Advanced Hydraulics
Prof. Dr. Suresh A. Kartha
Department of Civil Engineering
Indian Institute of Technology, Guwahati

Module - 4
Hydraulics Jumps
Lecture - 4
Features of Hydraulic Jumps

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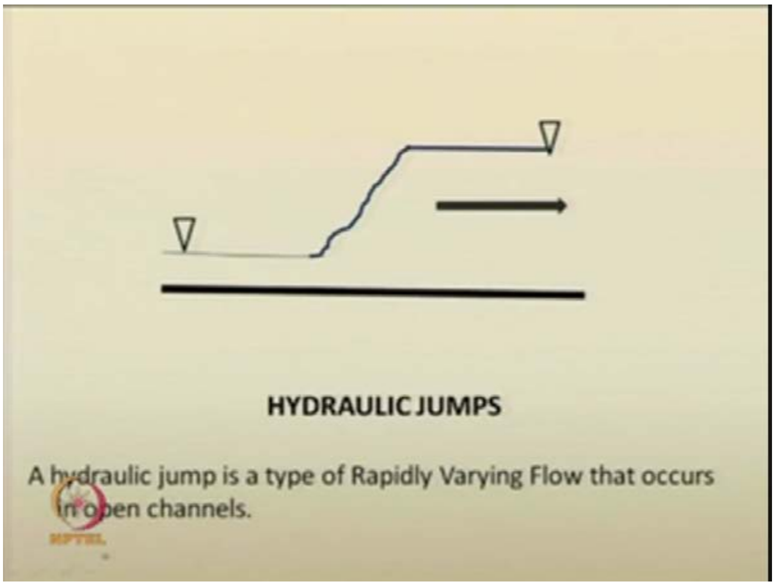

Welcome back to our lecture series on advanced hydraulics. So, we are in the fourth module on hydraulic jumps. If you recall them hydraulic jumps, it is a type of rapidly varying flow that occurs in open channels.

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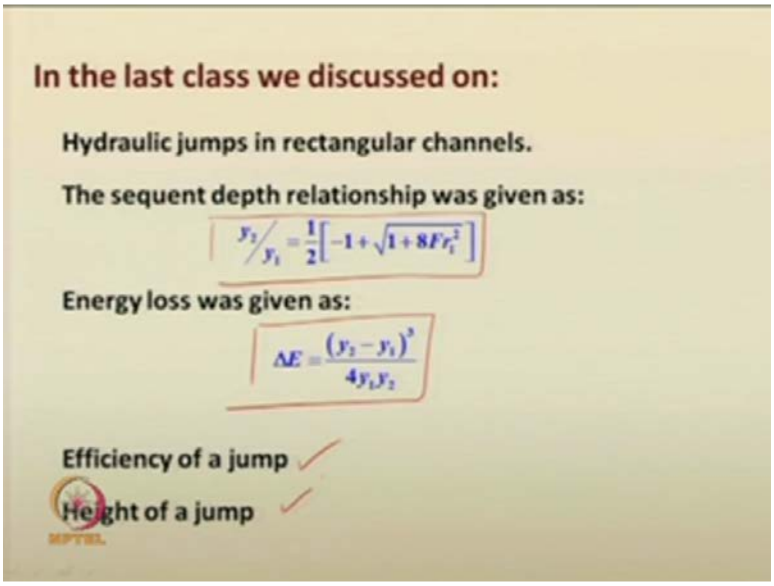

In the last class, we had discussed on hydraulic jumps in rectangular channels. We had discussed on the sequent depth relationship as, as is given by this particular equation y 2 by y 1 is equal to half of minus 1 plus root of 1 plus 8 F r 1 square. Then, we had discussed on the energy loss that can occur in rectangular channels due to hydraulic jumps, related to the characteristics of hydraulic jump, we discussed on the efficiency of hydraulic jump. We also discussed on the height of a hydraulic jump. Today, we will discuss some more features of jumps in the rectangular channels.

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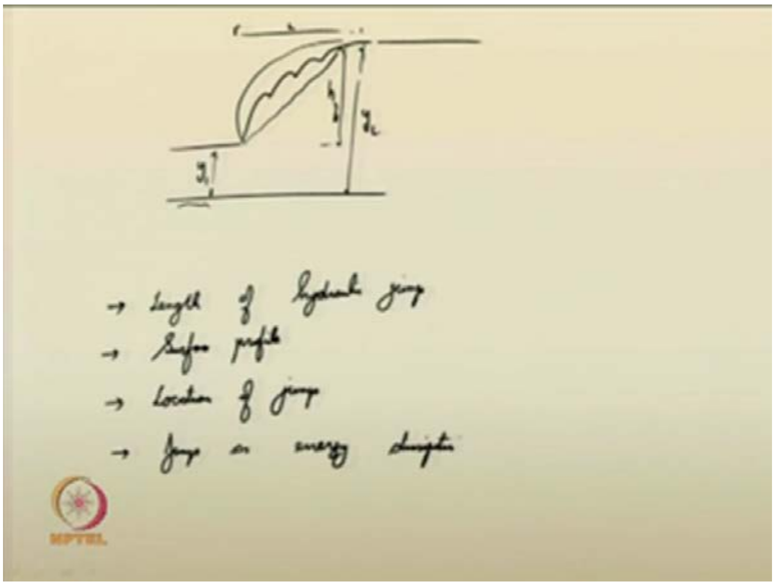

If you see that length as we have seen for a jump, you have their sequent depths y 1 and y 2. You have the height of jump as was given earlier height of jump. Now, there are other properties as well, you can also think of the length of a hydraulic jump, the length of the hydraulic jump, how will you evaluate? Or it could also be considered as a property of the hydraulic jump. You can also find or you can also think of this length of hydraulic jump. You can also think of a feature in jump that is the surface profile, how the surface profile will be? Here, you can see the profile is in this form, some in some cases it may be like this, some cases it may be like this.

So, we do not know what could be the profile of the hydraulic jump. So, that also you need to determine, what type what are the parameters that determine the surface profile of the jump? Location of a jump that is an important criteria, where do the jump occur? We have seen that the jump occurs from when flow changes to supercritical to sub critical. So, in that case where does the jump occur? Whether it occurs in the steep channel first, and then it goes the flow goes into the mild channel or whether the jump occurs in the mild channel or whether it occurs in the intersection? What are what could be the criteria? Thus those things also we will see today. We may also see jump that can be used as energy dissipaters. So, we will briefly just tell about this thing and if time permits, and if not we will discuss in detail in the next class related to jumps as energy dissipaters.

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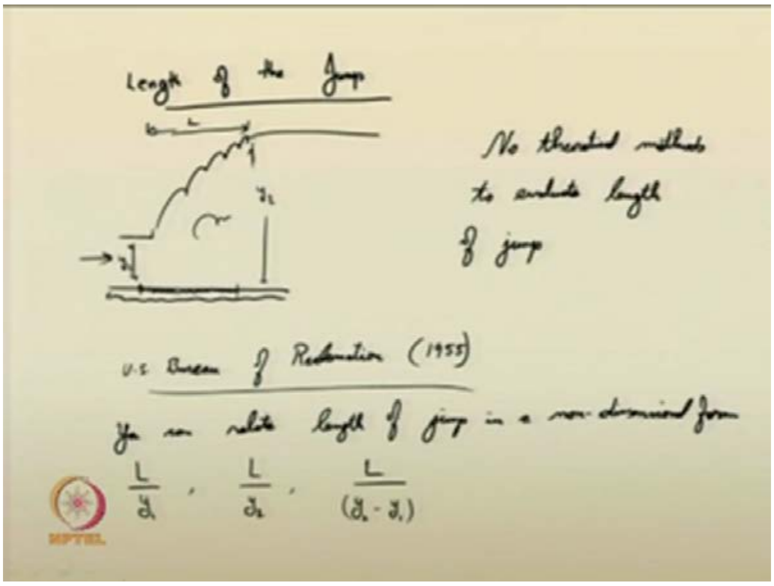

So, the length of the jump, length of the jump, you can define the distance there is if as shown earlier. If you have the jump, then the distance from the beginning of the jump position that is around this location to the distance in the, to the point in the downstream where the rollers are almost stopping. See these are the rollers when it stops here. So, the up to that location you can consider as as the length of the hydraulic jump. The starting of a jump it is a fixed phenomenon, there is no ambiguity there. But in the downstream, at which location the jump stops? Or means we can suggest that this is the location where jump ends that cannot be determined exactly. And there is also there is no there is no theoretical methods, no theoretical methods to evaluate length of jump.

So, as there are no theoretical methods, you have to do the experimental things. So, they there are many scientists who have done immense experiments related to hydraulic jumps. They have come up with some or the other empirical relationships to compute the length of jumps. We will just briefly see one or two of them. So, before understanding why the length of jump is important? Why do you need to compute the length of jump? What happens if you are not taking into account the jump length and all? Jump, when you do for example, in this channel from the starting of this jump to this end of this jump there is a sudden rise of water. Due to the sudden rise of water the pressure exerted on this channel bed that will be the channel bed that will be quite drastic that could be a difference in the thing

So, that or suppose if a high velocity water is coming here, if a high velocity water is coming here, it can scour the channel bed. You are now going to create a hydraulic jump to dissipate the energy that we will be discussing later. But due to this high impact velocity high jet flow there could be change there can be scouring. So, how much protection you need to incorporate? For how length how much length you need to incorporate protection in the channel bed? For that case also you need to understand the length of the jump.

So, these up to these much region you can give a proper protection a well protected or a better protection compared to this region that way you can economise your channel beds and all. So, the as we suggested in the beginning of the channel jump channel beginning of the jump is well defined, but end it is still ambiguous there from the experiments. For example, U.S bureau of we have taken there that earlier also, U.S bureau of reclamation. They have conducted experiments on open channel in 1935. And they have reported their experimental data with various analysis one analysis, one idea which they suggest is that you can have or you can relate length of jump in a dimensionless form or a non-dimensional form, you can relate the length of jump by a non-dimensional form.

So, how will you do that? So, you can relate these things say for example, if you have this length of the jump that can be made into a non dimensional form by various criteria. You can either use L by y 1 that is length by the pre jump depth or you can take another ratio L by y 2 length by post jump depth. You can also think of taking the ratio l by y 2 minus y y 1. So, various in various way, one can define a non dimensional form for the length of the length of the jump. So, these non dimensional forms if you can relate it with certain quantities for example, Froude number of the pre jump location, then because the pre jump location Froude number is only the known quantity to you. How much will be the post jump Froude number? It is not available means, you have to solve for this. So, in that case, if you know the pre jump Froude number, and if, if you have certain relationship of that pre jump Froude number with respect to this non dimensional length, you can easily get the length of the jump. So, as the U.S bureau of reclamation they have in one of their analysis.

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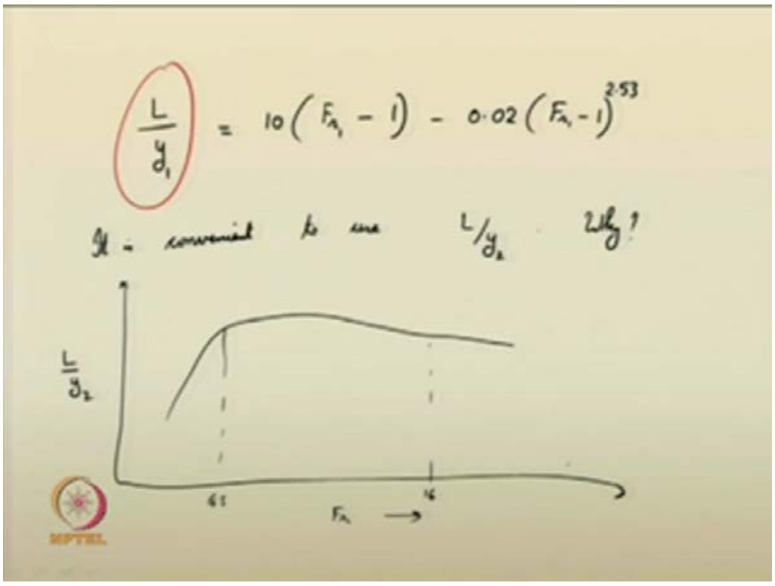

They suggested that the ratio of length of the jump with respect to its pre jump depth. This can be given as 10 times Froude number in the upstream or the pre jump location minus 0.02 times Froude number minus 1 to the power of 2.53. So, if you have this, this was one relationship, they have developed empirically from their experimental data. You can see that this ratio was obtained by using the length of the jump with respect with the pre jump depth, but mostly it is convenient.

It is convenient to use the ratio L by y 2, why that is L by y 2? It has been found from the experimental analysis that it is the more convenient way of identifying the length of the jump. One of the reason is that from their experimental things when they plotted the upstream Froude number with respect to the ratio L by y 2. They found that the curve is more or less uniform for a certain region, say from Froude number 4 or 4.5 to 16 and all. They are roughly having the same magnitude the ratio L by y 2 is almost in the same range it is not fluctuating.

For example in L by y 1 when you plot it, you may not get the relationship in this form. So, convenience convenient to design for design purpose and all, people have started using the L by y 2 ratio with respect to Froude number for analysing or evaluating the length of the jump.

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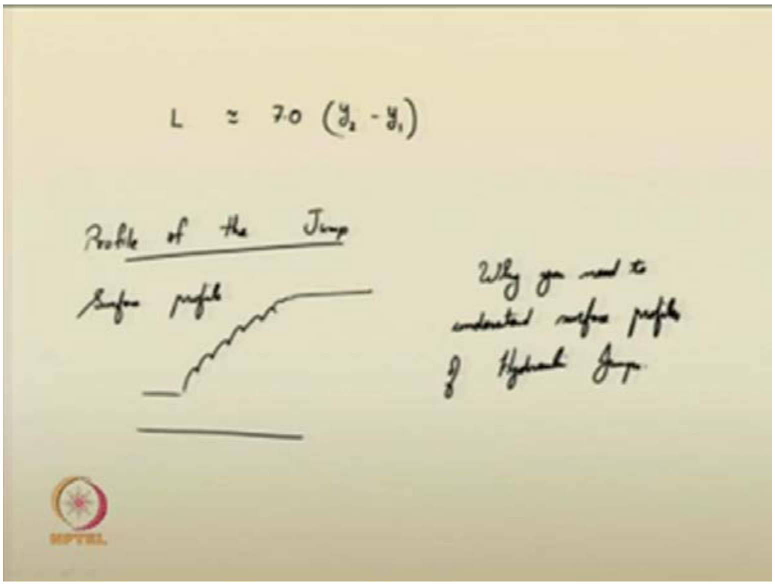

Another expression, you have is another empirical this thing was developed from some of the experiments were length of jump is approximately 7 times that of the difference in post and pre jump depths. This is also one of an empirical relationship so none of them are theoretically developed cases.

So, another next portion which we have to cover is now the profile of the jump profile of the jump. So, we are mainly talking about the surface profile, if you have a so this entire portion it is called surface profile, how the jump is occurring from this steep from the supercritical to this subcritical flow? How the jump is occurring from in that case? What is the water profile? Due to this change in profile it is called rapidly varied flow as you know earlier we have studied that. So, why surface profiles are essential? Why you need to understand surface profiles, so why you require them?

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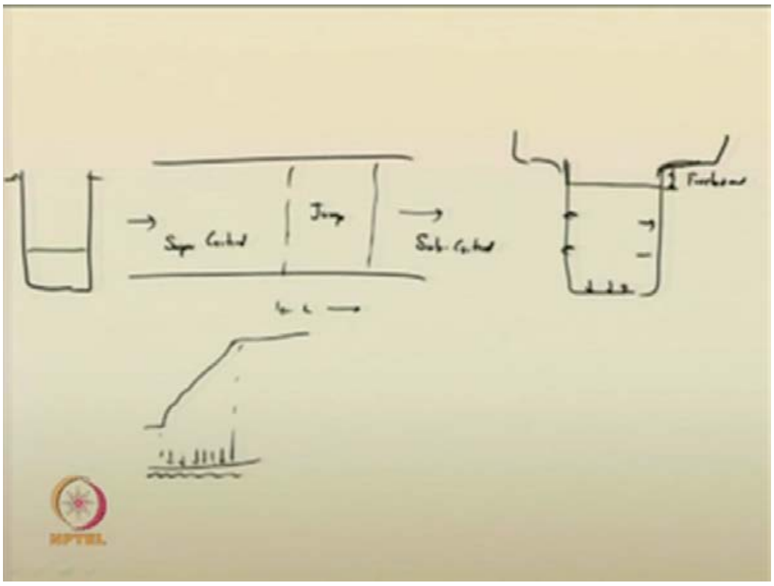

So, if there is a, channel water is flowing, say here it is in supercritical and at this location you are providing the location for jump and say if this is the length of the jump and from here it is subcritical. This is the top view of a in a channel where jump is occurring. So, when you design the channel in this case, say if the channel cross section, if that channel cross section you had the depth of flow like this, here the depth of flow as this particular quantity.

So, based on the depth of jump that is being considered, you have to associate the free board in the design. The length this particular length is called free board, how much free board you will be providing on the top? So, for designing of the free board or also for designing the length means or to identify how much quantity of water may spill off in the planes? Some of the people provide free board in this aspect like this. So, those also you need to take into account. So, for those cases, you require the profile of the hydraulic jump. Not only that profile will also help in, say if you have profile like this in the channel bed, in the channel bed with respect to with the water depth the pressure will be exerted by the water here on the channel bed. So, based on the profile, you will be able to evaluate the pressure force, and that pressure force will be used in the structural design or the material design of the channel beds and all, both for the sides of the channel as well as the channel bottom.

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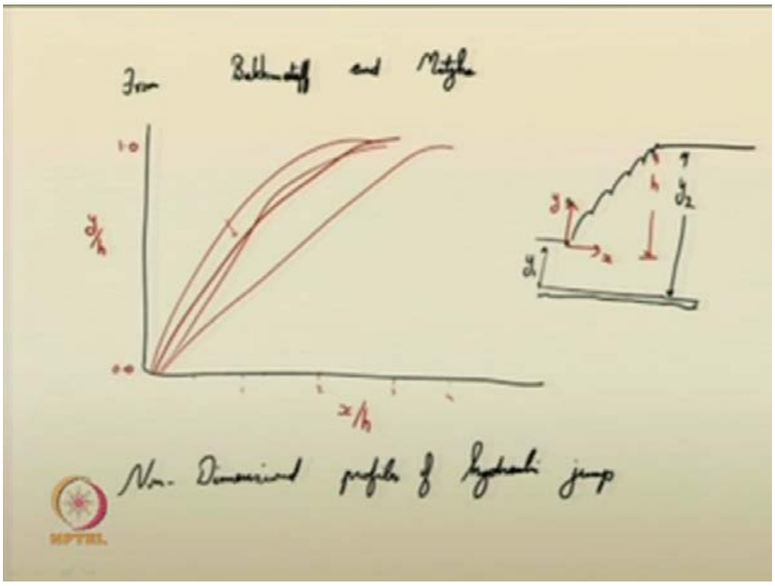

From the experimental data of Bakhmeteff, Bakhmeteff and Matzke in 1950s, back 1940 since around 1950s. They conducted several experiments on open channels. And they have suggested the profiles yet again with respect to some Froude number or that aspect. So, if you have a hydraulic jump, say if the, if in the approximately horizontal channel you have the depth of the channel as y 1 this as y 2. Say the starting point if you consider it as the origin, if I consider this starting point as the origin, say this is y direction; this is x direction. And as you know that this is the height of the jump fine. One can easily find the profile or those scientists they have determined the profiles of the jump in such a way that for this particular ratio x by h that is the x, how much distance he was travelling from the jump origin in the right direction or in the flow direction? And y is the depth of the jump or the height of the jump starting from 0 here.

So, this thing you can; you can have the quantities profile like this that is the y by h versus x by h if you plot it. For various Froude number, say one particular diagram, what

I have seen is that it is of like this nature. Definitely, you know that the maximum possible here is 1, and minimum possible here is 0 the range. So, this can definitely exceed more than 1 also, it can be 1 2 3 whatever be it can exceed like this. So, this is for a particular Froude number, for another Froude number they had a profile like this, for another Froude number they had a profile like this they have for different. For larger and smaller Froude numbers they conducted various experiments and they came up with such profiles non dimensional profiles. So, they are also being used extensively used now a days for determining the profiles of your hydraulic jump, non dimensional profiles of hydraulic jump.

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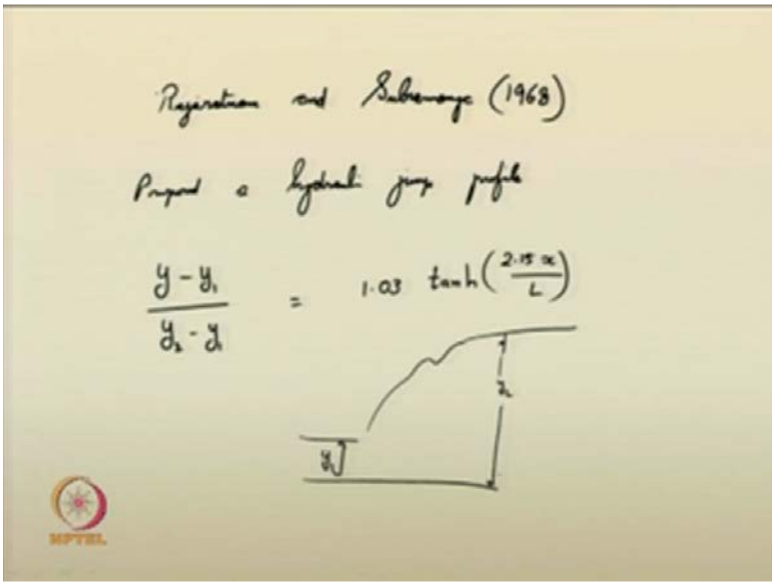

From India itself Professor S. Rajaratnam; Rajaratnam and Subramanya in 1968 they, they have also published the things with their various experimental analysis. They found that using a large experimental data. They proposed a hydraulic jump profile as such that is y minus y 1 by y 2 minus y 1 is equal to 1.03 tan h, 2.15 x by L with this also they had proposed the quantities. This is your depth y 1; this is your depth y 2.

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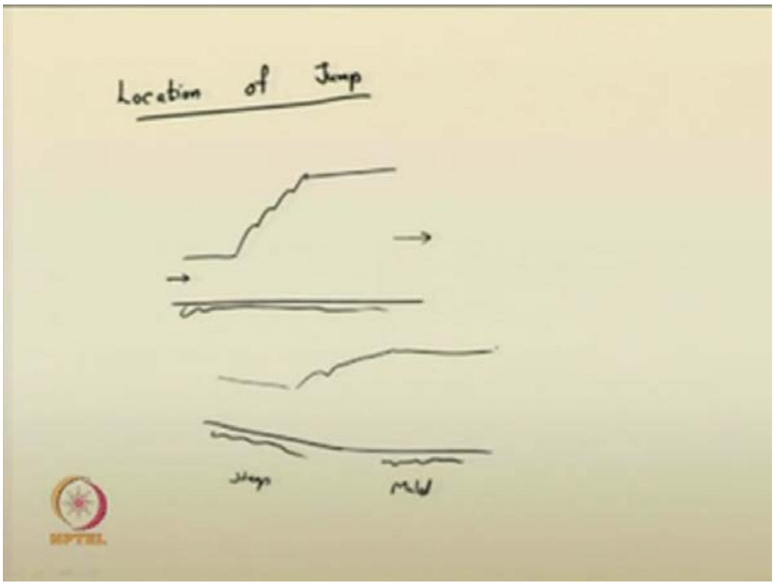

Next, we are going to discuss on the location of jump. So, we know that a in a the hydraulic jump occurs from a supercritical flow to a subcritical flow. This we have seen from last few classes onwards. This is a process of hydraulic jump, when you studied the gradually varied flow in one of the situation we have seen that when a steeper channel merges with the mild channel there are probability of occurring hydraulic jumps. We had stated at during that time, even though we did not discuss on the hydraulic jumps in that module the, these things are discussed here.

So, though that is when a steeper channel merges with a milder channel. So, there is a probability of occurrence of hydraulic jump. We do not know at which location the hydraulic jump may occur.

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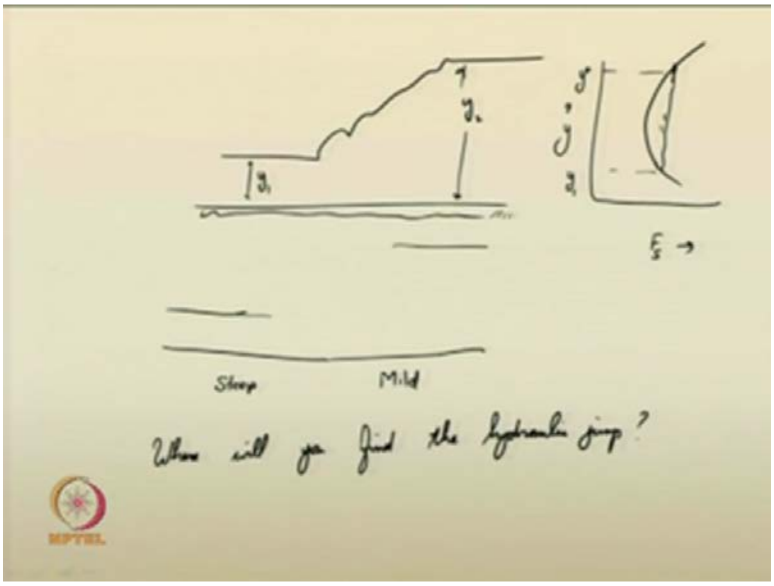

So, when we studied the hydraulic jump, you have already seen that the hydraulic jump consist of a pre jump depth and a post jump depth, we have seen these things. So, the specific force in the pre jump location and the post jump location, they are the same. Also for rectangular channels and all in our previous analysis and all we have approximated the bed channel to be almost horizontal and all.

So, when you are dealing with such steep and mild cases, although the channel slopes are approximated to be nearly horizontal. Based on the condition of flow we suggested that it could be a steep channel or a mild channel. There is a specific force, if you have seen that it may consist of a curve like this specific force versus depth and you have for the same specific force the corresponding. So, this is the sequent depth of the previous depth in the upstream. So, the question I would like to ask is for such a differential slope channels, say if there is a steep channel in the upstream and a mild channel in the upstream. So, steep channel is carrying a supercritical flow, mild channel is carrying a subcritical flow, there it will be naturally some hydraulic jump when the change is from steep to mild or there is some change from supercritical to subcritical flow.

How will you incorporate jump? Whether the jump will be on the steep slope channel, whether the jump will be in the mild slope channel or it will be somewhere else. This is the question I would like to raise, where will you find the hydraulic jump? How can you find the hydraulic jump? So, this you need certain analysis.

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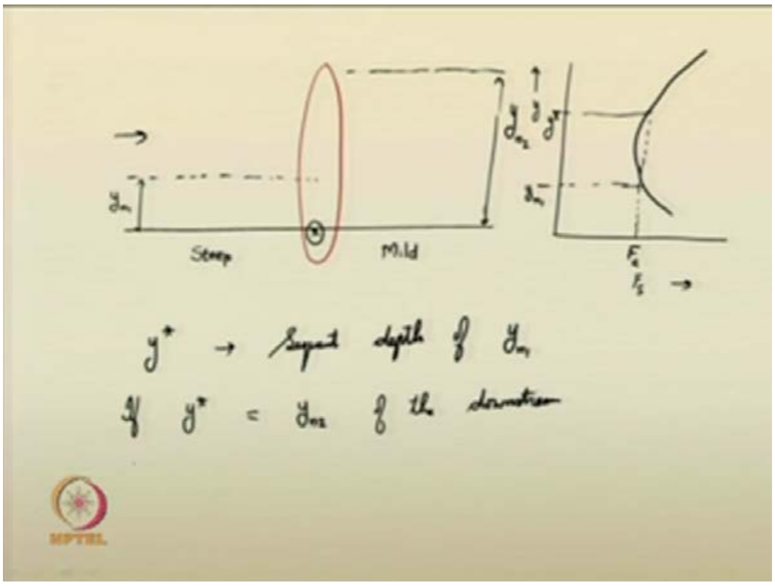

You can just again go through the things say I am just redrawing that. Let me say this is the, this particular portion is the junction point on the left side you are having a steep channel on the right side; you are having a mild channel. The normal depth in the steep channel it is given by y n 1. The normal depth in the mild channel let us consider this as y n 2. You also have some critical flow in between these two normal depths that also you are aware of those things. So, how the change occurs if from this junction point whether the jump occurs on the left side or on the right side, consider or you just replot them again.

Now, if I am drawing the specific force versus depth curve, if I plot the specific force verses depth curve, you will see that specific force curve may be something of this form. So, you can just note it down, what is the corresponding specific force based on the normal depth in the steep channel, because the flow is occurring from steep channel to mild channel. So, this depth it is already existing. So, what is the specific force? Say if I write it as F a, the corresponding sequent depth will be somewhere here. And if I write it as y star, the corresponding sequent depth of the normal depth in the upstream portion that is given as y star.

So, y star is the sequent depth of the normal depth in the upstream portion. So, the normal, when the flow comes with the normal depth in the upstream portion, and if the slope of the channels are changing from steep to mild, the hydraulic jump, the location of the hydraulic jump, how to determine it? We can suggest in the following form, you have this depth as y n 1, the corresponding sequent depth as y star if your y star is equal to the normal depth of the downstream. If your y star is equal to normal depth of the downstream, you will see that the jump occurs in this junction itself in this particular junction itself your jump occurs.

So, there is no shifting of the jump that is it is not in the steep channel or not in the mild channel it is exactly in the junction itself the jump occurs.

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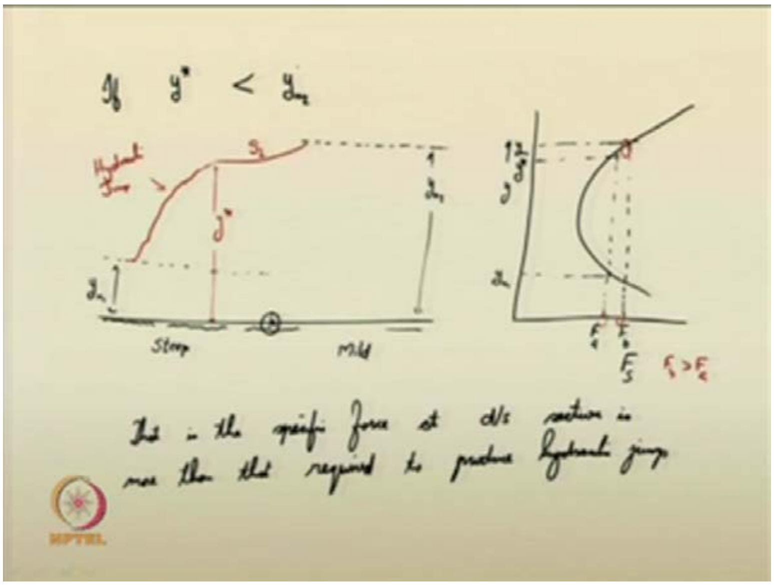

Next case is if your y star is less than y n 2, normal depth in the downstream what happens? So, I can just again redraw the cases the bed channel, say let me assume this as the junction point and this is the steep channel. This is the mild channel, you have the normal depths I am just drawing the specific force versus depth curve, something of this sort and say this is your y n 1 and the corresponding y star; this is y star, and if your normal depth in the downstream section or the post jump section y n 2. If y n 2 is greater than y star you will see that this y n 2 portion in the specific force curve, this is having more specific force compared to the upstream section. So, in the upstream section you had a specific force F a, here in the downstream section for the corresponding normal depth the specific force is F b that is the specific force at downstream section is more than that required to produce hydraulic jump.

So, that how will the water these things balance? How the flow will balance? Then the 4 here the specific force is more you can see them I can just give in a different ink here. You can see this portion; this portion is having a more specific force compared to the downstream section where F a it is the specific force. So, in this case, what happens is to balance the flow or to maintain the equilibrium, the flow it just pushes the hydraulic jump into the upstream portion, it just pushes the flow into the upstream portion. And what it does is that you have F b greater than F a, that is when required for the hydraulic jump at the downstream. So, what happens the flow adjust in such a way that the flow the hydraulic jump is now pushed to the upstream location. It is pushed to the upstream location in such a way that the jump is formed in the upstream location here. And it is followed by an S 1 curve then it joins the normal depth of the downstream that is the process. So I can just draw it here it is pushed the hydraulic jump is pushed here, it it reaches y star depth and from here it follows a S 1 curve.

So, this is your S 1 curve; this is your hydraulic jump and its sequent depth is y star the pre jump depth is y n 1 and the sequent depth is y star. It is followed by an S 1 curve and it joins the mild slope channel with an S 1 curve. This is how the flow gets adjusted or this is where the location of hydraulic jump can be found for such a situation? Where your sequent depth of the normal depth in the upstream location is less than the normal depth in the downstream location? Next we can discuss.

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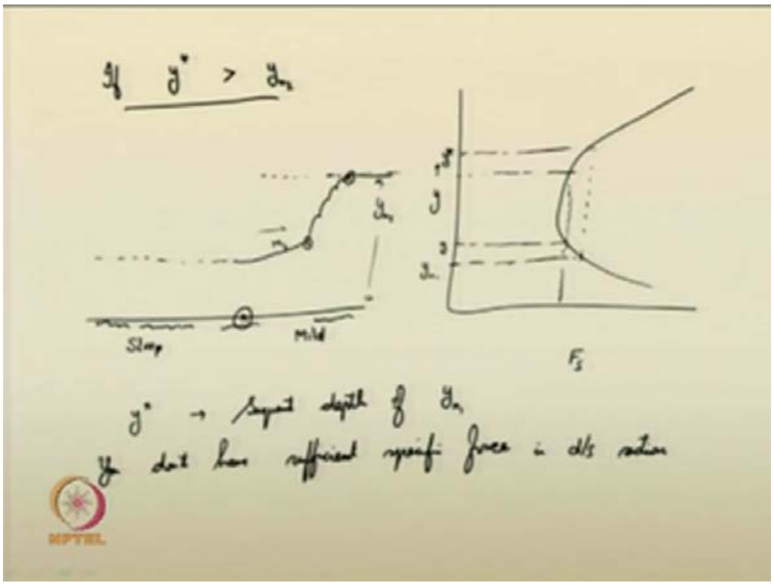

If y star is greater than y n 2 if y star is greater than y n 2, same diagram I am just repeating it. And let me assume that this is the intersect or the junction of the 2 slopes, this is steep slope; this is mild slope the corresponding normal depths. So, the specific force versus depth curve, we have just plotted it in this case, and let me suggest that the corresponding sequent depths are y n 1 y star. So, y star sequent depth of y n 1, if the this is available. And if it happens in such a way that the normal depth y n 2 is less than y star if y n 2 is less than y star or y star is greater than y n 2, how the flow gets adjusted? Now to, you do not have sufficient in this case, sufficient specific force is not available, in the downstream section for the normal depth of the downstream section to cater the hydraulic jump. You do not have that sufficient specific force in downstream section.

So, how the hydraulic jump will be formed then? The hydraulic jump will be formed in such a way that it will realign the flow. First the hydraulic jump is now pushed to the downstream section that is it is pushed into the downstream section here it is it will be pushed like this jump will occur that is it will be pushed and that pushing of this thing is being described through a gradually varied flow profile. It will be an M 3 profile as we know that and it is the hydraulic jump will be formed and it will attain the. So, whatever raise occurs here, say if water from here it raises like this through an M 3 profile, you have to check, say the corresponding depth is here. So, this up to this depth, up to this depth M 3 profile will occur here a jump occurs and it attains the specific.

Now, you can see that at both these location, this location and at this location they are having the same specific force that is the requirement for a hydraulic jump. So, this is how you identify the location of hydraulic jump for a situation where the normal depths are not sequent to each other are not sequent depths. So, as we have seen in the previous case, the jump is pushed upstream and in the subsequent case we have seen the jump is pushed downstream. So, this you should be able to understand the phenomenon.

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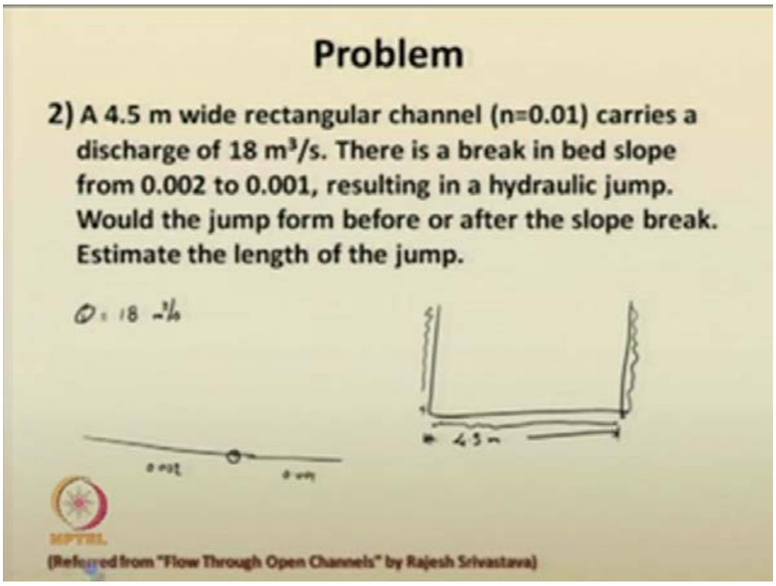

We will just solve an example problem related to the same concept. So, this particular example problem, part of that we have already done it in the last class also. Again I am just repeating it is a 4.5 meter wide rectangular channel is there, 4.5 meter wide rectangular channel, whose roughness coefficients are given as n is equal to 0.01, it carries a discharge of Q is equal to 18 meter cube per second. So, there is a break in bed slope from 0.002 to 0.001, say if the longitudinal profile if it is taken like this there is a break in slope.

So, this is 0.002 0.001 bed slope. So, due to this break in slope, the hydraulic jump is resultant. Now, we are asking you whether it is not necessary that it is due to the break in slope, any how the hydraulic jump is to be formed in that location and there is also a change in bed slope. We are asking you would the jump formed before or after the slope break, estimate the length of the jump, can you work it out. We have given all the data now Q is equal to 18 meter cube per second.

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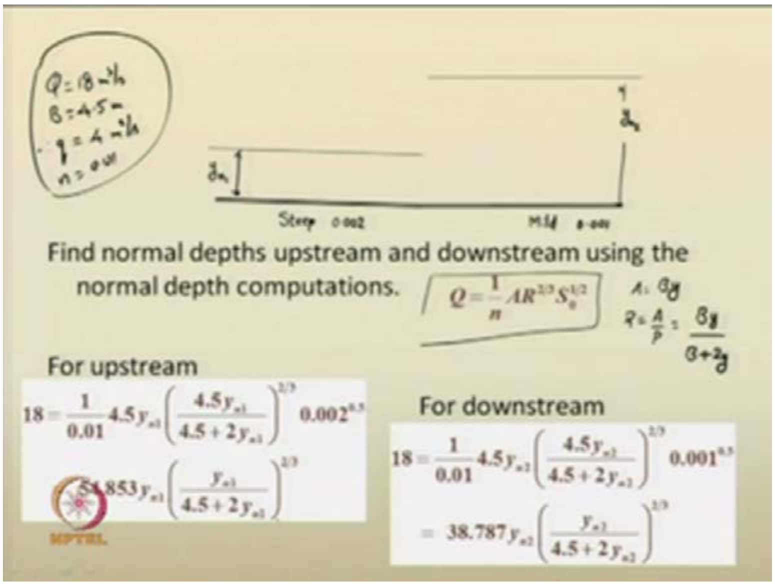

So, we are given that Q is equal to 18 meter cube per second, width is 4.5 meter. Therefore, discharge per unit width is equal to 18 divided by 4.5 4 meter per second. This was seen in the last class also similar case. So, let us consider this as steep slope channel and this portion as mild slope channel. This is having 0.002; this is having 0.001, here the normal depth is y n 1 and here the normal depth is y n 2.

So, where do the jump occurs? Whether it is in the downstream portion or whether it is in the upstream portion that you need to find it out. Based on the given data to you now find the normal depths upstream and downstream using the normal depth computation, you remember the manning's equation for computing the discharge uniform flow computation. So, based on that you find the normal depth in the upstream section using giving based on the given data we can just rearrange this particular equation can be substituted. And I have just substituted it here I am obtaining the corresponding equations that is I had substituted Q is equal to 18, substituted manning's n is equal to 0.001 depth, area is equal to you know for rectangular channel it is B y, hydraulic radius R is equal to A by P, this you know it is nothing but B y by B plus 2 y.

So, those things I have just substituted it here I have substituted the bed slope 0.02 to the power of 0.5. From this similarly, in the downstream section also I just substitute the appropriate data I am not I am not showing you how the computations are done.

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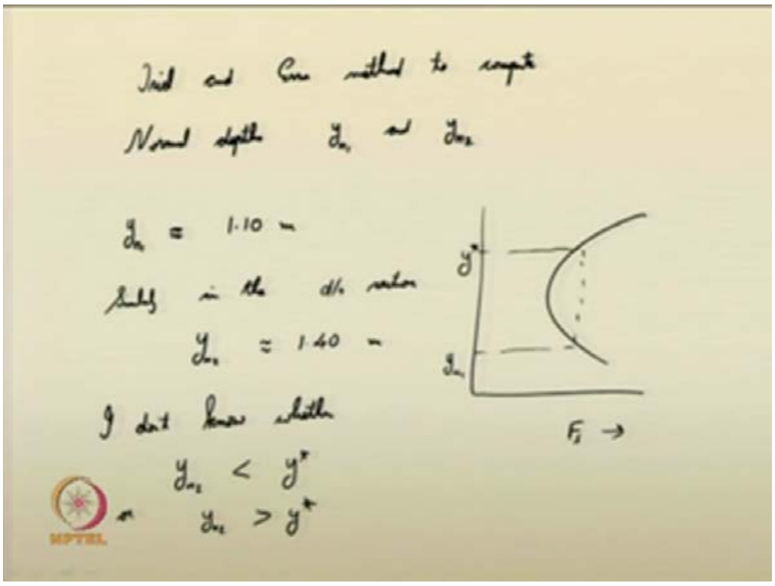

You can use trial and error method. So, you can use trial and error method to compute normal depths y n 1 and y n 2. So, once you compute the normal depths based on the given data I have observed that normal depth in the upstream portion it is approximately equal to 1.10 meter, it may be 1.095 meter and all. But I am just taking at the 2 decimal level.

Similarly, in the downstream section y n 2 approximately equal to trial and error method I got it as 1.40 meter. So, you have been now given, see again you know the specific force diagram you can one can draw it specific force diagram. So, I am getting y n 1 and I am getting y n 2 so y I do not know in this case, at present I am not aware I do not know whether this is y star, y n 2 less than y star or y n 2 greater y star that you need to determine.

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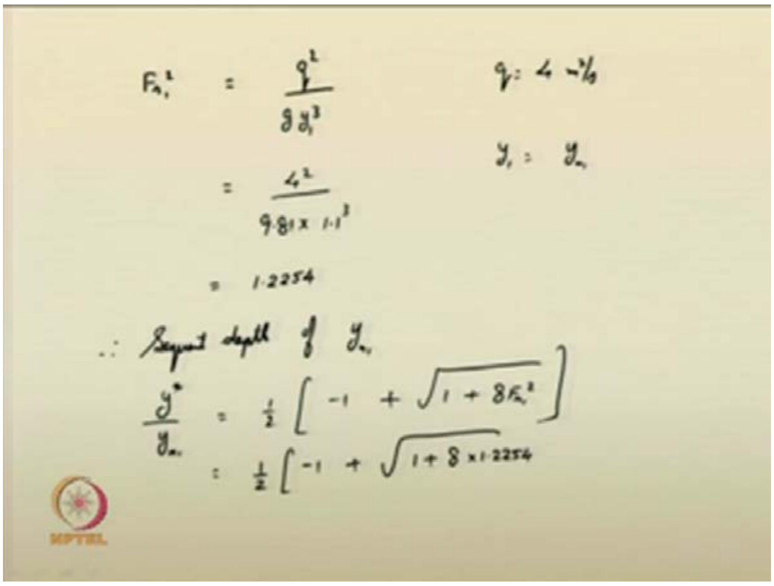

So, I can now easily suggest the thing, you just find the Froude number in the upstream portion Froude number you remember that, this is nothing but q square by g y 1 cube. So, I have q, q is equal to 4 meter square per second. So, 4 square by 9.81 into y 1 is nothing but your normal depth in the upstream portion. So, this is 1.1 to the power of 3 I am getting Froude number as 1.2254, Froude number square of the Froude number as 1.2254. Therefore, the sequent depth of y n 1 can be computed by the following relationship y star by y n 1 is equal to half of, because this is a rectangular channel. So, this can be directly substituted 8 F r 1 square. So I am getting half into minus 1 plus root of 1 plus 8 into 1.2254.

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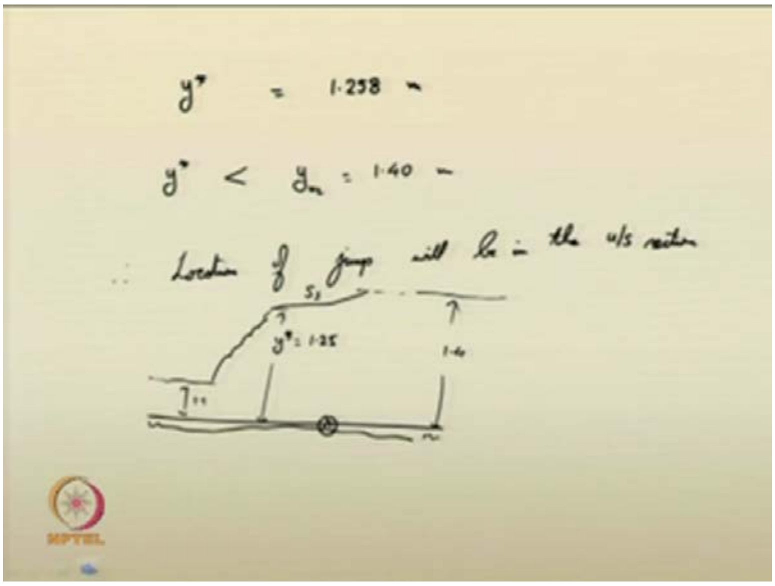

So, from this ratio we are getting that y star that is the sequent depth is equal to 1.258 meter you can verify that. You can see that this is some ratio this is equal to 1.1434. So, therefore, y star is equal to 1.258 meter. So, you are seeing that y star is now less than y n 2 which is nothing but 1.4 meter. Therefore, location of jump, hydraulic jump will be in the upstream channel it will be in the upstream section that is in the steep sloped channel fine.

So I can just suggest in the following form. So, it will be something like this say this is the normal depth, this is the normal depth here and if this is the section. So, there will be a jump on the, of the following form then an S 1 profile will be followed. So, here the depth is y star is equal to 1.25 or 26 whichever be here, this is the following depth 1.1 and this is 1.4. So, this is how the jump can be witnessed it is in the upstream section.

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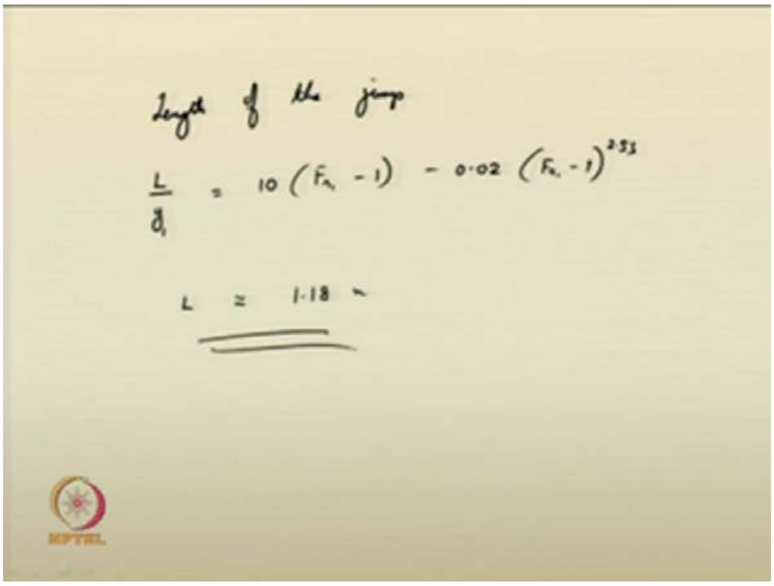

The length of the jump, we can use the empirical relationship as stated earlier L by y 1 from the U.S bureau of reclamation and all we have seen that so 10 into F r 1 minus 1 minus 0.02 into F r 1 minus 1 to the power of 2.53. So, you are getting length of jump approximately, substitute all those values 1.18 meter I am getting the length of the jump that is this is the length of the jump. So, all those things I have solved it very easily. So, now we are concluding this lecture, we will just quickly follow with the following quiz.

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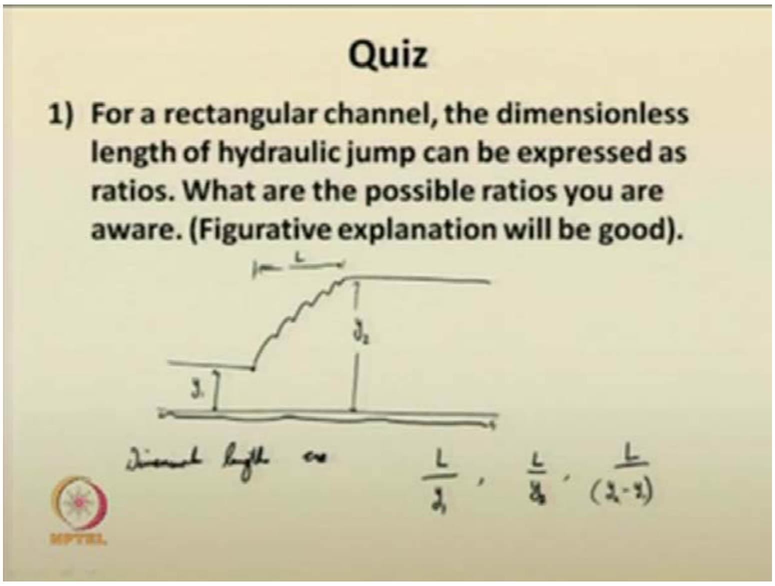

The first question for the quiz is “For a rectangular channel, the dimensionless length of hydraulic jump can be expressed as some ratios. What are the possible ratios that you are aware?” You can give in a, you can give a figurative explanation for those ratios.

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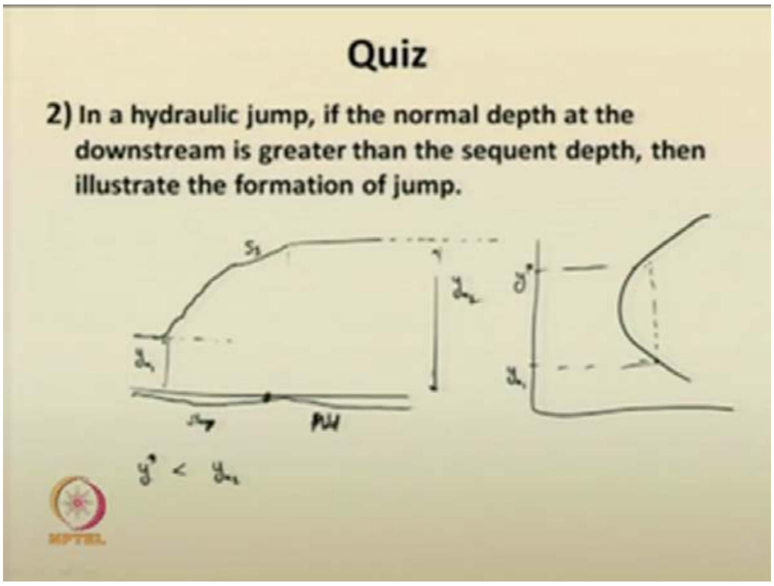

Second question; “In a hydraulic jump, if the normal depth at the downstream is greater than the sequent depth, then illustrate the formation of the jump.” You have to figuratively illustrate that; I am not asking you in a mathematical formula. You can illustrate that; you can just figuratively explain solutions for this quiz.

The first question we asked you, what are the dimensionless properties? Or how you can evaluate the length of hydraulic jump using dimensionless quantities? So, first you should be aware is that is the hydraulic jump. So, the hydraulic jump, it has a pre jump depth and a post jump depth. So, based on this pre jump depth and post jump depth, the starting of the jump to the portion where the rollers in the jump concludes which is haphazard and all that is called the length of the hydraulic jump.

So, normally you express the length of the hydraulic jump as some dimensionless quantities with respect to the available parameter that is the, which available or distinct parameters like the depth of flow pre jump and depth of flow post jump. So, that dimensionless lengths are the ratios, the length of the hydraulic jump divided by the prejump depth one can easily define it. You can also have relationship between this particular quantity with respect to the Froude number in the upstream section or you can have l by y 2 or you can also have relationships of l by y 2 minus y 1 that is the height of the jump. Like that also one can easily define, you can empirically relationship between the length of the hydraulic jump and Froude numbers.

The second question we asked is in a hydraulic jump, if the normal depth at the downstream is greater than the sequent depth, then illustrate the formation of the jump. Again, you just draw the channel bed. So, you have this portion as the upstream section, this portion as the downstream section. Let the upstream section is have the super critical flow with y n 1 as the normal depth. Let the downstream section have the normal depth y n 2 in subcritical conditions. Let us consider a junction between 2 slopes, say this is steep; this is mild. So, your hydraulic jump will now occur in such a way, that from this you need to plot the specific force versus depth for the corresponding specific force. See this is the sequent depth for y n 1 and y star is less than y n 2. So, from here the jump occurs up to height y 2 and it follows a S 1 curve, then the normal depth is followed. So, this is S 1 curve this is the hydraulic jump; this is your y n 2. This is how we illustrate the formation of the hydraulic jump in the upstream portion for such a case.

Thank you.