Free Surface Flow
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Lecture 46

Welcome, students, to the 10th week or Module 10 of our free surface flow course. The next two weeks will be dedicated to discussing unsteady flow. So, unsteady flows can be broadly divided into two categories. One is gradually varied unsteady flows, that is GVUF. And the second one is rapidly varied unsteady flows.

So, the two weeks will be dedicated one to GVUF and the other to rapidly varied unsteady flow, that is RVUF. And then, in the last week, we are going to discuss mobile bed channels. With that being said, we will now start. So, the first question is: What is unsteady flow? So, unsteady flows are also called transients. It occurs in an open channel. when the discharge or depth, or both in practical terms, we can say flow properties vary with time at a particular section of the open channel. Now, these changes can be due to several factors. It can be due to natural causes. It can be due to planned action by humans. For example, building a dam or any other structure or sometimes accidents can also promote rapidly varied flows sorry rapidly varied or gradually varied unsteady flows.

Accidental happenings. Now, how do we classify further classify these two types of you know I mean this type of unsteady flows. So, it depends on the curvature depending upon the curvature of water surface transients can be broadly classified as the first is gradually varied unsteady flows or GVUF.

This week is dedicated to this particular topic. Secondly, rapidly varied unsteady flows also called as RVUF. So, now, what are the characteristics? what are characteristics of these two types of rapidly varied unsteady flows.

The first one is gradually varied unsteady flows, or GVUF. Rapidly varied unsteady flows, or RVUF. So, gradually varied unsteady flows (GVUF) are characterized by a small water surface curvature. So, the curvature, as in normal gradually varied flow, here also the water surface curvature is very small.

Compared to gradually varied unsteady flows, for the rapidly varied ones, there is an appreciable change in water surface over relatively short distances. Another thing is, since it is gradually varied, the assumption we have always been taking about hydrostatic pressure will again be valid. So, here also, pressure distribution is assumed to be hydrostatic. Thirdly, here, pressure distribution in rapidly varied flows is not considered hydrostatic during that phase, but before and after this process, we consider the hydrostatic pressure in rapidly varied unsteady flows as well.

Third, we must include friction in our analysis; friction is included in the analysis. Here, as we have seen in rapidly varied normal flows (rapidly varied steady flows), similar to that, here also in unsteady flow, friction plays a minor role in determining the flow characteristics. So, here, since it occurs over a very short distance, the role of friction is negligible in rapidly varied unsteady flows.

Some of the examples, I mean, for example, flood flow in a stream. One of the typical examples here is the formation and travel of a surge due to the sudden closure of a gate. These are some of the different characteristics of gradually varied unsteady flows compared to rapidly varied unsteady flows.

We will discuss about some field situations which gives rise to transients. Water is transient, transient is unsteady flows. So, one of the field situation is heavy rainfall in a catchment. So, heavy rainfall and catchment, snow melt, breaking of log or ice jams, etc. I mean, this all gives rise to, which give rise to flood in rivers, streams and surface drainage systems. The second field situation could operation of control gates in hydraulic structures and navigation acceptance and rejection of a sudden load by turbines. in a hydroelectric installations.

This could be another situation. Another situation could be sudden starting. or tripping of pumps. This all will lead to surges, all leading to this phenomenon. Possibility of surges. A third similar situation in the field could be tides in estuaries and tidal rivers.

Estuaries are places where a river or a stream meets the ocean. That is called the estuarine region. And tidal rivers causing a surge are usually called a bore. which is propagated upstream. So, these are some of the field conditions in which you will find the occurrence or which gives rise to transients or unsteady flows. So, now we are going to discuss, so we will give some numerical treatment to this first component, which is gradually varied unsteady flow.

So, we are going to talk about the continuity equation for gradually varied unsteady flow. So, in our previous lectures, we have already derived the continuity equation for unsteady flow. I will write it down. Therefore, you will be able to recall. We have already derived the continuity.

For unsteady flow in a channel. So, what was the equation? If you remember, we had $\partial Q/\partial x + \partial A/\partial t$ equal to q_L. What is q_L? q_L was the lateral flow discharge. So, this was the general equation we derived previously.

Now, we are going to start with this particular equation. We say, in the absence of any lateral flow, we get. So, if lateral flow is not there, then that means q_L is equal to 0, right? Therefore, we can write the above equation as $\partial Q/\partial x + \partial A/\partial t$ equal to q_L, which is 0.

So, this is the equation that we also know from before a particular condition—I mean, an equation that relates top width to the area, but $\partial A/\partial y$ is nothing but T, okay. Here, T is the top width, and y is the flow depth. We can write $dA = T\ dy$. This we can write very easily.

Thus, we get $dQ/dx + T\ dy/dt$ is equal to 0. So, what have we done? This was dA. So, we replace dA by $T\ dy$. Let me write it down very neatly. dQ/dx plus $T\ dy/dt$ is equal to 0. And now, what is Q?

We know that Q can also be written as area multiplied by velocity. So, instead of this Q, we can write $d(AV)$ divided by dx plus $T\ dy/dt$ is equal to 0. Now, let us look at this particular term here. So, let me write this equation down again here: d/dx of $(AV)\ plus\ T$. So, writing this down, we can write $A\ dV/dx$ plus $V\ dA/dx$ plus $T\ dy/dt$ is equal to 0.

Cross-sectional area A can be a function of depth. It can also vary from section to section. Hence, what it means is that area can be a function of depth (depth is y), and it can also vary from section to section, meaning it is also a function of x. So, area can also be a function of both x and y. The next step, therefore, is the derivative of A with respect to x at constant time, at one fixed time, is.

So, let us try to write dA/dx. What is dA/dx? It is nothing but $(dA/dx)y + (dA/dy)$ at $x\ dy/dx$, and these two y and x are the variables to be held constant. So, this is dA/dx. We also know that dA/dy at one particular location x is also called the top width. So,

The above equation will become dA/dx is equal to (dA/dx) at $y + T$, because dA/dy is nothing but T. So, it becomes $T\ dy/dx$, and this is another equation. And what is this? The first term here, the first term is nothing but the gain in the area—so the first term is this one the gain in the area due to the width change at a constant flow depth. And what is this second term?

The second term is the gain in the area due to an increase in the depth. So, the first term is the gain in the area due to width change at a constant flow depth here, y is held constant—and the second is the gain in the area due to an increase in the depth because of dy/dx. So, if we are going to use this particular equation this particular equation, that means this one in the first equation, this equation. What we are so this equation means this equation that we are going to get now using all the above equations together.

We get $A\, dV/dx\ +\ V[(dA/dx)y\ +\ Tdy/dx]\ +\ Tdy/dt$ is equal to 0. Right, or more I mean, in a more not simplified but in a more expanded form, it can be written as $AdV/dx\ +\ VdA/dx$ at constant water depth + $VT\ dy/dx\ +\ Tdy/dt$ is equal to 0. Now, this particular equation is called the equation for the gradually varied unsteady flow (GVUF) without any lateral flow. Here, there is no lateral flow. So, what would be the next step? We should also be in a position to write the gradually varied flow with lateral flow. So, what we say if the lateral flow is considered, then we get A—it is the same equation, just that in the right-hand side of the previous equation it was 0, now it will no longer be 0: $A\ dV/dx\ +\ V\ dA/dx$ at a fixed water depth + $VT\ dy/dx\ +\ T\ dy/dt$ is equal to q_L, and that is the lateral flow. Instead of 0, just a special case—a special case is what happens for a prismatic channel, OK. So, for

Prismatic channel. What is going to happen for a prismatic channel? The change in area at each section at a fixed water depth will be equal to 0, and therefore, the above equation as $AdV/dx\ +\ VT\ dy/dx\ + Tdy/dt$ is equal to 0.

So, this particular term dA/dx at fixed y becomes 0. Sorry, this is not equal to 0 for in the absence of lateral flow. This is okay. So, I think this is where we are going to end our class today. In the next class, we are going to start the equations of motion for gradually varied unsteady flow. So, see you in the next lecture.

Thank you so much.