Advanced Hydraulics
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Module - 4
Hydraulic Jumps
Lecture - 1
Rapidly Varied Flow- Introduction

Welcome back to our lecture series on advanced hydraulics. We are now starting today the module 4 on hydraulic jumps. If you recall our earlier lectures and all, we had covered 3 modules.

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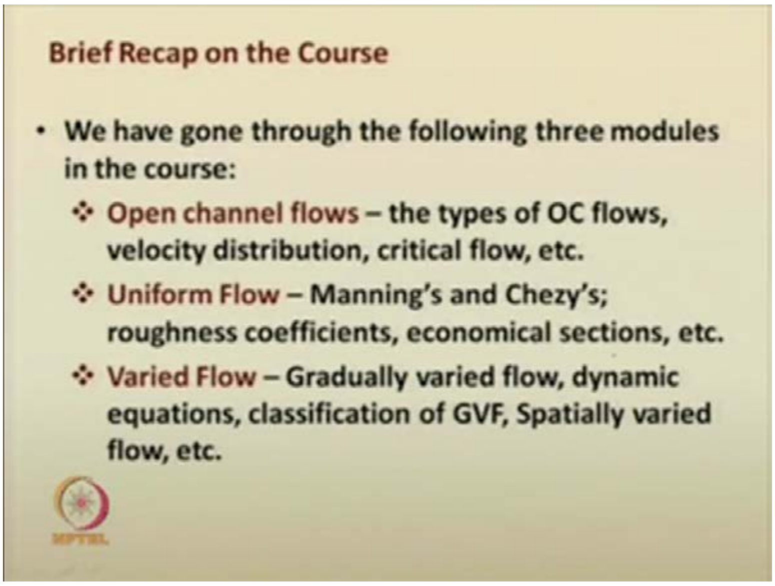

First module was on open channel flows. We discussed there on the types of open channel flows, what is meant by the velocity distribution? What is meant by critical flow? In the second module, we have discussed on uniform flow, we have discussed on the Manning's equations, Chezy's equations. Also we have discussed on the coefficients roughness coefficients, how to design economical sections, etcetera. Subsequently, in the third module, we discussed on the varied flows; like gradually varied flow, spatially varied flow. We had derived the dynamic equations to understand the gradually varied flow or to compute the gradually varied flow profiles, what are the classifications of gradually varied flow that also we had studied.

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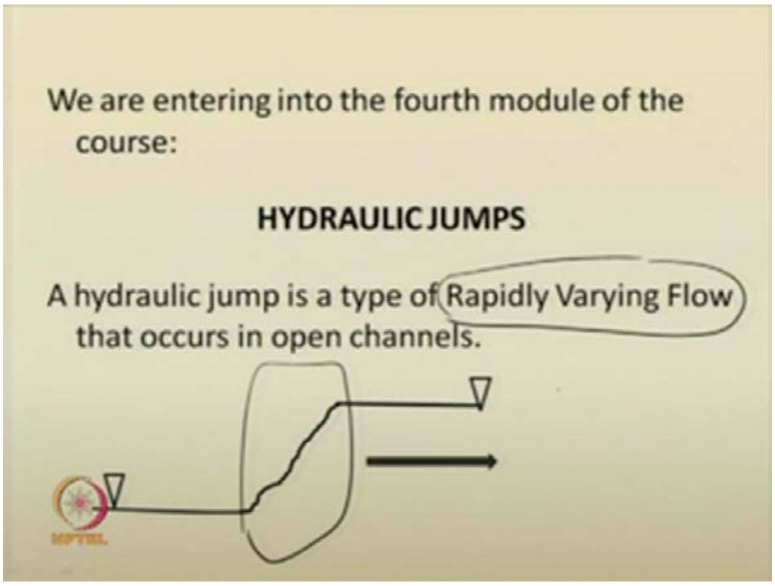

Today, we will start on the fourth module that is on the hydraulic jumps. So, the first question you would like to pose is what is meant by hydraulic jump? A hydraulic jump is a type of rapidly varying flow. So, as stated earlier, till the last module, we studied on gradually varied flow as well as this spatially varied flow also the flow profiles were occurring. The changes in the flow profiles were gradual, so here the rapidly varying flow, a hydraulic jump is, the change in the water profile that occurs in a rapid form. You here, see here this is the water surface profile, maybe it is a super critical flow and here it is a sub critical flow. All of a sudden, the depth of the water changes in a short reach. So, all of a sudden it jumps to a higher level. So, this is a hydraulic jump.

You can see such phenomenon in lot many places in the nature as in, a as in the nature as well as in the canals, in the engineered flows, in dams, structures, and all you will see in many in many locations hydraulic jump. So, as we suggested earlier in the last module and all we had discussed on gradually varied flow. In the last class, we discussed on the features of spatially varied flow. If you recall those features of spatially varied flow, we did an example problem on the spatially varied flow for a rectangular channel and all. So, all those in all those situations, wherever possible, we had taken almost a parallel flow approximation, even the gradually varied flow or even the uniform flow distribution and all, we had taken the parallel flow assumption. Here we will just go through what is meant by rapidly varied flow.

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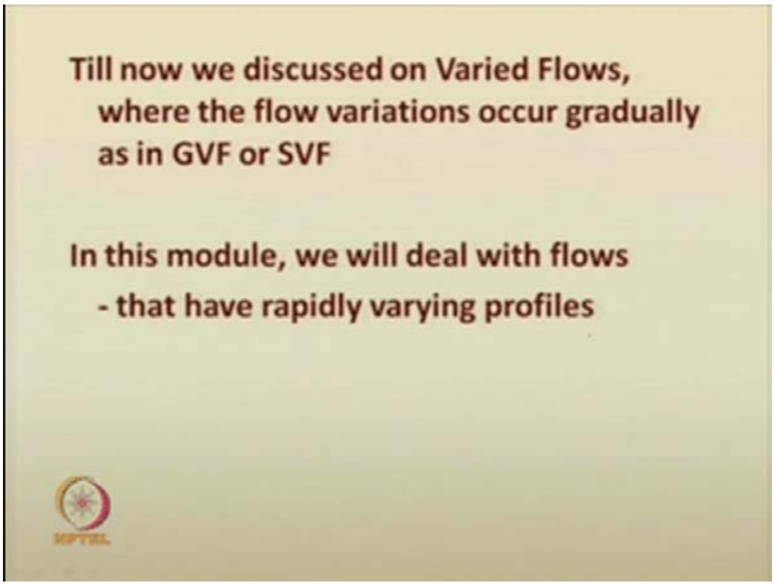

So, rapidly varied flows which have a rapid change in the flow profile, those flows are called rapidly varying flow. What is rapidly varied flow?

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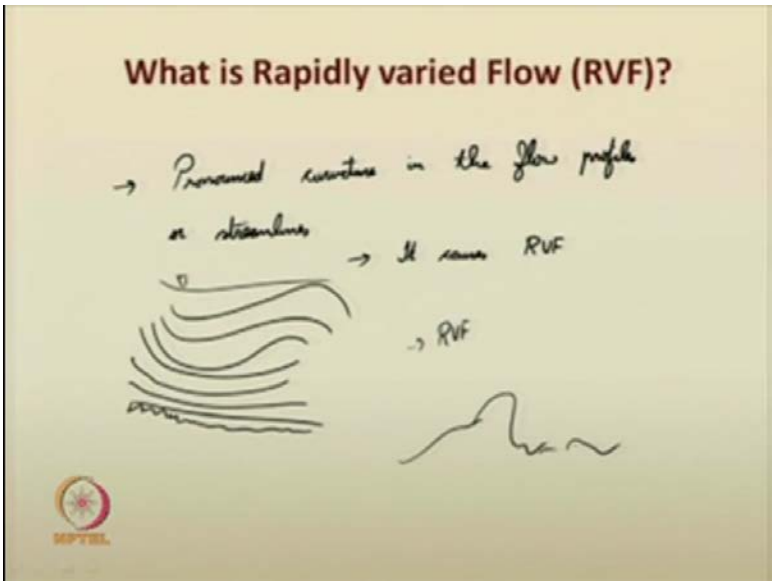

Again I am posing the question in front of you. If any guess and all, because you had already studied the gradually varied flow, so can you come up with an idea on what is meant by rapidly varied flow? Wherever there are pronounced curvature, wherever there are pronounced curvature in the flow profiles or stream lines, it causes rapidly varied flow. Say if there is a channel bed like this, the stream lines up to the water surface, says if you try to draw it, say may be in this location, you can see and let this be the water surface. The stream lines if you draw it, you can see the curvature of the stream line. It is rapidly varying within a short reach itself it is rapidly varying. And the stream line curvatures, 2 adjacent stream lines are not having same curvature, so this causes a rapidly varied flow situation in.

You may encounter such type of flow in various locations. So, what rapidly varied flow usually it is defined as the rapid or pronounced variation in curvature of the flow profiles, both in the as well as the water surface as well as the stream lines. If there are pronounced curvature in those lines, those types of flows are called rapidly varied flow. You may see that some of in some places, the flow profiles gets broken, the water surface it may get broken, that is also a type of rapidly varied flow. And we will see what is that type of rapidly varied flow called.

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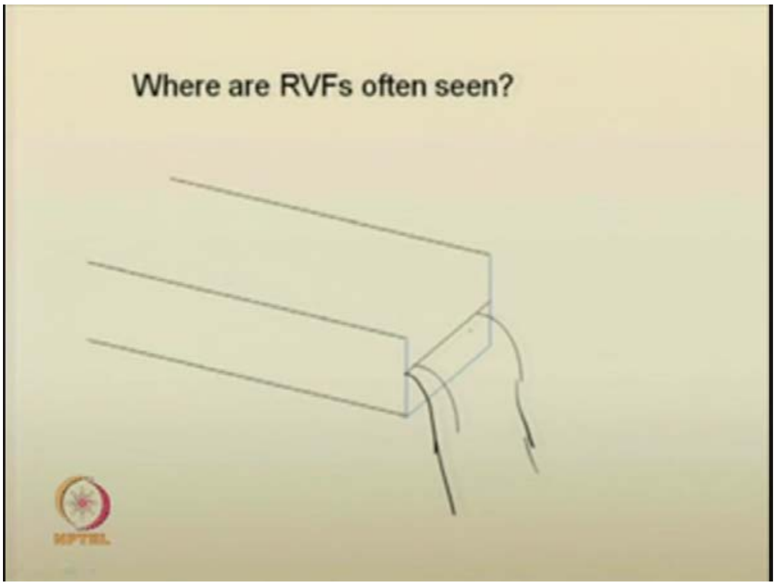

Where are the rapidly varied flows seen? Where do you see rapidly varied flow? Say here, I have just drawn a rectangular channel, may be a sloping channel and there is a free over fall of water. Now, if this free over flow over fall of water, if you closely look into that, we do not know the depth of the flow. How, what is a, where it is merging and all? But this free over fall here the flow patterns it means, it is rapidly changing from at this location it is rapidly changing. The curvatures of the flow it is changing, it is an example of rapidly varied flow. I can just give in a more detailed way.

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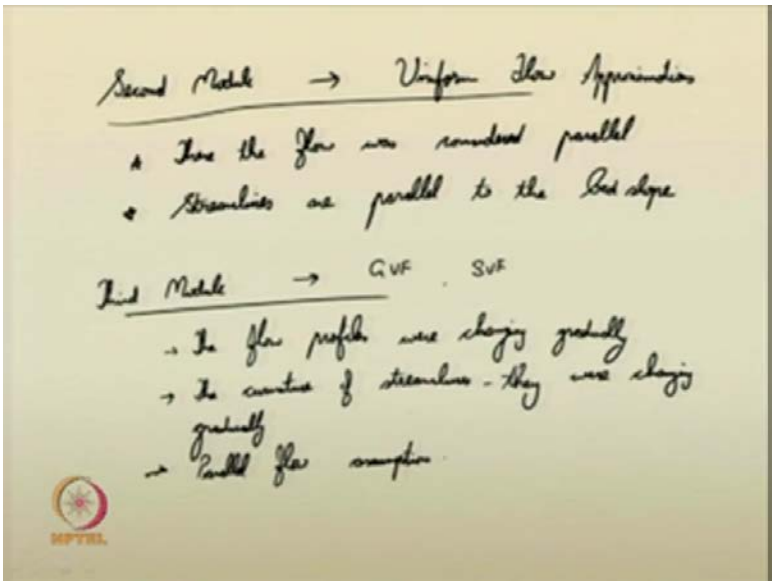

If you look into the second module of the course, in the second module, we had mostly dealt with uniform flow approximations. You had dealt with the uniform flow approximations in open channels. So, there the flow was considered parallel. Also, we suggested that stream lines are parallel to the bed slope. Like this also, we had suggested in the uniform flow assumptions. But seldom in the nature may you encounter uniform flow. Therefore, uniform flow may be only in a very engineered situation. Suppose, a canal is being designed, and in canal is designed in such a way that you have to carry so and so amount of discharge regularly without any fluctuation and after a certain time, it becomes a uniform flow in that canal and all. So, such situations are very rare in nature, river cannot have uniform flow in every location. Because the boundaries of the river they are varying the boundaries are not most of the rivers may not have a means, a solid boundary. That is solid means, non erodible boundaries and all.

So you may encounter varied type of flows. So, in rivers, or even in natural such as streams, channels and all, you cannot give a uniform flow approximation at all times, may be at certain extent, certain duration of the time or certain portion, you may be able to approximate uniform flow assumptions and all. But that is not true in all the senses. Therefore, the second module in which ever we have studied uniform flow approximations, we may have to modify them for the natural channels. In the third module again in the third module, we had given gradually varied flow approximations or even in the spatially varied flow, the flow profiles were changing gradually, the also we suggested that the curvature of stream lines, the curvatures of stream lines they were changing gradually. Therefore, in such situations you were able to incorporate the parallel flow assumptions. So, you were able to incorporate the parallel flow assumptions. What is the parallel flow doing?

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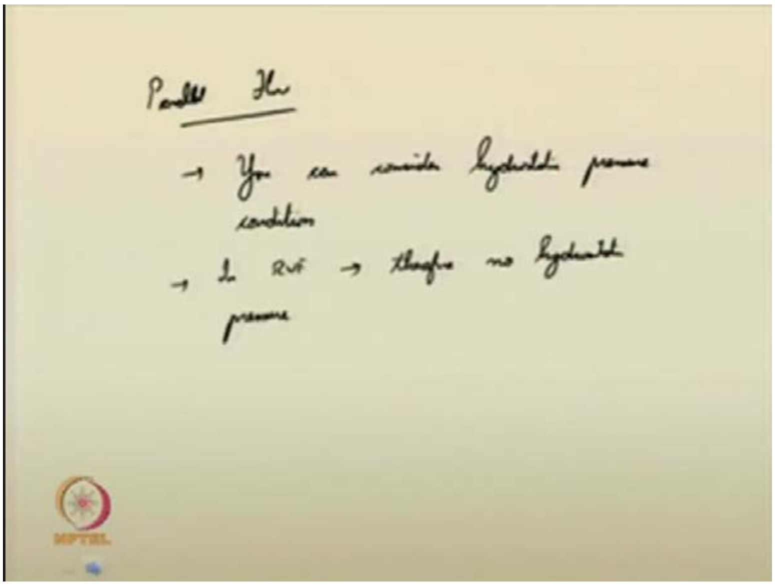

Parallel flow means you consider hydrostatic pressure conditions. You consider hydrostatic pressure conditions, but in rapidly varied flow, you do not have parallel flow, therefore, no hydrostatic pressure. So, you may have to use different as theory there actually our question was where you often see rapidly varied flow?

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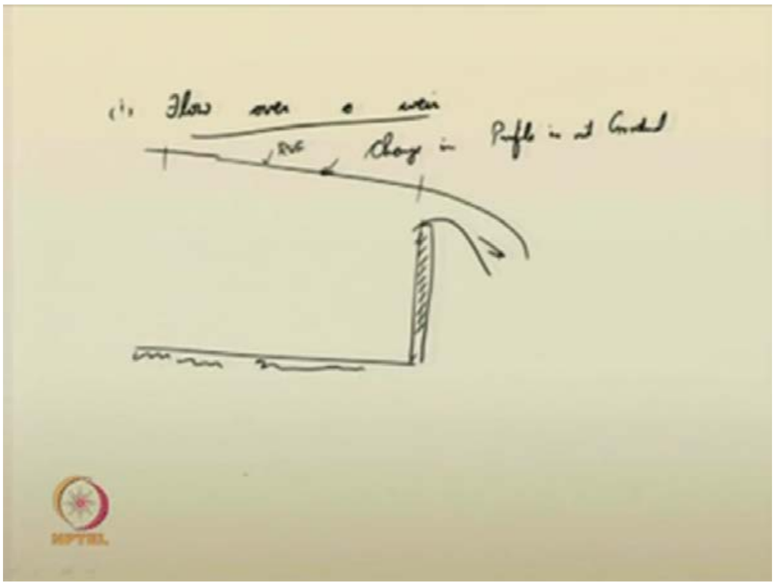

So, now to coming to that, you will see rapidly varied flow may be first flow over a weir, if I want to just draw that, say a channel is there, or a stream, whatever be, if you are constructing a weir, may be rectangular triangular whatever shape you can assume them, a weir is being constructed to block the flow. Now, what happens, whatever flow over flow means that occurs by overflowing or flowing over through this weir and all? So, it falls like this right. So, if the channel was already having a uniform flow earlier, now it may just dip like this. So, here the change in profile is not gradual in this stretch. You can suggest that this is a rapidly varied flow profile water surface it is dipping sudden. So, flow over a weir has means in flow, wherever flow occurs over a weir, you will be encountering rapidly varied flow.

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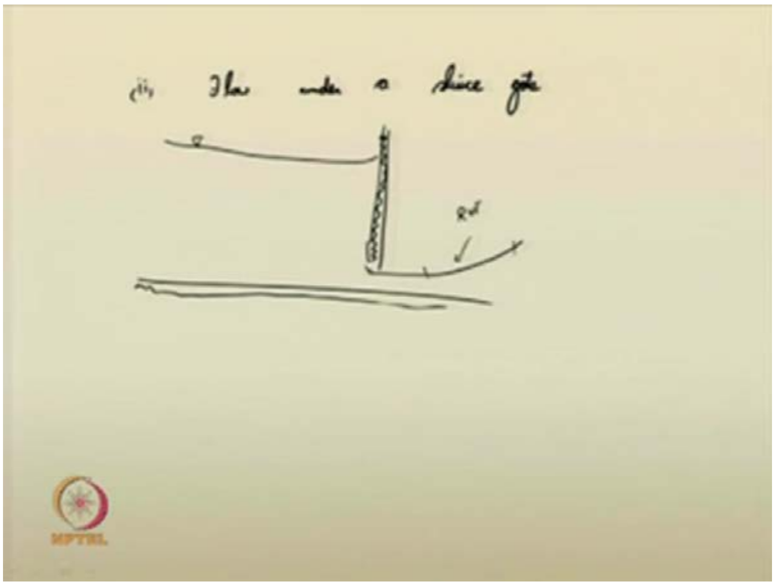

Similarly another example like a coat here is, flow under a sluice gate. So, these examples are clearly described in Professor Rajesh Srivastava's book on open channel hydraulics. You can refer them also for more details, and all I will just briefly explain here. Say, if there is a sluice gate that is blocking the flow, may be in the uniform channel, flow channel and all, so you know that there will be a gradually varied flow profile in the upstream of the sluice gate that is quite understood. Now due to the narrow passage in the bottom, the flow here gushes up and flow profile changes like this. Means this entire stretch it is having a rapidly in this small stretch itself. The flow profile or the curvature of the flow it is changing rapidly. So, it is having a rapidly varied flow profile.

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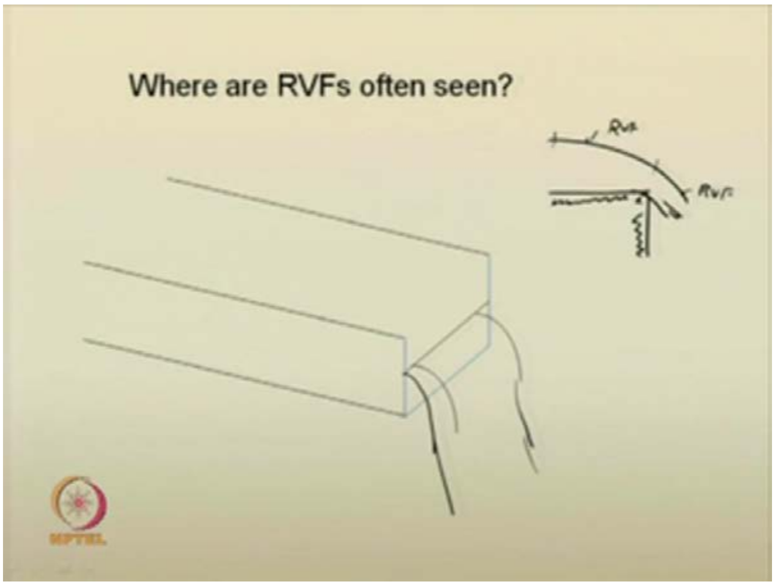

Another example we can see is, wherever a canal fall or canal drop is there, as we have seen here in this particular, this is the rectangular canal or channel. There is a canal drop or canal fall. Now, this also gives you a say I can draw the cross sectional form now like this, say if there is a canal and it is dropping like this, whatever flow was there now, so in this entire stretch it is having rapidly varied flow. This is also a rapidly varied flow profile. Like this along the drop. So, such phenomenon's you can see in such a various phenomenon's you can see in the rapidly varied flow.

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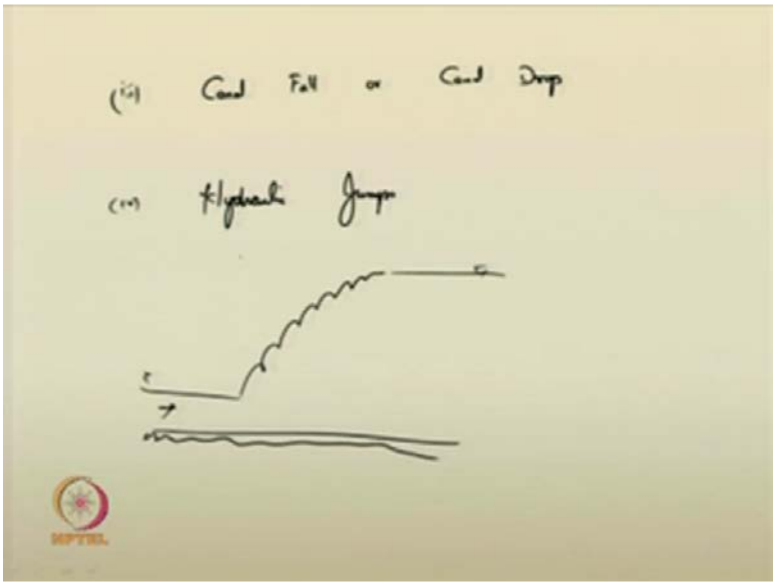

A most important of the rapidly varied flow profile is the hydraulic jumps. There is a canal, here some low depth flow is there. Here a large depth flow is there. The flow within a short reach, it jumps to the higher elevation from lower elevation to higher elevation. It jumps all of a sudden. It is caused by various reasons, we have not come into the scientific study, we will that we will be going in the later classes and also. But in that short reach, the elevation of the water jumps from a lower elevation to a higher elevation.

So, this causes means this is a rapidly varied flow phenomenon and it is the most common of the all of the most common phenomenon. You will witness in rapidly varied flow even in this entire module. We have named it as a hydraulic jump although it can be called this module could have been renamed or it could have been more in a more general way are called as rapidly varied flow. But because we will be studying in more detail on the hydraulic jumps and its aspects for the open channel design of the canals and all, we have given the name or a name of the module as gradual hydraulic jumps.

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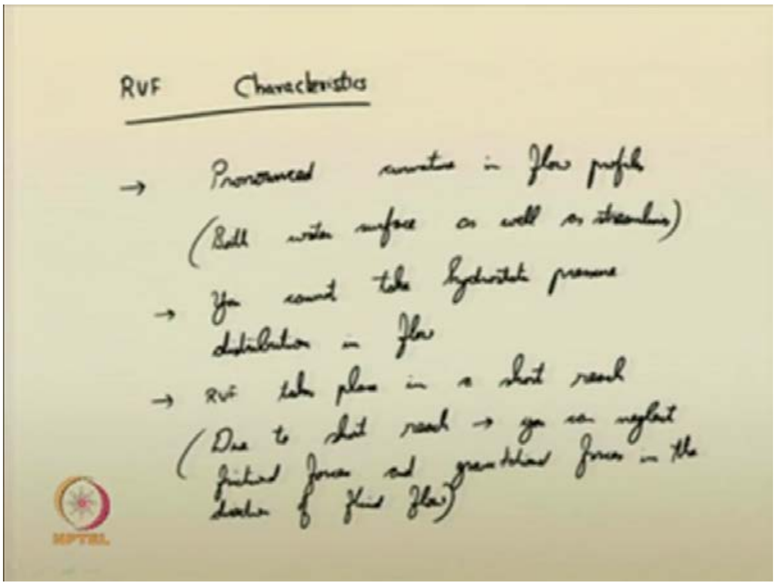

What are the rapidly varied flow characteristics? How can I suggest that a flow is rapidly varied flow? What are its general characteristics? So, as we mentioned earlier rapidly varied flow will be having pronounced curvature in flow profiles both water surface as well as stream line. So, these quantities will be having pronounced curvatures, so based on that the flow is considered as rapidly varied flow, as the curvature is significant. As the curvature is significant, you cannot take hydrostatic pressure distribution in flow. It cannot take hydrostatic pressure distribution in flow.

So, then this takes place, we also suggest that, rapidly varied flow takes place in a short reach unlike the gradually varied flow. If you recall the gradually varied flow, we suggested that the gradually varied flow phenomenon occurs in a large reach, may be up to 2 kilometers, 3 kilometers and all we have suggested, we had even done some examples on that. But rapidly varied flow, it occurs within a short reach within I mean say 1 meter 2 meters or within those things it occurs.

So, what is the significance of this short reach? Due to the rapid, due to this thing, say I can suggest that one of the curvature due to short reach your control volume for analyzing rapidly varied flow that will also be a having a small length. Due to short reach, you can neglect frictional forces and gravitational forces. Please note that you can neglect frictional forces and gravitational forces in the direction of flow. We are not talking about in the vertical direction in the direction of flow, you can neglect them and that in the direction of fluid flow. The vertical components still exist and we are not neglecting them.

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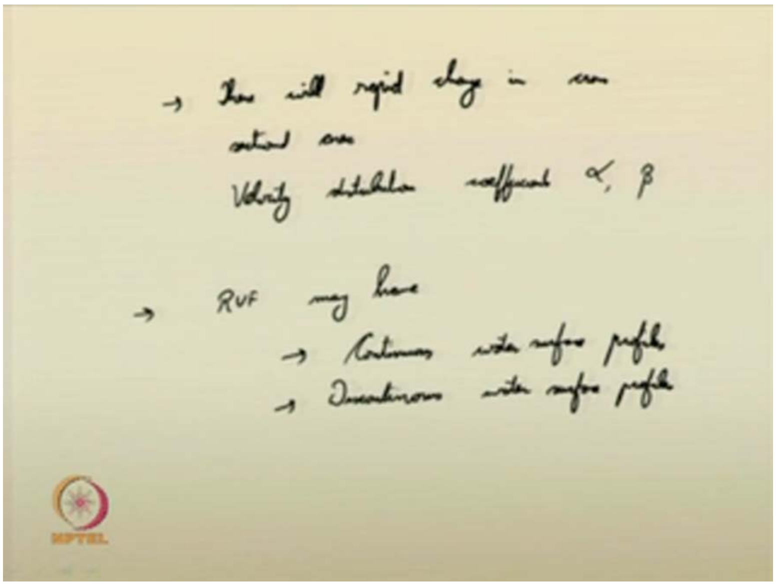

Again one of the characteristic you have is that, there will be a rapid change in a cross sectional area. Cross sectional area of the channel or stream whatever it is. So, due to this rapid change in the cross sectional area, your velocity distribution coefficients, your velocity distribution coefficients like energy correction factor alpha, momentum correction factor beta, and all they will be much much greater than 1. So, you cannot neglect them in the analysis. You may have to use them always in most of our earlier studies we had neglected or we have approximated these quantities as one, so we cannot do it rapidly varied flow. Some of the rapidly varied flow means or the rapidly varied flow phenomenon, it may have or I can rewrite it here. Rapidly varied flow may have continuous water surface profiles or discontinuous water surface profiles.

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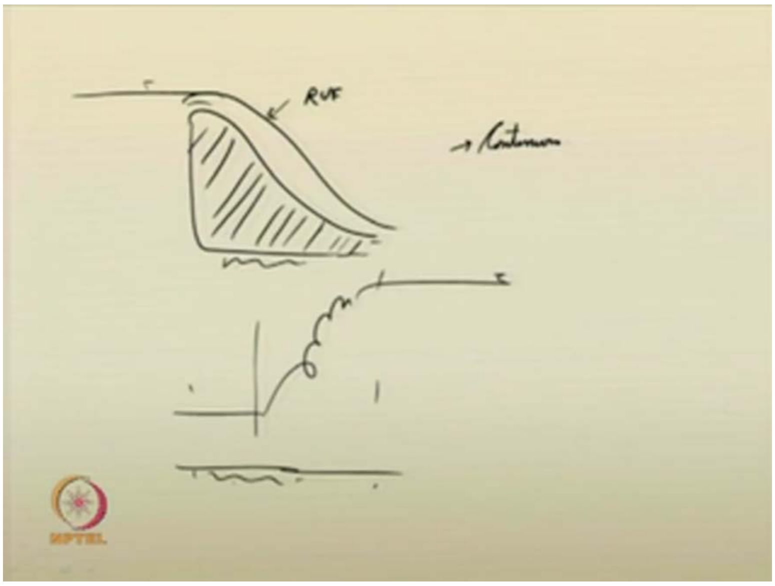

So, continuous as you have seen in say we have suggested that flow over a weir flow over a whatever now you see here, the water surface here in these regions and all, say this is spill way or we. So, the here the profile is rapidly varying within a short reach, still in the due to the rapid change in the profile. The profile is not water surface is not getting discontinuous, it is still continuous. However, in jumps if you recall them you have disjointed water surface profiles here. So, you can in the rapidly varied flow therefore, you can have continuous water surface, profiles or discontinuous water surface profiles. A classic example of discontinuous water surface profile rapidly varied flow is hydraulic jump.

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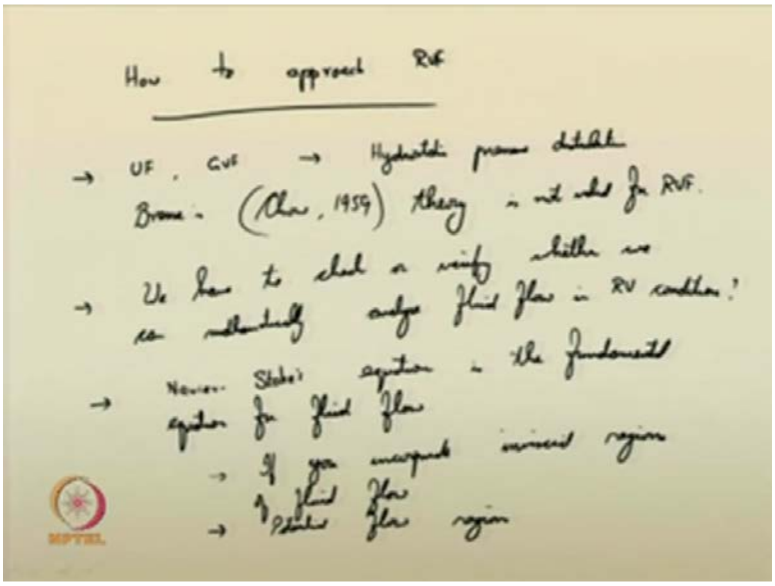

How to approach rapidly varied flow? How do you approach in general the rapidly varied flow or for analyzing the rapidly varied flow and all? So, we suggested that for both for uniform flow and gradually varied flow; you were taking hydrostatic pressure distribution that cannot be taken here for the rapidly varied flow. So the theory which suggested parallel flow or hydrostatic pressure distribution, this was formulated long back by Bresse as stated in Ven Te Chow's book 1959 book. So, this is called Bresse's theory, the concept of parallel flow or taking hydrostatic pressure distribution for fluid flow, so that Bresse's theory is not valid for rapidly varying flow. So, what we have to do is that, we have to check, to check or verify whether we can mathematically analyze fluid flow in rapidly varying conditions.

So, is it possible? So, fundamental according to fundamental principles, if you take the control volume approach and all, it should be possible but how far what are the assumptions required, what are the quantities required, or what all simplifications you may need to do to understand or to analyze the rapidly varied flow, that we need to go through. So, the scientist had worked on that by say you know that Navier stokes equation, Navier stoke's equation that has been derived using the momentum approach and all it is, is the fundamental equation for fluid flow. So, by incorporating proper assumptions you can suggest Navier stoke's equations for fluid flow in open channels also. In addition to that, if you incorporate in viscid regions of fluid flow as well as potential flow regions, if you incorporate these two assumptions in the Navier Stoke's equation then.

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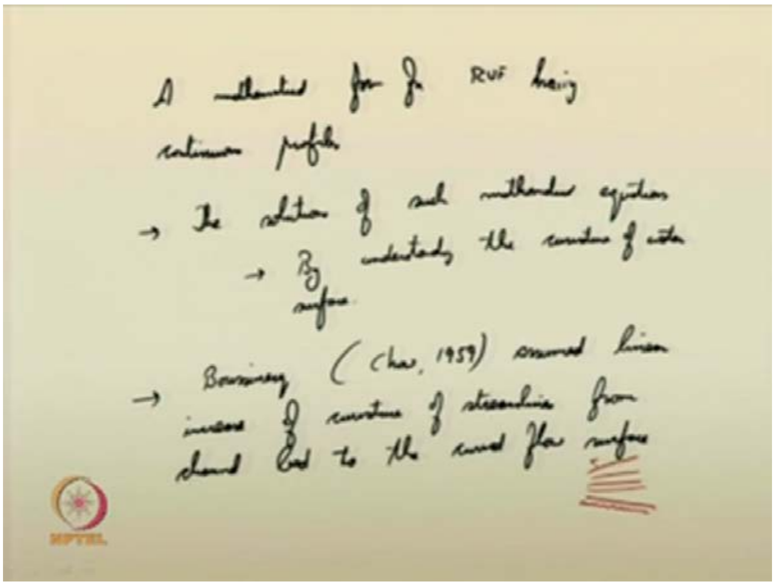

You will be able to get a mathematical form for rapidly varying flow having continues profiles. Please note that having continuous profiles, you will be able to describe mathematically based on the assumption that is the region is having in viscid flow, then it also having potential flows. On those assumptions, you will be able to mathematically describe rapidly varied flow for a continuous profile. The solutions for such type of governing equations, the solutions of such mathematical equation, it can be obtained by understanding the curvature of water surface. By understanding the curvature of water surface, you can analyze the, I mean analyze such mathematical equations. So, from earlier days means scientists several scientists long back may be some few 60 years before itself and all they have started analyzing them.

For example, scientist Boussinesq this is given in Ven Te Chow's book. He developed the theory that is, he assumed that assume linear increase of curvature or stream lines from channel bed, channel bed to the curved flow surface. So, what is the meaning here, say if you have a channel bed like this, from this channel bed, he suggested linear increase in curvature. So may be like this and then like this, like this so there could be a linear increase as we go from the up to the curve surface, whatever be so there will be a linear increase, the curvature of the flow profile it is increasing linearly with respect to the depth that was the simple assumption incorporated by Boussinesq and he then started, he analyzed the fluid flow for rapidly varying conditions.

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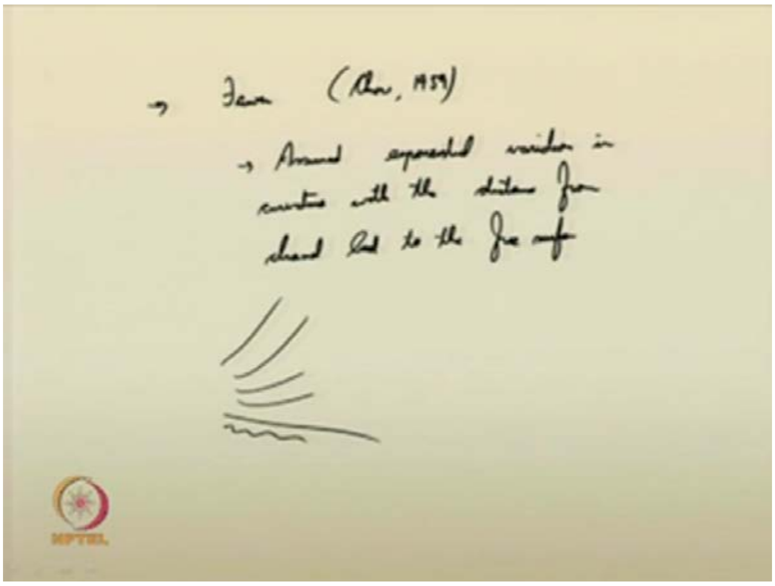

So they will use the moment momentum equation and all to solve such fluid problem, another theory was suggested by Fawer, this was also this is also described in Ven Te Chow’s book. So, it assumes exponential variation in curvature with the distance from channel bed. So, as you move away from the channel bed, the curvature of the stream line increases exponentially. So, you can just substitute and see how the curve looks. So, may be it could be like this, it can be like this. So, we it is up to you to decide within a stretch particular stretch how the curvature varies. So, these are all old theories

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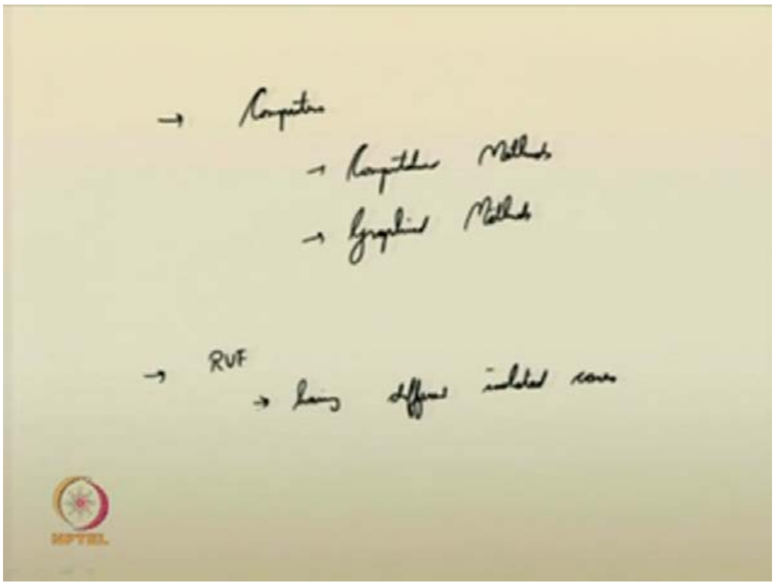

Now in this modern age, you are able to analyze using computers using computers and computational methods or even graphical methods. So, there are advanced computers that used good graphical methods or there are advanced instruments that are able to use maps or proper graphs and all. They will be able to interpret the flow profiles and all. So, graphical methods are used, computers are also used. So, in this age you can still you will be able to analyze the rapidly varied flow in a much better way. Still although these things are there, as we mentioned this for the continuous flow profile, a general solution for the rapidly varied flow for all aspects it is still not available.

Scientists have since then worked in such a way that they consider various phenomenons of rapidly varied flow as isolated cases means they consider rapidly varied flow having different isolated cases. Each of them are having their own solutions, may be empirical, may be mathematical, whatever be. So, they will be analyzing it in. For example, they consider hydraulic jump entirely as a different phenomenon flow over a spill way. They considered as a different phenomenon. So, they may have been having a different approach for each of the solution. You cannot have a general solution that will solve both the flow over a spill way as well as hydraulic jump as well as flow under a sluice gate and all. So, you have to analyze it in a independent way.

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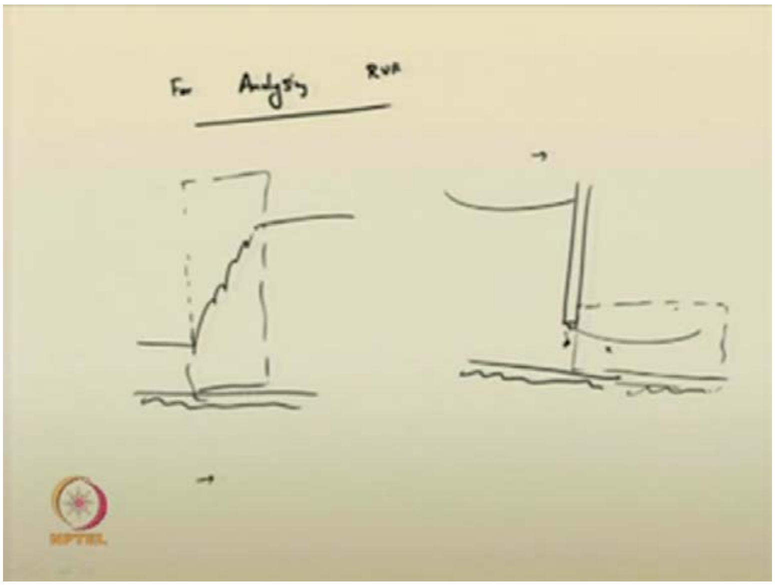

Now for analyzing rapidly varied flow, we suggested that the curvature is pronounced in rapidly varied flow. For example, in the hydraulic jump within a short reach the elevation of water rises. So, if you use the your standard continuum approach that is with control volume and all, you have to select the continuum or control volume in such a way that, it is incorporating the entire details of the rapidly varied flow. So, here now we are taking the control volume as shown in the box here for the hydraulic jump. Say, for the sluice gate, for the sluice gate, your control volume should be such that it is incorporating the details. Because the pressure the reason is that the control volume should be appropriate, it is due to the sense that you are not taking hydrostatic pressure distribution.

So, if you are not taking the hydrostatic pressure distribution, then whatever flow is there, whatever pressure distribution is available, you may have to take into that consideration. For that, you have to evaluate pressure at those locations which are not hydrostatic in nature. Those phenomenons, if you in this particular for the sluice gate, at this entrance of this sluice gate, you know here you can take the pressure as hydrostatic. But you will be not able to take this situation everywhere in that situation downstream. Everywhere in the downstream you will be not be able to take it as hydrostatic. So, at the entrance, it was possible. So, if you incorporate your control volume starting from that, then at the outlet of the control volume it is easier to evaluate pressure.

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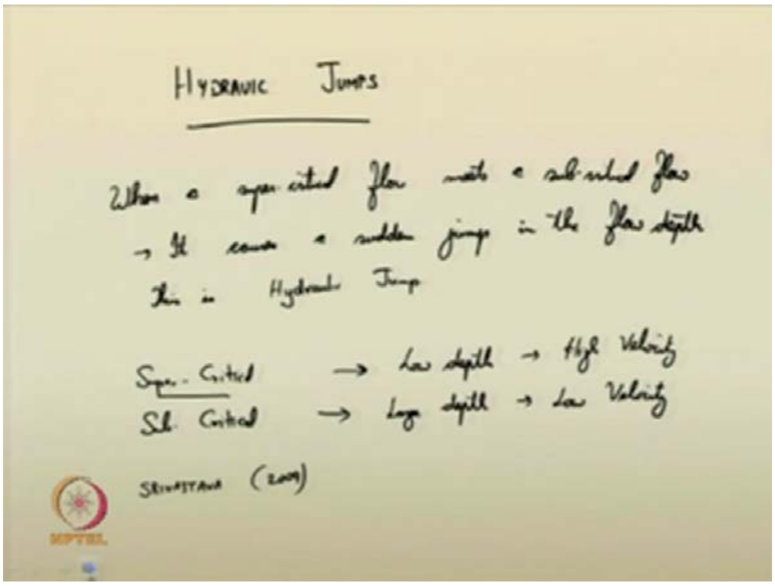

So, we will start this module on this first with the hydraulic jumps itself, and then later on we will briefly cover the other types of rapidly varied flow. So, hydraulic jump; the definition of a hydraulic jump is when a super critical flow in an open channel meets a sub critical flow, it causes a sudden jump in the flow depth. This is hydraulic jump, fine so you know that in super critical flow, in super critical flow you have low depth as well as high velocity. So, that means low depth high velocity flow, if it meets a high depth low velocity flow, and then there is a sudden jump in the elevation that is given as hydraulic jump. You can similarly write for sub critical. It will be having large depth, low velocity. So, the some of the examples of hydraulic jump as we have you are taking it from Srivastav’s open channel book, that was published in 2009, so those examples we are just again quoting it here.

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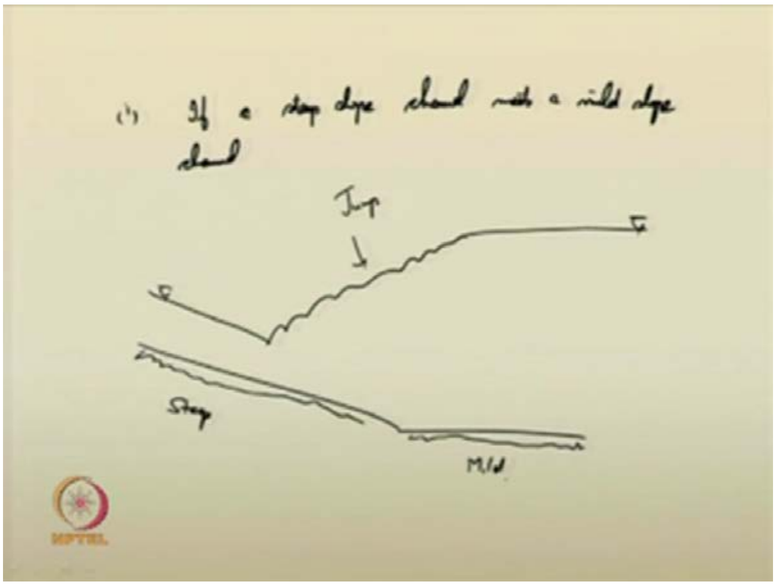

Some of the classic examples where we can see hydraulic jump say, if a steep slope channel meets a mild slope channel, what happens? A steep slope channel meets a mild slope channel. So, here the depth of flow it is low, because it is a super critical flow and here the depth of flow it is considered as sub critical. Now there is a significant difference in the elevation. So, here there occurs a sudden jump up to the means from the super critical depth to the sub critical depth of the mild slope channel. So, this is a jump, this is a hydraulic jump. So, here we have a steep slope channel and a mild slope channel. So, this causes sudden channel, so the super critical depth in the first channel changes to sub critical depth in the second channel.

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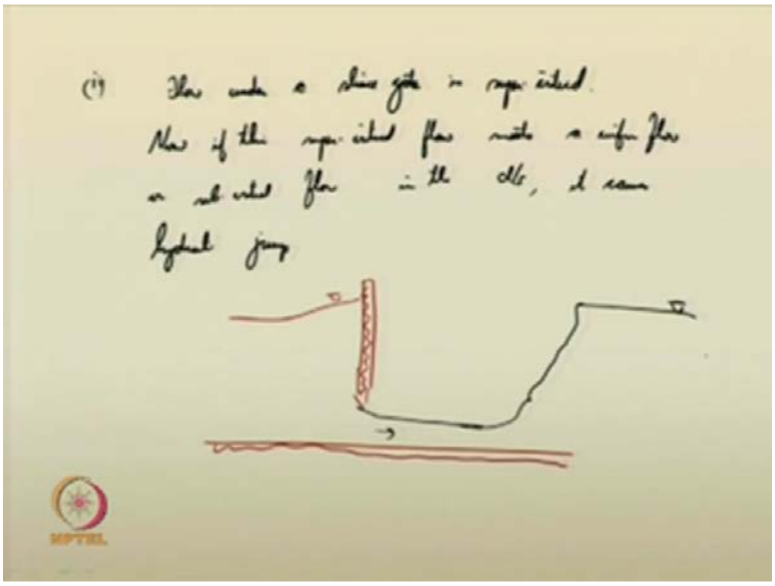

Another example you can see for hydraulic jump say, if you have a sluice gate, you know that flow under a sluice gate is super critical. Now if this super critical flow meets a uniform flow or sub critical flow in the downstream, it causes hydraulic jump. So, I can just show it in the diagram, there is a sluice gate flow occurs. We considered that the downstream there is a uniform flow. Now the flow here it becomes rapidly varied flow means, it is a super critical flow now, it gushes at a high velocity. This becomes it is a super critical flow, then after that it all of a sudden it jumps to the sub critical flow or uniform flow conditions. And all if this uniform flow it is maintained as it is the downstream, then such type of events occur, such hydraulic jump occur. So, this uniform flow in the downstream can be maintained by various methods and all, so those things we are not studying right now here. We are studying that wherever hydraulic jump occurs, that is those locations we have specified now.

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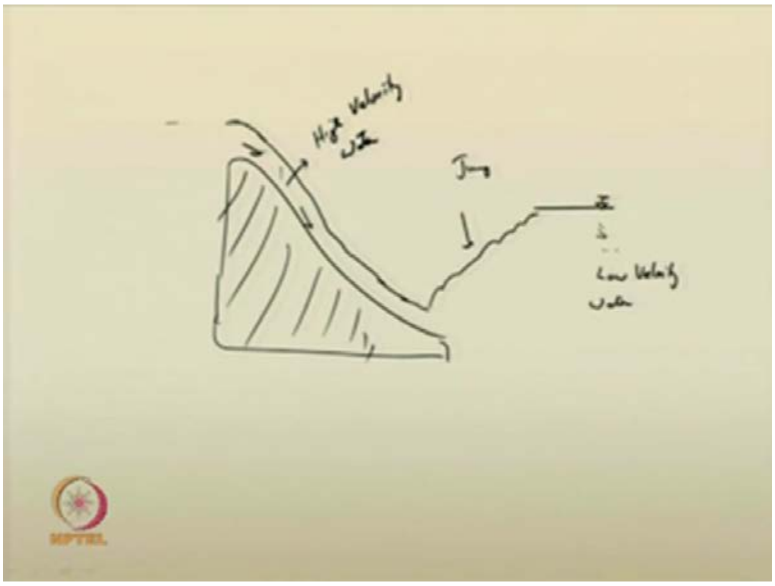

Another example you can see is that, if there is a spill way, if there is a spill way and the downstream depth of water is having a certain depth, water flows over a spill way at a high speed and at a low depth along the spill way and it reaches here. See the depth here and all here it is very small. But here in the downstream, however we are having a larger depth, so this change, this change in depth causes a hydraulic jump, say this is the spill way water is flowing over the spill way like this at a high velocity and there is a low velocity jump depth. Here this low velocity can be maintained by various spill basins and all can incorporate them. So, once this low depth is low velocity depth is available here this causes a hydraulic jump. So we can say low velocity water here and this is high velocity water. So, this also causes a hydraulic jump. So, properties associated with hydraulic jump.

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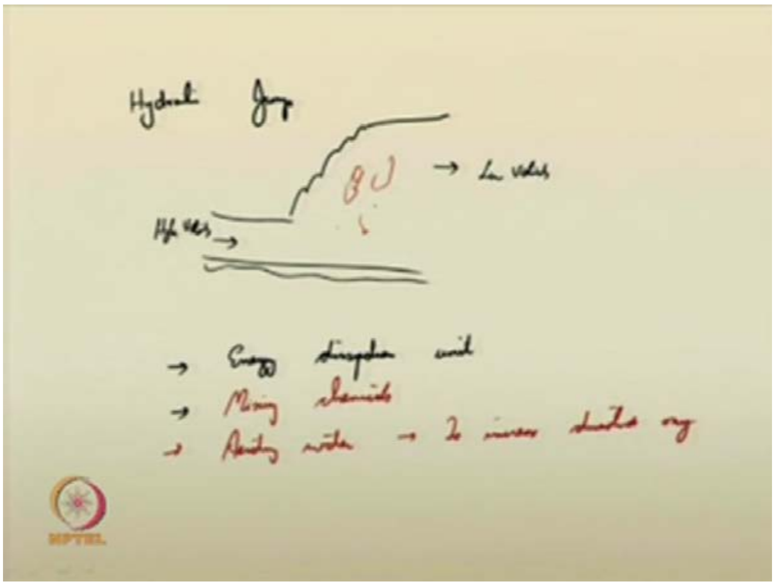

So hydraulic jump if you look it practically or if you look it in a simple way in a Leyman's form itself, you know that in the upstream it is the water is coming with a high velocity, in the downstream water is going with a low velocity. That is the general form of hydraulic jump. So, what is actually doing, why when water is coming with a high velocity, it is mean it is having high kinetic energy and all and when it is going out with a low velocity that is some energy is getting dissipated? So, this energy dissipation of energy it can be beneficial for the fluid flow in the channels and all. So, most of the time hydraulic jump is used as energy dissipation unit also but that we will come into later also, hydraulic jump it is used as energy dissipation unit. Hydraulic jump is also used for mixing chemicals. Suppose, if you mix chemicals in the very high velocity, water is coming here. If you mix chemicals here, it gets mixed entirely thoroughly in the water. For mixing chemicals, you can use hydraulic jumps or for aerating water or to increase, dissolve oxygen for that also you use hydraulic jump.

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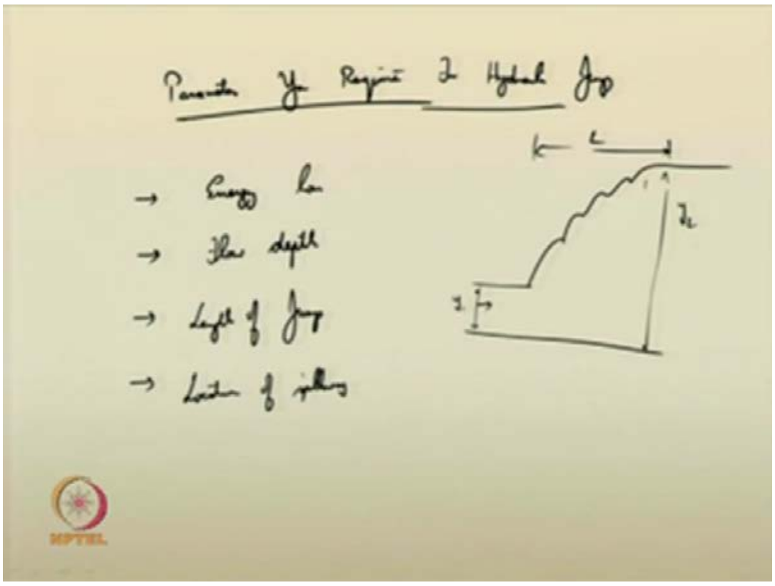

So hydraulics jumps they are usually mean some of the things aspects or parameters. You have to, parameters you have you require, you require for analyzing hydraulic jump. Some of the parameters require for hydraulic jump. We can suggest say energy loss as a parameter. You can also associate say the energy at this location upstream and energy location whatever change in energy is there, that energy loss. If you are designing and hydraulic jump based on energy loss so then energy loss becomes a parameter, flow depth say, if you are designing based on flow depth you have a upstream flow depth say y 1 here, and downstream flow that and y 2 here. Based on the flow depths, difference in flow depth you can design the flow I mean you can design the hydraulic jump.

Based on the length of the hydraulic jump say from here to here, how much length is required? How much length you have suggested? That also becomes a parameter, location of the jump whether it is below a spill way, whether it is below a sluice gate, whatever be location of spill way. So, these are some of the parameters that are essential for analyzing hydraulic jump. So, we will be using these parameters. In our next class, we will be studying or you will you will be using the continuum approach that is the control volume approach for studying the hydraulic jump and these parameters will come into picture there also. So, that way we are concluding today’s lecture. We can take a brief quiz now. So the first question for the quiz is, briefly explain in 1 or 2 sentences, what is meant by rapidly varied flow. That is briefly explaining 1 or 2 sentences. What is meant by rapidly varied flow? Your second question is, cite few examples of rapidly varied flow phenomenon, and cite few examples? The third question, what is hydraulic jump say, whether the hydraulic jump has a continuous or discontinuous flow profile?

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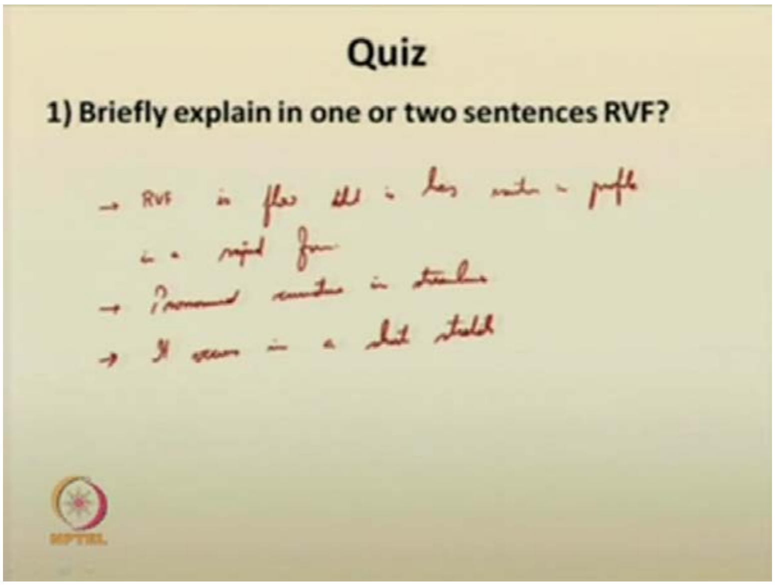

So the solutions for today's quiz; the first question we asked is briefly explain in one or two sentences rapidly varied flow. So, I can easily suggest rapidly varied flow are nothing but where flow that is having variations in profile in a rapid stretch in a rapid form. So, they have rapidly varied flow have pronounced curvature in stream lines it occurs in a short stretch. That is why it is called rapidly varied flow. Like this you can answer them.

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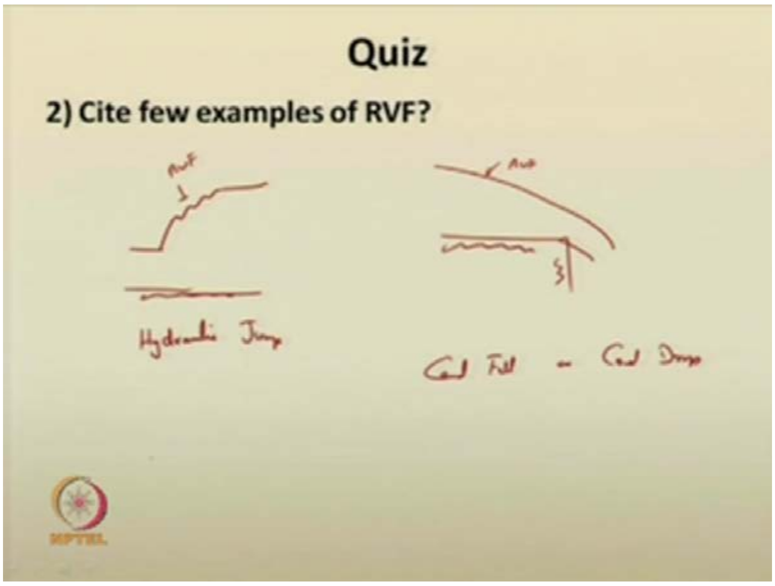

Your next question asked was, cite few examples of rapidly varied flow. So, we have I will just give it in a figurative way again. Standard example is the hydraulic jump. This is an example of rapidly varied flow. Another example is canal fall or canal drop. We suggested that, so this is having rapidly varied flow profile. This is having rapidly varied flow profile, we also suggested about the sluice gate.

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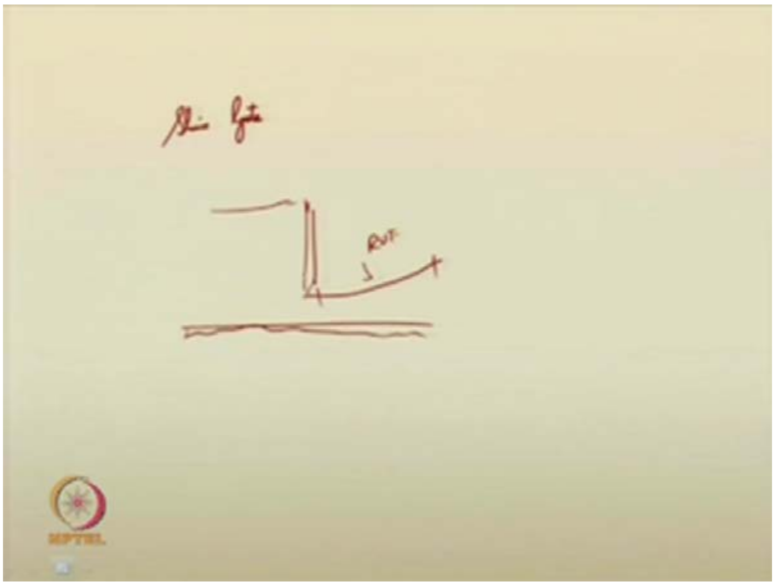

In the sluice gate, sluice gate, so under the sluice gate the flow profile rapidly changes. So, this is this stretch is also rapidly varying flow profile. So, there are various examples you can quote, you can write some other examples also if you are aware of them.

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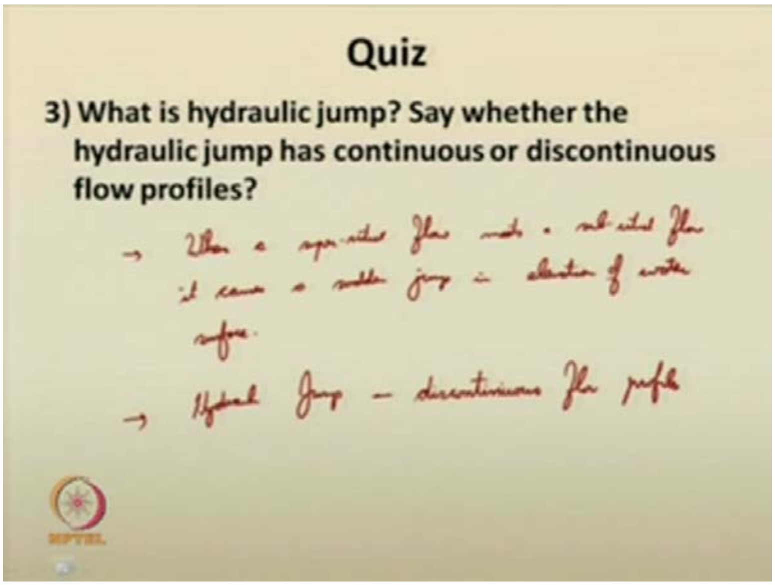

Our third question what is meant by hydraulic jump? Say whether the hydraulic jump has continuous or discontinuous flow profile, you can suggest that again hydraulic jump is defined as when a flow or when a super critical flow meets a sub critical flow. It causes a sudden jump in elevation of water surface, this is called hydraulic jump. So, the second part of the question whether hydraulic jump is continuous or discontinuous, hydraulic jump is suggested that hydraulic jump is having discontinuous flow profiles. So, hydraulic jump is having discontinuous flow profiles. So, that way we have we have given the solution also for the today’s quiz. Next class as we mentioned earlier, we will be dealing with the theoretical aspects of the hydraulic jump. It is what a, how do you analyze the flow phenomenon there all those things.

Thank You.