**Hydraulics**
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**Module No. # 05**
**Rapidly Varied Flow**
**Lecture No. # 01**
**Hydraulic Jump**

Friends, today we shall again continue with our topic of the last class that we were discussing, that is the Hydraulic Jump. Well, that is of course one of the important topic in hydraulic engineering and before going to this topic or rather before continuing that topic, let us see what we did discuss in the last class about the Hydraulic Jump.

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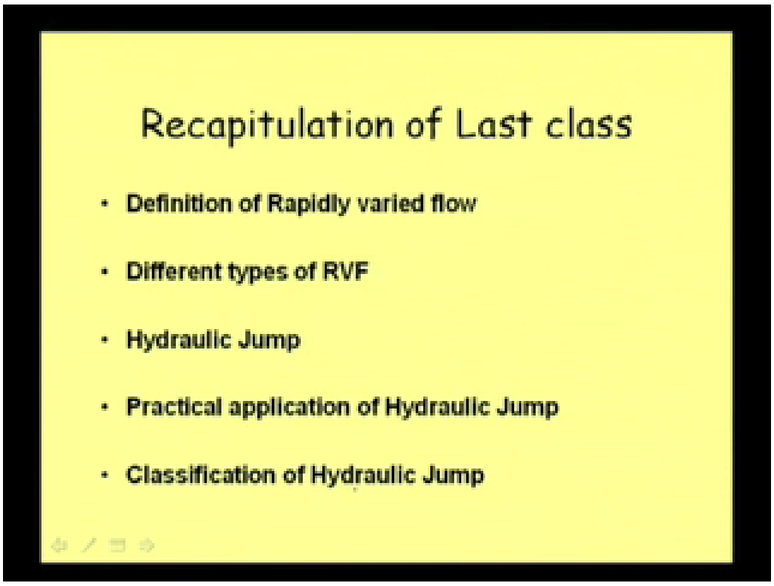


Well, we started with definition of rapidly varied flow, well and then when we were talking about rapidly varied flow, then we could see that, there are different situation, where we can have rapidly varied flow means, where the flow depth changes within a very short reach of the channel and that, we call as a rapidly varied flow. And there can be different situation or that leads to formation of rapidly varied flow. And one of that is hydraulic jump, one of the flow phenomenon hydraulic jump that is coming under the class of rapidly varied flow.

And we were starting discussion on hydraulic jump and then, while discussing on hydraulic jump, we are also talking about practical application of hydraulic jump. This is because first, the hydraulic jump was investigated long back in 1818 and then still today it is remaining as a topic of interest, why? Because the hydraulic jump has lot of practical application and knowing those practical application is very much necessary to appreciate the importance of this particular topic and that is why we discussed, some of the important field where hydraulic jump is applied for solution of some of our engineering problem, well.

And then we could see that hydraulic jump again can be classified into different types and we started that topic in the last class, that is classification of hydraulic jump and again there are different basis of classification. Say based on the tail water depth, what is depth of downstream side, what is the depth occurring there due to natural condition, that is the depth of downstream side we called as a tail water depth and based on that depth, we classify the jump as different classes.

Again based on the strongness, rather by strongness of hydraulic jump, what we mean? Basically, when it is high energy is coming and that is why Froude number of upstream is very high and then, suppose more turbulence will be there, more eddy will be there and that sort of situation, based on that level of that strength, based on level of that strength if the upstream Froude number is small, we call that as a say I mean weak jump like that and if it is very high, then we called that is strong jump, in that way also we can classify the flow hydraulic jump.

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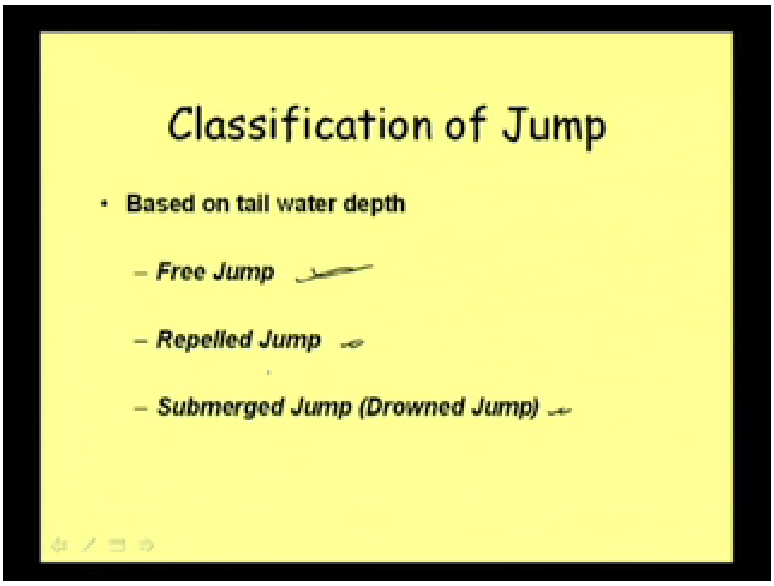


Well, with this understanding, in the last class we were discussing about free jump, we started discussion on free jump and then of course, we told that we were discussing what repelled jump is and what submerged jump is, we just named those things, we did not discuss.

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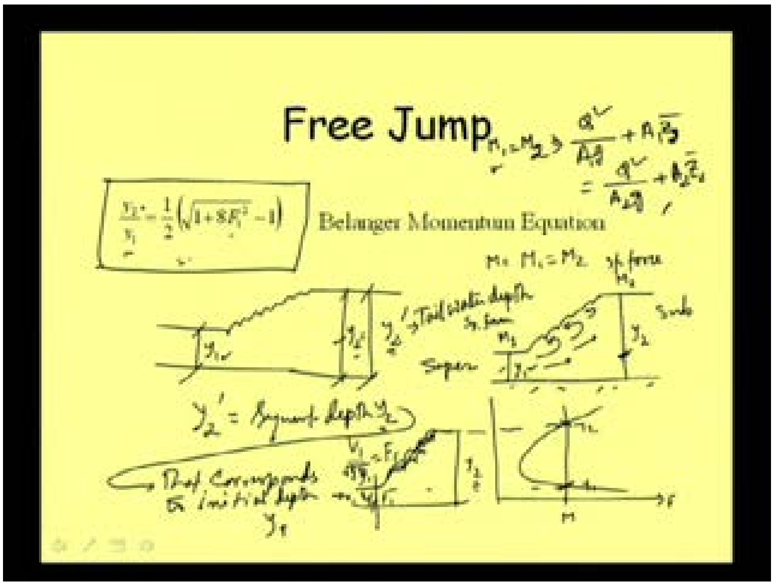


Well, let us start with free jump, what we did discuss. Well, then we need to recall our equation of hydraulic jump that is y 2 y by y 1 is equal to 1 by 2 root over 1 plus 8 F 1 square minus 1, this F 1 is the Froude number of the upstream side. And this equation is nothing but, actually we started with the momentum equation, then equating force and that we are equating the forces to the I mean rate of change of momentum. So, that way we could derive this equation and that particular momentum equation or this momentum equation is called as Belanger Momentum Equation as per his name, ok.

Now, when we were talking about that equation, basically why we are bringing this equation again here, that this y 1 and y 2 are called sequent depth of hydraulic jump; say if this is the channel and we are considering this as horizontal and say hydraulic jump is occurring from here to here, then this depth is y 1 and this depth is y 2. If we draw the specific force diagram, we draw the specific force diagram then for a particular specific force because the specific force if I say here as F sorry F I am already using to represent Froude number, so let me use the term say M, specific force is M 1 here and M 2 here (Refer Slide Time: 05:40).

And we know that specific force this M 1 and specific force this M 2 are always equal, M 1 equal to M 2, but as we know that, when the flow is moving from this supercritical, this is super and that is sub (Refer Slide Time: 06:40). So, when it is moving from supercritical to subcritical, then only this sort of hydraulic jump forms and then lot of eddies forms in this way and then, some flow move this way and now because this eddies are forming here, energy get loss in this part. So, I mean energy dissipate here in this portion and that is why, the energy of upstream and energy of downstream is not equal, there is significant difference of energy and that is why hydraulic jump itself is used for energy dissipation.

Well, now what we want to say that here, at a particular specific force say M means M 1 equal to M, suppose this is equal to M, now for this force we are getting y 1 and y 2, y 1 and y 2, if I draw the hydraulic jump here, then I can draw it like that also, I mean just referring to this point say this depth is y 1. So, this is coming here this will correspond to this particular point and then jump is occurring and this will correspond to this particular point, it is going like this and this part is hydraulic jump and this is what our y 1 and y 2.

Well, now this y 1 and y 2 are called sequent depth and this has a definite relationship based on the Froude number of upstream, that is Froude number here F 1, we can calculate g here, suppose g 1 is the flow velocity of this point, then g 1 by root over g d is g y root over g y 1 is called F 1 and based on this Froude number, we have that we have a particular depth y 2 at the downstream point of the hydraulic jump.

Well, now what we refer as free jump that we did discuss in the last class, just as a review we are discussing again, because starting from this will be moving on to the other topic. Say, when we have the depth of upstream y 1, this one here and then the depth of downstream due to I mean, may be due to slope say uniform flow is occurring under downstream or you have some barrier by which you are suppose increasing the flow whatever may be the way, but somehow you have the tail water depth y dash, y 2 dash. This we are writing as tail water depth tail, tail water depth, now this tail water depth if this tail water depth is equal to this sequent depth y 2 which correspond to the y 1; that means, for this y 1 there will be a corresponding y 2 and if this y 2 is equal to the tail water actually existing tail water depth y 2 dash, then from this depth directly, jump will occur to this point and this sort of jumps are called free jump, this jump is called free jump.

So, what is the condition, that y 2 dash tail water depth is equal to sequent depth y 2. So, what this y 2 sequent depth y 2 corresponding or that correspond to initial depth y 1, that correspond to initial depth y 1. So, if our initial depth is given y 1, then we should calculate what is y 2 and if we find that our tail water depth y 2 dash is equal to y 2, then we know that there will be a free jump, well then what are the other type of jump. Once the free jump concepts is clear then, let us see that if it is not free jump, then what it can be, one case is repelled jump.

Well, what is repelled jump? Say for that we will have to draw again the specific force diagram; well this is the specific force diagram. And then say this depth is our y 1, now here we are having a slope of flow which is almost horizontal and please remember one point, we should know that this relation what we are talking about y 2 by y 1, this relation is particularly for a situation when the flow is horizontal and we are talking about rectangular channel and for other situation, this will there will be a different relation, we cannot go by this relation directly. Say if I mean for computing hydraulic jump or for computing the relationship or deriving the relationship between y 1 and y 2, if this y 1 and y 2 I am talking about, if this is not a rectangular channel, then we need to go for trial and error procedure, how? Because we know that specific force at this point and that point is equal, say specific force M 1 that we can write as say Q square by A g A

1 g Q square by A 1 g plus A 1 z 1 bar, that we discussed earlier, that is this is the expression for specific force and for Hydraulic Jump this is M 1 and say this is equal to Q square by A 2 g plus A 2 z 2 bar.

So, that relation we will be getting, we are writing M 1 equal to say M 2, M 1 equal to M 2 and this implies that, this is equal to that and knowing that suppose for a particular depth y 1, we can because known depth y 1, initial depth y 1, we can calculate the area, then we can calculate the z bar also based on the section; if it is trapezoidal we can find the z bar is the average I mean depth of these things, depth up to the centroid that we can find out of the area. So, this way we can find out this area and z value and then we can calculate this part, this M 1 we can calculate, then we need to calculate the y 2 value, we need to calculate the y 2 value by trial and error procedure in such a way that, this y 2 will give us value of specific force, which will be equal to the specific force that we have already calculated with the depth y 1. And one point we should remember, this y 2 will be greater than critical depth, y 1 is less than critical depth and next, y 2 will be greater than critical depth. So, this part we need to know just I thought that it will be better if I just inform you that part, because when we are always using this equation or talking about this equation, we should not forget that this equation is particularly for rectangular channel.

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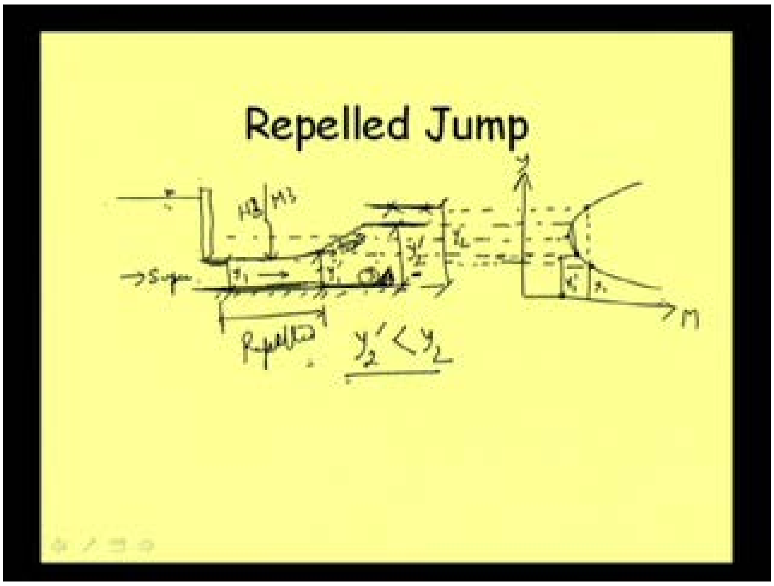

Well, then in case of this again if we refer to this particular equation, we have y 1 and then y 2 we need to know, suppose this is the y 1, this is y 1 (Refer Slide Time: 15:00) And this y 1 we can get by different way, say we can have a sluice gate here, well that I will be coming later, first let me show you if this y 1 is the depth here, then say tail water depth is, tail water depth y 2 is this one, this is the y 2 dash tail water depth, but the y 2 this y 1 correspond to let me just draw this diagram, so that we can just refer this with this diagram itself. This is the diagram say and suppose this point is this one, this is what the y 1 or y 1 and this correspond to critical depth and in this direction we are putting the specific force F, let me use the term M, specific force M and on this side, we are putting the depth y ok.

Now, for this y 1 depth, our y 2 that is sequent depth y 2 is actually this one, that is now I can say that sequent depth corresponding to this y 2 is actually here, what we see here. This is what the y 2, but in nature whatever may be the reason, but in nature the tail water, the depth occurring at the tail water is not the sequent depth, rather it is this y 2 dash, this depth is occurring. Now, we know one point that if the jump is to occur from this point if this is the y 1, it is corresponding y 2 is this one, but you do not have that depth at the downstream point. So, to (( )) it will jump, you are not having that depth, we are not having rather.

So, what will happen in this situation? Then we need to see that, this depth is y 1 and if this is to become y 2 if this depth, that is at the downstream tail water depth, if this tail water depth need to become the sequent depth y 2, then what will have to be the initial depth, that we need to see. So, if this is the sequent depth, then we know that we can see that, y 1 should have been this one, y 1 should have been this one, this should have been the y 1 (Refer Slide Time: 18:00) and if this is the y 1 depth and then only the flow can jump, so for this corresponding initial depth is this one ok.

So, what will happen? The flow from this point will gradually rise; flow from this point will gradually rise in this direction. Well, why the flow will rise because this is always this is a supercritical flow, supercritical flow and then supercritical flow means, it is a supercritical flow means it is less than the critical depth, less than the critical depth means and it if it is horizontal slope or say mild slope, generally we are talking about a slope which is very small. So, if it is horizontal slope or if it is mild slope, then the normal depth will be higher than the critical depth, if it is horizontal of course, it is infinity, but if it is mild slope still normal depth will be higher than the critical depth. So, that way normal depth will be somewhere here and this zone is basically zone 3, this zone is zone 3 and we got that in zone 3 gradually varied flow profiles are rising profile, whether it is if it is over horizontal flow, then it will be H 3, if it is over mild slope, this will be M 3, so that way it is a rising profile.

And of course, the flow you are releasing by force at this point because in normal condition, if it is a mild slope in normal condition the depth should have flown at the normal depth. So, you are forcefully or rather we are forcefully putting the water at this somehow and how we are doing it, may be that we have a I mean some spillway here on this side, we can have a spillway on this side and say from the spillway, this water is coming and then it is flowing at this depth, this can be one situation or that can be another situation like that, we may have say a sluice gate here and water is up to this much of depth here, we were having normal depth, but we are blocking it and then we are allowing the y 1 to flow here, we are forcefully.

So, this water normally or in naturally it will try to move to its normal depth and that way it is always moving upward and of course, that we have already discussed a lot, how this flow can move upwards. So, it is moving upward and then once it reach this level, once it reach this level, that we can write as new initial say depth say y 1 dash. Suppose, this is our tail water depth and this depth we can refer as new initial depth y 1 dash. So, it is rising to y 1 dash, once it is reaching this y 1 dash as a supercritical flow and critical depth will be corresponding to this one, so critical depth is here, critical depth is here. And once it is rising to the y 1 dash depth, which correspond to the or corresponding to which we are getting sequent depth of tail water, which is actually existing depth at the downstream point, then it can jump because we know that, from this depth if it jumps then only it will be reaching this point. So, from here it will jump and it will be meeting the tail water depth, and this depth is actually not existing so, the flow is not going there neither from this point, so it is rising and it is going.

One important point we should know, that if tail water depth is less than, suppose here is the initial depth and here is the sequent depth, if tail water depth is less than the sequent depth, when it is less than the sequent depth, then initial depth required is higher, initial depth required is higher, this higher depth corresponds to the lower depth at the subcritical flow. So, when in supercritical flow condition depth is rising, in subcritical flow condition depth is corresponding depth is getting lower, so that is one important point that we should remember.

And in this process, the jump has been repelled from this point to that point, from this point to that point initially, of course it will it may have some downward motion in this way, then suppose it should have jump from this point, but it is not jumping from this point rather it is jumping from a distance away from this (Refer Slide Time: 22:50). So, this part is actually repelled, so jump has been repelled by this much amount and by a gradually varied flow profile, which can be H 1 H 3 or say M 3 based on whether it is horizontal, whether this slope is horizontal or whether this slope has some mild slope. So, depending on the slope of that particular bed, we can have H 3 or M 3 profile by which the flow will be repelled and that jump is called repelled jump ok.

So, this is one type of jump and that is why this tail water depth here this part is important, suppose we have low tail water depth, then this water is emerging with a high energy and to meet the low tail water depth, this water will be moving in the downward direction, which as supercritical flow that is with high energy. And then there is a longer portion that can that is subjected to high energy flow or high velocity flow, which can cause damage to the bed and that way when we have a very low downward flow, but it is subcritical of course, jump will be there, but once jump is there, then only energy will be dissipated here at this point, energy will be dissipated and once energy dissipated on the downstream side, we are getting less energy or we can say that flow is not flow will not damage the downstream part that we can say, but before that, it is it can damage the bed, it can cause the erosion to the bed, that is why we need to put concrete bed in this portion, we need to put concrete bed in this portion, now up to hydraulic jump.

So, that way if the jump get repelled by significantly longer distance, then the concreting required or the safeguard required to the bed will be longer and cost will also be larger and when cost is larger, we become very much concerned that what can be done about that and that way people are doing or engineers are taking different measures. Sometimes they put a rising portion here, so that not here actually but somewhere upstream, so that water will be rising here and depth will be rising and jump will be occurring before this reaching this particular point. That to different devices is there, which try to contain the hydraulic jump closed to the upstream structure, so that the concreting required or safeguard required is less and that to your cost is less, well. And that topic is important of course, we may not get scope to deal with this particular topic, that is called stilling basin we construct some structure here, which is called stilling basin which ensure that jump will be forming within a very closed distance from the upstream structure, from the upstream structure, well we may discuss that briefly in this particular topic.

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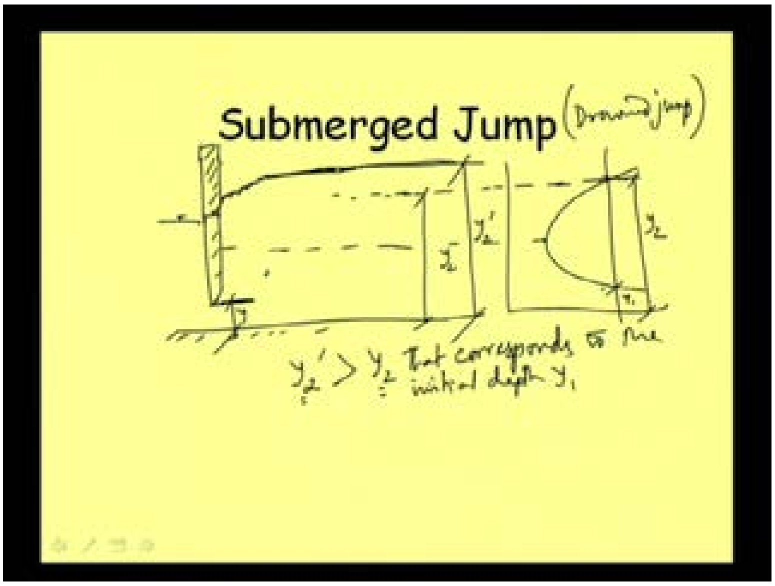


Then we are moving on to another type of jump that we call as submerged jump. Now, what is submerged jump? Again, if I draw this diagram, if I draw this diagram y 1 and of course, corresponding y 2 is this one, so say water is flowing at this level and maybe we are putting a sluice gate just like that case I have drawn earlier and water may be here on this side, and then water is coming here and its corresponding depth is, let me make this get larger because we have sufficient space here, well its corresponding depth is that sequent depth is correspond to this initial depth is actually this one, this is the y 2, this is what is y 2, so y 2.

Now, the tail water depth that is existing at the downstream side is, say higher than this y 2, actual water level is here, that we name as say tail water depth y 2 dash, actual depth of water is this one. Now, in this case, the water of course, it has a water level here water existing here, it can jump from here to here, but what will happen to this part of water? This is we know that this depth is critical depth (Refer Slide Time: 28:00), so at downstream of our I mean when the depth is higher than critical depth, this is subcritical flow and when you have a higher depth here, this flow will be coming back.

So, what will happen in this case? Basically, this water will be coming back and will cover up this jump, there will be a underwater jump, but this will be cover up by this tail water depth and its reflection that some turbulence is there, its reflection will be seen will be visible here, its reflection will be visible here, that some turbulence is going on and that sort of jump is called basically submerged jump or drowned jump; as because it is basically drowned under the water level, so this jump is called submerged jump or drowned jump. Well and that occur when our y 2 dash, tail water depth is greater than the sequent depth y 2, corresponds that corresponds to the initial depth y 1, sequent depth y 2 that corresponds to the initial depth initial depth y 1.

Well. So, these are the three types of jump that we have observed, which we can classify based on the position or say position of tail water depth or we can say level of tail water depth. And one important point, as this jump is drowned here, the energy loss, energy loss in this jump will be submerged jump will be less than the energy loss in the free jump, energy loss in the free jump. And we cannot directly calculate what will be the energy loss here, but energy loss will be less than the energy loss of the free jump and in case of repelled jump, in case of repelled jump energy loss can be calculated directly from this and that and that will of course will be less and then we can see that this case is we did not write here, let me write it again here. That is y 2 dash is less than y 2, that leads to repelled jump and when y 2 dash is greater than y 2, that leads to submerged jump or drowned jump.

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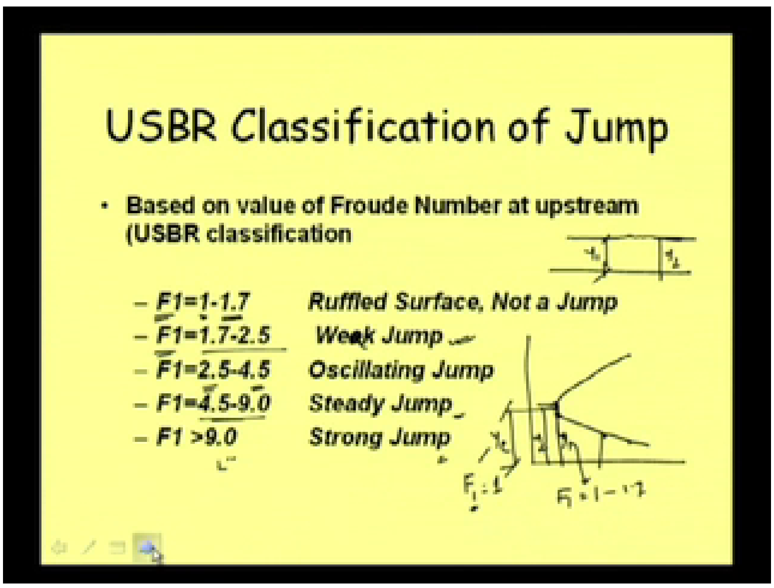

Well, then United State Bureau of Reclamation, that they did some classification of hydraulic jump based on the Froude number, based on the Froude number and Froude number means, Froude number of upstream side. So, say hydraulic jump is this one then, based on the Froude number at this point, based on the Froude number at this point I can write it as F 1. Well, they conducted several experiment and then they could see that when one point is that Froude number at upstream should be or will be always greater than 1 if we need to have a hydraulic jump. See if the Froude number is equal to 1 then the depth of flow at upstream will be critical flow and if it is less than 1, if Froude number is less than 1, then with Froude number less than 1 the flow will be subcritical and we know that hydraulic jump occurs only when the flow changes from supercritical to subcritical.

So, if Froude number is less than 1, flow coming in itself is subcritical and so there is no chance of hydraulic jump formation, well that way this is one important point and we should note that, as we are talking about F 1 Froude's number 1 based on which we are classifying the jump and there we are not talking about the Froude number less than 1 because Froude number will have to be greater than 1, that is the flow have to come as supercritical flow performing a hydraulic jump and at downstream of course, the Froude number will have to less than 1 at downstream, that is the downstream the flow must be subcritical.

Well, now when this F 1 is say just exceeding the value 1 and from 1 to 1.7, for that range of Froude number it was found that the surface profile cannot be regarded exactly as a jump, theoretically it is a jump because Froude number is less than 1, but see when it is very close to... Well, here I think it will be better if I draw 1 diagram say well, let me draw this specific force diagram again, say specific force diagram is this one and when we have it is at this point (Refer Slide Time: 34:00).

Well, when we have depth at this level that is it is more supercritical, critical depth is this 1 y c, so when our depth is much less than critical depth Froude number is increasing as we are moving in this direction, that is our depth is decreasing Froude number is increasing, when it is in supercritical zone and when we are just coming very near to this particular point say here, our Froude number when our depth y 1 is this one, Froude number is at y c Froude number is equal to 1 Froude number equal to 1. Now, when it is just slightly less than y c say y 1 then Froude number is just little higher than 1, say may be for this y 1 we can say that Froude number 1 is suppose 1 to 1.7 let us consider like this, I mean may be up to certain range now within that range what will be its corresponding y 2 if I extend it is just this point.

So, the difference between y 1 and y 2 is very small and when it is very small and that too there will be some wave formation at you cannot distinctly see a water jump there or hydraulic jump there, because difference of this 2 level is very small, say it may be it is coming like this and may be jumping to this portion and just so this depth is y 1 and this is y 2 and this difference is almost negligible. So, what you are getting is practically a ruffled surface, rather than calling that as a jump, we get it as a ruffled Surface and so I mean that situation we do not call as a Hydraulic Jump, just Surface will be having some wave and it is not a hydraulic jump.

Then they observe that, when the Froude number ranges from 1.7 to 2.5, 1.7 to 2.5 then we get a jump that is called week jump. And when Froude number is from 2.5 to 4.5, then this week jump means this is also just some wave will be forming and the shape you will be getting a typical week jump we can draw that, I will be drawing later and then say when it is from 2.5 to 4.5, we are getting a oscillating jump that is surface is oscillation is increasing and that sort of jump we called as a oscillating jump. And then for a Froude number level of 4.5 to 9 that is a proper jump we can say, that it is called as steady jump it is called as steady jump and it is at that sort of jump generally we get in our natural field, that is when we try to form jump then we go for this sort of jump because in this sort of jump energy loss is significant. And then if F 1 is greater than 9, then we get strong jump, this is very strong jump when our F 1 is greater than 9 and to draw this sort of to draw this sort of I mean figure say, we can draw it like that suppose in week jump this y 1 will be little higher say this one and then you have your on the downstream side what you will be having your y 2 (Refer Slide Time: 38:28).

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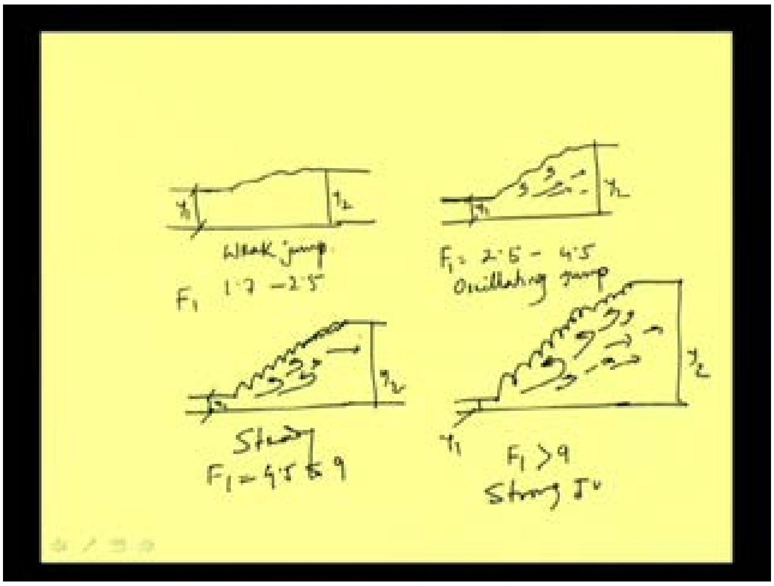

So, this y 1 and y 2 this we can call as a week jump and then next jump say when and this range is as we have indicated it is 1.7 to 1.7 to 2.5 F 1, then F 1 is equal to 2.5 to 4.5 here this depth will be little less than this one y 1, it is like decreasing. When depth is decreasing then our Froude number is increasing, because Froude number is v square by g y and as you know that when depth is decreasing, velocity is increasing of course, for a particular discharge we are talking about. When for a particular discharge our depth is decreasing then velocity is increasing, so v square is increasing and again it is divided by Froude number, Froude number is v by root over g y. So, v is increasing and root over y that is which is in the denominator that is again decreasing, further decreasing so entire ratio is increasing. So, this depth is decreasing and then we are getting a this sort of jump, where we have small eddies like that some flow is moving like that and then this is say y 1 and y 2 this is called oscillating jump, oscillating jump and that is I am talking about this particular jump.

Then when it is steady jump that depth is further low, say this is y 1 and then we get a very definite jump like this and this eddy sizes are increasing and it is going like that and then this is what and when this difference is increasing, when this difference is increasing one point we should remember, the length of the jump is also increasing. So, that is what say steady jump y 2 and strong jump y is further less, y is further less and here for steady jump of course, our F 1 is from 4.5 to 4.5 to 9 and when F 1 is greater than 9, then we are getting a very strong jump like this and here eddies are little bigger.

So, that way flow is moving on this side and then it is y 2 and this is y 1, well this sort of jump is call strong jump well. Once of course, we must agree one point that, just from this figure it is difficult to realise, what how this jump will look different, but will try to demonstrate these things in the lab to show you that different type of jumps can be there, exactly which one is steady, which one is strong, for know to know for knowing that we need to do some calculation, but at least we will be able to show you that some jumps are weaker and some jumps are stronger that we will be able to demonstrate you and hope you will be able to do that.

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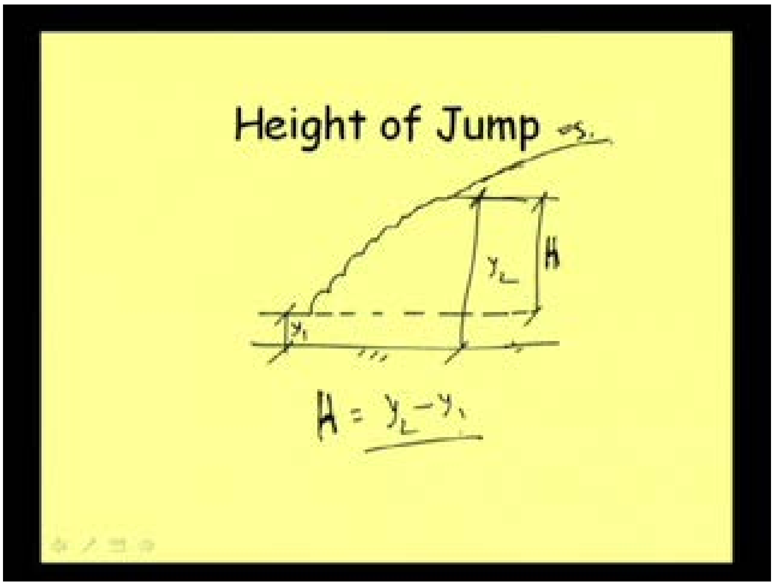


Well, with this now we can move on to another term that is used for hydraulic jump is height of jump. Well, what we mean by height of jump? For a jump if it is jumping from this point to that point, then this depth is y 1 and this depth is y 2 and by height of jump we mean the difference between the initial flow or the initial depth and the final depth, so this is what the height of jump H. Well, now why we should be interested to know the height of jump because say for various purpose we required this particular aspect and one more important point is that, it will not be forming in a isolated way.

Suppose, sometimes it may have that jump is occurring, then it might move as a S 1 profile again then it might move as an S 1 profile, suppose height is forming and then again after the hydraulic jump, the hydraulic jump may be followed by a say curve now whether we will consider the height of jump as from here to that point it is not. So, we should be able to identify where actually the jump is getting ended and that particular level we need to know and that observation is very critical because to find where the hydraulic jump is ending is really difficult because some wave will be there, so we need to take care in observing the height of jump and then we will be discussing another point. So, we can say that height of jump H, normally capital H is used here, height of jump H capital H is equal to say y 2 minus y 1.

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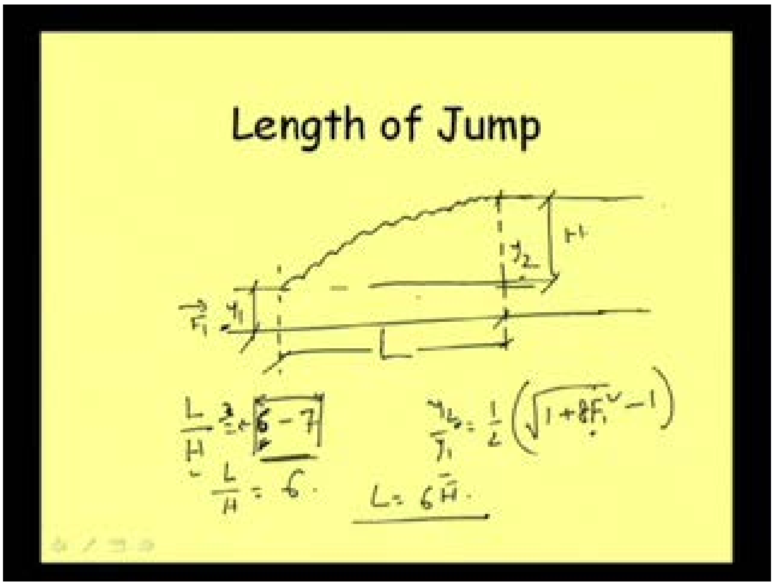


Well, then we will go to another term that is a length of jump. In fact, height of jump is to some extent easier to measure if we compare that with length of jump. Length of jump is more difficult to measure, because see even if it is a simple horizontal flow and the jump is occurring like that and then we will find that this flow will be actually disturbing, a disturbing flow will continue up to certain extent then only it will be coming to a say non-wavy form and that is why the length of jump what we mean if this is y 1, then from where the jump is starting and then where it is ending, that where it is ending is of course very difficult. But still, we need to take care and we need to see that this level is becoming horizontal if it is not continued by some other profile, if it is continuing by other profile then of course, it is further difficult to find a length of jump and if it is not continuing other profile, if you are forming it like that, then for practical experiment we need to form the jump in a way that no it is not continuous or it is not continuing with other another rising profile. If it is a falling profile then it is fine, on the downstream suppose there is a drop and then it is again falling like this, then it is easier for us, but if it is a rising one then it will be difficult.

Now, for that situation we should see where the flow is becoming almost horizontal, then we can say the jump is ending and when jump is ending, that very precisely we can we should try to see very precisely where the jump is ending that point we should refer as the end of the jump and of course, depth is y 2. And another technique we can play here, rather than observing yes we are observing practically, but at the same time if we know the y 1 because this is comparatively easier in the practical experimentation to find the y 1 is comparatively easier, so once we can find the y 1, once this y 1 is found then, we can if it is a free jump if it is a free jump of course, even if it is not a free jump suppose it is a repelled jump then from where it is starting that we will be knowing. So, then that I mean initial point of the hydraulic jump if it is known, then if it is a rectangular channel we can use the formula that is y 2 by y 1 is equal to root over 1 plus 8 F F square F 1 square minus 1. So, that formula we can apply and we can and of course, half was there, so and that way we can find out what the value of y 2 and then we can try to measure the y 2.

So, now we can apply both the point that is from our observation, we are observing something because there will be some error in the calculation of y 2 or as well because practical things because we are neglecting the friction in this formula, that is say y 2 by y 1 if I refer to this formula is equal to half of root over 1 plus 8 F 1 square minus 1 in this formula, if you remember that we are neglecting several point; that is first the slope of the channel is being neglected it is considered to be to have no effect in this particular formula and then say frictional resistance offered by the channel is not considered here, this is also neglected.

So, that way this part is I mean because of this we may have some computationally, but in reality there will be some frictional resistance acting on a boundary side, there will be some frictional resistance or there may be some formulas also. So, that way these losses will influence the value of y 2, but still now you have some idea that where the y 2 will be and then you observe carefully. So, by observing it carefully and then having some idea about the y 2 value, we need to decide that where our actual jump is ending. Of course, practical observation is important and to give guidance to the practical observation these calculations may help.

Well, then knowing this y 2, this length is basically L and then we can have a relationship between the length of the jump and height of the jump. Say, length by height of the jump we can have a definite ratio because lot of experiments were carried out and it was observed that, this length height ratio maintain for different type of jump, this ratio remains within a limit. Say it will depends on the Froude number 1, one point then say when Froude number is very less, I mean less means as compared to say it must be greater than one of course, but when it is Froude number is say 3 of that range, that means, when it is week jump something like that, then our this ratio of L by H will be less.

And then when our Froude number is increasing, this length by height ratio is also increasing well, but for very large Froude number again it comes down to some extent, but for most of the cases, but for most of the cases it was found that this length height ratio it varies from say we can say 5 to 7 of course, there are value here. That means, it can it starts from 3 and then it moves on to 5, but this range is less, for most of the portion it will be between say well, we can say it is from 6 to 7, it is from 6 to 7 not 5 to 7, for most of the portion it will be from 6 to 7.

So, well some books in some experimentation it is found that 5 to 7, that way average value considered as 6 and then we also conducted one experiment and there we could see that this Froude number, this length height ratio also depends on the slope of the bed and other investigators also conducted that sort of experiment and observed that. So, now, when we are conducting the experiment or when in a real field suppose we are finding a jump, then exactly it will not be say 5 or 6 or something, we cannot very definitely say but for some of our purpose, if we want to know that to what extent the jump will be going, then based on these experimental data, some standard curves are also there and using those standard curve as a just information we can say, right.

Now at this point that some curves are available, which give us idea about the length height ratio based on the Froude number. Similarly, some relations are there which gives us some idea about this length height ratio when the slope of the bed is changing. So, these information's can be used to have some idea of a jump when we are observing in the field and we want to know that what can be the length of the jump, then we can use this point that length height ratio can be considered, as in general length height ratio can be considered as 6, so length is equal to 6 times the height of jump, this is can be used in general.

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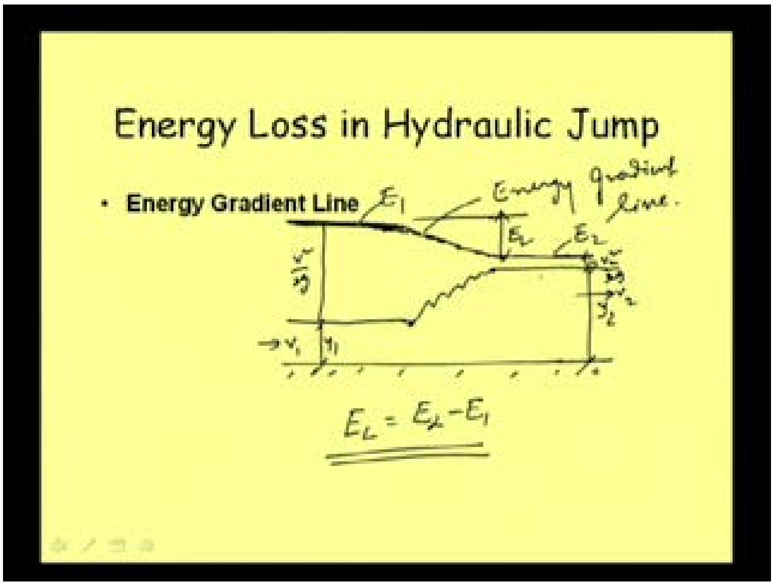


Well, then another important topic is Energy Loss in hydraulic jump because as we remember, that in the last class itself we did discuss that is what is our prime use of Hydraulic Jump. One prime use of hydraulic jump is to dissipate energy, that is we need to use we need to generate or we need to produce a hydraulic jump at a particular location so that the energy of flow can be reduced and that is why when our intention is to apply hydraulic jump or use hydraulic jump to dissipate energy, then we need to know that how much energy will be dissipated.

So, that is a very important topic or point that we need to know, energy loss in hydraulic jump. Of course, the mathematics is very simple, once we know the y 1 depth at upstream, once we know the depth at downstream, then we can calculate energy at upstream discharge being known, we can calculate velocity at upstream and velocity at downstream. So, we can calculate specific energy y 1 plus v square by twice g because we are considering that the channel is horizontal, we are considering that the channel is horizontal and of course, this assumption of horizontal channel is quite valid because hydraulic jump is generally formed in most of the cases in manmade structure. So, we have great control over the other issues like what should be the slope of the bed where the hydraulic jump will be forming or say, whether it should be rectangular or trapezoidal in those aspects we have our control; so that way if we are considering as horizontal, if information's of horizontals are available, we can go for horizontal that is there.

Well, then loss we can calculate that way also and of course, we can have one expression for loss in hydraulic jump, that expression relates the depth y 1 and depth y 2, well. So, relating the depth y 1 and y 2, we can calculate the I mean the energy loss and that directly also we can use that expression, but right now we should know that what is how our energy gradient line will be in case of hydraulic jump. Say this is the bed slope, this is the bed slope and our water is flowing like this and then this is y 1 and a jump is occurring and then it is moving there y 2. Now, say total energy at the upstream point somewhere here, suppose energy line at the upstream point is starting at this point and definitely towards downstream there will be a slope, so it is gradually coming down.

So, this energy is say as it is y 1, suppose v is this one and then this v 1, so this total energy say this is v square by twice g and that we were having some energy and it is gradually coming down, when it is moving downstream, well. And then we know that at this point, up to this point we are not having hydraulic jump so it is coming like that. And at downstream our y 1 is this one and v 2 will be small as compared to v 1 so we will be having some energy here, say v 2 square by twice g, v 2 square by twice g that amount of energy is there, y 2 plus v 2 square by twice g.

Now, between this point and that point and from here also energy loss will be gradual like this and between this point and that point there will be sudden drop of energy, there will be sudden drop of energy. So, we can have that there is sudden drop of energy and of course, if we assume that friction loss is not that much then, from here to here also we can assume that energy level is horizontal, here also energy level is horizontal, friction level is friction loss if it is neglected and then from here to here the drop of energy.

So, this is the shape of energy gradient line, this is the shape of energy gradient line and using this energy ingredient line or drawing this part now it is clear that how much is the energy loss, this is our E 1 level and this is our E 2 level and this is of course, in subcritical zone, this is in supercritical zone and energy loss means delta E is equal to this one or we can write this as E L energy loss, we can write this as E L energy loss; so, E L energy loss is equal to E 2 minus E 1, fine. So, this energy loss from the diagram it is clear, now we need to know what will be the expression for this energy loss, how mathematically we can calculate this energy loss.

Well, we will continue one more class on hydraulic jump, where will be of course not fully on hydraulic jump, in our next class we will be taking up some of these issues that are left that is that we need to cover on hydraulic jump and then we will be moving on to some other topic of rapidly varied flow like some other situation, where we can have varied flow which is not gradually varied flow and within a short race the flow profile varies and that part we did discuss, thank you very much.