Hydraulics

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Module No. # 04

Gradually Varied flow

Lecture No. # 04

Gradually varied flow and its computation

Friends, so let us go to another topic of gradually varied flow. Of course, a part of that topic we have already discussed in the last class, and today, we shall be discussing on that is gradually varied flow and its computation. Of course, before going to the computational aspect, we need to know some of the finer details of the gradually varied flow and as such first we will be covering that part and then only we will be going through computation of gradually varied flow.

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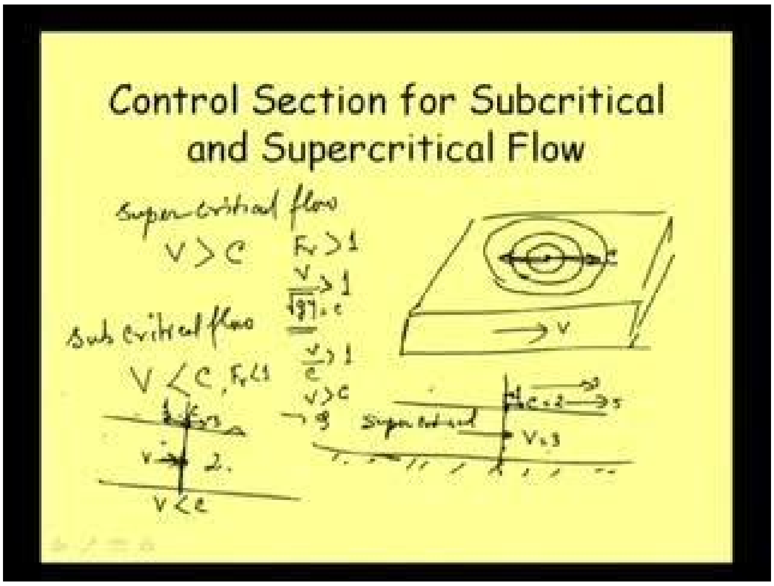

In the last class, we did discuss about the control section, and then we were talking how a super-critical flow get affected only by the disturbance that we create at the upstream of that, and sub-critical flow gets affected by the disturbance created at downstream of that flow section. So, let us go to some more detail of that particular issue.

Let us start with the fact that many of us, all of us rather, we have seen that say if we have a still water like this and say this is the still water and there if we make any disturbance, say we are throwing a stone into it or some if we talk about say larger size of disturbance some explosion can be there. Well, whatever may be suppose if you throw a stone here, then this part get disturbed and then what we see the waves are moving like this, with time these are moving like this. So, this is a common thing which I think almost all of us have seen them.

Now, this disturbance that is moving in the form of a wave and that the speed at which the wave is moving relative to the speed of the media that is suppose when our water is in static condition. If it is a pond, then of course that media is not having any speed and then any velocity rather and then when wave is moving over that means its absolute speed of the wave is equal to the relative speed and that speed of the wave we call as celerity. Now, say in a channel when it is suppose it is in rest, so say it is moving in this direction with a speed c and of course if this is moving in this direction, it is moving in the opposite direction also, in all this direction in all around in all direction it is moving with a speed c that is what.

Now, if we give a velocity to this media v, suppose now let us talk about a channel where this fluid media is flowing with a velocity v. Now, if we create any disturbance at this point and suppose that wave is moving with a velocity c in this direction, then of course this there will be motion of this wave in the upstream direction as well. Now, for super-critical flow what will happen and for sub-critical flow what will happen that we need to see.

Now, for super-critical flow we have that this velocity v is greater than the velocity c that is celerity c. So, in fact we got that Froude number is greater than equal to 1 and Froude number is nothing but v by route over gy is equal to 1 and it can be shown that for rectangular channel, this route over gy is nothing but say c. So, we can write v by c is greater than 1 rather we are writing all these as greater than 1. So, this is greater than 1 that means what we can write that v is greater than c that is what we are writing from this part. Now, as v is greater than c, suppose for example, let us take if suppose v is equal to 3 and c is equal to 2.

Now, this wave is moving at a speed to relative to v that we need to know and now, what will be its speed in the opposite direction because the media is moving opposite direction means if I talk about the upstream direction of this point, then as v is 3, c is equal to 2, suppose c if it is trying to move in this direction also, it is 2. So, it will be the relative speed in this direction if I write that will be that means if we just think that fluid is moving and the wave is also moving with that, then what is trying to move upstream is also moving. Suppose 3 minus 2 that means what we will have that sorry say 2 is in this direction and in this direction it is 2 minus 3, it will be moving to total net speed of this will be say 1 in this direction. Net speed of the wave which is trying to move in the opposite direction, net speed of that wave will be 1 in the downstream direction.

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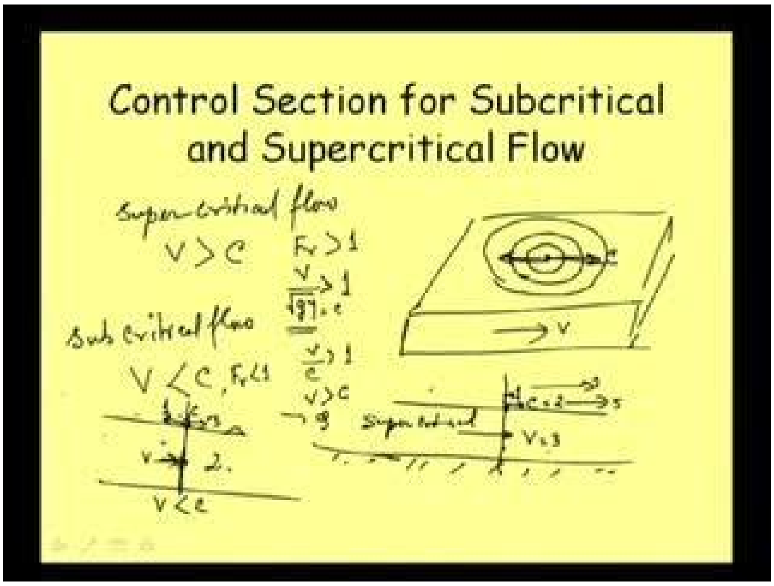

So, in reality when you are creating a disturbance and net speed of this in the downstream direction will be of course, that is which is trying to move in the downstream. This part this part will be again absolute will be 3 plus 2 in this direction and which is trying to move the wave that is trying to move in this direction that will have 1.

So, what we can say that if we create any disturbance in super-critical flow, it is not at all propagating in the upstream direction. This disturbance is not propagating in the upstream direction, it is moving. All the disturbance is net movement is always in the downstream direction, so that is not affecting the upstream flow. Whatever disturbance you create, that entire disturbance is moving in the downstream direction. This is moving with 5, this is moving with what but entire disturbance is moving in the downstream direction and disturbance is not propagating into the upstream direction.

In unsteady flow situation when we will be discussing characteristic equation, then we will see that this characteristic curves are always in the positive direction in case of super-critical flow. Well that part we are not discussing here. I am trying to explain these in terms of a very simple situation which is very familiar to us. Well and that is why the statement that we pass in the last class that is in case of super-critical flow any disturbance created at any section will not affect the upstream of the flow.

So, if a super-critical flow is coming, suppose this is a super-critical flow, then this flow is coming if you are creating something that is not influencing this flow. It is coming due to some slope due to some discharge here say for this slope for this discharge, it is coming. It will flow as it is. This disturbance is not influencing this one but in case of sub-critical flow, you can see in case of sub-critical flow, v is less than equal to c because say we have Froude number is less than equal to 1 in case of sub-critical flow.

So, as v is less than equal to c. Now, for sub-critical flow if I draw this one, it is coming like this and say it is moving with a speed say 2 and then c we are creating the disturbance here and that disturbance may be y for whatever it is, then it is moving with a speed say 3. It is celerity c is higher than the velocity v, so this is what I am drawing v and this is what I am drawing c.

Now, relative speed in the positive direction and in this direction if we want to see absolute speed rather than in this direction also, it is trying to move with a speed 3 and so absolute speed of this wave in the upstream direction will be that this 3 minus 2. So, there will be amount of 1 velocity is there in the upstream direction, so always there will be some amount which is moving in the upstream direction.

So, any disturbance if you create here that will be moving in the upstream direction and as it is moving in the upstream direction, this will influence the flow of the upstream part if it is sub-critical flow as v is less than equal to c. What about the downstream point that when this flow is moving in case of sub-critical flow when suppose the flow is moving with the velocity v and c is very faster, so disturbance we are creating is moving much ahead of that.

So, this flow as such will not be affected. This is moving with a velocity v, it is moving, c is faster than this. So, wave is moving far ahead of the velocity, so this is not getting affected in the downstream part. So, at downstream this will not be affected as such and control section, I mean there will be influence but so far the control is concerned that in case of sub-critical flow, we get it on downstream side and then at upstream this will influence the upstream flow. This is that I have tried from my side to explain with some simple case of example and from physical understanding of the situation which really shows that why the control is at downstream for sub-critical flow. If you do something on downstream, this is influencing the upstream. So, if we want to compute sub-critical gradually varied flow, then we should see what is there with the downstream point. That is suppose the control section we are getting that value and that value is influencing the entire flow, so we will have to start computing from the downstream side. This is one way.

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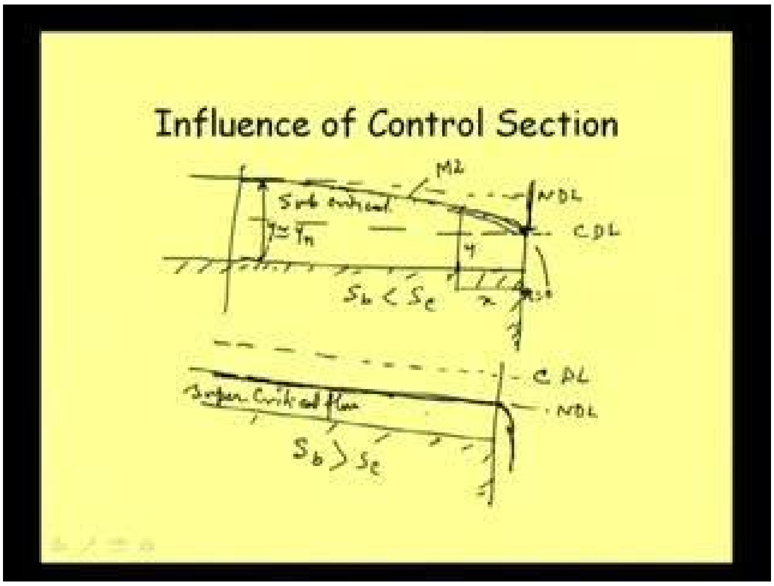

Then in case of super-critical flow, if we see that is why the what is the important influence of the control section. Suppose, if we talk about well let me show you one example here, say this is a mild slope Sb less than equal to Sc, so critical depth line is this one CDL, normal depth line is this one NDL.

Now, there is a free fall, so free fall means also a control section there. This free fall will decide what the depth of flow here it will be. Let me extend this line CDL, so we know that in nature the flow will be moving based on this bed slope. The flow is coming as uniform flow here and then when there is a free fall over fall, so this drop canal drop or whatever it is, it is this. So, the flow will have to go like this and then actually this water profile will start from this point and it will be coming here and it is meeting. So, this profile is basically M2 profile.

Now, this profile is moving like that and it is meeting the CDL line normally at this point. Now, so at downstream point this is also called brink depth or in depth and from practical point of view as hydrostatic pressure is not prevailing here, that assumption was there for hydrostatic pressure. So, we can see that some investigator analysed what is that brink depth or in that is not exactly equal to critical depth. There are some differences but for approximately we can consider that this is equal to critical depth. Now, from here we are starting say critical depth and this is our downstream point.

Now, so as it is sub-critical flow because depth is here, so flow is greater than critical depth or entire the flow profile is greater than critical depth. So, it is sub-critical flow. So, in case of sub-critical flow, suppose we try to compute this profile, compute means we need to know at what x, suppose this is x and this is y, at what x what the y value is at different x what will be the y.

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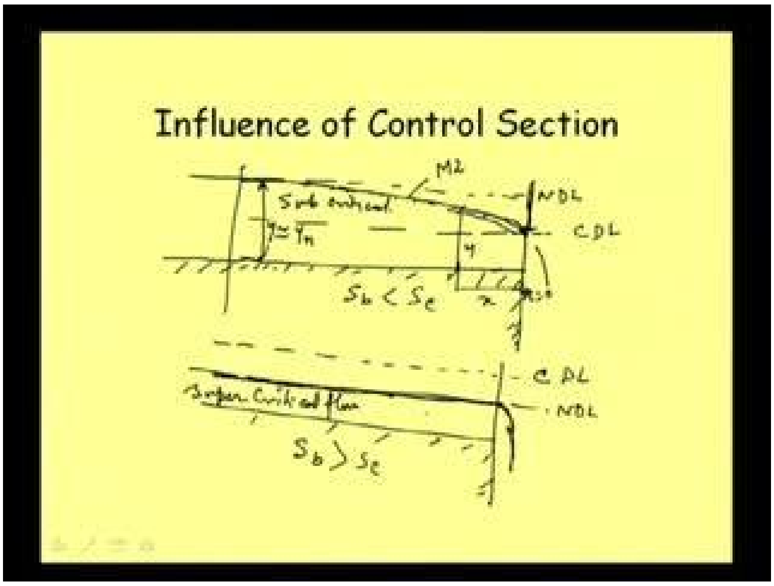

Now, for our purpose we know that at upstream end, the profile meet the NDL asymptotically but at what distance that we do not know. What will be this distance that we do not know? At what point it is meeting? So, where from we will start our computation well and that is why one thing we can do that we can start from uniform flow and then we can start computing in this direction. We will compute till the flow is just higher than critical depth because at critical depth this cannot be computed because our slope becomes infinite and that is not computable. So, just above the critical depth, we can compute and we can stop that way we will be getting what is the total length that we can get.

Another way is that we can start computing it from just above critical depth here. At this section, we can start computing. That first point, suppose we know at this point just above critical depth at x equal to say 0, we can take at this point x equal to 0 and then we can start computing in this direction that at different x. What will be the y from the equation of gradually varied flow and we are computing and then we can stop computation when our depth will be just y is just little less than or when it approaches yn. Of course, exactly at yn we cannot go, it will take I mean it will be uniform flow. So, we need to stop it just little less than when it is just little less than yn. Well, so this is the condition of flow when it is a sub-critical flow and that is what we are talking about control at downstream point.

Now, if we take a same bed condition that is but it is suppose steep slope and it is like this, there is a drop and if it is steep slope that is Sb is greater than equal to Sc. Now, if Sb is greater than equal to Sc, then we can have our normal depth line. Well, first let me draw the critical depth line. Critical depth line is here, CDL and as Sb is greater than Sc, normal depth line will be below this one and this is normal depth line.

Now, in nature if we do not make any disturbance, then that flow depth will be coming along the normal depth line. So, it is coming like this and at this point it will be falling like this. Now, as this is a super-critical flow, this flow will not be affected by the disturbance that is created at this section. So, what will happen? The super-critical flow will be moving straight this way and then it is coming up to this point and then it is dropping like this. So, there will not be any gradually varied flow forming at the upstream point here and the upstream point will not be getting any gradually varied flow if the super-critical flow is forming here and that will straight continue and it will fall like that. So, that is how the knowledge of control section is required.

Generally, feeling may come that whether it is super-critical flow or sub-critical flow is coming, it will be dropping like this but no in sub-critical flow only, it will be coming like this, it will be dropping like this but in super-critical flow this will go straight and then it will fall like this. So, this sort of understanding will be required while computing gradually varied flow and of course, analysing different situation under gradually varied flow.

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Now, with this understanding we can go to another topic that is gradually varied flow over series of slopes. Series of slopes means varying slopes say mild slope is there, then in the nature it is changed to steep slope or may be mild has changed to milder slope, I mean further flatter. So, that sort of combinations are very common in nature and rather in nature we will be getting this sort of combinations only. We will not get a channel with say uniform slope or through it. So, in that sort of channel, how we can compute gradually varied flow? For first for computing gradually varied flow first, we must know that what sort of gradually varied flow profiles are forming and once we know that this sort of gradually profiles will be forming there, then only we can go for computation of gradually varied flow and before that we cannot. So, understanding of that part is definitely important.

There can be different combination of slopes in series, say there can be a steep slope coming and then that steep slope is changing to a mild slope say from the hill the slope is coming like this, it is a hill and then it is becoming flat. So, this may be a steep slope and then this is becoming a mild slope. There can be some other combination that a mild slope is coming and then it is again changing to mild slope but it is steeper than this mild slope. That means, this particular part is milder, we can say that this is milder and this is mild.

Now, here we shall be discussing some of such cases and why we are taking some of such cases only that is we are taking this sort of case say mild to milder. Mild to milder means first it is coming like this, it is a mild slope Sb is less than equal to Sc, then it is becoming still milder. Here also, Sb is equal to Sc less than equal to Sc but it is flatter than this one, then we can discuss milder to mild that means this case. Then we can discuss mild to steep say mild slope is coming, then it is becoming steep, mild to steep. Then we can discuss steep to steeper. A steep slope is coming, a steep slope is coming like this and then it is becoming further steeper. So, it will be steep to steeper and then we can discuss steeper to steep that means it is otherwise also steep and still it is becoming steep but this is steeper and this is steep.

So different combination we can have and we are particularly choosing here under the gradually varied flow chapter to discuss these different slope. The reason is that we out of all these, you can see we are not talking about this particular case. Now, the reason is that here in this part, the slope is steep means water will be coming as super-critical flow and then here it is mild means flow will become sub-critical. So, when the flow changes from super-critical to sub-critical, then the phenomenon that takes place is called hydraulic jump. We are yet to discuss hydraulic jump, so once we will be covering the hydraulic jump chapter and then only we will be able to appreciate this change. We will be able to understand the flow situation or flow profile of this type where along with the gradually varied flow, there will be some portion of hydraulic jump and right now, of course it may be little bit difficult because we are yet to cover the hydraulic jump topic. That is why, we are excluding those situations and just as a typical example, we are giving some of these examples. So, let us take first this mild to milder.

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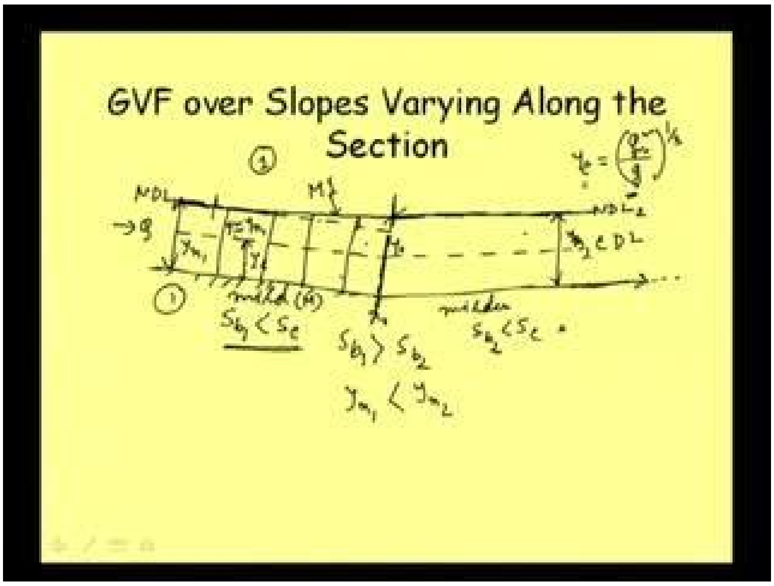

Say, it is a mild slope coming mild slope and then it is becoming further milder. This is not horizontal, this is also mild slope but it is milder than the existing one. So, this is also Sb is less than equal to Sc, here also Sb is less than equal to Sc. Now, if I give this as Sb1, this is Sb2, then we can write that Sb1 is greater than equal to Sb2 but this is comparatively steeper than this one but of course, in mild slope portion.

Now, so far critical depth is concerned let us see what sort of profile it will be during the entire flow portion from here to here. So, for critical depth is concerned yc, let us consider this as rectangular channel, then so far critical depth is concerned we know that this is equal to q square by g whole to the power one-third.

So, for a given discharge Q for a given bed width of the channel, if we consider this to be prismatic for a given width of the channel, this q is known or constant. So, what will happen? This yc is equal to q square by g, this value is constant. So, whether we calculate critical depth over this channel or over this slope which ever slope, it does not at all get influenced by the slope bed. So, if I try to draw the critical depth line, I can draw it like that say this is CDL suppose yc calculated is like that and this depth will remain same here also CDL line, so this is our CDL. Now, what about the normal depth line?

So, normal depth line here Sb is less than equal to Sc this mild slope, so normal depth will be above critical depth line. So, here suppose our normal depth line is this one, say this is NDL, if we do not create any disturbance normally over the slope, the flow will be occurring over the slope. I mean flow will be occurring at this particular depth.

Now, in the second section or second reach, here depth yn here say this NDL means I can draw that I can say this is in the first case. This is yn1 and this yc, so for yc is concerned, I am not using any index yc1 or yc2 because critical depth is same whether it is on this first section or whether it is on the second channel portion, so it is same. So, yc is yc and so far yn is concerned, this I am writing as yn1 and yn2, that means in the channel portion 2 as it is flatter than the earlier mild slope; it is milder than the earlier mild slope. So, yn depth will be a normal depth or uniform flow depth will be more than the earlier one because it is flatter.

So, if I draw a uniform flow line, then it will be uniform flow. Depth line is this one that is NDL normal depth line for the second portion, this is for the first portion and this will be say yn2 and we know that yn1 is less than yn2. Now, the flow needs to move, suppose it is coming without any disturbance at upstream, so it is coming at this line. So, flow is moving in this line. Now, ultimately the flow will be moving over this slope. So, suppose after certain portion where there will be some changes in this portion, then it will be moving at this level because this is the normal flow condition. So, it will be finally moving in this line. How the flow profile will be changing from this point to that point?

So for this part, for this downstream portion, for this downstream channel section, here we can see that there is some disturbance at the upstream for this particular point. As we know that this is sub-critical flow, this is not influencing that and we need not be worried about that part. We should know that this will be like that as long as at downstream we have infinite reach this is going up to infinite extensive; it is going, so we need not be worried about that. So, far this first part is concerned, here we are finding that at downstream portion the depth should be this much and another depth will be this much. So, this will influence the flow because it is sub-critical flow and that is why the flow from here gradually, it is rising to that particular level and then it is moving as it is.

So, these portion from here to here, this profile I mean I hope you can name this now because this profile is occurring in zone wise, it is say above normal depth and critical depth that means here normal depth is higher, it is above normal depth. So, it is zone 1. Zone wise, it is zone 1 and then slope wise, it is over a mild slope. So, we name it as M. So, this profile we can name as M1 profile. So, this is how we find or we need to know where the profile is, where the profile will occur and how it will occur then?

Now, if we talk about computation of this profile, then if we recall our earlier discussion on M1 profile, we know that at upstream it will be uniform flow depth nearly equal to uniform flow depth and at downstream, it will be govern by the control section here. This section is fix channel reach, this depth is one, so this depth is known to us. So, we can start this as the control section say this y naught is known at x0 and then we can compute upstream and then we can try to find out depth at different point and then coming where depth will be almost equal to yn. When y is almost equal to yn1, we will stop. So, we are getting the flow profile and this part is uniform flow that way we are getting. Now, this is how we need to know about the change of flow profile over a channel portion where the bed slope is changing.

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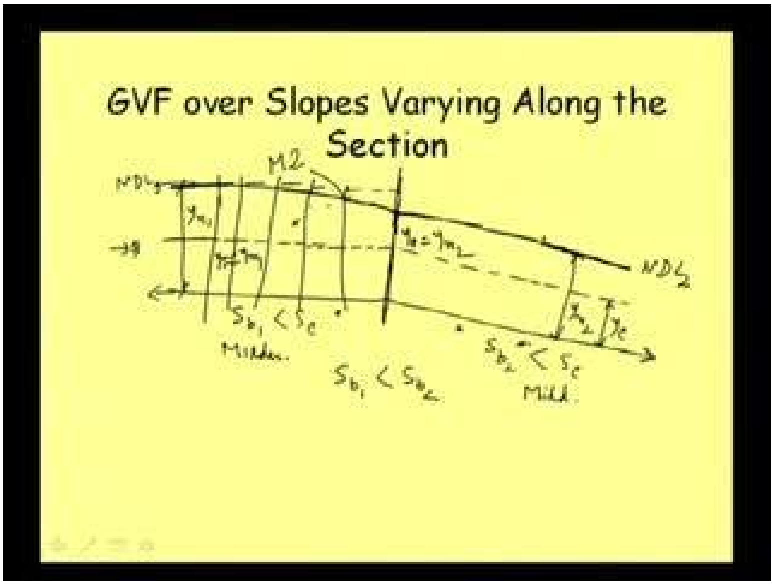

Now, let us take another case. We have discussed this first case, then the second case say milder to mild. What will happen to that particular channel milder to mild? So, this is a milder portion and then it is changing to a mild. This is I mean slope is Sb2 say it is Sb1, this Sb1 is less than critical slope that is obvious this is also less than critical slope but Sb1 is smaller than Sb2, this is steeper. So, this we can write mild and this is milder. Again, so far critical depth is concerned, this will be same for a given discharge this will be same. So, if Q is the discharge flowing, we can calculate the critical depth and let me draw a line here which is indicating that boundary of this channel and that channel. So, critical depth is fixed, critical depth is constant, it is not changing. So, that is our critical depth yc.

Now, let us see what about this mild slope. So, this normal depth at this portion will be somewhere here, so this is NDL1. Now, if we just try to recall our discussion, here also normal depth will be in the channel 2 also, the normal depth will be above of critical depth because these are mild slope but the normal depth line in channel 2 will be less than the normal depth line in channel portion 1. So, suppose normal depth here is in this portion say this is the NDL2, so I can draw this or I can state this as yn2 and this as yn1.

Now, what will happen to the flow profile because if the flow occurs normally without any obstruction, then the flow here will be coming in this line? That is obvious uniform flow is coming and then at downstream if this channel is extending, let us consider this is also to the infinite extent. It is like that and in downstream also it is in this direction to infinite extent. Well, then it is also moving like that, it is there, so at downstream portion it will be in this line. So, it will be it will have to move along this line. Now, what will happen to this in between portion from here to here? How it will change? How it will come from this point to that point?

Again, if we see that it is sub-critical flow, so disturbance or changes basically at this point. So, this change is here, it is this much depth here, it is this much depth, this will not influence this one. So, what will happen that this depth will remain as it is like that and then for this particular flow portion, this section depth will influence this part of flow. So, what will happen that this depth will come down to this portion and then it will continue like that.

Now, how we can name this part of flow. Here from here to here, it is definitely a gradually varied flow profile and here it is going like that as it is. Well, this profile as it is occurring over mild slopes, so it is name if we try to give it will be M and then let us see in zone wise. Zone wise it is between critical depth line and normal depth line, so in zone 2. So, this name will be M2 profile. The name of this one will be M2 profile. So, this M2 profile is forming here like that and in this portion, it is uniform flow is remaining. Well, so we could see that when the channel changes from mild to milder, it was M1 profile forming but when that channel is changing from milder to mild, we are getting M2 profile.

Then we can have some other type of situation. Well, let me just talk about computation also. Now, when we think about the computing, this profile again we will have to take this as the section known because from this depth we will be knowing y0, the control section is nothing but yn2 we know that and from here, we are starting computing. We can start compute and then we can go up to this point where y is almost equal to yn1, so that way we can complete the computation.

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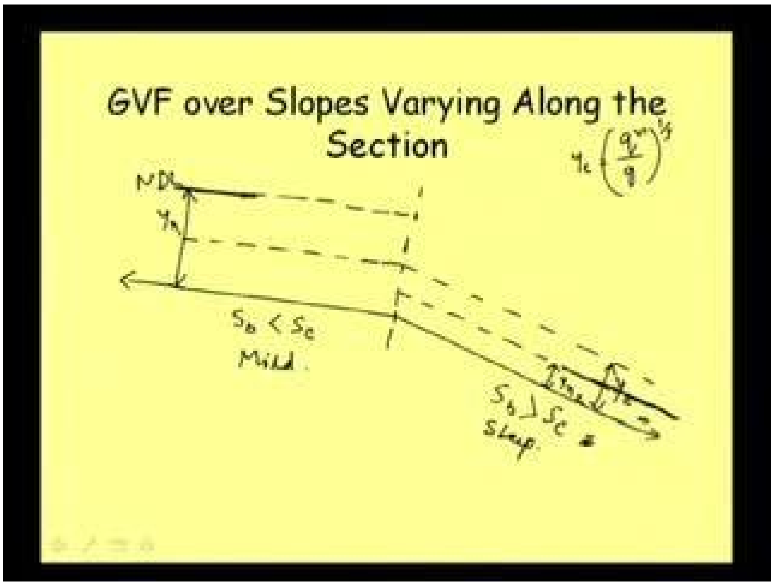

Now, how we compute that is of course a different issue. We are yet to discuss about that. We will be discussing soon. Then let me talk about this condition, mild to steep. Then this slope is mild slope and then it is changing to a steep slope. So, Sb is here less than Sc, it is mild and here let me just draw a line indicating this two parts and here it is Sb is greater than Sc, it is steep. So, mild slope is changing to steep slope and then so far critical slope is concerned or critical depth is concerned, again critical depth yc if it is a rectangular channel, this q square by g whatever may be the channel, it is not basically depending on the type of slope on which it is occurring. So, we can draw the critical depth line at a section like that.

Say this is yc, this is yc. Then let us think about the normal depth. What will be the normal depth that we can see? Here, it is mild slope, so our normal depth will be greater than the critical depth. So, normal depth line will be somewhere here. This is say NDL normal depth line and we can say that this is our yn1 but in this portion in the second reach of the channel second portion of the channel, here as it is steep slope, so normal depth line will be less than the critical depth line. Well, so it will be somewhere here. So, the normal depth line we are drawing here. This is say yn2.

Now, without having any disturbance in the downstream further or any disturbance in the upstream further, this flow will be coming at this line along this line and this flow will be moving along this line. Now, how the flow profile will be changing from this point to this point, this level to that level and that part will be gradually varied flow profile?

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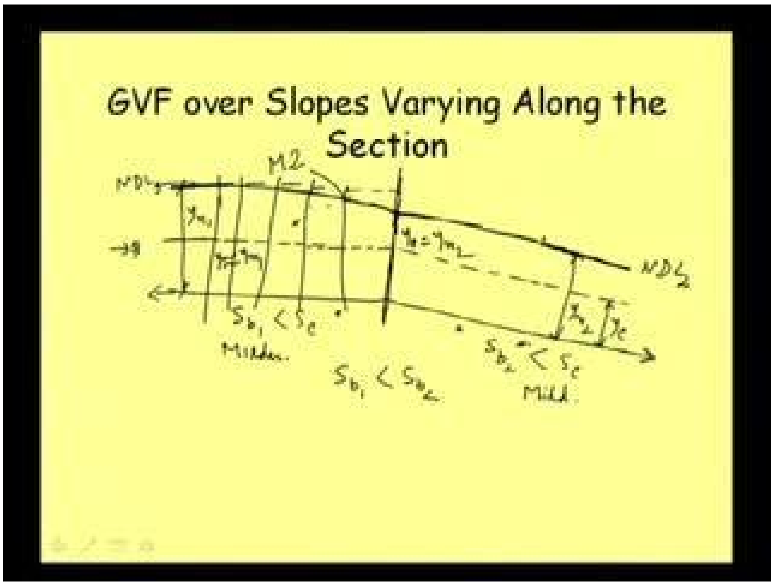

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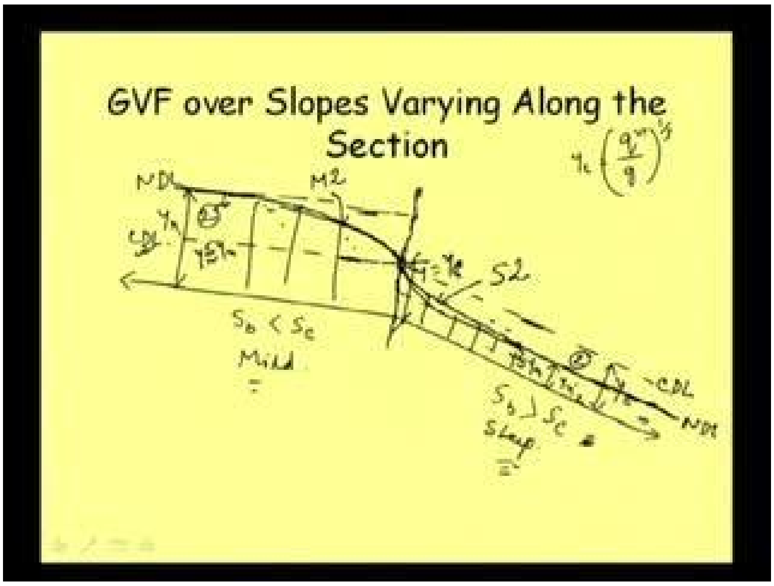

Now, let us see how we can do that. In this portion, in the second portion, it is a steep slope. So, the flow is below critical depth and that as such the uniform flow what is occurring is super-critical flow. This is super-critical flow and as it is super-critical flow, so any disturbance at the upstream point will influence this flow. Unlike the earlier case, here this was sub-critical flow. So, this disturbance was not influencing this one but here it is super-critical flow, so this disturbance will be so this disturbance at this point will be influencing the flow and as such we can say that this is the control, this section at the junction is the control for this downstream flow portion also.

Similarly, when we talk about the upstream flow, upstream of this section, this is sub-critical. This flow is sub-critical because this depth is more than critical depth and this flow as it is sub-critical will be influenced by the control at downstream at this point. So, both the flow, I mean the downstream being super-critical will be govern the flow will be controlled by this particular point section and upstream being sub-critical will be controlled by this depth. So, this will influence both.

So, ultimately what will happen? We know that this depth is critical depth and so from here as this flow will be affected by this one from here this is the controlling point. At this point when the flow is changing, this point will be critical depth, so from here it is starting like this. The flow will have to change from sub-critical to super-critical. Here it is sub-critical, here it is super-critical. So, at this point it will change and it is moving like this and this profile will meet the critical depth line normally. So, it will be moving like this, like this and it is gradually rising and then it is meeting this NDL line asymptotically.

So, that will be the profile and here also it will meet the CDL line normally and it is coming like this and then it is gradually expanding, not expanding rather it is gradually decreasing and then it will meet the normal depth line like that.

So, ultimately the flow profile when this is changing from a mild slope to a steep slope, it will be coming like this, then it is moving and then it is going like that, it is this way. Then let us now name this profile well. So, the name of this profile is concerned, it is our mild slope, so definitely M is coming and then it is zone 2 because it is between normal depth and critical depth, this is the critical depth line, this is the normal depth line. So, this will be M2 profile.

Then this profile, if we try to name this is on a steep slope, so this will be S. On steep slope means nomenclature coming as S. Then in which zone it is? This is also in zone 2 because this one is critical depth line, this is normal depth line. So, between CDL and NDL if the flow is there, then it is also zone 2. So, this is also zone 2, this is between NDL and CDL, this is between CDL and NDL. This is also zone 2. So, this profile is S2 profile.

Now, if we recall the characteristic of S2 profile and M2 profile that we did discuss, then we are getting what we did discuss about this boundary point about downstream and here in case of S2 about upstream. So, it is just behaving in the same way and we are getting the total flow profile. So, as surface we are getting one profile may be visible that it is going like that but so far name is concerned, we are having two names for two parts and when we will talk about computation of profile, then what we will have to do at this section? We know that this y is equal to yc, so say that is our known point and what we can do from this, we can compute this profile up to yn at different point and then from this again, we can compute this profile up to yn at the downstream point. We need to compute here when y is just greater than yn, just greater than something greater than yn and here it is. We need to compute when y is just less than equal to yn, so that way we can complete our computation starting from this point this way and starting from this point in the downstream side, this is in the upstream side.

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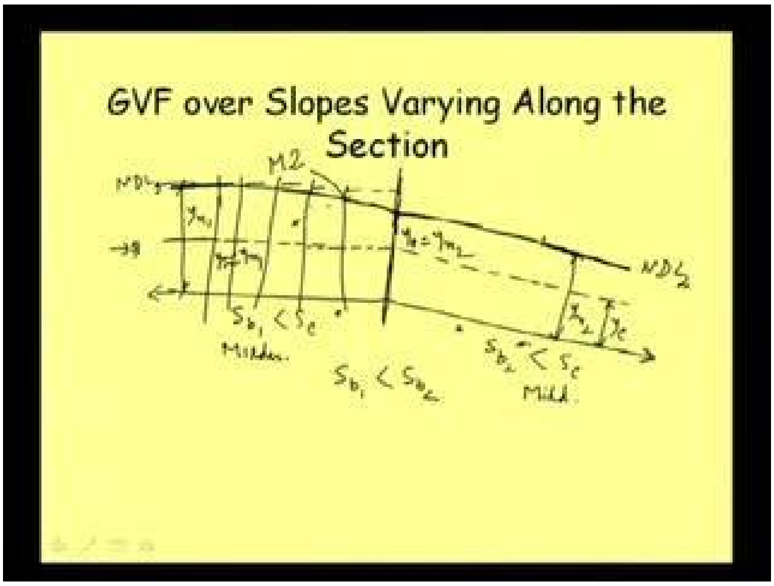

Another point here I want to highlight that in this case when we are computing the M2 profile, we are moving on to the critical depth point. We are starting from here because we know that here the depth will be critical depth but here if we see the M2 profile, although in our earlier discussion we said that M2 profile at upstream it is meeting the uniform depth line asymptotically and at downstream it is meeting critical depth line normally but in this case this profile is not moving to the critical depth line because here you can see that depth is not coming down to the critical depth. This depth control depth is governed by the flow here and we are having this depth is this much. So, it is never coming to this point, it cannot come to this point.

So, although when we were discussing about the profile, we were giving the extreme boundary but it is not necessary that always the profile will be complete or profile will be moving from one extent boundary to other extent boundary. We can always get a small portion of the profile which is not completely going to the critical depth here as it is seen and similar other example can also be there.

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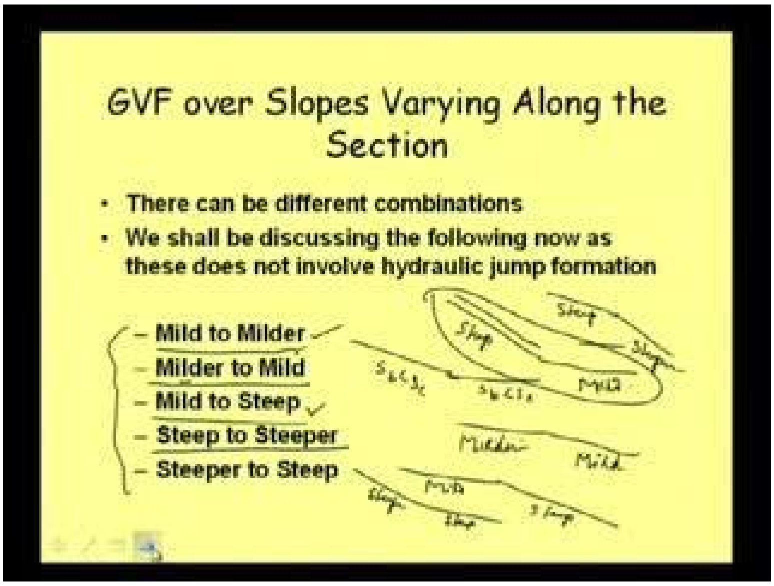

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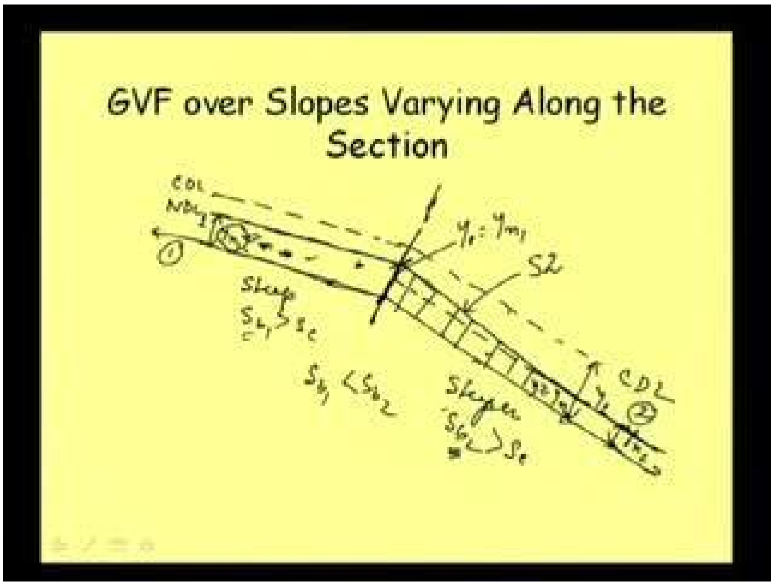

Now, let me discuss another case. We have discussed three, then we need to discuss steep to steeper. This slope is steep slope and then it is going further steeper. Let me again draw a boundary here and then say this depth critical depth line is suppose this one. Critical depth line will depend on as we know that will not depend on slope. So, this is what our CDL say this is yc and what about the normal depth line here. This is steep slope, so normal depth line will be Sb is greater than equal to Sc. In both cases, Sb1 is greater than equal to Sc. Sb2 is greater than equal to Sc but Sb1 is less than equal to Sb2, Sb2 is steeper.

Now, normal depth here will be suppose at this level, let me take it as this level NDL and this is CDL. This I am writing NDL1, this is yn1 and at this downstream portion of the channel as this slope is steeper than this particular slope. So, what we can have that normal depth will be further lower because it is steeper, so it will be further lower and we can write that this is yn2 and we can consider that this is going up to infinite extent and this is also coming from infinite extent. So, there is no question of having any disturbance on the upstream side or in the downstream side, then I mean that is not influencing the flow here. Now, how the flow will change?

Now, both the flows are, this and that both the flows are in super-critical region. So, as we know that the flow at upstream or disturbance at upstream will be controlling the super-critical flow. So, we can take that for this is a section where we are having some changes are there, some disturbance will be occurring but this being super-critical flow, this will not be effected by this disturbance because it is super-critical flow. This disturbance at this section is at the downstream, so for the flow super-critical flow of the channel reach one is concerned and that is why this flow is coming as it is. This is not getting disturbed because it is super-critical flow as I did explain earlier, it will be coming like this and so far this downstream section is concerned, this depth of flow is normally it will move after certain distance. It will have to move in the normal depth line, so the change will occur from this point to that point and that will be coming like this, it will be moving like this.

That means what we have seen if we try to name this profile, this is our steep slope. So, it will be S and then it is in zone 2 because in it is between critical depth and normal depth, so this is normal depth here. We should not confuse whether it is between critical depth and normal depth because normal depth here is this one and this is of course, less than normal depth of section 1 but of channel reach one but we are talking now about the channel portion 2. So far channel portion 2 is concerned, this is between normal depth and critical depth and we should always see what is happening over that particular channel portion, not on the other one. So, not here but here, so this is S2 profile.

Again, if we recall when we were discussing that S2 profile, then we could see that S2 profile start from critical depth line and then go up to normal depth line but here in this case, it is going up to normal depth line here but it is not starting from critical depth line. It is starting from in between which is governed by the flow at the upstream point. So, here also we are starting from this point and then we are moving downstream. So, when we are ask to compute this profile, what we will have to do? First, we need to calculate what is the normal depth of flow over this particular first channel reach that is what is yn1 that we need to know from the given channel section, from the given discharge, from the given roughness value. First, we need to calculate yn1 and this will be the control depth or control section depth at this point, at the central point. So, this y0 is equal to say yn1 and from here, we are starting computing in the downstream direction and we will keep on going till our y is just greater than equal to say yn2. So, that is how we need to know how the profile will be forming first and then only we can compute the flow profile.

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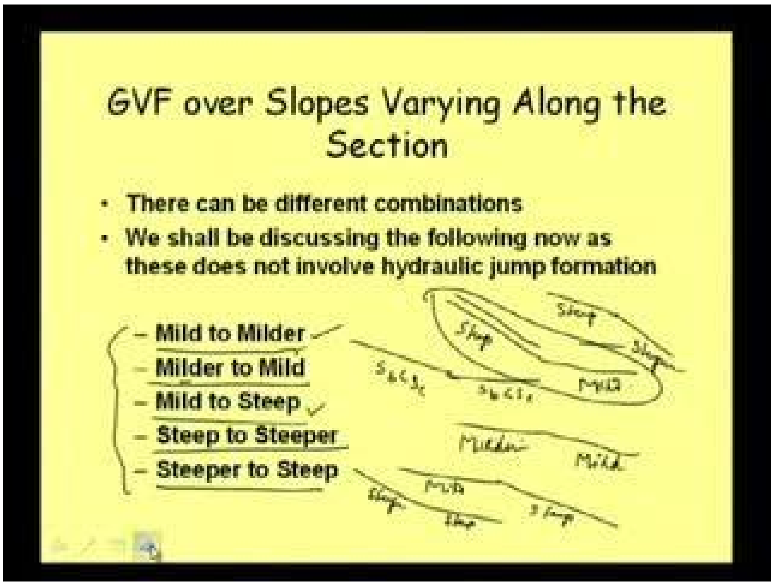

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We are left with another case that I intend to discuss is that steeper to steep. Well, let us take a steep slope first and then it is becoming it is steeper, then it is becoming steep. So, Sb is greater than Sc. Of course, Sb2 and Sb1 are also greater than Sc and let me draw this line here and say critical depth line, let me draw say this is critical depth line, so this is CDL and then Sb1 is greater than Sb2. So, for normal depth is concerned here, normal depth will be this one. Suppose NDL this is my yn1, this is steep, so in the second case also in that second channel portion also it will be less than critical depth but this normal depth will be higher than the normal depth yn1 because so this NDL 2 will be higher than the NDL1 because this is steeper and this is comparatively flattered. Second portion is comparatively flattered than the first one, it is like that.

Now, again if we see both the flows are super-critical flows because CDL line is always above the normal depth line and flow normally will occur at end at this point, here also it is coming at this point. As the flow is coming along the NDL line, so depth of flow is always less than critical depth and so these are super-critical flow.

Now, in case of super-critical flow as we know that control is at upstream, not at the downstream, so we know that there are some disturbance here. There are some disturbances in this portion change of depth but this disturbance will not influence the upstream flow, so as it is it will come straight at this portion. It is not disturbing this one, rather this disturbance is not propagating upstream to influence this flow that we have already discussed and then at the downstream point, it is like that this depth. So, it will have to meet this depth, so it will be gradually rising like this and it is going like this. It is gradually rising from this point and then it is moving up to this point and now to name this profile, what we can do? This is over steep slope, so definitely S is coming and zone wise in which zone it is that we need to see.

So, zone wise this is zone 3 because this is less than CDL as well as less than NDL. That means it is between the bed and the lower most line NDL or CDL between NDL or CDL lower most line. So, this in zone 3 and that is why we are finding that this is a rising profile and this profile name is S3 profile.

If we remember our discussion earlier that S3 profile, what will happen at downstream? We were discussing that it will meet the CDL line normally. Of course, if the flow move up to CDL, then only it will meet the CDL normally and of course, we are talking about downstream point that when it is rising say at this point upstream point, suppose sorry at upstream point we are talking about there, it is y is equal to 0. Then we mathematically, so that is the undefined but in reality we will not get 0 depth here because at this one you can see this is the normal depth coming and from here it is rising basically. So, it is going up to this portion, so that way in real situation we will be getting this sort of profile in different condition and then we must know first that how the profile is forming, where the profile is forming and then only we can start computing.

So, here to compute this profile what we can do again say first knowing the discharge q, then knowing the channel shape and knowing the roughness, we can compute this particular depth and then knowing this depth, we can start our computation from this point. That this is our first say y naught where x is equal to 0 suppose and then this is equal to yn1, then you start computing in the downstream direction and we can go up to the point when y is just less than equal to say yn2. So, this way we can compute.

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So, that is why we have discussed today the different combination of channel and we have seen that knowledge regarding formation of profile. These are very basic fundamental knowledge regarding formation of profile and this knowledge is essential. Once we can have this knowledge, after that only we can go for computation of flow profile and that is why this different flow formation we are giving as introductory part to our computation of gradually varied flow profile.

Of course, we are not including here hydraulic jump which is very very important phenomenon and that will be including once we complete the hydraulic jump topic and then we will see if hydraulic jump is there, how the flow profiles are formed? How it is influencing the flow? Well, with this in the next class, we will be going to computation of gradually varied flow profile. We will be finding that different methods are there, different techniques are there, how we use those techniques for solving gradually varied flow profile. That we will be discussing in our next class.

Thank you very much.