to, if it varies with respect to space, it is called distributed flow; or in hydrology especially, in hydrology courses and all, one might have already studied distributed flow, lamp flow and all.

So, these things we will see according to our course structure and all; how to study this non uniform flow mechanisms? How the flow may vary with respect to space or with respect to time or with respect to both?

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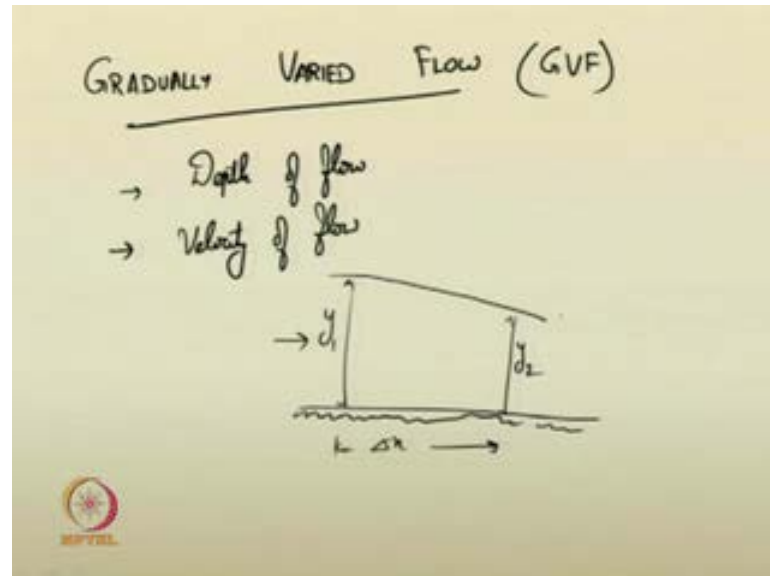


So, there are mainly two types of varied flow, that is gradually varied flow and rapidly varied flow. So, we can, in general call them varied flows, both of them. The, how the flow varies gradually with; so here let me inform you, the varied flow we are considering the space variable. So, it is not the temporal component that is been taken into account. So, this, in this space variable, so how in specially the properties of the flow that is the depth of the flow, the velocity of the flow, all those things; how it vary with respect to the space, or one, if one travels from upstream to downstream these properties of the flow if it varies, that is non uniform flow.

And, in this non uniform flow, there are two main categories that is, gradually varied flow and rapidly varied flow. So, two varieties are there, two types of non uniform flows, or two types of varied flows are there. In addition to that if the flow varies with respect to the time, that is also taken into account and those category of flows are called, specially

varied flow. So, I have not written it here, but those quantities are also coming into picture in general open channel flows.

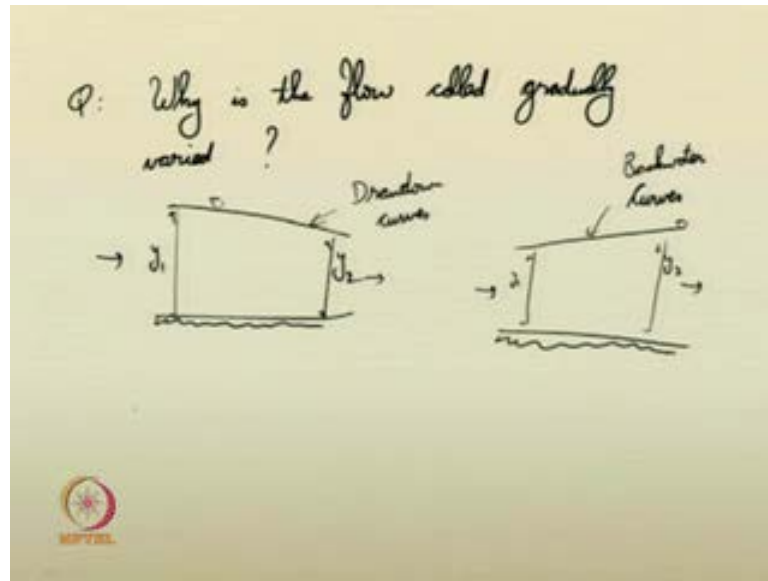
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So, we will begin with the gradually varied flow. So, we can give in a short, GVF also. So, here onwards, wherever I give this abbreviation GVF, it means the gradually varied flow. So, gradually varied flow in open channels, it is a non uniform flow as we mentioned earlier, the flow aspects like depth of flow, velocity of flow. So, especially these two properties they changes gradually along the reach of the channel.

So, if you have certain reach of the channel, then it may gradually change the depth of flow, say, here the depth is y_1 , here the depth is y_2 . So, as it proceeded from upstream to downstream, a certain distance when you travelled, travel, the depth of the flow is getting reduced. So, this is the gradually varied flow, means, so that variation in the depth of flow is gradual. Similarly, the velocity, the change in velocity of flow is also gradual. So, it is not happening all of a sudden; and therefore, it is given by the name gradually varied flow. Gradually varied flow has certain assumptions and all, we will come into those things; precisely though, or those reasons only it has been named as gradually varied flow.

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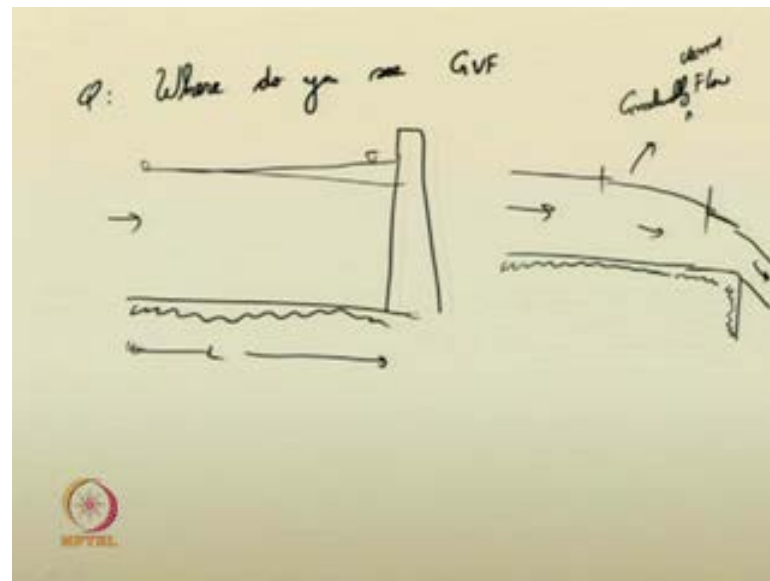


A question I like to ask to you is, why is the flow called gradually varied? Why is it called gradually varied flow? If you have specific answers, or if you know the things about that, you can please tell them. So, the flow aspects, as I mentioned earlier, it changes gradually. So, even Leman, if he may not able to witness the change in the flow aspects that is the depth of the flow and velocity of the flow and all, the changes in the considerably waiting one section to another section, that cannot be seen. So, it is varying only gradually. Therefore, many of such flows are called gradually varied flow.

So, I can just give in a figurative way, say, the depth of flow from initial to this thing, it is gradually varying of a certain traverse, this is y_2 as it, this is a particular type of gradually varied flow. You may also see a gradually increase in the depth of flow. So, such type are also witness in many of the open channel conditions. So, they are all due to the change, due to the change occurring gradually, it is generally called gradually varied flow.

Moreover, if the depth of the flow, if it is decreasing, as you, as it flows from the upstream to the downstream, then the surface of the water that is the water surface profile, they are called drawdown curves. If the water surface, if it is increasing gradually as it flows from upstream to downstream, then the water surface curves are called back water curves. So, the, one can easily understand the, those things, the meaning of this thing. So, we are not going to further discuss on the language of those two terminologies.

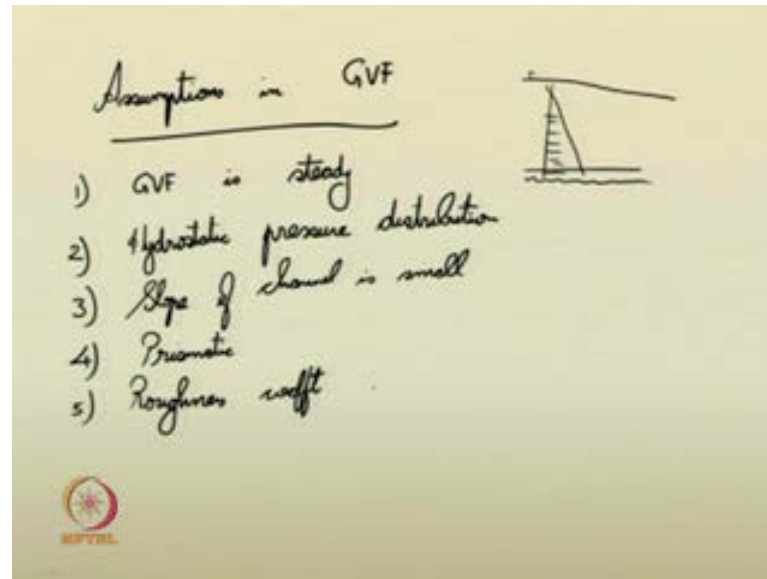
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Next question I would like to post in front of you is, where do you see gradually varied flow? Where do you see gradually varied flow? So, if a dam is constructed on a river, for example, let me just draw our river bed, you are taking a considerable reach of the river, say, there was a uniform flow initially in the river, the river was having uniform flow; suppose, if you construct a dam now, across this channel, so initially the flow surface, the water surface was of this form. Now, due to the dam construction, you may see that there is a gradual increase in the water surface. This is a back water curve. This is, you can see gradually varied flow of, in this case, the depth of the flow is gradually increasing as you move from upstream to downstream.

One can also see, for example, in the same type of uniform flow, a channel if it is having uniform flow, suppose if it is witness to some sought of sudden drop in the bed of the channel, say, the bed of the channel, it can suddenly drop, you may have seen some step channels and all, or the bed just drops in step form and all. So, now, the channel was already having a uniform flow. Due to this drop here, you may see a gradual reduction in the depth of water like this, then it will flow like this. So, this portion, this is also a gradually varied flow; it is also gradually varied flow phenomenon. So, you can see gradually varied flow in such situations as well. So, these are some of the two classic examples where gradually varied flow has witnessed.

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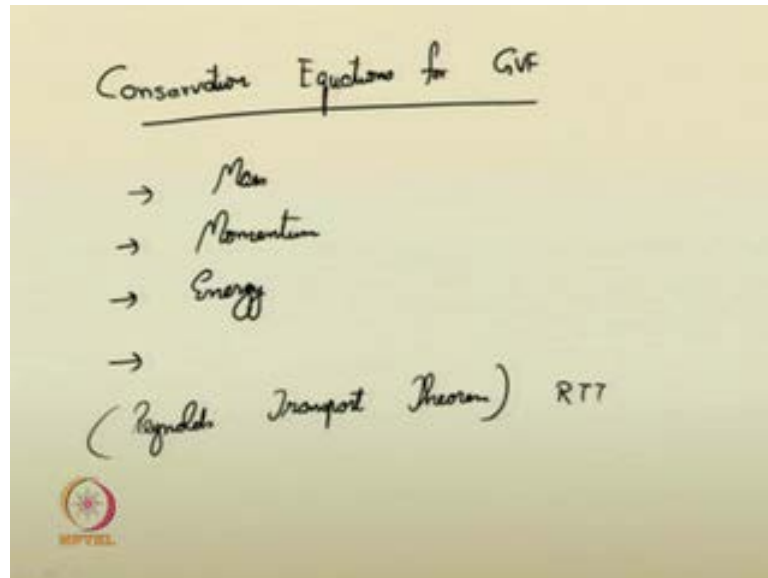
What are the assumptions involved in gradually varied flow? Let us innovate some of the assumptions in gradually varied flow. The premier most, the one of the most important criteria is, the gradually varied flow is steady; I mentioned earlier, you can have varied flows with respect to non uniform flows, with respect to space as well as time. So, here the flow is not varying with respect to the time, it is a steady flow; still as it is varying with respect to space, therefore, this, it is, it comes under the varied flow criteria category, and the parameters are changing the gradually; therefore, it is gradually varied flow. So, gradually varied flow, it is a steady flow phenomenon.

Mostly we consider the hydro static pressure distribution. So, inside the, say, if the channel bed is like this, the flow profile is like that. So, as you go by depth, the hydro static pressure phenomenon is valid here, that is the pressure increase with respect to the depth from the surface of water, from surface of water, as you go down the pressure increases hydro, in a hydro static way. So, that assumption is true for the gradually varied flow.

We assume that the slope of the channel is small, we assume the slope of channel is small; we are also considering the channel as prismatic that is the channel is not changing its cross section as we proceed from upstream to downstream. So, that prismatic condition has to be maintained; we are also suggesting that roughness coefficient is same, roughness coefficient, it is not varying with respecting to depth of

flow, it is constant for the problem. So, based on these assumptions one can start analyze the gradually varied flow.

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So, as this is a post graduate course, we will be trying to analyze it in more regress, regress, in a more philosophical way, or you have to use the general equations that are holding good in any of the physics. So, those things you have to apply here in the gradually varied flow and try to analyze them.

So, let us see the conservation of equations, the conservation equations for gradually varied flow. What are the basic conservation equations? Conservation of equation for mass, conservation of equation for momentum, conservation of equation for energy, then conservation of equation for enthalpy and all, it is a, however, as we are dealing with open channel flow where the flow is predominantly incompressible and all, the conservation of enthalpy and all, we are not going to consider here in the syllabus. So, the conservation of mass, momentum and energy, let us see how these equations, how these property or how these principles are applied in the gradually varied flow.

So, if you recall the uniform flow, in the uniform flow also we had developed some fundamental conservation equation, especially while deriving the Chezy's equation and all, we have suggested the fundamental conservation equations that can used. So, there we applied for the conservation of mass from the continuing approach, if anyone who study continue mechanics, or if anyone who have studied flood mechanics, hydrology,

all this courses and all, you might have heard about the equation Reynolds transport theorem.

So, this we have already informed to you, means we have already covered this portion Reynolds transport theorem, briefly we have informed about it in the module on uniform flow as well. So, again I am repeating it here, the Reynolds transport theorem. Reynolds transport theorem suggest the material derivative that is the material concert, it is from Reynolds transport theorem one can develop many conservation equation.

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The slide is titled "RTT" and shows the following equation:

$$\frac{DB}{Dt} = \frac{\partial}{\partial t} \iiint_{cv} \beta \rho dV + \iint_{cs} \beta \rho \vec{V} \cdot \hat{n} dA$$

Below the equation is a diagram of a rectangular control volume (CV) with dimensions Δx , Δy , and Δz . A velocity vector \vec{V} is shown entering the volume. To the right, a small diagram shows a control surface (CS) with a normal vector \hat{n} and a differential area element dA . At the bottom, a diagram shows a fluid element (a small cube) with a velocity vector \vec{V} and a normal vector \hat{n} . Below this, the text "Water -> Solid -> Continuum" is written, with a small circular logo to the left.

So, the Reynolds transport theorem, RTT, it suggest that the material derivative of any extensive property B, capital B. So, I am denoting the material derivative as capital D B by D t. So, this material derivative of this quantity is nothing but the time beta change of that property stored inside the control volume, plus the net out flow of that extensive property across the control surfaces, across the control surfaces of the volume. So, now you may be confused, why I am using certain terms called control surfaces, control volume, control means extensive property, intensive property and all, I have used those terms here, in this equation, what do you mean by those things and all.

Control volume, you can just suggest, say, if I take arbitrary shape, any arbitrary; here I am just taking a rectangular box of dimension del x, will be del y, del z, if I take such an arbitrary shape, now this shape can be incorporated in any volume, or any of the continuum we are taking into account; you are fluid, the water which is a fluid, I hope

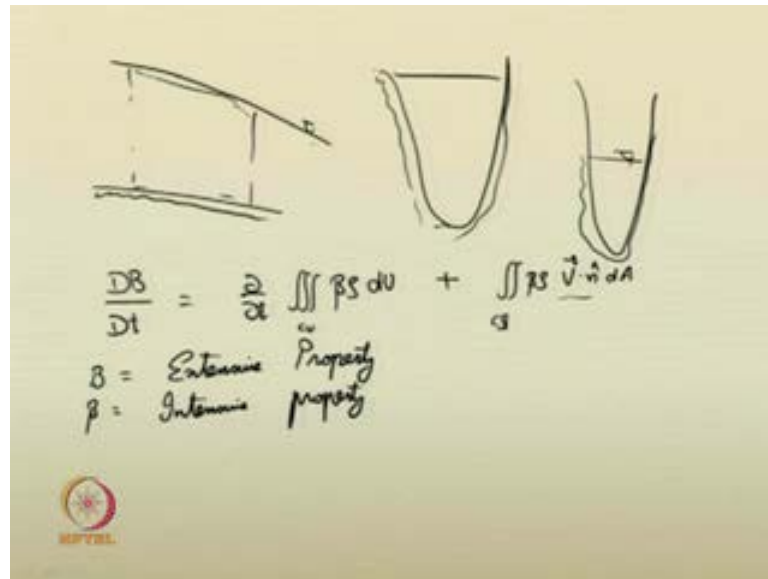
you know it is a continuum, most of the analysis on water is based on the continuum approach. So, it is a continuum.

So, if you take any arbitrary volume, arbitrary volume of the water, so if you have a specific size, specific dimensions for those things and all, then based on the continuum approach, you can suggest that volume as a control volume; you can also infer that any property, extensive property on that control volume, so that material derivative of that extensive property is nothing but the time derivative of, the time derivative of the net extensive property generated or lost inside the control volume, plus whatever outflux of the, outflux that is net outflux, both in outflux as well as influx is been consider here, of this extensive properties across this control surfaces, they are also coming into picture. So, can one easily denote that; when you consider the channel reach the of a gradually varied flow, when you are taking the two sections, now these two sections, the volume included in, within this two sections, you can consider as a control volume now.

So, whatever mass, or if the extensive property if you are taking it as mass, or if you are taking the extensive appears momentum or energy, whatever extensive property, that material derivative of that extensive property in this control volume is equal to the amount of extensive property generated inside this control volume, plus whatever moment or whatever quantity of this extensive property is transferred through the control surfaces of this control volume, they have to be related.

So, that way we are now going to, that this thing we have clearly discussed in the derivation of Chezy's equation also, if you remember them; so the same property now we are going to apply in the gradually varied flow.

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So, here, the channel reach is been taken, control volume is suggested. So, you can have the cross section in the upstream like this, in the downstream like this, may have that, whatever be. So, in this control volume, the Reynolds transfer equation, if you use them; so please note that here the velocity has been represented in a vectorial form, $\vec{V} \cdot \vec{n}$, that is the, it suggests the component of velocity in any of the plain surfaces, any of the surfaces of the control volume, that is any of the... So, along that surface, that is across that, perpendicular to that surface, how much amount of that fluxes coming out, that is being suggested by this quantity $\vec{V} \cdot \vec{n}$. So, that you have try to infer them. B is your extensive property, so extensive property, that are related, the properties that are related with mass, if you recall them, that is n by B ; small β is the intensive property; then you have volumetric as well as the aerial integral.

So, if you apply to the control volume of the fluid in the gradually varied flow phenomenon here, you will see, let us start with conservation of mass first, start with conservation of mass first.

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Conservation of Mass

$$B = m$$

$$\frac{dB}{dt} = \frac{Dm}{Dt} = 0$$

$$\beta = \frac{m}{m} = 1$$

$$0 = \frac{d}{dt} \int_{CV} \rho dV + \int_{CS} \rho \vec{V} \cdot \vec{n} dA$$

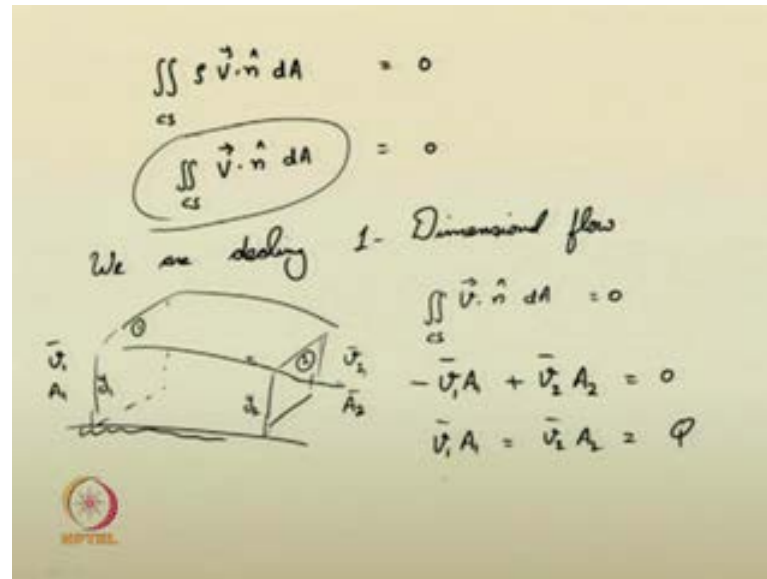
Total rate of change of mass stored inside the CV
The net outflow of the mass across the control surface

So, your extensive property is mass. Therefore, the material derivative of mass is 0. I hope you understand them; mass can neither be created nor destroyed. The intensive property m by m is equal to 1. We are considering incompressible fluid, so ρ ; it is not going to be change with respect to the space as well as with respect to time. So, you have your Reynolds transport equation as dA ; now, very simple thing.

There are two terms in this equation; on the right hand side there are 2 terms. So, the first time term suggest the total rate of change of mass stored inside the control volume, it is the total rate of change of mass stored inside the control volume; and this quantity gives the net outflux of the mass, the net outflux of the mass of water across the control surfaces of the control volume.

Now, recall the assumptions given in the gradually varied flow; so as we have suggested, the flow is steady. So, definitely, you can see that, you can see this quantity can vanish; the flow is steady, this quantity vanishes.

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So, you can now easily suggest, the net outflux of mass across the control surface of the volume, control volume is equal to 0. What does this mean? As we have suggested the water liquid considered in the control volume, water is incompressible. So, this is nothing but $\vec{V} \cdot \hat{n} dA$; \hat{n} is the unit outward normal vector of any control surface, we are taking into account. So, $\vec{V} \cdot \hat{n}$ is the component of velocity of water that is perpendicular to the plane of the surface which you are going to take into account.

So, if you expand this thing; we are dealing with one dimensional flow, as mentioned in the beginning of this lecture series itself, mostly the river flow or channel flow they are one dimensional in nature that is predominant dimension, predominantly it will be moving in the horizontal direction, in the x direction. So, that one dimensional flow is been taken into account. So, we are dealing with one dimensional fluid flow.

So, the control surfaces, if you have, if you draw it in a 3 dimensional way, so this is the 3 dimensional way. So, this particular surface as well as this particular surface, they, those 2 surfaces allow the flow inside to the control volume as well as it allows the flow outside the control volume. So, you can now easily find the things here. I can write this particular equation. So, this is section 1 1, this is section 2 2. So, the quantities here are V_1 , the average velocity across this cross section is V_1 bar, area in A_1 bar; let us suggest the, here it is V_2 bar, A_2 bar, depth of flow it is y_2 here, it is y_1 here.

So, this thing $\mathbf{V} \cdot \mathbf{n} dA$ is equal to 0, as this is a dot, you understand this is a dot product means we are only taking the magnitude. So, I am taking the magnitude of the velocity, and that to the average velocity for the entire cross sectional of the area. So, you know this outward normal vector for this left hand side, it is in the negative direction of the x; whereas for the second section, section 2 2, the outward normal vector, it is in the positive direction.

So, $\mathbf{V} \cdot \mathbf{n}$ for the section 2 2, it is a positive quantity; whereas $\mathbf{V} \cdot \mathbf{n}$ for the section 1 1, it is a negative quantity. So, I can write this as $\bar{V}_1 A_1$ plus $\bar{V}_2 A_2$, definitely we are not writing A_1 bar like that, $\bar{V}_2 A_2$ is equal to 0, where \bar{V}_1 is a average velocity in the cross section area A_1 , \bar{V}_2 is a average velocity in the cross sectional area A_2 .

So, what does this mean? $\bar{V}_1 A_1$ is equal to $\bar{V}_2 A_2$. So, this is your discharge Q . And as we have already mentioned the flow is steady, so the discharge across any cross section it will be same, only the velocity and the cross sectional area will be the different. So, that gives you the continuity equation.

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Conservation of Momentum

$$\frac{DB}{Dt} = \frac{\partial}{\partial t} \iiint_{cv} \rho \mathbf{u} dV + \iint_{cs} \rho \mathbf{u} \cdot \mathbf{n} dA$$

$\mathbf{B} = m\mathbf{u}$
 $\rho = \frac{m}{V}$
 Rate of change in momentum = Net force acting on the cv
 (One dimensional flow)

If you, if you want to deal with a conservation of momentum equation, so same control volume approach you take, again let me write the same equation $\frac{DB}{Dt}$ by $\frac{D}{Dt}$ this is equal to $\frac{d}{dt}$ of integral, volumetric integral $\rho \mathbf{u} dV$, plus control surface $\rho \mathbf{u} \cdot \mathbf{n} dA$. So, I hope you are able to understand the dV is the integral variable, that is

So, we are suggesting that if you integrate ρu for the entire whichever volume is taken into account, that will give you the total volume all those things.

So, now your extensive property B is equal to ρ into V , actually. So, I can give it in vectorial form also, it does not matter. Now, if I give it to you, let us give it in vectorial form to you in the beginning, later on we will take the magnitude. Therefore, your β , small β will be equal to V . What does this mean? What does this Reynolds transport equation clear on? Or, Reynolds transport equation meant for the momentum, for the momentum quantity.

So, if you apply the extensive property as momentum, you will see that the left hand side is the net change in, that is the rate of change of momentum in the control volume, change of momentum in the control volume, that is equal to the net rate of change of momentum stored inside the control volume, plus the outflux, net outflux of momentum, or the net momentum flux across the control surfaces of the control volume. So, like this one have to interpret the equation here.

According to the physics law, so rate of change in momentum, what is this is? This is equal to the net force acting on the control volume, that is the physics law. According to the Newton's law, you can see that rate of change of momentum is equal to net force acting on the control body. What are the, as we are suggested again, one dimensional flow we are taking into account, we are taking one dimensional flow into account, so the net force now you have to deal it in the direction of flow, that is say, in the x direction.

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$\sum F_x = \text{Rate of change of momentum in } x\text{-direction}$

Flow is steady

$$\frac{D(m\vec{V})}{Dt} = \iint_{CS} \vec{F} \cdot (\vec{V} \cdot \hat{n}) dA$$

\downarrow
 $\sum F_x$

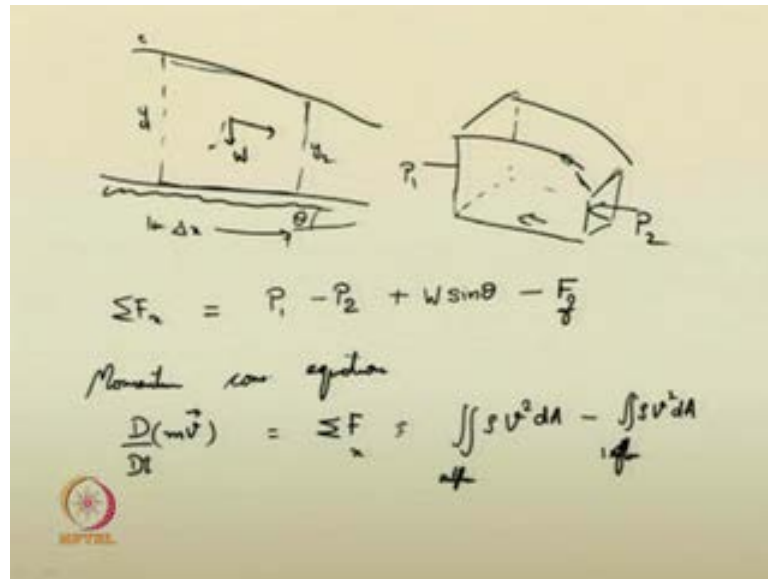
- \rightarrow Forces due to pressure
- \rightarrow Gravitational force
- \rightarrow Frictional forces



So, I can give the net force as $\sum F_x$. This is equal to the rate of change of momentum in x direction, it is the rate of change of momentum with respect to time in the x direction. Flow is steady, so if the flow is steady, what does that mean? This particular portion of the equation, this particular portion of the equation, it vanishes. So, you will have, this is equal to $\vec{V} \cdot \rho \vec{V} \cdot \hat{n} dA$. So, the net forces, what are the various forces acting on the control volume? That you need to interpret; so this gives you the net force.

So, as we are dealing in the x direction, so we can suggest $\sum F_x$. So, the net force acting in the x direction, what are they? Forces due to pressure, gravitational force, and of course, the frictional forces. So, if you recall the uniform flow, there are also have dealt with the same approach. So, the various forces due to pressure gravitational force, frictional force, all these things you need to take into account.

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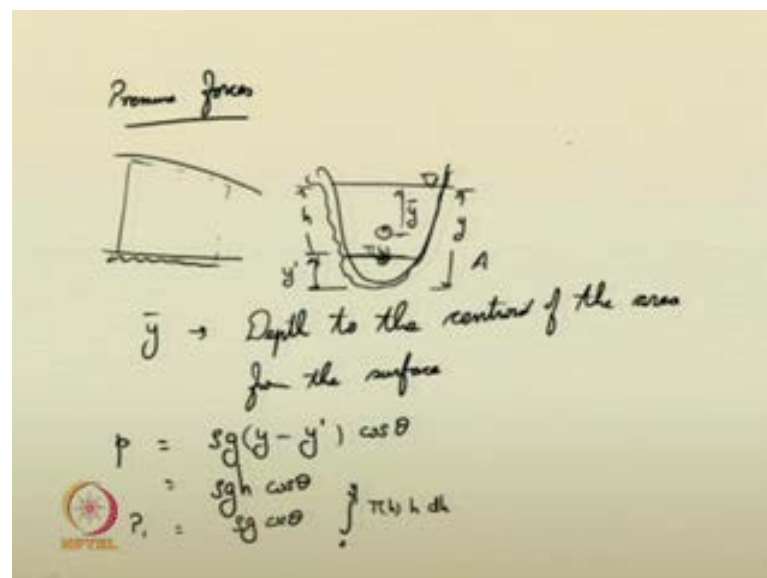
So, if I take the control volume like this, so here the depth of flow is y_1 , here the depth of flow is y_2 , let us assume it as y_2 ; let us suggest that the separation is Δx . Then in this case, let us consider that the weight of the liquid acting, it is vertically down, the bed slope, this angle is θ . Then you know that in the flow direction, this is the x direction, there is one component of the weight, there is one component of the weight in the flow direction. So, that can you compute easily. Similarly, you can compute the normal component of weight. Now that is normal to the bed surface, that also you can compute.

So, as we have dealing with the net forces in the x direction, you know that this is the control surface, as I have drawn earlier. So, I have drawn them earlier also. So, along this, in this control volume, you will see in this control surface, along this control surface, the pressure force will be acting in the wall, so as the control volume, in this direction; whereas, the pressure force will be acting on the walls of this control surfaces in this direction. So, let me suggest this as P_1 , this as P_2 , all other control surfaces are immaterial because we are dealing only in the x direction.

So, now, you can suggest that, so ΣF_x is nothing but equal to P_1 minus P_2 ; then the w that is acting vertically downwards; so the component of that allowing in the direction of the fluid flow, $w \sin \theta$; and another prick quantity, there will be friction force in the bed that will be in this direction, so let me give this as F_f . So, this will be your equation for the net forces acting on the control volume.

Your momentum consideration equation now, in the x direction for the gradually varied flow; so in the x of course, in the x direction, I can now suggest this as rho, the component of velocity as mentioned earlier along this, in this control volume the flux, the momentum flux that is coming out of this control volume from, along this surface, that is positive quantity; whereas the momentum flux quantity in the, along this, across this surface, perpendicular to the surface that will be a negative quantity, because the outward normal vector is in the opposite direction of the positive x. So, therefore, like that you can suggest now. So, I can write this quantity now as rho v square, I have taken only the magnitude now, influx rho v square d A.

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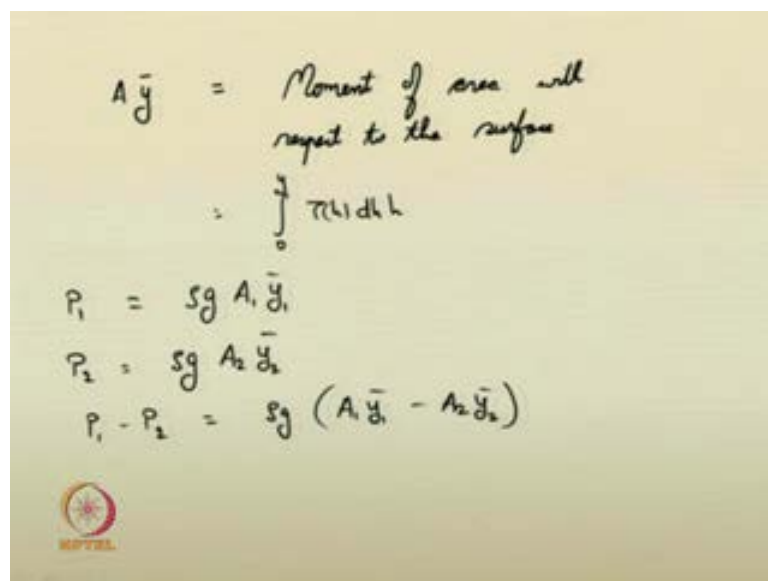
So, this equation can be further rearranged now. Let us see, what are the pressure forces? How we will compute the pressure forces? Again, I am just drawing the thing for your benefit. So, you consider any cross section. So, if this cross section area, if it is given as A, if the depth of flow, if it is given as y, the depth of flow is given as y; and suppose if this is the centroid of the area, so the centroid of the area naturally will be at a certain depth and we give it by the depth \bar{y} , \bar{y} is the depth to the centroid of the area, centroid of the area. So, this depth is calculated from the water surface. So, one can easily identify many properties now.

If I give these quantities here, at any depth, say, any arbitrary depth, if I just suggest this quantity, so this is, say, from the bottom at height y dash, then the pressure p, at this

point p, it is nothing but as you suggested the hydro static condition, $\rho g y \sin \theta$ minus $y \sin \theta$ dash $\cos \theta$. So, if you want to give this height as h, say, that is y minus y dash, h if you want to describe it, you are most welcome; you can then just give this as $\rho g h \cos \theta$.

Similarly, therefore, the pressure if you then consider this width of the water there, if you consider the width of the water there, you will see that the pressure force acting in this entire area, whichever area you are taking into account area, that can be given as the pressure into area, you just give that, that will be give you the pressure force. So, $\rho g \cos \theta$ 0 to y, and if this is the width, I can suggest this is now as t of h into h d h; like this you can evaluate the pressure force, that is most welcome, it is up to you to decide on that. So, one can easily use this relationship. Now, what does the quantity integral 0 to y, t of h into h, what does that denote actually; t of h into h d h, what does that denote?

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Handwritten notes on a slide:

$$A \bar{y} = \text{Moment of area with respect to the surface}$$

$$= \int_0^y \tau h d h$$

$$P_1 = \rho g A_1 \bar{y}_1$$

$$P_2 = \rho g A_2 \bar{y}_2$$

$$P_1 - P_2 = \rho g (A_1 \bar{y}_1 - A_2 \bar{y}_2)$$

At the bottom left of the slide is a small logo with the text "KAPTEL" below it.

You know, the depth or the area of the, area of the cross section, if it is A, and depth of the centroid is given as y bar, A into, A into y bar is equal to moment of area with respect to the surface of water, A into y bar.

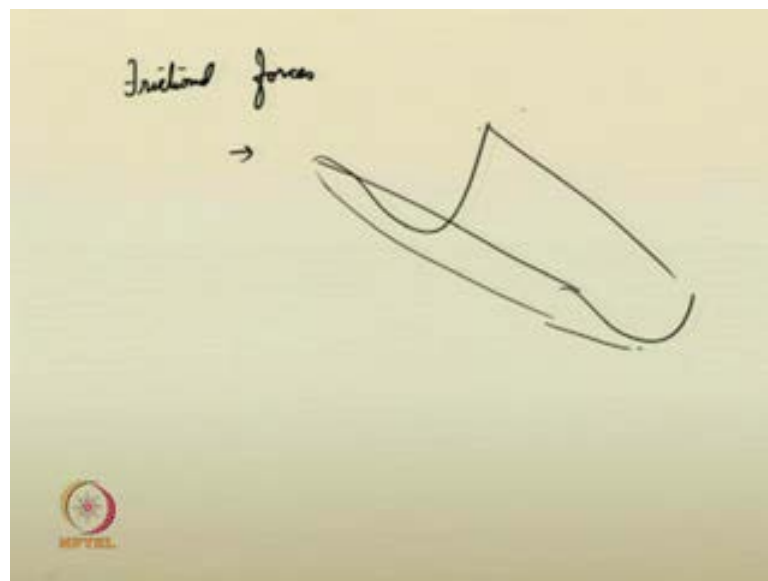
So, according to the notations given here, this quantity, 0 to y, t of h d h that will also give you the same quantity that is t of h h d h if you integrate it, if the along the total depth 0 to y; this is same as t of h d h into h. So, one can easily suggest now, you can think that you can incorporate now this quantity, A y bar directly instead of this

particular integral. So, P_1 , I can write it as P_1 is equal to $\rho g A_1 y_1$ bar; similarly, P_2 is equal to $\rho g A_2 y_2$ bar. So, the net pressure force will be equal to $\rho g A_1 y_1$ bar minus $A_2 y_2$ bar, understand.

Now, the next quantity in the net pressure, net forces, so net force include the pressure quantity that which we have already suggested. So, this quantity you have already suggested, P_1 , P_2 ; $w \sin \theta$, what is the component of the weight, if you know this in this control volume, weight that is density into, this distance is Δx , area into Δx , that should give you the weight. So, when $\sin \theta$, you just get the component in this $\sin \theta$ direction. So, you will get the component in the x direction.

The next quantity is frictional F_F , that is, what are the frictional forces? What are the things that can give you the friction forces? So, those things how to continue our derivation and all, we can see them.

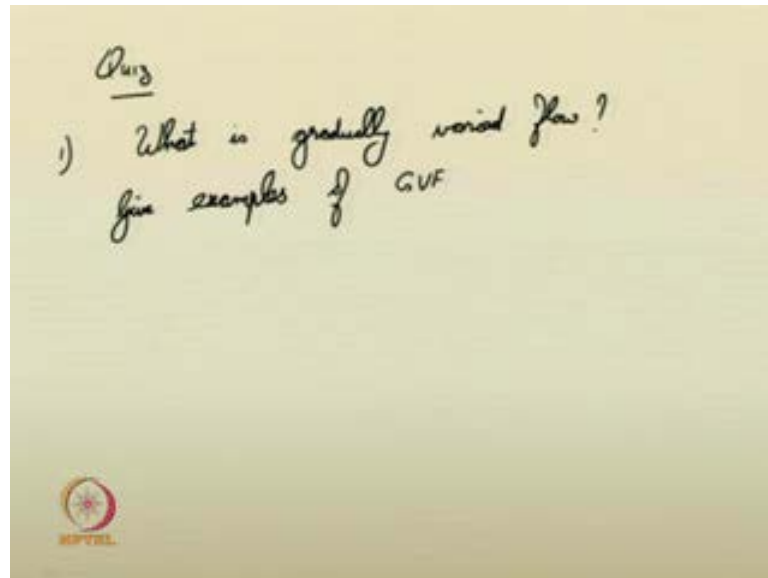
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The frictional forces, you can see them now; that is, entire bed of the channel, as you mentioned, as you are given the figurative representations earlier for many of the cases; now, entire side section as well as the bed of the channel, all those things will contribute to the shear force or that will oppose to the, oppose the motion of the liquid. So, you need to take into account the friction being developed, that is mostly due to the shear stresses; you need to take into account all those things. So, we will see them. The

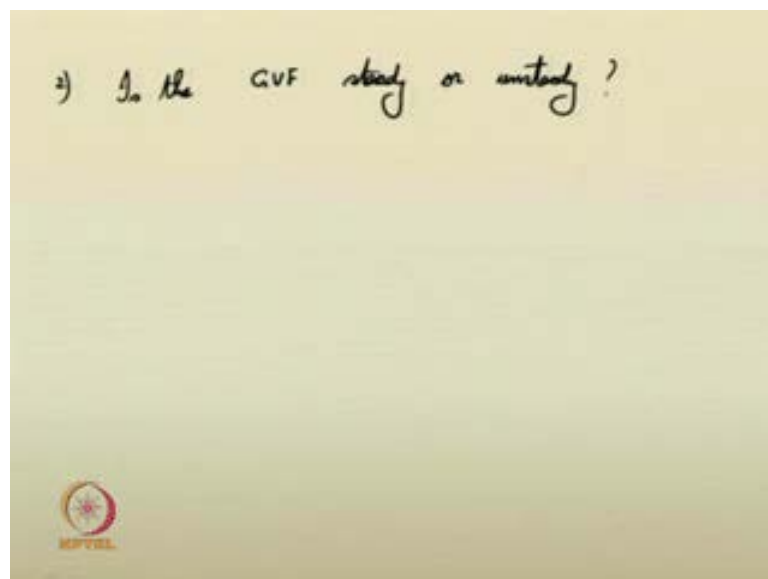
frictional forces, how to develop and all, we will see it in the next class. Today, we will have a brief quiz.

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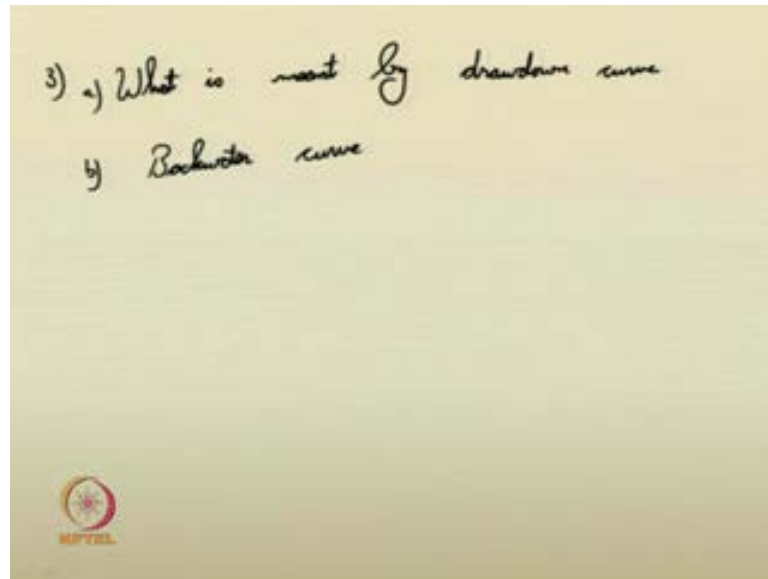
You will see the brief quiz; I would, I would be interested if you can just tell, what is gradually varied flow? What is gradually varied flow? Give examples of gradually varied flow.

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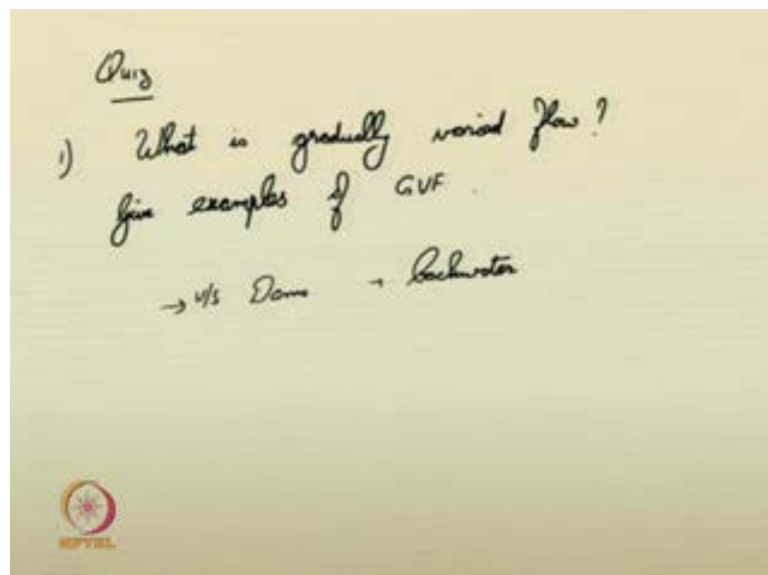
The second question: Is the gradually varied flow steady or non steady? Is the gradually varied flow steady or non steady?

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Third question is, what is meant by drawdown curve? And b, what is meant by back water curve? The solutions for this quiz: what is gradually varied flow and give some examples of gradually varied flow? The flow parameters like the depth of the flow, the velocity of the flow, they change gradually along the reach of the channel, that is called gradually varied flow.

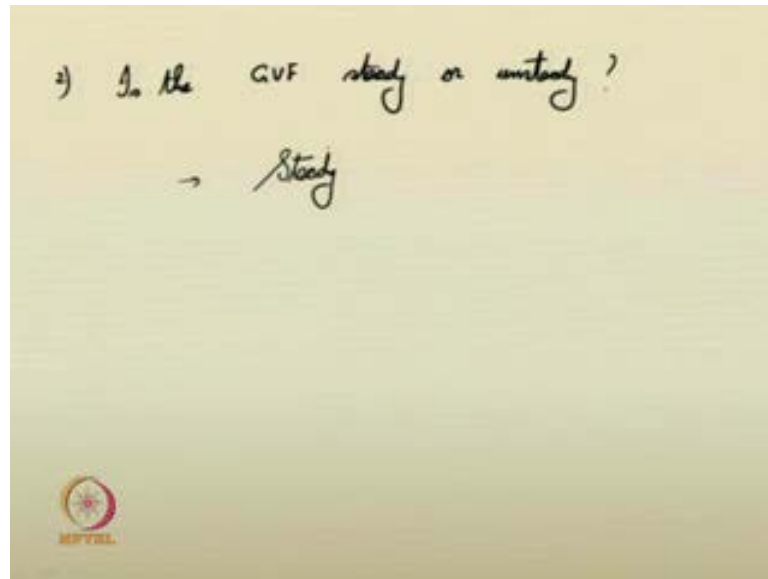
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We have some of the examples of gradually varied flow. Especially, the back water phenomenon in dams, upstream of dams, in the upstream dams you have back water

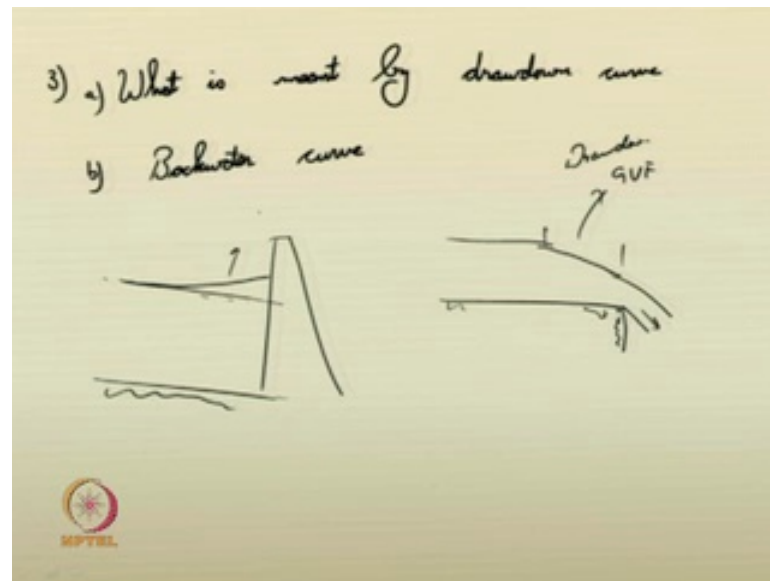
phenomenon; in the downstream or in the or in the channel steps where the, wherever there are step beds and all, say, the bed of, bed of the channels are made in step formations, you will witness gradually varied flow where the flow, depth of the flow gradually reduces before it reaches the edge of the step. So, those are the some of the examples.

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The next question asked to you was, whether the gradually varied flow is steady or non steady? I hope, all of you have answered that gradually varied flow, the assumption itself we have considered that the gradually, in the gradually varied flow the flow is steady. All the derivations are based on that, especially you have seen it in the conservation of mass equation in the gradually varied flow. The flow is being assumed as steady.

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What is meant by drawdown curve? And what is meant by back water of curve? So, we have seen that. As mentioned earlier, if you construct a dam across a, initially if there was a uniform flow, then will you see the gradual increase in the depth of flow. So, this particular curve is called back water curve. Say, if in a particular channel, if uniform flow was there, now all of us are, if you are constructing a step here, the bed, then you will see that the depth of the flow reduces gradually, before it jumps. So, this particular portion, this is also a gradually varied flow, and this curve is called draw down curve. The water surface curve in this phenomenon, it is called draw down curve, here this is called back water curve.

Thank you.