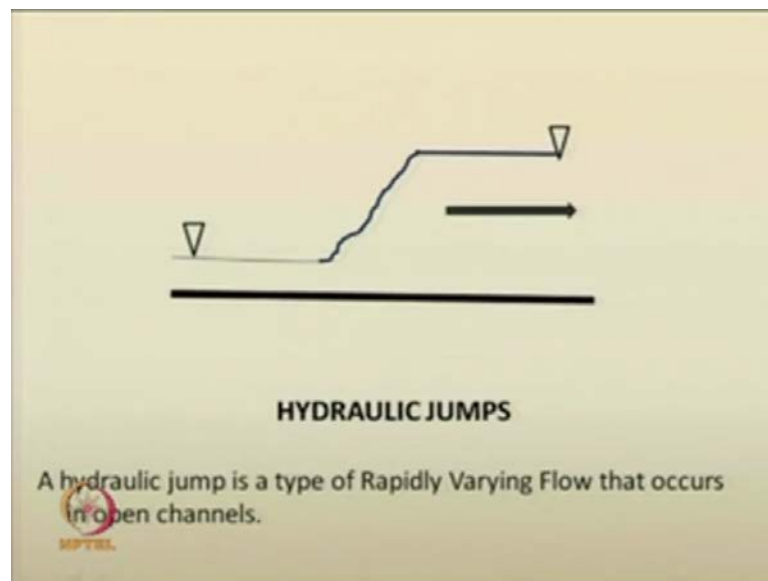


Advanced Hydraulics
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Module - 4
Hydraulics Jumps
Lecture - 5
Jumps as Energy Dissipators

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Very good morning to everyone. Welcome back to our lecture series on advanced hydraulics. So, you know we are in the module 4 on hydraulic jumps. I need not repeat the things again as what is meant by hydraulic jumps and all? It is a rapidly varying flow that occurs in the open channel.


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In the last class we discussed on:

- Length of Hydraulic jumps in rectangular channels.
- Profile of Hydraulic jumps in rectangular channels.
- Location of Hydraulic jumps in rectangular channels.

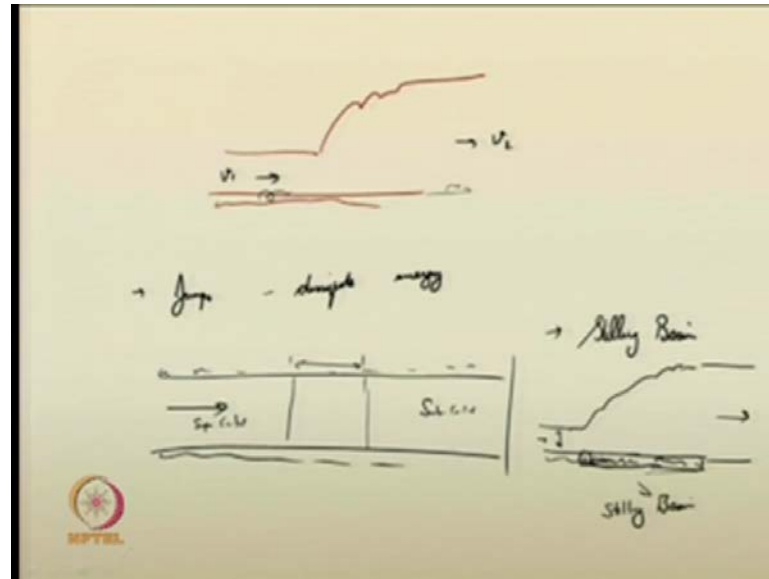
$$Y^* = Y_{n2} ; Y^* < Y_{n2} ; Y^* > Y_{n2}$$

An example problem was also worked out in the lecture.



In the last class, we had discussed on the length of the hydraulic jumps. We have also discussed on how to measure the profile or how to create the profiles of hydraulic jumps? How to find the location of hydraulic jumps? This was also discussed, based on various criteria. Suppose if Y^* is the sequential depth of the pre jump depth then, if this post jump depth if it is equal to the normal depth in the downstream, or if it is less than the normal depth, or if it is greater than the normal depth, how the jump location gets shifted? This was also discussed. We have also solved one example problem related to these aspects and all. So today, we will discuss how we can use hydraulic jumps as energy dissipaters?

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So, we know that hydraulic jump, in hydraulic jump you have a supercritical flow that gets converted into subcritical flow. So, a supercritical flow means it comes with high kinetic energy that is supercritical flow is having higher velocity and it will be having more kinetic energy. So, this energy needs to be dissipated, and the hydraulic jumps provides a provision to dissipate these high kinetic energy. So, generally for various hydraulic designs, and hydraulic structures, and all you create hydraulic jumps so that the energy gets dissipated.

So, what does the hydraulic jump do? How it dissipates the energy? That is the incoming flow with higher velocity, and outgoing flow from the jump with lower velocity the kinetic energy is getting reduced. Now in this aspect the jumps not only dissipate energy, wherever jumps are provided you will also be able to design the channel beds, or the channel shows in such a way that it gets protected. For example, if a supercritical flow is maintained for a longer reach due to its higher velocity. There will be more scouring action on the beds here along these regions, to avoid that if any provision for hydraulic jump is provided in that channel reach. Then, the velocity gets reduced and this velocity may not be able to scour the bed enough it may not be having enough velocity to scour the bed.

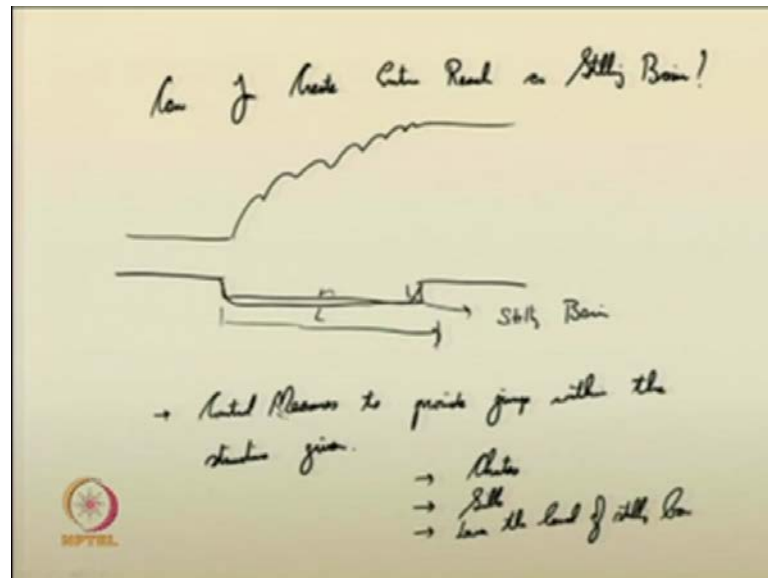
So, that way the channel beds are getting protected so that purpose for that purpose also, hydraulic jumps are provided. Hydraulic jumps as an energy dissipater if we use them,

you require means you actually say if I just give a top view of a channel reach. And if a flow is occurring from this left hand side to the right hand side, if a proper provision is given for a hydraulic jump within this reach. And if this is supercritical flow, subcritical flow channel beds can be appropriately rescued or rescued from the erosion cases and all.

You require a certain reach either the entire reach or the part of the reach of the channel. So, that the hydraulic jump is being made within that reach. So, the part of that reach where a proper provisions of hydraulic jumps are given that is called stilling basin. So, a stilling basin, if I just draw the longitudinal profile this thing so it may be something like say a supercritical flow is coming like this. And you are providing a provision in the channel bed, such a way that from here the hydraulic jump is maintained, or the hydraulic jump is created and the flow goes downstream.

So, this particular reach of the channel this is called stilling basin, why? It is, because it is a basin that provides the provision for hydraulic jump. Can you provide stilling basins means why it is called stilling basin? Because the beds of this stilling basin they are designed with proper aprons and proper paved materials, such that erosion or scouring is prevented in those locations and all. And it can also sustain the high pressure created from the hydraulic jumps and all. So, that way proper designing means stilling basin is a particular location in the channel reach where the jumps are provided and all like that we can design it. So, you can use stilling basins for dissipating energy that will stilling basins will create hydraulic jumps that can dissipate the energy.

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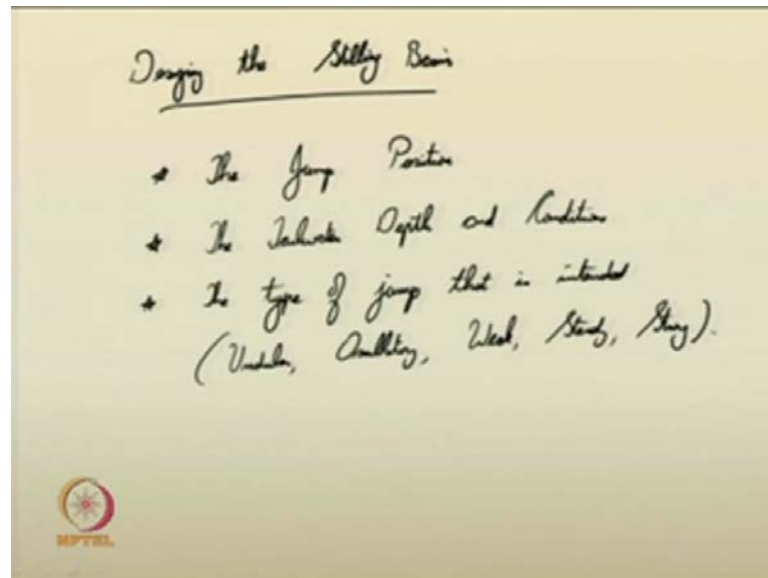
Can you create entire reach as stilling basin, what do you think? Now, once you are in engineering field you need to economise the thing. So, if you have this entire reach of the channel say an jump is like this, do you think that this particular length if I provide the entire length as the stilling basin will it suit the purpose.

Now, this will be non economical if the reach, if the length of the jump is too long. If it is a very long hydraulic jump, it will be quite difficult to provide the entire reach of that hydraulic jump as stilling basin. So, you need certain control measures, you need certain control measures to provide jump within the structure given. So, there are some control measures so it can resist scour means these stilling basins they are mainly used for providing hydraulic jumps and that can resist scouring.

So, how to design the stilling basins and all? So, we are not going into the technical aspects of construction process in this thing. We are just giving a brief idea, how to design the things as we suggested the entire length is non economical. You can provide control mechanisms like chutes, sills in the channel bed, or near the stilling basins, or you can even lower the level of stilling basin say if I just lower this portion like this and if you give like this.

So, you will be having something like this. So, this will also this stilling basin will also provide the jump, but it can be economical. So, that way we can design stilling basins according to the need and also it should be in an economical way.

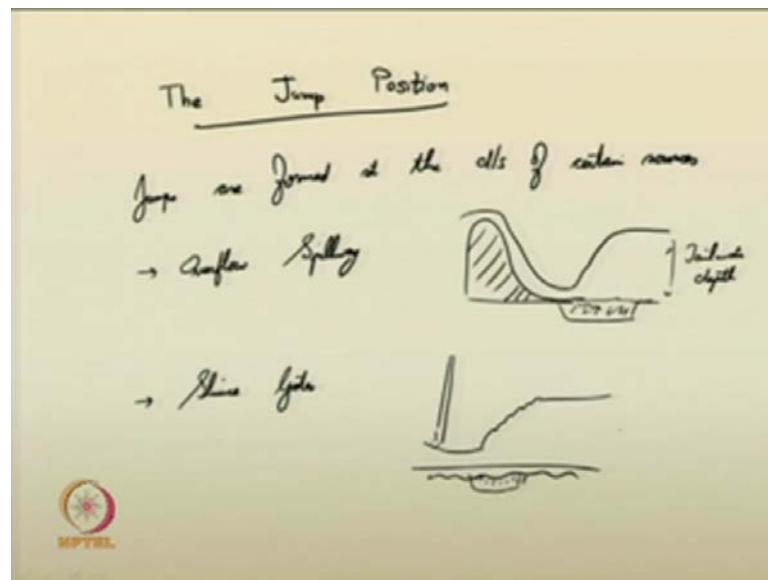
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So, for designing the stilling basins, one need to understand the jump position. So, for designing the stilling basins, for designing the stilling basins one need to understand the jump position, we have studied in the last lecture, how the location of the jump can be means, how you can infer the location of the jump based on the depth of flow in the upstream as well as downstream conditions?

So, the jump position is quite essential for designing the stilling basin. You also require the tailwater depth and the conditions and the tailwater conditions. These are also quite essential, we will discuss them again. Also the type of jump that is intended the type of jump that is intended in that location. You have studied the types of jumps for example, undular, oscillatory, steady, weak, steady, strong various types of jumps you have studied earlier. So, which type of jump it is the thing that you are means you have an intention to provide at that location. So, that is also quite essential while designing the stilling basin.

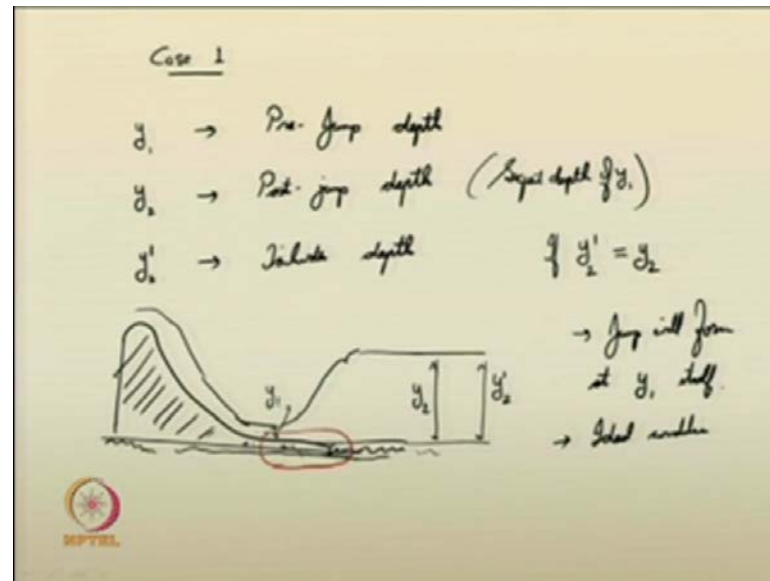
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So, the jump position we will deal with that first today, the jump position. So, jumps it is formed, jumps are formed at the downstream of certain sources, jumps are formed at the downstream of certain sources, some of the sources are like say for example, overflow spillway. So, you can say suggest that there is an overflow spillway like this, spillway cross section waters overflows like this and reaches here and here it just jumps. So, you can provide the stilling basin at this location, appropriate stilling basin.

So, this is overflow spillway, you can also have hydraulic jump near sluice gates say if a sluice gate is provided in a channel that means. And if it is lowered water just gushes out like this and here a jump may be formed. So, sluice gates also provide hydraulic jumps. So, these things how will, you now design stilling basins, you need to provide stilling basins where the jump is being suggested.

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We can suggest various cases now. Let us consider case 1; you have as we are mentioning now earlier, let me just suggest that the various y_1 is the pre jump depth notations, y_2 is the post jump depth, and let y_2 dash be the tailwater depth. So, just going into the previous slide, based on this tailwater depth, we can have various types of jumps means the jump location or the jump position will be varied these things also you have studied it again I am just repeating it here.

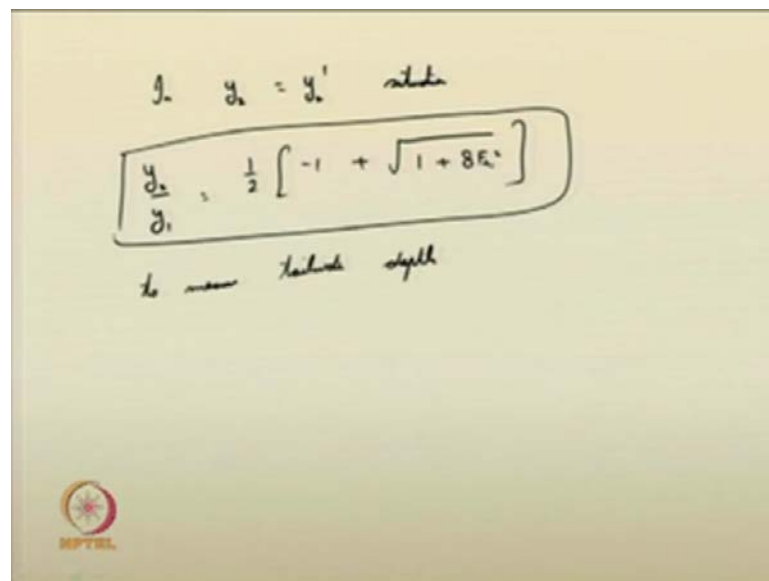
So, if you have this common notations for example, in the overflow spilled way case for them, as you know that we have approximated the channels as horizontal in many of the cases. So, let please consider this as a horizontal channel. So, the overflow spillway is a, water is overflowing like this it reaches here, and if this is your pre jump depth y_1 and here you have the depths. So, this is the channel apron, spill stilling basin and all in, let the tailwater depth be y_2 dash. So, case 1 is if the post jump depth or the sequent depth it is also sequent depth of y_1 .

So, if y_2 dash is same as y_2 then, this y_2 dash and this y_2 both are same. So, the jump will occur at that location wherever y_1 is there y_1 , wherever the depth of flow y_1 has occurred, or started at this location itself the jump is formed and it will jump into the sequent depth y_2 . So, this is jump will form at y_1 itself there is no shifting of the jump it is one of a ideal condition.

So, if such a situation is there, what is the peculiarity if such a situation is there? You can now easily suggest that you can design the stilling basin in this location. You know precisely the jump is going to occur here itself, because here the depth is depth of flow is y_1 as soon as it reaches becomes horizontal. And as soon as the depth y_1 is reached a jump is formed to a sequent depth. So, you can appropriately design the stilling basin there is no confusion in those situation it is an ideal condition, but in nature rarely, such ideal situations arise.

So, you have to design even if there is a marginal difference in the depth y_1 or y_2 or y_2 dash there can be shifting of the jump that may cause havoc wither in the downstream or in the upstream conditions. So, you need to means the, although the case 1 is an ideal condition it is rarely happen, or it can be rarely envisaged in practical situations.

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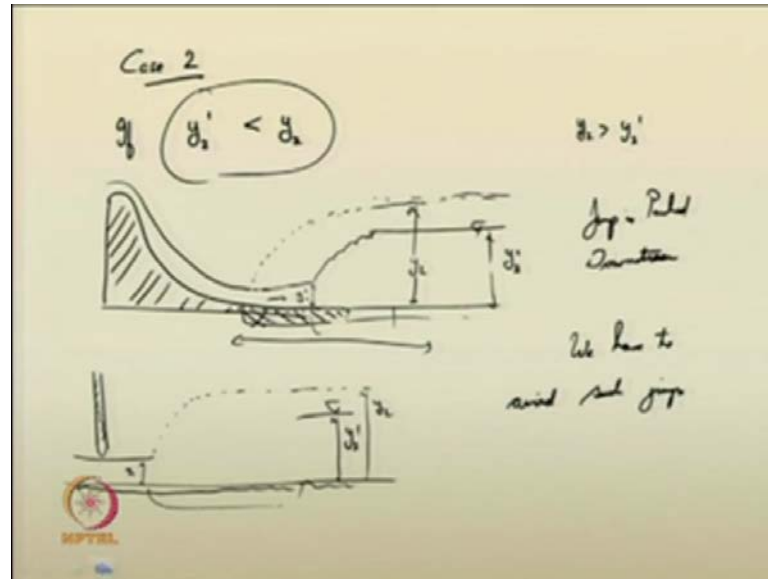
$$y_2 = y_1' \text{ stable}$$

$$\frac{y_2}{y_1} = \frac{1}{2} \left[-1 + \sqrt{1 + 8F_1^2} \right]$$

to know the sequent depth

So, what is the peculiarity here? In y_2 is equal to y_2 dash situation, you can readily use your for the as I am again retreating here we are using the rectangular channels. So, you can use the sequent depth ratio relationship F_r^2 to measure tailwater depth or the tailwater depth is easily obtained from these things from this particular sequent depth ratio and therefore, you can design it appropriately.

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Case 2; what is the case 2 suggesting? Suppose, if the tailwater depth is less than the corresponding sequent depth of the pre jump depth y_1 that is in, let me draw the spillway so water overflows and reaches this depth you are designing the stilling basin.

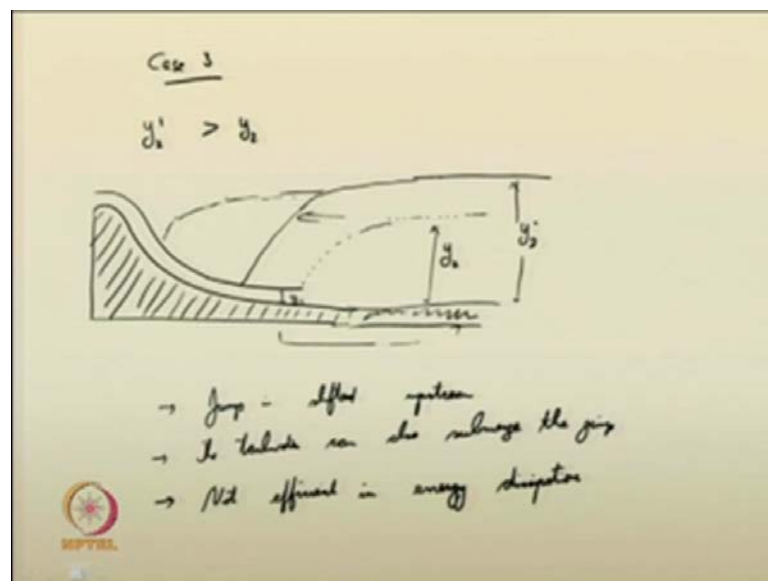
So, in this case, when the depth y_1 has reached it is observed that y_2 the tailwater depth, this is the tailwater depth y_2 dash tailwater depth is y_2 dash. However the sequent depth of the jump from this case is like this see it jumps into this position. So, this is y_2 so y_2 , y_2 dash is less than y_2 here is the tailwater depth. How the jump position whether the jumps position will be at the same location or it gets shifted or it gets changed to some other form? How will you understand this thing now? Same thing I can just retreat for the sluice gate also if you, if it re suggested for the sluice gate also similar way I can suggest.

So, if this is the depth y_1 ideally it should rise to y_2 , but however it is found that the tailwater depth is only y_2 dash. So, how the jump will occur? You have to design the stilling basin appropriately. So, in this case, what we have to suggest is that as y_2 is greater than y_2 dash that means, the specific force at y_2 it is greater than y_2 dash so that cannot be happen that means it cannot occur like that. Therefore, your flow, it gets shifted that is the pre jump depth occurs like this it gets shifted here we have studied the particular profile, and it reaches to a depth y_1 dash where the sequent depth of y_1 dash is same as y_2 dash and the jump occurs like this.

So, the jump is pushed downstream in this case, the jump is pushed downstream. So, if the jumps are pushed like this, you know you know that you cannot appropriately design the thing. We do not know the length of the jump also, and also proper protection may not be there within these particular portions and all. So, it can cause erosion of the bed, if it is considerably pushed downstream like this if it is considerably pushed the entire bed can get eroded. So, you need to find where the location of jump occurs. So, using proper control measures and all once gain you can provide jump wherever the stilling basin is being designed that is also quite possible.

So, we have to avoid such jumps that is wherever y_2 tailwater depth is less than the sequent depth. You have to avoid such depths, because such designs it is not economical also you cannot now you cannot provide this entire reach as stilling basin that will be too much costly. You have to think on such strategies where to design the stilling basin appropriately. So, you can avoid such situations these situations can be avoided if possible.

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Next one is case 3; I have the tailwater depth greater than the sequent depth provided. So, again I am just drawing the same diagrams, this way I hope that by repeatedly taking the same things it will just enforce in your mind the concepts in a better way.

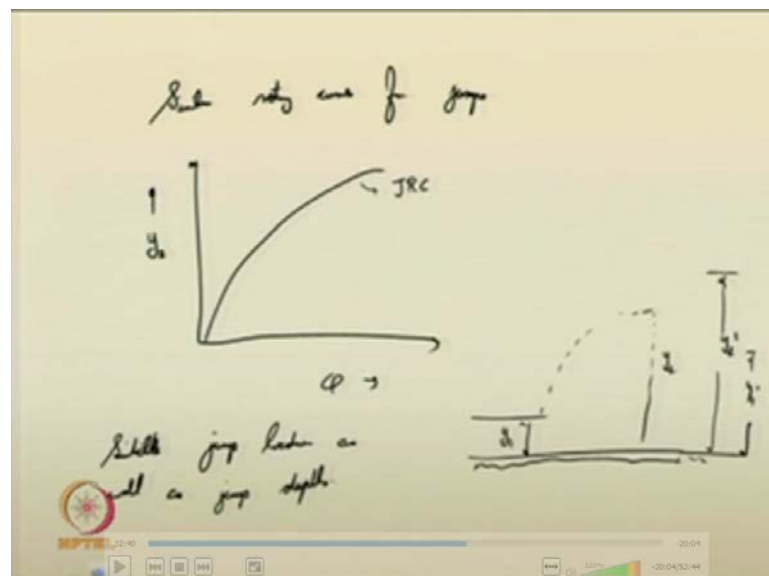
So, the depth of flow it has reached y_1 here, now whether I need to provide stilling basin within this reach, say if this is the sequent depth y_2 . However, it is observed that the

tailwater depth is y_2 dash now y_2 dash is greater than y_2 . So, how the jump will occur? Whether it will occur at this location? Now, you will see that depth y_1 this depth y_1 its sequent depth y_2 they are having same specific forces, but y_2 dash is more. So, it is having more specific force in that location. So, the pre jump depth, the pre jump depth needs to be shifted upstream like this.

So, this jump will occur something instead of occurring like this, it will occur something like this jump is in shifted in the upstream direction, or it can also submerge means jump is shifted upstream. The tailwater can also submerge it can also submerge the jump. See if this is getting shifted like this, you see that this entire portion is getting submerged.

So, submerged jumps are also possible. So, submerged for design purpose one can suggest submerged jumps, because it is not at all creating any havoc, you have proper protective measures everywhere and the for the purpose of jump, jump is also being suggested. But the drawback in submerged jumps are that it cannot dissipate, or it is not efficient in dissipating the energy, whatever energy is coming in almost similar energy may get transmitted. So, you cannot dissipate the energy that much in submerged jumps. Not efficient in energy dissipation.

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So, the next criteria, which we have suggested is the tailwater conditions about the jump location and all. There we assumed tailwater depth as constant, earlier we assumed tailwater depth as constant, based on that we suggested. See this is tailwater depth y_2

dash. So, you do not know whether the jump sequent depth of jump y_2 y_1 based on that we suggested the jump can move upstream, or it can be pushed downstream and all. So, there in all cases tailwater depths were considered as constant.

So, what I just like to ask, what happens if tailwater depth is not constant? What happens if your tailwater depth is not constant? It can happen that is the tailwater need not be constant always, based on the discharge available it can get fluctuated. So, if the tailwater depth is fluctuated, or if it gets changed you know that the location of the hydraulic jump gets shifted. Now, again in the stilling basin wherever you have design it may not become appropriate.

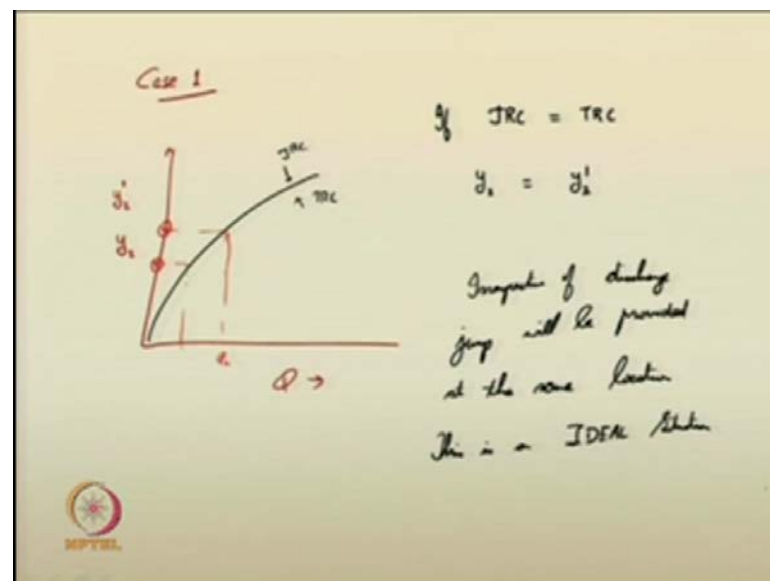
So, therefore, you require a certain analysis where the fluctuations of tailwater depth are also taken into account, say for design purpose for design, purpose as you might have studied in your hydrology courses and all. There are stage discharge curves, or rating curves a similar sort of thing for design purpose, you require tailwater rating curves, what is this tailwater rating curve? You can have for the given location, wherever this stilling basin is designed, and all wherever the tailwater will be coming after that. And the downstream of the source of the jump wherever it is there. You can design for various discharges the corresponding tailwater depth for this depth for this much depth for say for example, here if I just mark the there could be a corresponding discharge.

So, if I can plot a Q versus y_2 dash curve based on various historical data and all. If you can plot then, if you can keep it ready for that particular structure there then, that can be readily used for the design purpose further. So, now I have a tailwater rating curve tailwater rating curve, this particular curve is called tailwater rating curve. If this is given there one can easily now identify say for example, I have at a particular time I have a depth here some value here, the corresponding discharge can be easily identified here.

If I have another depth of tailwater at this location at another time, some other time, you can easily suggest that the discharge in that location is at this the magnet of discharge is this correspondingly, like that it can be suggested. So, using this tailwater rating curve you can use for design purpose. A similar type of rating curve you need to employ for jumps also, rating curves for jumps. So for jumps it is the post jump depth that we are taking into consideration. And if you can plot Q versus the post jump depth if you can plot it like this; this is now called jump rating curve.

So, if you have this jump rating curves, and the tailwater rating curves, you can easily use it for design purposes. So, we will now, you do not know say for this particular channel reach, you have only the fixed pre jump depth. So, this is the post jump depth y_2 , your y_2 dash it can be greater than y_2 or it can be less than y_2 . So, we have to suggest the suitable, we have to suggest suitable jump location as well as jump depth right. So, that is the requirement for designing this stilling basin. So, we can have discussions with several cases.

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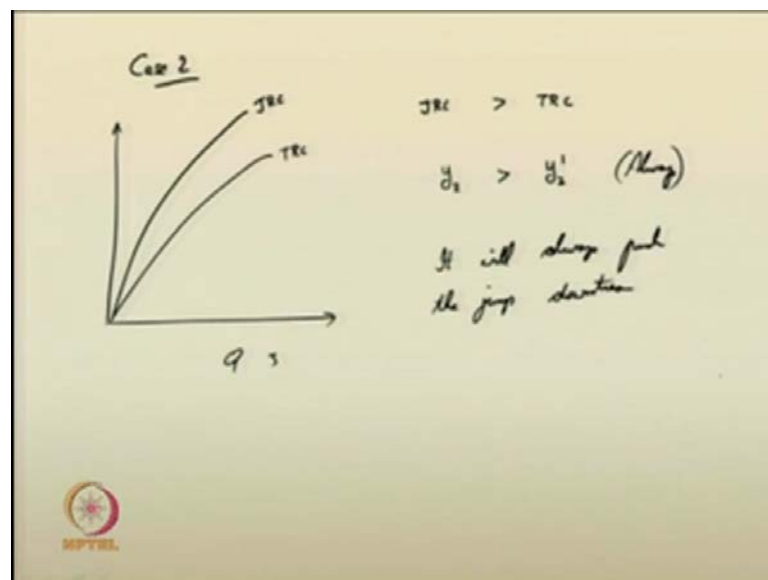
Case 1; now, case 1 corresponds to again if I plot the discharge rating curve that is discharge rating curve with respect to tailwater as well as the post jump depth. Now, in this case, if the rating curves if the tailwater rating curve as well as the jump, jump rating curve JRC and TRC. If they are same, what does this imply? That is if jump rating curve is same as the tailwater rating curve. This implies that y_2 that is the jump depth, and the tailwater depth y_2 dash, both are same every time that is the meaning. So, irrespective of the situation that is irrespective of see if I am taking this depth then, the corresponding means discharge is here.

So, if again if I take another discharge Q_2 its corresponding depth this thing that will be having same sequent that is the sequent depth as well as the tailwater depth will be same. So, irrespective of the discharge, irrespective of discharge jump will be provided. So, you know that in the source of jump that the pre jump depth it is the fixed value, let us

say from the overflow spillway and all y_1 depth y_1 it is a specific quantity means it is a specific depth.

So, therefore, whatever type of discharge is occur coming from the spilled way, now if y_1 is less still there will be some discharge in the channel. So, if the discharge is getting reduced it does not matter, the jump will be provided at the same location. So, jump will be provided at the same location, again this is an ideal situation which is not encountered practically. In practical cases it is difficult to attain such ideal conditions and all. So, therefore, you need to design it for more practical cases and all. You may not have the jump rating curve and tailwater rating curve same every time. So, they are very rare.

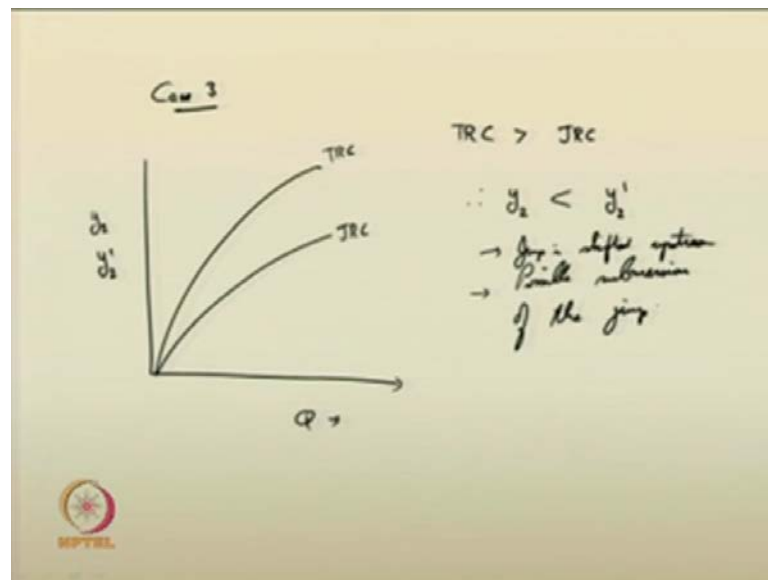
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I can have the rating curves, such that the jump rating curve is greater than the tailwater rating curve. If I have such a rating curve here the jump rating curve greater than tailwater rating curve that means the y_2 depth of y_2 is greater than the tailwater depth always. So, whatever discharge is there in the channel the jump depth is always greater than y_2 dash.

So, what does this what does this will create? It will always push for such cases it will always push the jump downstream we have seen that when the jump depth is greater than the tailwater depth, the jump is pushed downstream right. So, you can use the control measures appropriately to provide jumps in such situations and all.

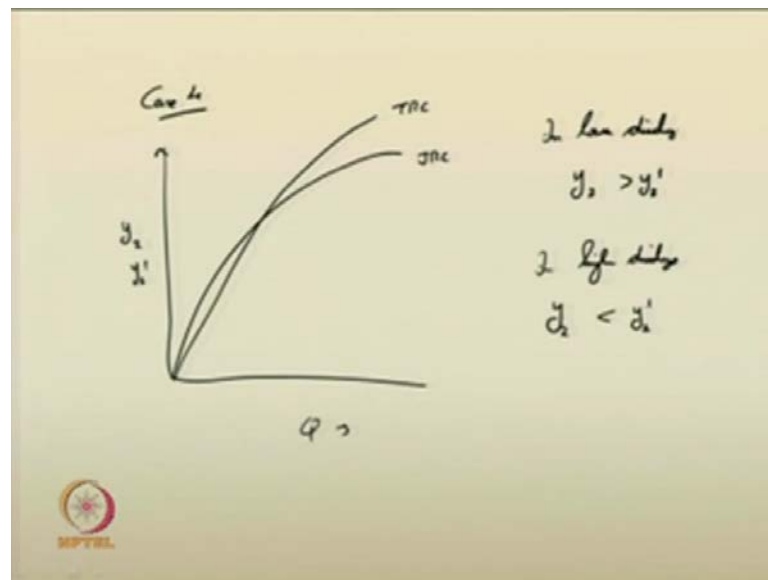
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We can have another case with respect to the jump water depth, and tailwater depth. If the tailwater depth is like this, and the jump water rating curve is like this. Here the tailwater rating curve is greater than the jump rating curve. Therefore, y_2 is always less than y_2' in this situation. So, possible always there is chance of possible submerged possible submergence of the jump that is jump is shifted upstream.

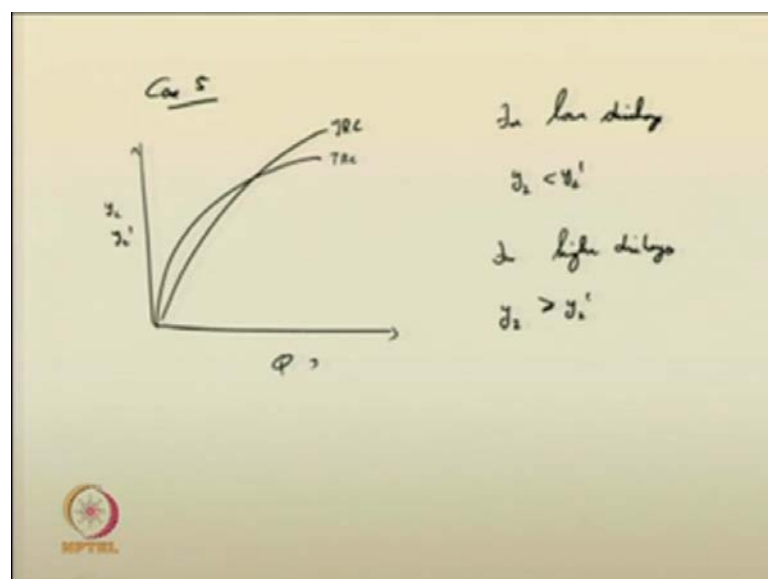
So, possible submergence of jump can also encountered in such situations by providing proper sloping apron and all. You can have effective jumps in this situation we have seen that such jumps are not efficient it cannot dissipate energy if you want to design stilling basins for energy dissipation. Then, such jumps cannot dissipate that much energy, but by providing proper aprons, and sloping aprons, and all in the upstream location you can have a better jump.

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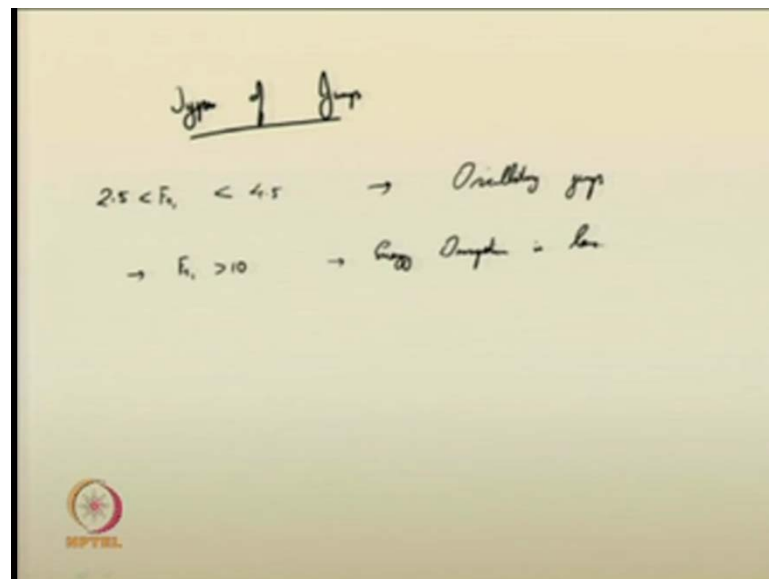
Next case, we can suggest based on the rating curves is if you have a jump rating curve like this, and if you have a tailwater rating curve like this, such curves it suggests that, such curves suggests that for lower discharge you have, for lower discharges you have y_2 greater than y_2' . Then, in that situation the jump is more downstream for higher discharges, you have y_2 less than y_2' then, you can have submerged jumps. So, you can design it appropriately.

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Next case is where the jump discharge curve is like this, and your tailwater discharge rating curve is in the following form, so y_2 and y_2 dash. In this case, for lower discharge for lower discharge you have y_2 less than y_2 dash, for higher discharges you have y_2 greater than y_2 dash. So, you can know where the submerged jumps can occur or where it can be used. So, these things stilling, if by providing proper stilling pools in these cases and all, you can have higher tailwater depth also for lower discharges that can ensure a better jumps.

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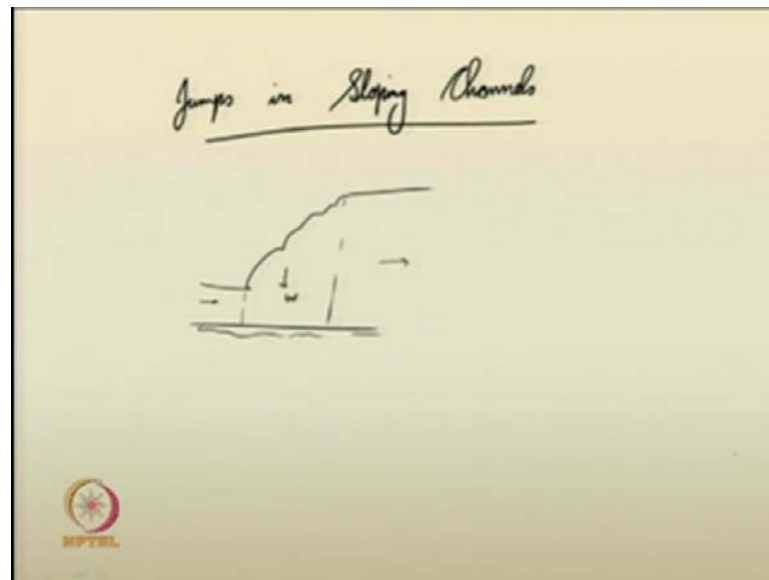


Now as for designing the stilling basins, you need to suggest the types of jumps; whether it is oscillatory, whether it is weak, whether it is undular, whether it is steady or strong, whichever type of jump is there that you need to provide it before hand itself. So, this usually in designs, jumps in the range 2.5 less than Fr_1 less than 4.5, they are oscillatory jumps. You it is better to avoid oscillatory jumps in design purposes, because oscillatory jumps it is always having some oscillations, and all it is not at all steady, you will not get such steady flow situations in those cases and all. So, it is better to avoid oscillating jumps. Also you need to means understand that the tailwater depth, in last two cases also we have suggested that tailwater depth is quite essential that is your jump depends on the tailwater depth.

So, that is also quite significant, what type of tailwater depth? How much amount of tailwater depth you are providing? Based on that, the type of jumps will also get vary.

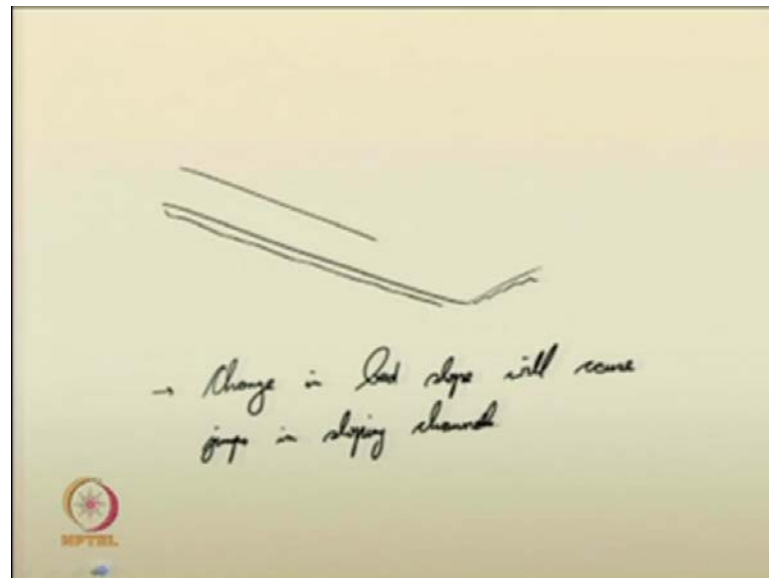
For strong jumps like having Froude number greater than 10, in such jumps energy dissipation is less means, if you want hydraulic jump for dissipating energy then, for higher Froude numbers it is not appropriate means by providing stilling basin and all. So, you need to take that into account.

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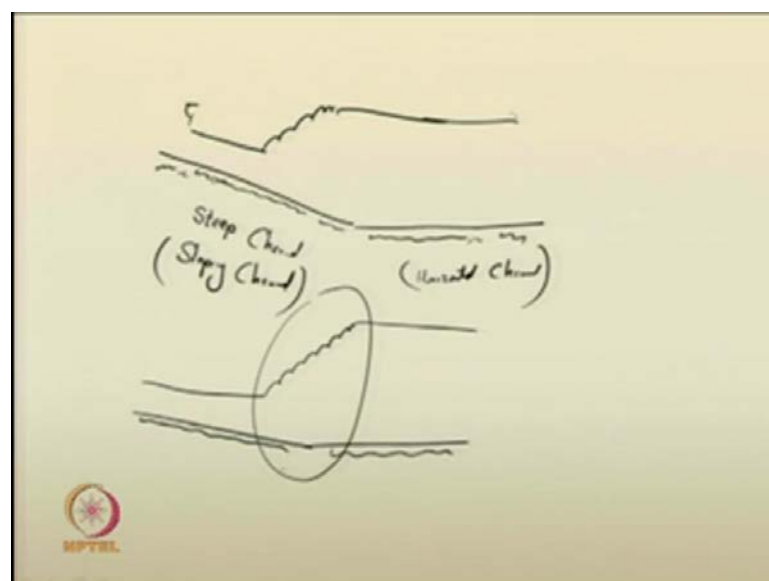
Now, we will just briefly discuss on jumps in sloping channels. So, earlier our jump analysis hydraulic jumps, we assumed the channel bed to be horizontal. Based on that in horizontal channels, whenever we considered say if the bed is horizontal, you have jump and all. The portion of hydraulic jump, whatever portion we are taking into account, and there the effect of weight was neglected that is weight in the. If the weight of the liquid in the hydraulic jump it is in the vertical direction. Then whatever component of weight in the flow direction they were neglected earlier. Now, in sloping channels that will not be possible. How the jumps are formed in sloping channels or why?

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You know that in sloping channels especially if it is a supercritical flow. How the jump will be formed? If there is any change in the bed slope in the downstream, say whether it becomes horizontal, or whether it becomes adverse, whatever be due to this change in slope hydraulic jumps may be formed. So, we have to understand what type of in what way it can be obtained? So, that is change in bed slope will cause, change in bed slope will cause hydraulic jumps in sloping channels. I hope you recall in earlier in our earlier lecture also we have suggested that.

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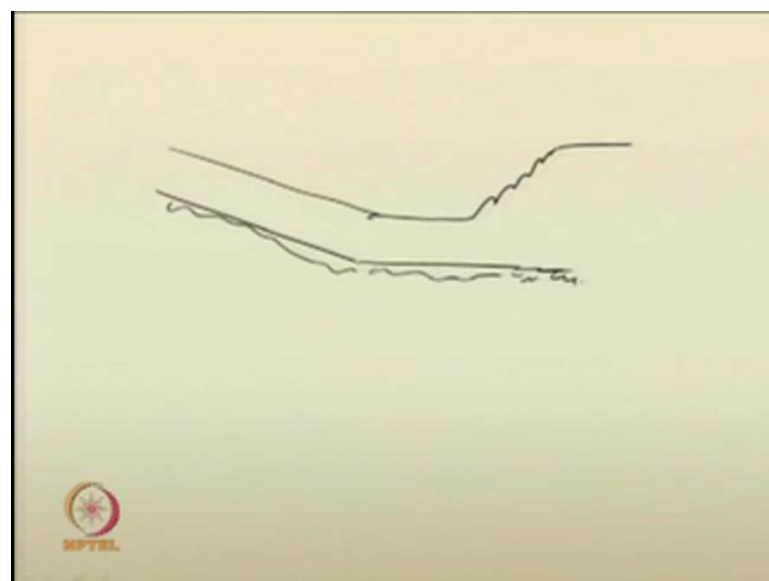


Suppose, if a super if a steep slope channel merges with a mild slope channel, or if it merges with a horizontal slope channel then, there is a high possibility of formation of a jump. And we do not know at which location the jump can be formed if the flow normal depths in both the locations are like this. So, we have to identify them.

So, depending upon the depth and velocity that is which, what is the depth? What is the velocity in the upstream condition and also on the tailwater condition? We can identify at which location the jump will hydraulic jump will form in the sloping channels. So, let me start it like this. So, the jump if a flow in the steep channel, this is steep channel or a sloping channel. Let me suggest now, earlier we took it as a horizontal channel in the sloping channel if it comes and merges with a horizontal channel.

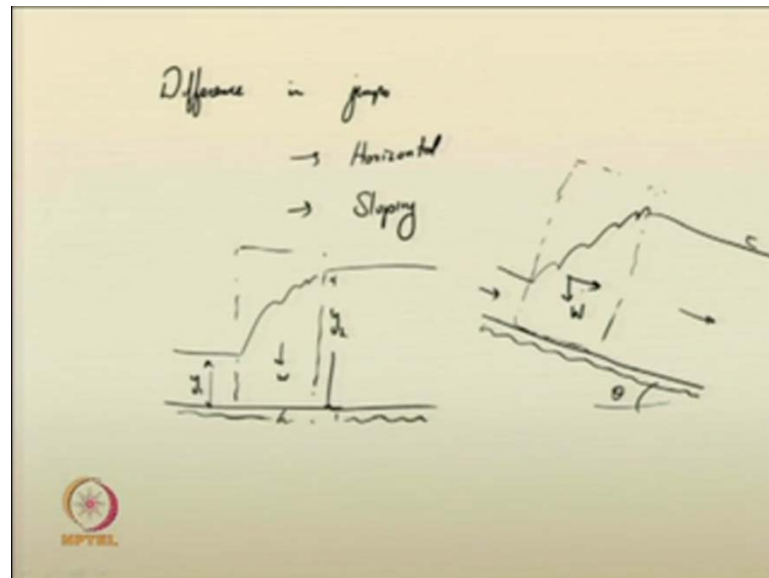
So, there are 3 distinct possibilities so the either the jump can form completely in the steep channel, or in the sloping channel, or the jump can form in the interface somewhere here, or it can form completely in the downstream channel which is the means. So I can just again redo it I will just for your this thing, say if jump can means jump can form in this case the jump is formed completely in the upstream channel in the sloping channel itself. Another case is the jump is encountered in both the steep in the sloping channel as well as in the horizontal channel, in both the location the jump positions are coming into picture.

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Another case is you have the jump like this, and this is completely pushed to the downstream the jump is completely pushed to the downstream. So, like that three situations one can assume for jumps in slope channels.

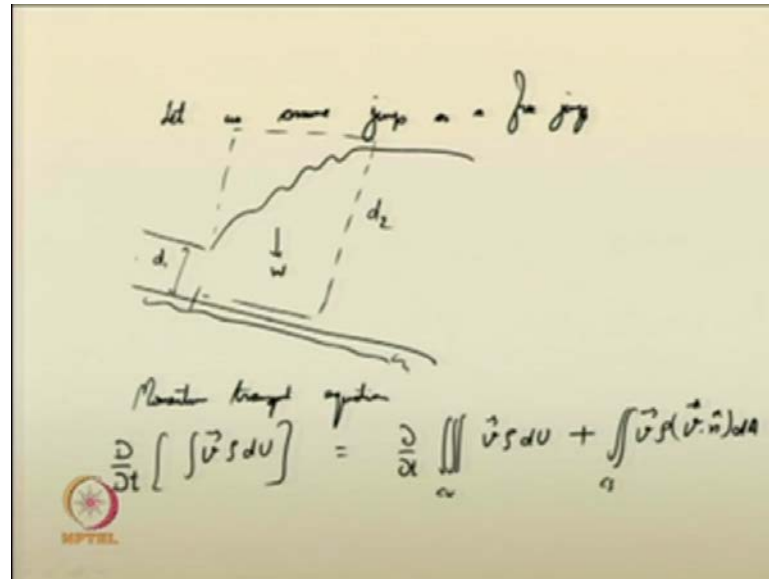
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So, what is the difference, difference in jumps for the horizontal and how do you analyse it in a different way for horizontal and sloping channels? So, as we suggested earlier in horizontal channels you neglect the say I am just redrawing them, a jump is there and there is a horizontal channel, and if you take the control volume for the hydraulic jump. So, you take these depths, this is the pre jump depth, and this is the post jump depth y_1 y_2 , and in this this thing the effect of weight is neglected. However in the sloping channel that may not be quite possible that may not be quite feasible, you will see that the water is flowing, and there is a hydraulic jump. If you take the control volume here enclosing the hydraulic jump definitely the weight of water will be in the vertical direction. But due to a considerable slope say if this is having angle θ , the bed slope is having an angle θ bed is having an angle θ with the horizontal. Then, there is definitely a component of weight in the direction of flow.

So, that will also aid for the flow and you cannot neglect that component. So, we need to incorporate those also into account when we do the analysis for sloping channels. So, we can suggest that.

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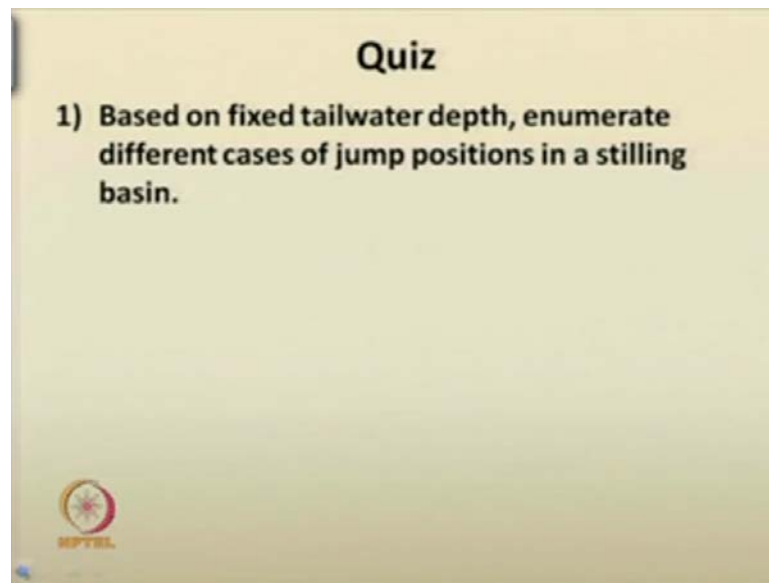


Let us assume jump as a free, as a free jump that is in our earlier lecture, we suggested that tailwater conditions can affect the jump location. So, we are assuming that the tailwater depth is free that is whatever jump depth is occurring that will be the depth in the downstream depth. So, if we have a free jump, so if I draw the control section for the jump then let this be the depth d_1 , let this be the depth d_2 .

So, you have the weight of water W acting like this. So, in this control volume, we can have, you know we can incorporate the momentum transport equation. If you recall the momentum transport, then using the Reynolds transport theorem I am just again writing it for your benefit, this is the volumetric integral.

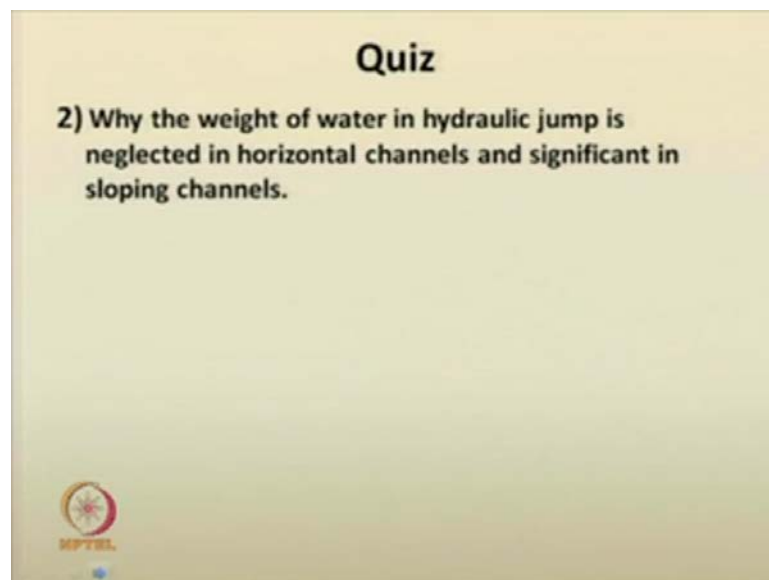
This is nothing but the time derivative of the volumetric integral $\vec{v} \rho dV$ plus the areal integral $\vec{v} \rho \vec{v} \cdot \vec{n} dA$. This we have done it earlier also so that is it is suggesting the rate of change of momentum in the control volume. This is nothing but equal to the change, rate of change of momentum stored inside this volume plus the net out flux of the momentum across the control surfaces. Now, we have two main control surfaces these on the left and on the right, all other control surfaces are not allowing the momentum as this is predominantly a one-dimensional case. We will continue with this portion on the next lecture; we will have a brief quiz.

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So, first question so as we have studied today's this thing based on the fixed tailwater depth conditions, enumerate different cases of jump positions in a stilling basin. And the second question you are having is.

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Why the weight of water in hydraulic jump is neglected in horizontal channels and it is significant in sloping channels? So, quickly you can quickly answer the questions and submit the paper.