Advanced Hydraulics
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Module - 5
Channel Transitions
Lecture - 2
Channel Transitions Part 2

Welcome back to our lecture series on advanced hydraulics. We are going through the fifth module, that is, channel transitions; or in fact, according to the syllabus, it was given as flow through non-prismatic channels.

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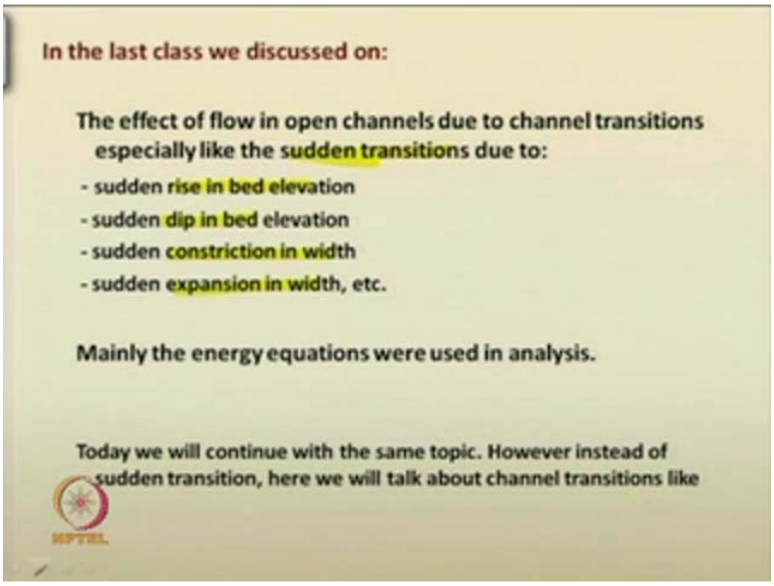

In this particular portion, in the last class, we had discussed the effect of flow in open channels due to channel transitions especially like the sudden transition that we had elaborately discussed it in the last class; the sudden transition; how due to the sudden transition in the channel, flow is getting affected. The sudden transitions that were dealt were sudden rise in bed elevation; sudden dip in bed elevation; sudden constriction in width; sudden expansion in width. These four cases we have elaborately studied them in the last class; means we have mainly used the energy equations to analyze these things.

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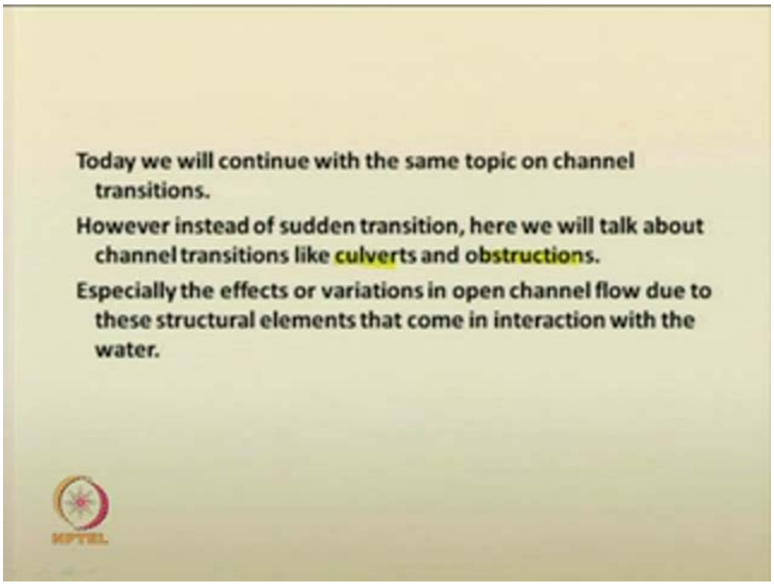

Today, we are going into the next part of the channel transitions; that is, mainly, we will be continuing the channel transition itself. But, instead of the sudden transitions, we will be talking about the channel transitions like culverts and obstructions that arise in any particular flow stream. By this time, you may be aware, what is meant by a culvert or what is meant by an obstruction and all. So, the effects of the variations in open channel flow due to these structural elements due to their interactions with the water body; means how it is getting affected. That we will be briefly going through. We are not going through the sediment transport process or the sediment deposition or erosion along this structure; we are only going through the open channel, that is, flow processes occurring there.

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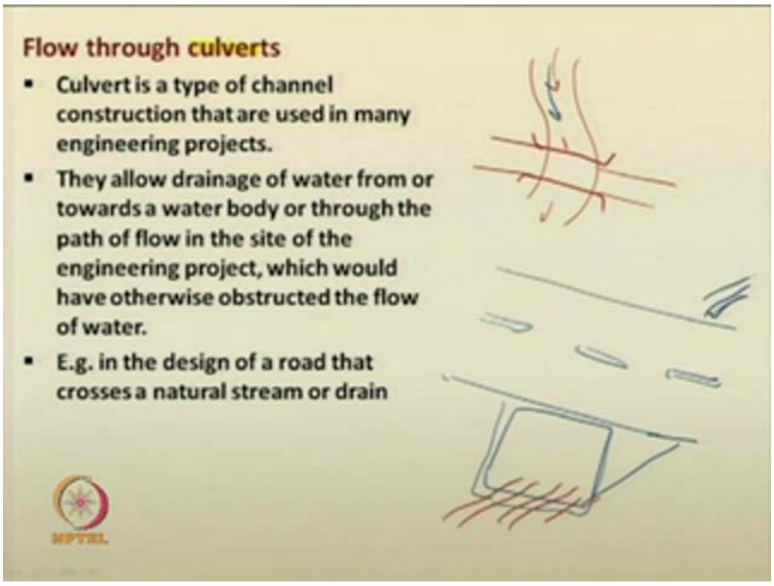

First, we will be dealing with flow through culverts. Culvert – it is a type of channel construction that are used in many engineering projects. If I just try to draw it for your benefit; if there is any natural drainage – small drainage or channel, that is, draining water from upstream to the downstream if you have a... And, if there is any particular engineering project in which that particular project demands passing through this particular draining; it is not advisable to block this particular natural drainage that is available there. Therefore, if this is a small drainage, you will provide some type of culverts that can allow the drainage. And, above the culvert, the particular project will be implemented. Such type of engineering structures are built across the natural drainages or even in the man-made drainages so as to avoid blocking of the drainages and all.

What they say here; if the drainage is like this; and, if we construct a culvert of this form; then, you can easily allow a road to be built across through this drainage and all. So, you can... So, water will flow through this culvert without... And, this road is not going to block the natural drainage of the path of the water also; that is, the culvert will allow drainage of water from or towards a water body or its natural path from upstream to downstream and all in the site of that engineering project. If you would not provide culvert, what the engineering project will do is that, it will absolutely block the natural drainage path. Say this is the natural drainage path of water here; in this case, this is the natural drainage path. If this block...Through an embankment, if you build road along this direction, this would have completely blocked this; means even though the channel width or the natural drain width may not be that much, it is still contributing to some water body or some other... means it is still draining to some water body or to a river or to a main channel and all. So, that way, it is advisable you do not block such natural drain paths and all. Therefore, you can get enough quantity of water in the water resources or reservoirs and all.

As mentioned here, you can have say a road is being built like this with sufficient this thing. So, this is the road. You can have... Say you can talk in terms of highway also. Now, at times, it is a time of highways and expressways and all. So, you require very wide roads and all. And still, there may be many natural drainages that may get blocked due to this particular roadways. Therefore, if we provide a box... One example is a box culvert. It is in the shape of... The natural drain of water is in this direction; it is in this particular direction; water is flowing like this. So, we provide a box culvert that will... It is an engineering structure; means you can have the box culvert like this. Water will flow through this and it will cross and it will reach at this location. So, water can reach at this location. So, like that, you can provide box culverts or any type of culverts. What is the peculiarity of culvert?

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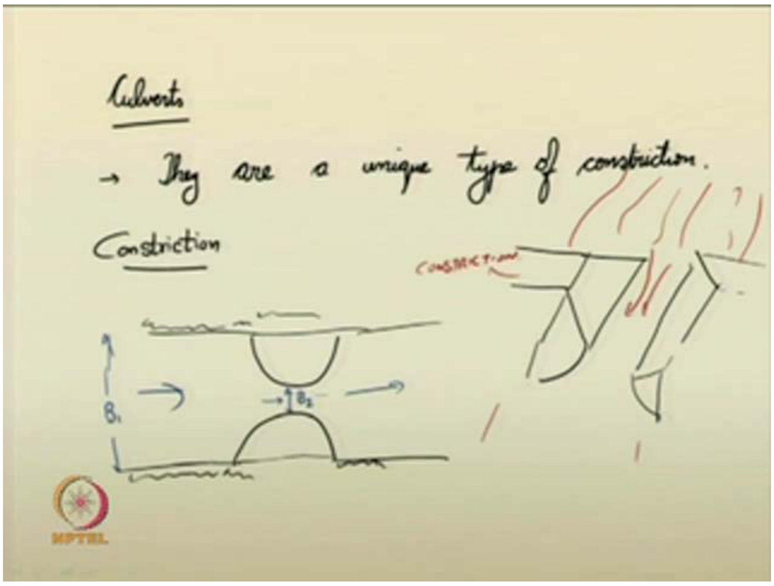

Culvert – if you look there culverts; they are a unique type of constriction. What is meant by constriction? The word constriction – what do you understand from this particular word? That is the path of the flow or the flow of water in a channel or in a river – they are getting constricted; that is, through a width – the width of the channel; it is getting constricted. That are called constriction. You might have seen... Say if I draw a particular this thing from the above; if there was a natural river like this; now, due to some man-made requirement – either it can be man-made; some of the natural constrictions are also there in some of the wide rivers. We are not talking about that the man-made things.

Suppose some engineering construction is being built; it is required, so that, that particular channel remains stable and all for certain purposes. Here the natural drain – the drainage path means water was flowing in this much width; say B here, B 1 here. And, all of a sudden, it is getting constricted to another width B 2. Then, it is coming out from that constriction. Such constrictions are provided in many engineering projects. So, culverts are also a type of constrictions. If we just try to elaborate the constriction forms and all; you may see that, say a sort of embankment is being provided with certain dimensions and all. So, the natural flow path was quite wide.

However, due to the... In this particular river; say in this river, you were having water coming from this much width; like this it is coming here; and, it is flowing now in a constricted path; then it will come out like this. So, this particular structure – this is a constriction. So, it is constricting the flow. So, we have already seen in the last class, flow through a constricted way; means sudden constriction in the width of the channel and all. So, those things we have studied. So, culverts are also a particular type of constriction, where the entire system – it is being closed; means that is, the culvert is a closed constriction.

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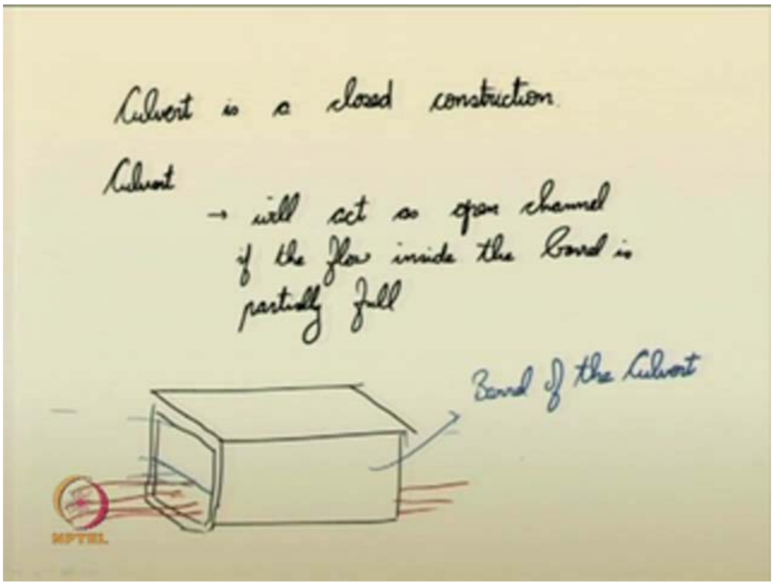

We can say culvert is a closed constriction. Culvert – it will act as open channel if the flow inside the barrel is partially full. So, I hope you can now understand. Say as we mention in the box culvert earlier; the culvert – it is a box shaped. So, it is being provided like this. Water – it is getting drained through the culvert like this; water will flow like this and it will come out. So, this is the barrel of the culvert. I can now say that. So, this portion is the barrel of the culvert. So, if the barrel of the culvert – if it is full; if the entire water if it is full like this from here inside this thing; then, the culvert will not act as an open channel; means you cannot call the flow inside the culvert as an open channel flow. You have some constrictions there.

So, if it is partially full; if the flow depth and all – it is only partially filling this only up to this height and all and the flow is to be maintained in the culvert; which is the case in many of the culverts. If you design many of the culverts; that is the better situation we require. Such flows are open channel flows. And you can use the open channel mechanisms to understand that culverts thing.

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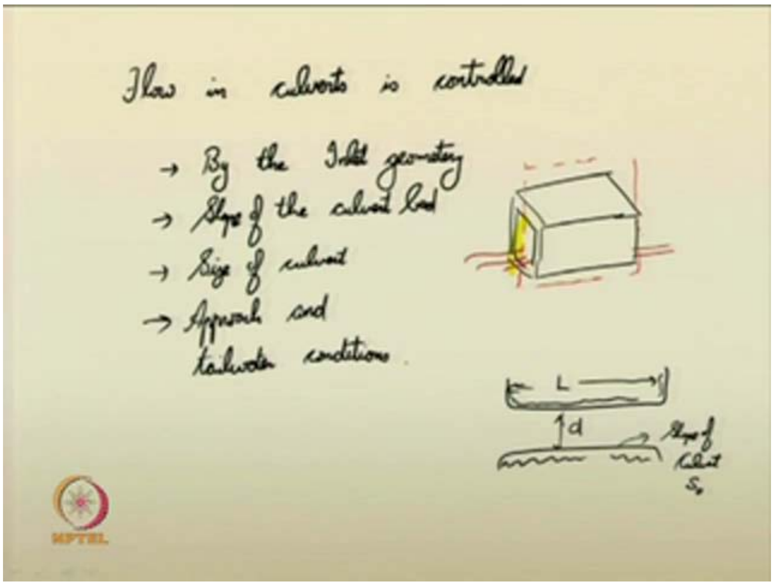

How do you suggest the thing? That is, what are the flow in culverts? How do you know whether the flow is full or not? Or, flow in culverts is controlled say by the inlet geometry. Again, I am just drawing the thing here. You have the inlet water coming like this. This is the outlet of the culvert. So, the inlet geometry also plays an important role – inlet geometry. Then, the slope of the culvert bed. So, if I take a section along this particular plane; if I say take a section along like this – along the middle plane, if you take this; this can be elaborated now. I can draw it. So, it will look like this. You have the depth of the barrel, which may be called d; you have the length of the culvert, which may be called L.

Then, the slope – slope of these culverts – slope of culvert – you can call it bed slope of the culvert S 0. So, the slope of the culvert bed – that is that is also important. Size of culvert – what is the size of this opening given to here? The opening given here around these portions and all; what is the size? That is also quite important. Then, you have another important this thing – the approach condition there. This is the inlet condition or the approach condition; and, the tail water outlet or tail water conditions. So, those things are also important. Approach and tail water conditions – they also play significant role in determining how the flow is occurring in the culvert.

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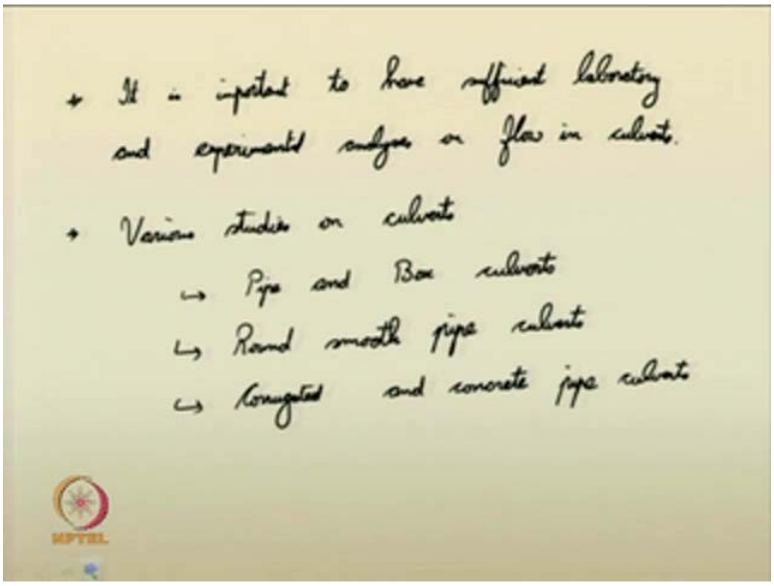

Usually, compared to the mathematical analysis and all; it is important to have sufficient laboratory and experimental analysis on flow in culverts. Actually, the mathematical analysis are not much developed at this particular state. It is not about the capability; if you are motivated, you can just give a new try and try to incorporate more realistic mathematical approach to the flows in open culverts and all. Right now, many of the documented literatures have works mentioned especially on laboratory and experimental analysis.

From that, they have inferred what could be the type of flows and all. That is, if you go through the history and types of various studies on especially experiment studies – culverts; they suggest some of them are... Some people have used pipe and box culverts in their studies. So, they have used a fully pipe... You might have seen cylindrical pipe in some of the road embankments and all or the rectangular box type and all; fully this thing. So, pipe and box culverts are used. Some use round smooth pipe culverts. So, there are many literature works related to such culverts and all. Some have used corrugated pipes or concrete and concrete materials and all, concrete pipe culverts. There are even reports of steel culverts and all used in some of the locations, so that based on your interest, you can further go for the higher journal papers and all and try to investigate the flows in culverts and all.

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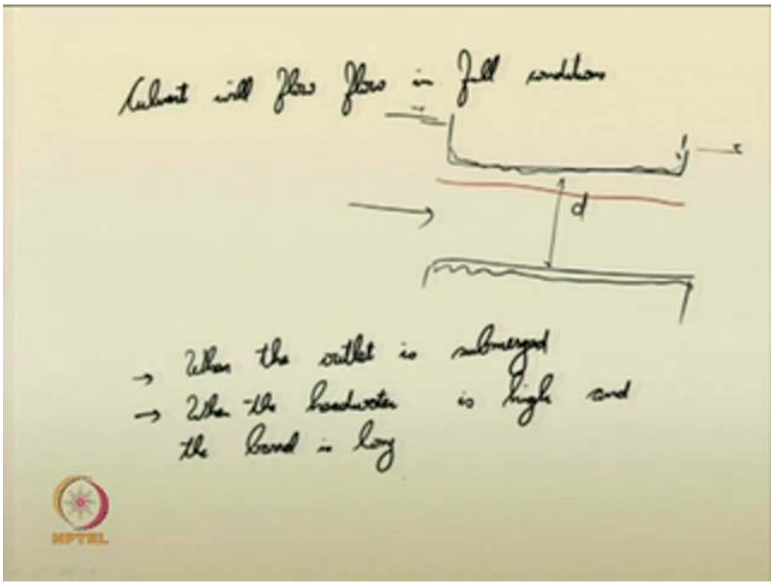

We can now suggest culvert – the flow in culvert; that is, you have seen that, this is the inside the culvert barrel. This is the depth of flow. So, inside the culvert, water is coming like this. So, this is the vertical section of the culvert provided here. So, the depth of flow in this portion inside the barrel – it can be either partly full or it can be full. So, we can now suggest, culvert will flow in full conditions for the following two cases. That is, you have the inlet portion here; you have the outlet portion here. When the outlet is submerged, you have... that is, if the outlet portion – if it is submerged; the water depth and all; here it is this much submerged; you have a submerged condition. Then, the culvert may flow full or when the headwater or the inlet water condition – if the headwater is high and the barrel is long, you may have full water condition. So, water in the inlet – if it is much, much higher; then you will see that, it may flow fully. So, these conditions may suggest that, the culverts may flow in a full situation.

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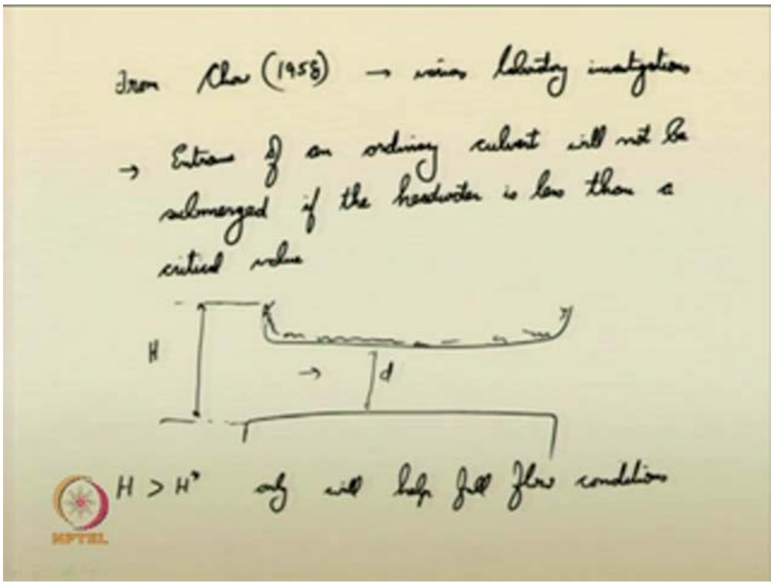

Next, we can suggest that, the following conditions are... Say especially, if you refer Ven Te Chow's book on... 1958, Ven Te Chow's book on Advanced Hydraulics and all – open channel hydraulics. You can see that, especially from various laboratory investigations, he has suggested that, the entrance of an ordinary culvert will not be submerged if the headwater is less than a critical value.

What we want to suggest is that, again, the vertical section, the headwater – say even if the headwater is little bit above this location; the culvert barrel have this location and all. So, this is the barrel depth. This raise in if the water... The headwater – if it is above the water level at the top portion of the culvert, it does not guarantee that, the flow inside the barrel will be full; it does not guarantee that. It requires another mandatory condition that, only the condition that if this height of water is above a certain critical value; then only, the conditions will help to make the flow in culvert as fully-filled conditions and all. So, we can suggest that condition; H greater than H star only will help full flow conditions.

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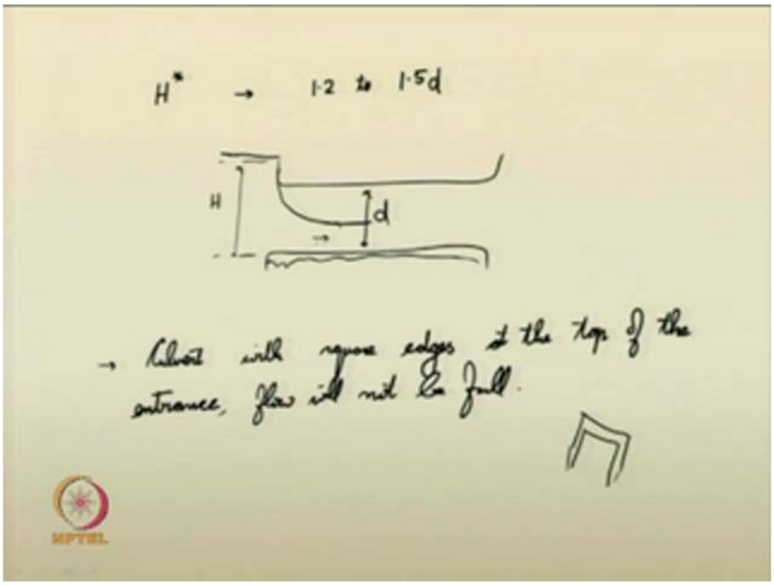

We can now also suggest that, this H star from many of the experimental investigations – they suggested that this H star varies 1.2 to 1.5 times... See again I am redrawing this. This is the culvert depth; this is the headwater depth. So, headwater depth should be above H star. That is the criteria. So, H star from various experimental investigation – they founded that, it is approximately around 1.2 to 1.5 times of depth of the culvert. So, culvert... Some of the experiments also suggested that, culvert with square edges; rather than round edges and all, if it has square edges at the top of the entrance... At the top of the entrance, if the edges of the culvert are square like this; in many experimental investigations suggested flow will not be full in such culverts. So mostly, the flow will be below headwater level.

So, what happens is that, even though if the headwater – if it is above a certain value; in such square conditions and all, it may dip; inside this thing, it will dip; it may give an orifice type of flow inside the barrel of the culvert and then it will exit from the outlet portion of the culvert. So, such situations can form or it may act like a sluice gate. In the sluice gate, as you know that, if the shutter is being raised or lowered; when it is lowered, you know that, water will gush out. A similar phenomenon may occur. For such square edge types, here the water may come like this; it may gush out like this and go out. Initially, it may be very high speed; then, due to the length, as it progress along the length of the barrel, its energy decreases and its subsequent velocity decreases; you will get a reduced flow and all. So, we can suggest that, the high velocity jet will continue through the barrel length.

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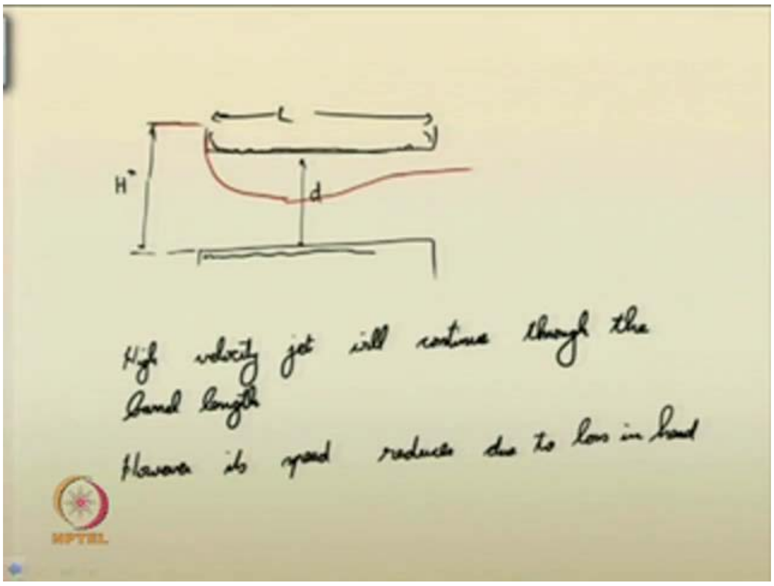

This is the length of the barrel. Even if it is H star; H at the square edge entrance, at the top portion of the entrance, even if it is square edge; we can suggest this as capital D or small d; whichever be. So, the high velocity jet... You can just give it in a different colour. Here this water portion – it will go like this – high velocity jet. So, that high velocity jet – it will continue through the barrel length like this and it will come out. However, its speed reduces due to loss in hydraulic head. So, those conditions will suggest the thing.

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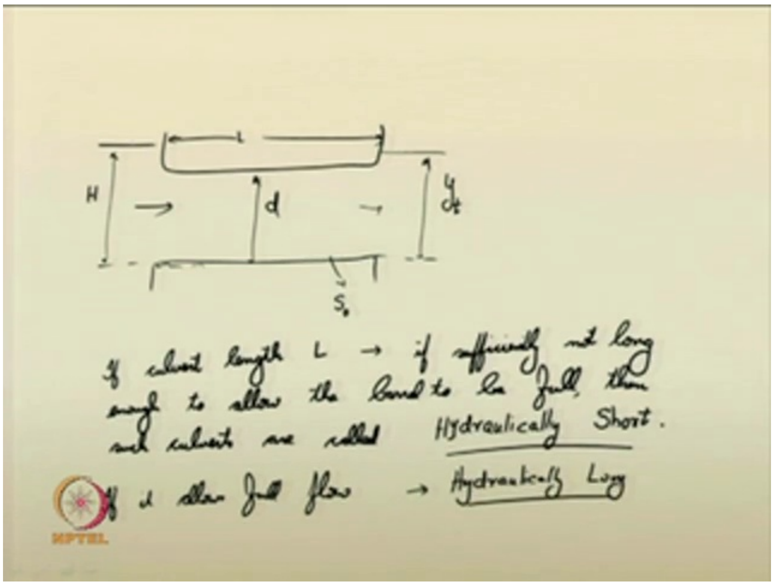

Now, based on the culvert length culvert and the type of flow inside the culvert and all, you can classify the flow in culvert. Institutionally, again, I am just redrawing the same thing. So, this is the length of the culvert and this is the depth of the culvert. This is the H; capital H is the headwater depth. And, you can say this here; let it be the tail water depth y t. Let this the slope of the bed of the culvert be S 0. So, this is the flow accustomed this direction to this direction. So, in this case, what happens is that, based on this thing, if we can suggest; if the culvert length L – if it is sufficiently not long enough to allow the barrel to be full; if this length of the culvert if it is not sufficiently long enough. So, that the flow inside the barrel becomes full. If it is not allowing that, then such culverts are called hydraulically... You can write it like this – hydraulically short culverts.

So basically, you can suggest two types of culverts: hydraulically short culverts and hydraulically long culverts. So, that is, vice versa is, if it allows full flow, then such culverts are called hydraulically long culverts. So, this is the two main classification; flow in a culvert can be hydraulically short or it you can suggest that, the type of flowing the culvert – it can be hydraulically short or it can be hydraulically long.

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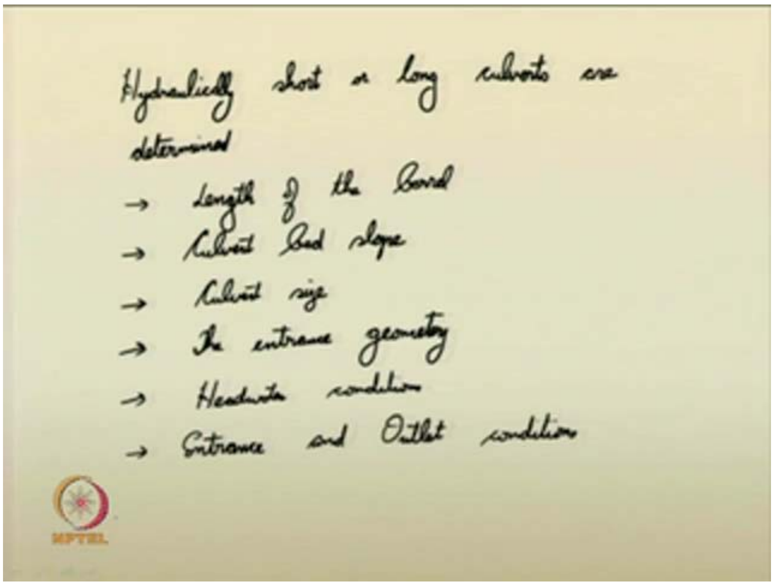

From these two classifications, we can suggest, what are the criteria for hydraulically short; that is, how the flow in culvert becomes hydraulically short or how the flow in culvert becomes hydraulically long. So, hydraulically short or hydraulically long culverts are determined as follows: based on the length of the barrel; based on the culvert bed slope; based on the culvert size; based on the entrance geometry. You have seen that, how you can have circular shape, you can have rectangular shape, square shape, various shapes or various things. Headwater conditions; also, the entrance. In the entrance, what all other features are there? Entrance and outlet conditions – they also a play significant role whether the flow in a culvert is hydraulically short or whether hydraulically long. So, these are the following some of the conditions. So, you can please note them.

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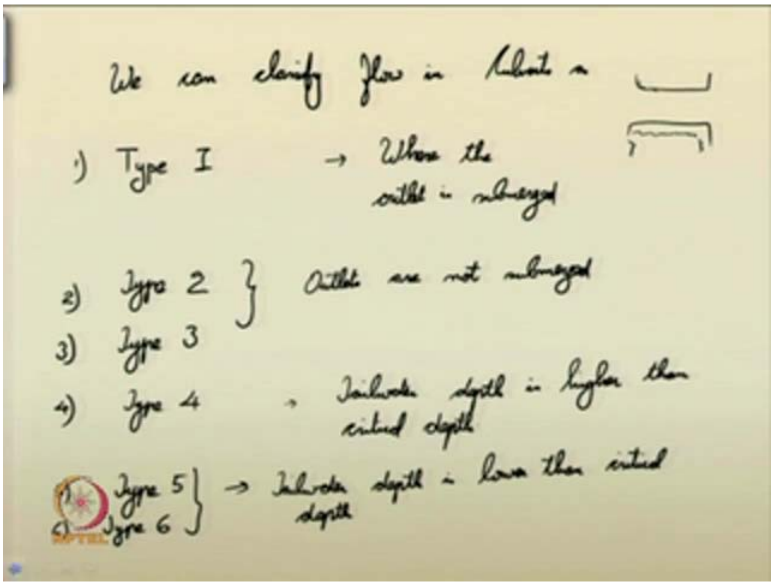

Based on this thing, we can now classify flow in culverts as say one is type 1. So, the type 1 flow means where... Please recall the culvert diagrams and all. We will just give a detail explanation now further in the next slides and all. So, just recall this – where, the outlet is submerged. Such types of culverts flow are called type 1 flow. You can have type 2 flow. You can just give either roman letter or you can give Indian numerals and all, Arabic numerals. You can have type 3 flows. In both type 2 and type 3, the outlets are not submerged. But, they are different. We will see that. Then, you can have type 4 flows. Type 4 – this type 4 flows are encountered, where the tail water depth is higher than critical depth. You can have type 5 flows; also, type 6. I can just mention both together here. So, there are basically six types of flows in culverts. Type 5 and type 6 are where the tail water depth is lower than critical depth.

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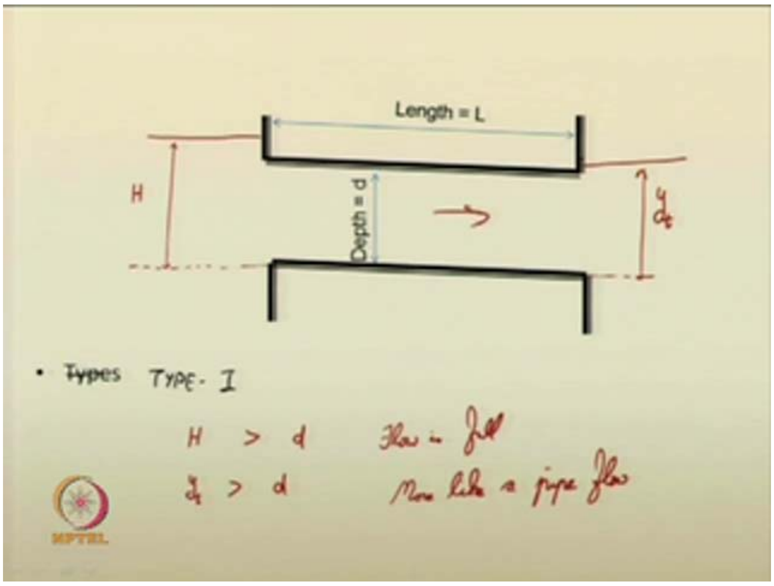

So, these conditions – I can now suggest it again. So, we can... The type 1 – this here I can just say type 1 flow. How it is encountered? Give the following this thing now. Let this be the water depth here and let this be the water depth here. So, you can now suggest based on this bed of the culvert; this particular depth is tail water depth; this particular depth is the headwater depth. And, this is you know, the culvert depth is equal to d and culvert length L. Flow is basically occurring in this direction from upstream to downstream. So, here this is called type 1. This is you can see H; that is, the headwater depth – it is greater than d. That is the depth of the culvert.

Similarly, the tail water depth – this is also greater than d. If both the conditions are depth... both the headwater and tail water depths are greater than the depth of the culvert; then, definitely, inside the culvert, the flow should be full. Mainly, it acts as flow is full in such condition. So, this is type 1. It is more like a pipe flow. Here you cannot apply the open channel principles to find the type of flow inside the culvert, because it is a constrict; means all around, it is bounded. So, it is more like a pipe flow. You have to use the pipe flow principles.

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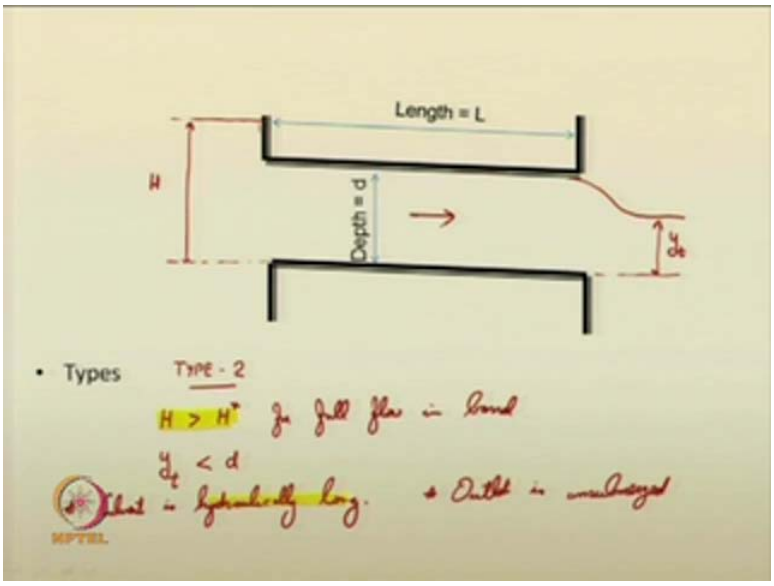

In the second condition, same thing; type 2 – if I give it as type 2. What is type 2 flow? In type 2 flow, what happens is that, the headwater depth – it is... Say this is the headwater depth; the depth of the culvert is given; flow is occurring in this direction; and, inside the culvert, it is almost full. Here the tail water depth – we suggest that, the water flow is occurring like this. And, from here the tail water depth is this much. So, let us assume that, this is the tail water depth and the flow profile is in this form.

So, what happens here is that, we are suggesting that, H should be greater than H star for full flow in barrel. So, we are suggesting H is greater than H star. y t – it is less than the depth of the barrel. So, these two conditions will make the flow inside the barrel full flow itself. Here the culvert is hydraulically long; outlet is... You can note the points: outlet is unsubmerged; say the outlet is not submerged here such type of flow is called type 2. So, you have headwater greater than the critical value. You have this headwater greater than the critical value. You have seen that, H star is the critical value; then, only... So, that will have ensured full flow. It is not ensured; that is the criteria. Then, you have the tail water that is less than the depth of the channel. Then, you have the flow is full here; culvert is hydraulically long.

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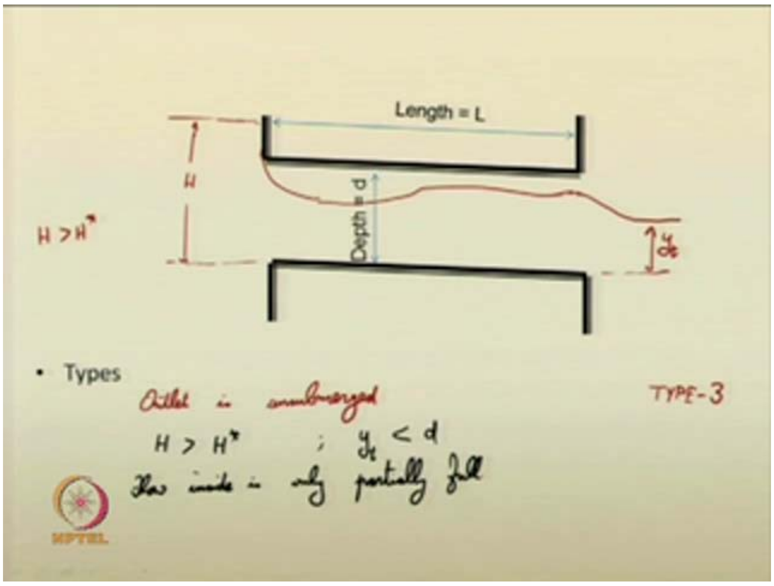

The next type, which we can discuss is type 3. Let me give this as type 3 here. This is called type 3. Type 3 flows in culverts. So, what is the peculiarity of type 3 flows? Here although you have headwater depth H like this; here H is greater than the critical value. Still what happens is that, the flow inside becomes like this. So, it will gush like this. Then, it will flow like this. Then in the outlet, it will come and drop to y t. So, such type of flow is called type 3 flow. Here the outlet is unsubmerged and you have H greater than H star; H is greater than H star; outlet is unsubmerged. How about the flow inside the... Flow inside is only partially full. So, this is type 3 flow. What happens is, this one is also less than d.

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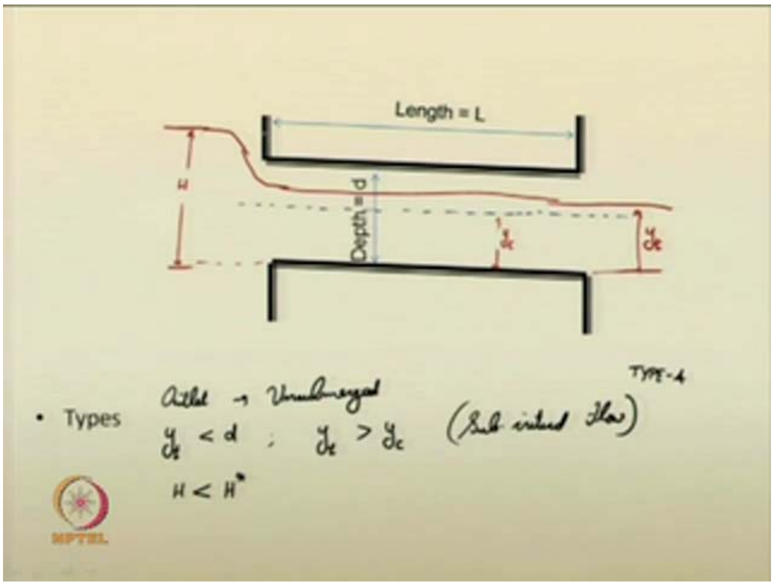

You can also have another type of flow; that is, type 4 flow. We can write it type 4. I will just draw. What is the type 4 flow? Say inside the culvert, let this be the critical flow depth line. So, I can now suggest, if this is the headwater depth H; depth of the culvert d; this is the critical flow depth inside the culvert. You may have a situation where the flow will go like this inside the culvert and it maintains this same depth in the exit also. So, y t. So, this is the type 4 flow. What is the peculiarity here? Here also, you have outlet as unsubmerged one; outlet is unsubmerged. You have the tail water depth less than d; but, also, the tail water depth is greater than the critical flow inside the culvert; that means that, inside the culvert, you have subcritical flow throughout. That is the peculiarity here. And, you have H less than H star here. So, here H is definitely... means it has to be less than H star; then only; otherwise, it would have touched the boundary (( )) and all. So, that way we can classify type 4.

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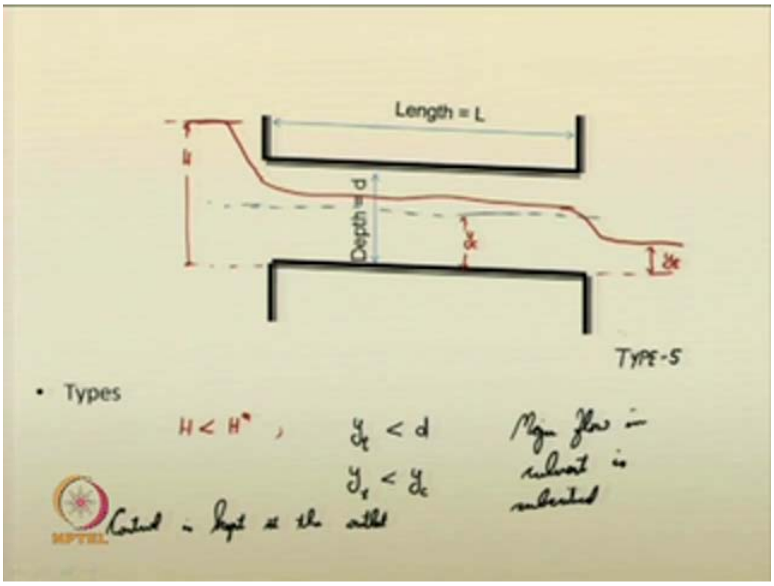

Next one is type 5. Let me write this as type 5 here. In type 5 flows, what happens is that, the depth of flow H – the headwater or upstream – H is less than H star. You have a critical flow depth line. You can just draw it for the culvert. The flow profile will be such that from here, it goes like this; and, at the tip, it goes into the y t, that is, depth y t. Tail water depth is y t. So, this depth is critical depth, y c. So, you have H less than H star. Now, also, you have y t less than d. So, hydraulically short; it is y t is less than the critical depth flow inside the barrel. So, this way, it can... The flow inside will be subcritical. Major flow in culvert is subcritical. Only at the outlet, it goes into the supercritical depth y t, which is less than the critical depth. So, in this situation, the control is kept at the outlet. So, if you have a definite control here, such mechanisms can be provided; and, the flow inside the culvert is also subcritical.

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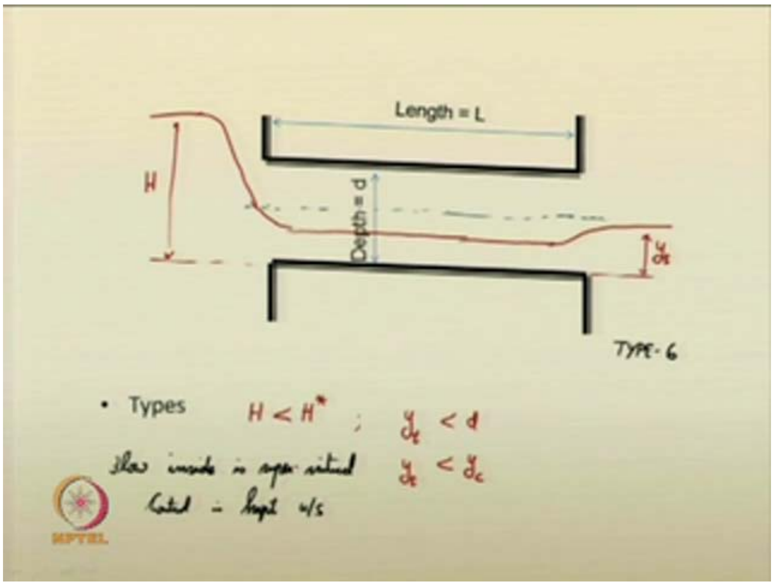

Next, the type 6 flow you can discuss is where we can suggest type 6 such a way that... Let me draw the critical flow. Say if this is the critical flow depth inside this thing; and, if this is the headwater depth H. So, we are suggesting H less than H star. In the flow, it goes all of a sudden into the supercritical form; the flow inside the culvert barrel is supercritical; and, it may just raise little bit to y t. So, what does this mean here? y t is less than d; that you are quite aware; y t is also less than y c; flow inside the culvert is supercritical. So, if you want to provide supercritical flow inside the culvert, the control is kept upstream. Here if you provide a control in this portion; you will get the supercritical flow inside the barrel. So, like this, we have discussed the flow types in culverts. Based on this particular course level and all, we would like to conclude the portion of culvert at this location.

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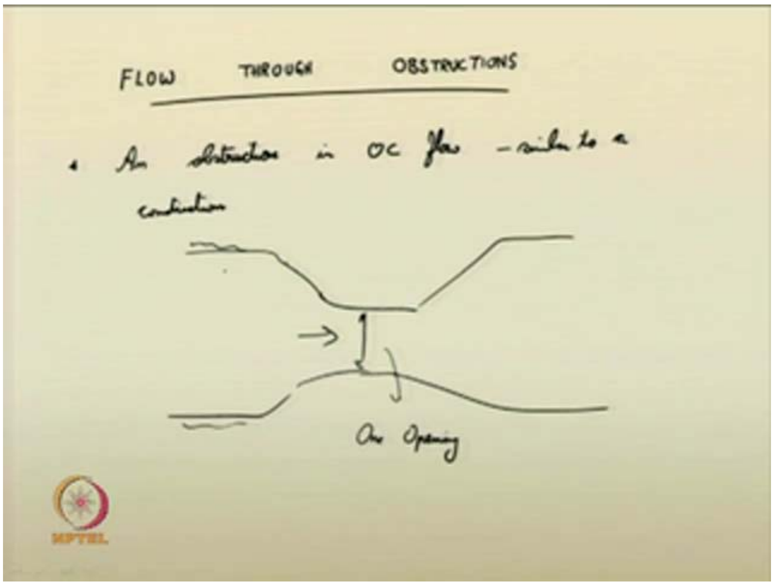

Next, we will discuss on flow through obstructions. What is meant by an obstruction? An obstruction in open channel flow – it is similar to constriction. You have earlier seen, what is meant by constriction. Say in a stream, if all of a sudden due to some engineering projects or engineering works and all; if the stream is getting constricted in the width, this is called constriction. So, you have seen that. Similarly, an obstruction is also a constriction. It is a type of constriction in width of the flow. But the difference is that in the constriction, you have only one opening. So, the entire flow is getting constricted in one opening.

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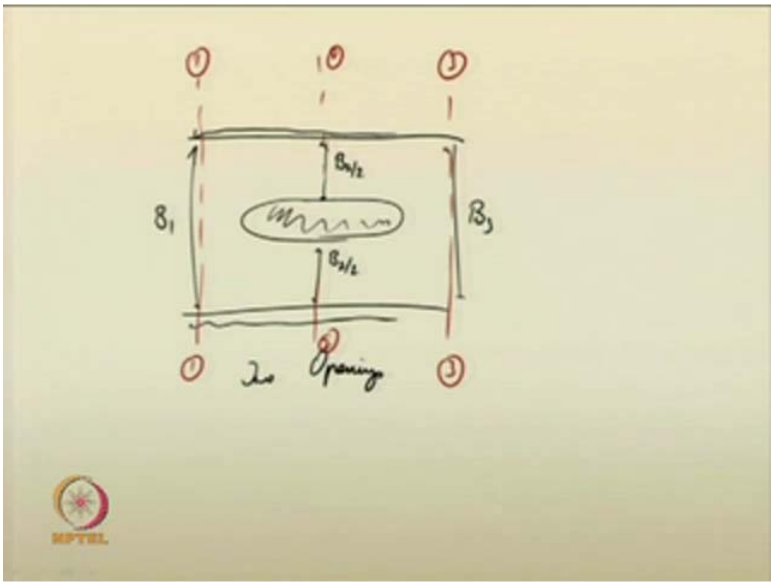

In obstructions, what you face is that, say in the stream, if you incorporate a pear here like this; what it is going to happen is that, the width; say here let us assume that, it is B 1; let us assume it is B 3; and, here let us assume it is B 2 by 2 and so. You have two openings, where the flow is occurring there. So, two openings are there when obstructions at least two openings will be there when obstructions are incorporated in the flow.

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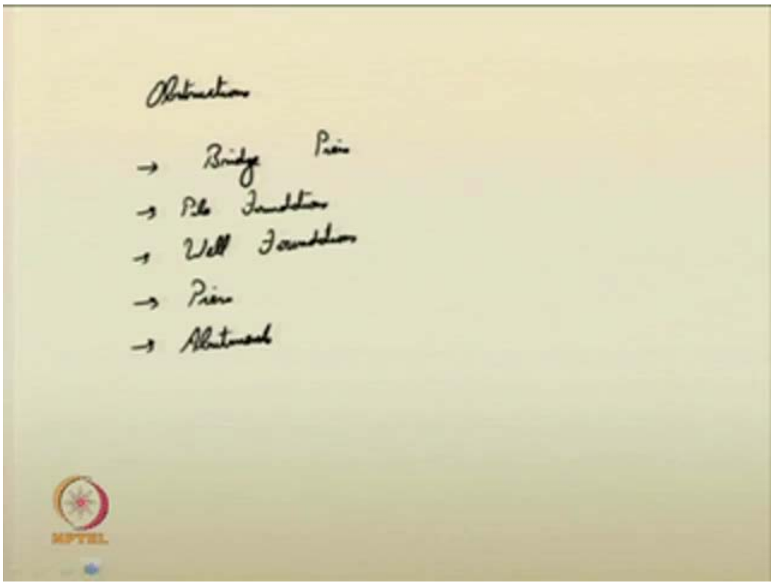

What are the various types of obstructions you may observe? Obstructions commonly encountered are bridge piers or pile foundations; well foundations; piers; abutments – many such obstructions you may see when you... Next time when you travel or when you pass, cross a river and all, you can see such many type of man-made obstructions; or, even natural obstructions can also be there. That obstructs the flow. Such obstructions also play a significant role in the type of flow that occurs in the channels.

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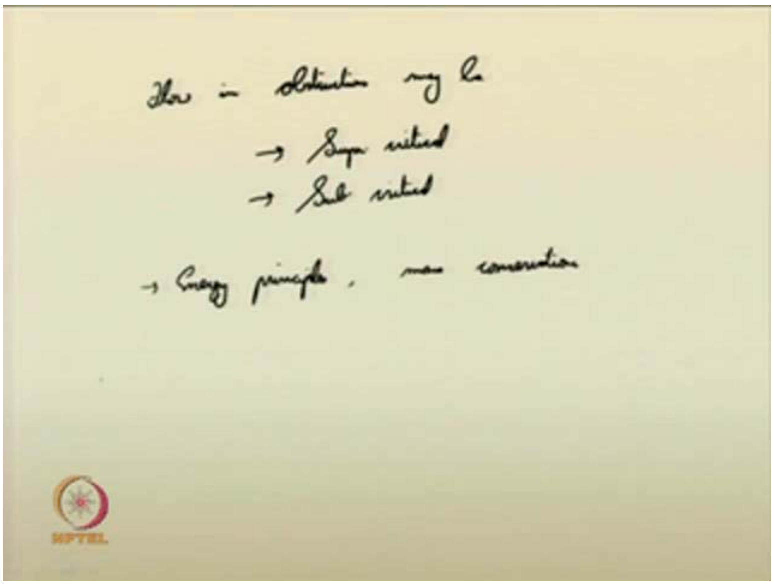

Flow in obstructions – it may be supercritical or subcritical. Flow in open channels – it can be supercritical or subcritical. You can use the energy principles energy principles as well as mass conservation or continuity equation. They can be incorporated to analyse the flow in such obstructions and all. So, we can quickly suggest the energy equation say between two sections. In the previous slide, if I go there, here if I just draw two sections; say this is section 1 1; this is section 2 2; this is section 3 3; then, I can just draw the cross section of this particular region.

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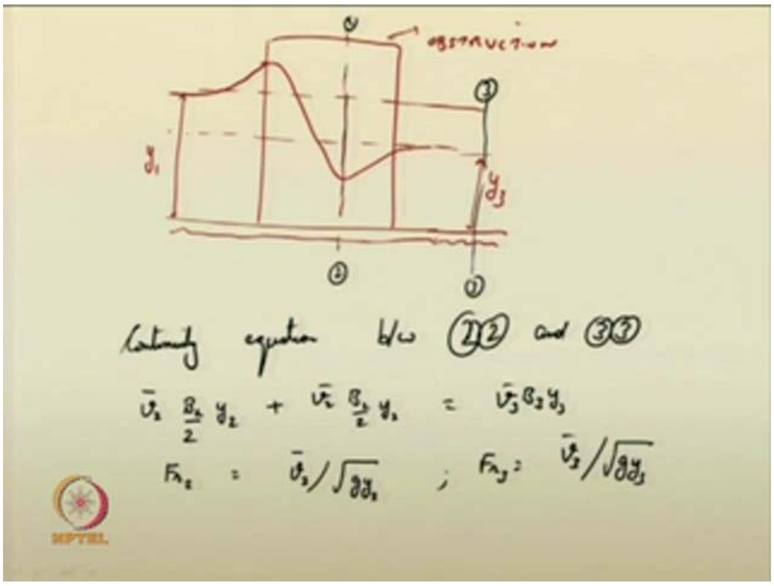

I can now easily suggest that the... Say let this be the channel bed. Then, let this be the obstruction employed. Various flow depths we can suggest now. Say let us at section 1, let us assume that, it has been the normal depth there y 1; then, the flow – it raises due to the obstruction; it reaches certain value; it just reduces to a certain value here. Then, it raises like this. So, this is depth y 3 at the section 3 3; the depth. So, this is the obstruction. If I apply continuity equation between section say 2 2 and 3 3; if I apply continuity equation between section, you can see that B 2 by... The flow conditions are steady. So, B 2 by 2 y 2 plus v 2 B 2 by 2 y 2 is equal to v 3 B 3 y 3. So, you can now easily infer the Froude numbers. Froude number at the section 2 2 – this is the section 2 2; and, this is the section 3 3. So, we can suggest that v 2 by root g y 2. F r 3 is equal to v 3 by root g y 3. At both the sections, we can find the Froude numbers; we can suggest the Froude number quantities and all. So, this continuity equation can be developed like this.

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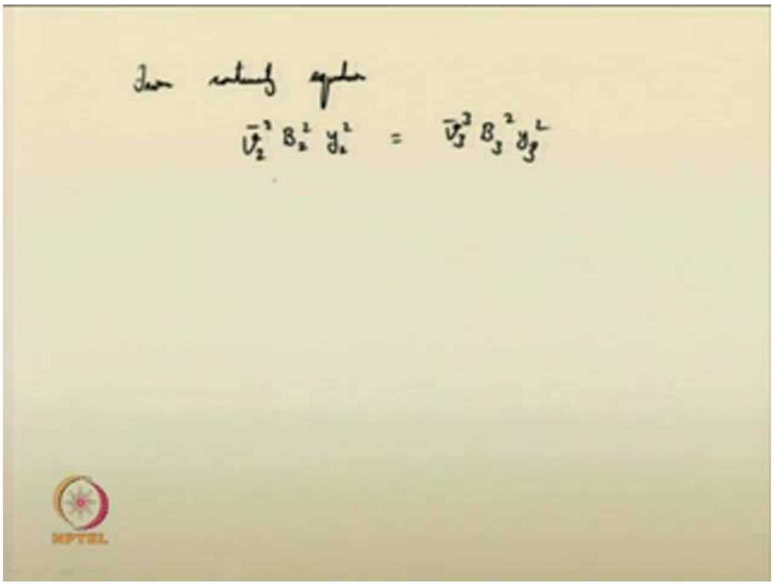

I can form a particular relationship now from the continuity equation. And, in the next class, we will derive or we will suggest the relationship of a particular parameter for the obstruction. From continuity equation, I can just suggest now, by squaring the terms B 2 y 2 square is equal to v 3 cube B 3 square y 3 square; like this. So, just incorporate the Froude number and we will see. We will get a particular relationship. We will continue regarding this portion in the next class.

Thank you.