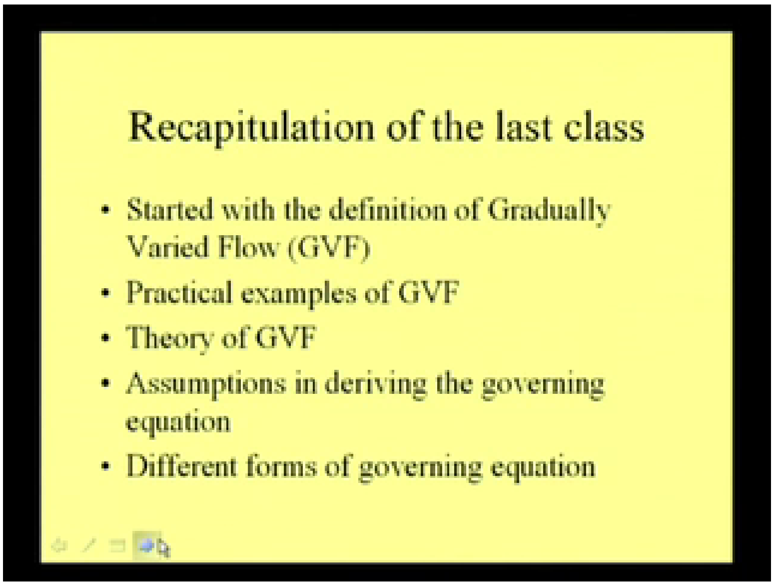
Hydraulics
Prof. Dr. Arup Kumar Sarma
Department of Civil Engineering
Indian Institute of Technology, Guwahati

Module No. # 04
Gradually Varied Flow
Lecture No. # 01
Classification of Gradually Varied Flow

Friends, we shall be starting today one new topic on gradually varied flow, that is classification of gradually varied flow. In the last class, we have started the topic gradually varied flow, which is of course a very important topic of hydraulic engineering. And in many of our practical field activities, we come across with these gradually varied flow topics and today, we shall be just trying to see, we shall try to see what are the different classification that we make to classify gradually varied flow. And before that let us recapitulate what we did in the last class.

(Refer Slide Time: 01:40)



We started with definition of gradually varied flow, well, so we define what we call gradually varied flow and then, we gave some practical example where this gradually varied flow can occur. Like say in a river if we give a barrier, then on on a upstream of the barrier we can get gradually varied flow or suppose in a river or in a canal, if we put a sluice gate, then just on downstream of the sluice gate we can get again another type of gradually varied flow. Then in a channel, when flow is occurring and suppose there is a canal drop at a downstream in, there also we can have gradually varied flow. That way for different situation we can have gradually varied flow in those details we have discussed in our last class.

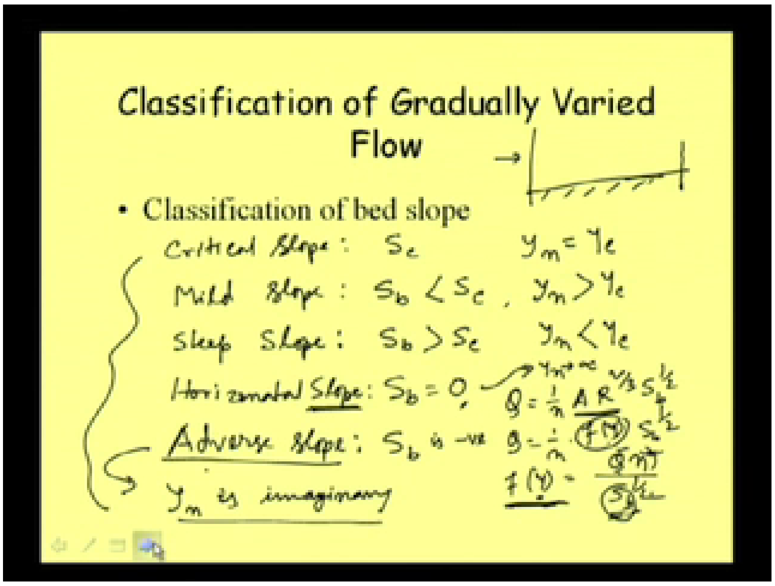
And then, we started with theory of gradually varied flow that is how mathematically we can express the relationship of gradually varied flow. That means, we can just see gradually varied flow profile as a water surface profile and how we can derive an equation that will represent that particular profile, so that is what we call as a governing equation of gradually varied flow. So, once we get this equation, then if we can solve that equation, then we will be knowing at what distance, how much depth it is with distance the depth will be changing. And once we get this governing equation, then mathematically we can solve that equation and we can understand or we can compute before hands. Suppose in a practical field we want to do something and we want to know in beforehand that what will happen, that we can get.

Well, and while deriving the governing equation, we should always remember, in the last class, we emphasize on that there is lot of assumptions we made, several assumptions were made for deriving the gradually varied flow equation. So, when we apply this equation for practical field, then we must be sure of our self that, yes, we are applying this equation, we are solving for a gradually varied flow profile for obtaining a gradually varied flow profile. But, these equations has all those assumptions behind, and if those assumptions are not valid for that particular situation, then the computed result may have some amount of error involved.

So, that way knowing the assumptions is very important, because then only we know limitation of our work, well. And then, we could see that the governing equation, this can be again expressed in different form. Well, when one form is advantageous for some of the computational work, another form may be more advantageous for explaining or for understanding some of the very basic phenomenon of gradually varied flow.

So, that way we can have it in different forms and with these understanding of gradually varied flow today we shall try to see how we can classify the gradually varied flow profile. It is necessary to classify the channel bed; channel bed is one basis of classifying gradually varied flow, well. So, let us classify channel bed first and then we will go for classification of gradually varied flow in general.

(Refer Slide Time: 05:37)



Well, we know that one slope we call as a critical bed slope, so we will start with that critical bed slope, critical slope. Well, what is critical slope, suppose we write this as S c, well a for a given discharge and in a given channel, so for a given discharge in a given channel, for a given slope we can have uniform flow at critical depth. That means if we set the channel, if we set the channel in that particular slope then uniform flow will occur at critical depth.

So, uniform flow depth will become equal to the critical depth and that particular slope we call as a critical slope. So, when we talk about critical slope, it is always related to a particular discharge and of course, in a given channel we are talking about… So, that particular slope we refer as critical slope, where we get uniform flow depth equal to critical depth that is we can write that at S c normal depth, y n is equal to y c. Now, if our slope bed slope is less than that critical depth, then we call that slope as mild slope.

So, if what is mild slope? Let us write here, mild slope is that when our bed slope S b is less than the critical slope, bed slope is less than critical slope, means flatter than critical bed slope then that slope is called mild slope. And in a mild slope our flow depth, uniform flow depth will be greater than critical flow depth, so we can write here that y m normal depth will be greater than critical depth. Well, then we have a slope that we name as a steep slope, steep slope. We did discuss about this before also, again we are just refreshing that and we are going into some of the finer details of that. Then steep slope means when our slope, that is the bed slope is greater than critical slope, then greater means steeper than critical slope and then we call that as a steep slope, ok.

So, S b is greater than critical slope S c. And when our bed slope is greater than the critical slope obviously, suppose we are getting a uniform flow at a particular depth equal to normal depth, then when we increase our slope normal depth will come down, means y n will become less than the y c. So, these ways these are three different slopes that we are getting, critical slope, mild slope and steep slope and apart from that we have two more slopes, one of course is horizontal slope, one is horizontal slope. Well, though when we say horizontal slope in reality, when it is horizontal there is no slope, slope is basically equal to 0. But still we name it as a horizontal and then it is S b is equal to 0, bed slope is equal to 0. Why we are defining it as a slope? Just to say if someone asks that what the slope is, we say that it is horizontal, means slope is horizontal, there is no slope and bed slope is equal to 0.

And well, what will happen to the normal depth if the slope is horizontal? Well, that needs some discussion, of course we could have discussed that before and when we were discussing uniform flow depth, but briefly let us discuss this here itself. If we write the equation of gradually varied flow, not the gradually varied flow, if we write the equation for uniform flow, then we got that is discharge say Q that is equal to 1 by n and A R to the power 2 by 3 n S b to the power half, S b to the power half. And out of this part, that is on the right hand side, A R to the power 2 by 3, these are basically function of y, these are basically function of y.

So, what we will get, that is from here if we bring y, suppose that if I write as a function of y, then we can write Q is equal to 1 by n into function of y into S b to the power half. So, if I just try to find out S b, sorry if I try to find out y, that is the normal depth y, which is remaining in this part, then what will happen, this is say this function of y we can express as Q n, then S b to the power half.

Well, if we cannot separate out this part, then definitely we will be requiring trial and error procedure, but what about that procedure? May be depending on the channel tide, if it is a wide rectangular channel, we can get it very easily, of course that I will show you later, but say a this being a function of y, we can see that if we put S b equal to 0, then this anything Q is the discharge and is having some positive value, so this part divided by 0, so that term is becoming infinity.

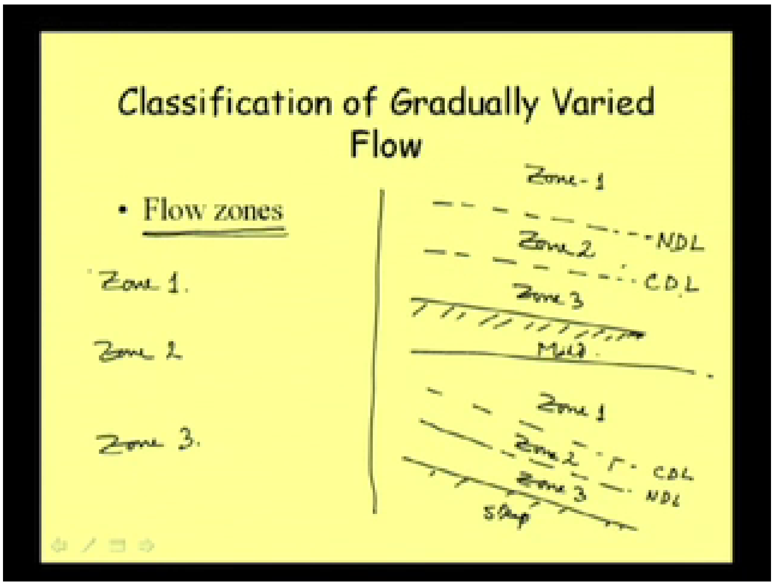
Well and on the left hand side on the left hand side of this part, that is here, we have a other than this say say sectional dimension like B, side slope j, if it is a trapezoidal one, then we have n. And other things remaining fix, suppose y n will remain on the left hand side, so y n ultimately, if this left hand side is to become equal to infinity, this y n will have to become infinity, so that way of course if we take a rectangular channel, if we take a wide rectangular channel, then we can explicitly show that y n is infinity in this part.

So, S b equal to 0 means, anything by 0 that become infinity, so normal depth become infinity. So, we can write that for horizontal bed, for horizontal bed y n is infinity, y n is infinity well. And then we have another type of bed that is adverse slope, adverse slope. Well, say when our channel is of the type that, I am drawing here, say water is flowing in this direction and bed is having adverse slope in the opposite direction. Normally, our beds are always falling down in the direction of flow and that is why water is flowing due to gravity, but many a time we can encounter in nature some slope where our bed slope is in adverse direction, means it is raising inward adverse direction. In the it is a rising slope and water is flowing on that, of course how water will be flowing, that is one point is definite that. Although it is adverse slope total head on the upstream side must be greater than the total head on the downstream side and then only water will be able to flow. So, that part is there, but still the slope is adverse and that sort of slope we refer as adverse slope, ok.

So, means, when S b is less than 0, S b is less than 0 or we can write it in other way that S b is negative, S b is negative. And in case of adverse slope, in case of adverse slope there is another interesting situation about y n, so for adverse slope what will happen to the normal depth? Now, if we can see that this part, this equation again if we see, what I am writing here that this function of y is equal to Q into n divided by S b to the power half. Now, when S b will negative, then it is minus something to the power half and square root of a negative value, square root of a negative number is we know that it is an imaginary number.

So, this right hand side becomes imaginary and this becomes imaginary means our y n is also becoming imaginary, so this y n is imaginary that we can write for adverse slope. So, these two are with a special case, that is for adverse slope y n is imaginary, normal depth and for horizontal slope y n is infinity, y n is at infinity, well.

(Refer Slide Time: 15:53)



Now, with this basic understanding of different type of bed slope now we need to go for another classification, that is before going to classification of gradually varied flow, we need to classify or rather we need to divide the flow zone into some specific zones. That is, flow zone means, say when a channel is there, then flow is occurring above the bed and it can of course go up to infinity in that part. In this portion, the flow is occurring and this particular zone we divide into three different zones.

Well and when we will try to name the gradually varied flow profile, different type of gradually varied flow profile we will try to name. And when while naming those different type of gradually varied flow profile, we will be requiring, we shall be requiring these zone name. First, we will be requiring the bed name and then we will be requiring the zone name.

So, let us first give the name of this zone, well. Now, say if this slope is a mild slope, then what will happen? Say this line indicate critical depth line, that means for a given discharge critical depth in this particular channel. This channel I am just drawing here the bed line, but this will be having a definite section and for that section that is bed width or side slope z whatever it may be so those we have and for those we will be getting a critical depth and that critical depth for that given discharge we call as a critical depth line. And if it is a mild slope, our normal depth line will be above the critical depth line, say normal depth; uniform flow depth for the discharge is this much, so that we call as a normal depth line.

Well, so this line that is the bed line and the C D L, critical depth line and the normal depth line N D L, these lines divide the entire flow zone into three distinct zones. So, the zone above the N D L we call as a zone one. Now, there is one more important point that we need to mention, say our N D L line will be above the critical depth line for a mild slope case, but for a steep slope case, for a steep slope case our N D L will be less than the critical depth line.

So, zone 1 is the zone above either N D L or C D L, whichever is at the top, whichever is at the top; that means, if I draw this as a mild suppose, this as a mild and say if I draw another slope it is steep, say this is steep slope. If it is steep slope N D L line will be here, N D L is here, N D L and C D L will be above N D L, C D L will be above N D L, then say for this steep slope channel this will be zone 1, this will be zone 1.

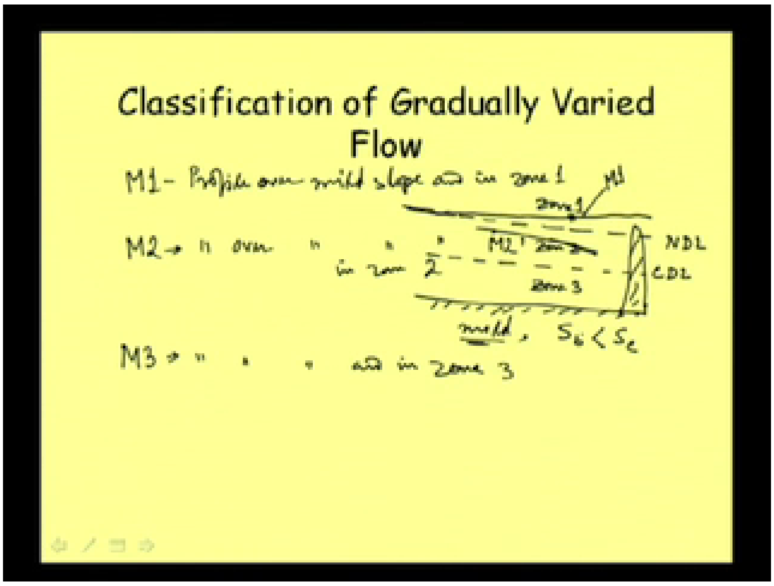
So, we should not confuse that zone 1 is the zone above N D L; this is not the statement actually. Zone 1 is the zone above either N D L or C D L whichever is at the top, so that we refer as a zone 1. Then the zone between N D L and C D L, that is the zone between normal depth line and the critical depth line is called zone 2, is called zone 2. Well, similarly here also zone between C D L and N D L that is called zone 2. And lastly, the zone between the bed and C D L or N D L whichever is at lower depth, so it can be C D L or it can be N D L, whichever is at a lower depth.

So, this zone, that means, this portion is called zone 3, is called zone 3, so here it will be zone three, here this will be zone 3. So, like that the entire flow zone above the bed we define as, we vocalized noise we divide as zone 1, zone 2 and zone 3; zone 1, zone 2 and zone 3, and we are not giving in writing. But these figures, these two figures, this and that clearly define what is zone 1, what is zone 2 and what is zone 3, well. And say now for some situation, if it is horizontal, if the bed slope is horizontal, if the bed slope is horizontal then our normal depth line will be at infinite distance.

Now, if normal depth line is at infinite distance, then where we will get a space above normal depth line. We know that zone 1 is the space above normal depth line that is normal depth line if it is at the top. Now, in horizontal slope normal depth line will be definitely at the top, but it is at infinite extent or infinite distance, so beyond infinity we cannot get anything and that is why for horizontal slope there will not be zone 1, there will not exist zone 1.

Well, that we will define when we will be coming to further classification of gradually varied flow. Similarly, in case of adverse slope also it is imaginary, so y n is not existing it is and that is why that zone 1 will not be existing there. Well, now, with this understanding of different zone and with the understanding about different bed profile, bed slope, now combining these we can classify gradually varied flow profile and we can give name to these different gradually varied flow profile. So, we will be now going to gradually varied flow profile.

(Refer Slide Time: 22:50)

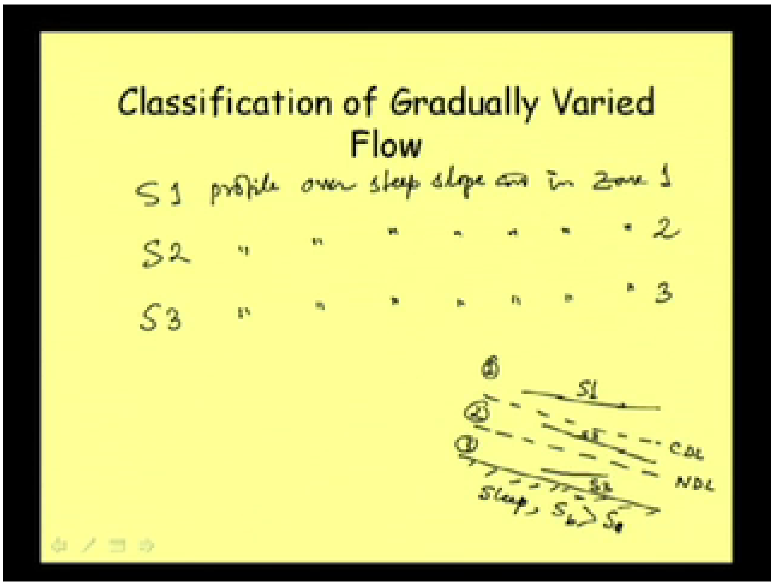


So, let us take the first case, say our slope is mild, our slope is mild, that is mild slope and mild by mild slope we means that S b is less than critical depth S c. Well, now when S b is less than critical depth, S c we know that critical depth will be lower here, C D L and N D L will be at higher depth, normal depth line will be at higher depth, so it is N D L. So, this zone is zone 3, this is zone 2 and this is zone 1. Now, if a profile, if a gradually varied flow profile occur at the zone 1, means on the top zone and on a mild slope then we name that profile as M 1 profile. That is, first classification we are making like that, when a profile, that sort of profile we can have suppose, we are giving a barrier in this form and then say normal depth line water was flowing either earlier like that, then it is gradually rising and like that then this profile is named as mild slope and zone 1, M 1. So, our first profile we are naming as M 1 profile.

Well, so M 1 means the profile over mild slope, over mild slope and in zone 1, so that is what the profile will name as mild slope M 1 profile. And of course, what will be the characteristic of this M 1 profile that we will be discussing later. Well, then we give another name called M 2 profile, so this M 2 is as you know that if any profile occur over mild slope, over mild slope and in zone 2, and in zone 2 this profile will be of course a draw down profile like this, but that we will be coming later, but this profile we name as m 2. So, M 2 is the profile over mild slope and in zone 2 and in zone 2.

Well, following the same trend if we get a profile in the third zone that is in zone 3 and over a mild slope then we name that as a M 3 profile, well. So, lastly we are coming to M 3 profile, so that is profile over mild slope and in zone 3, so that way over mild slope if we get profile, gradually varied flow profile g v f, we name it as and if these are on zone 1, then it is M 1, zone 2, M 2 and zone 3 means, it is M 3 profile.

(Refer Slide Time: 26:34)

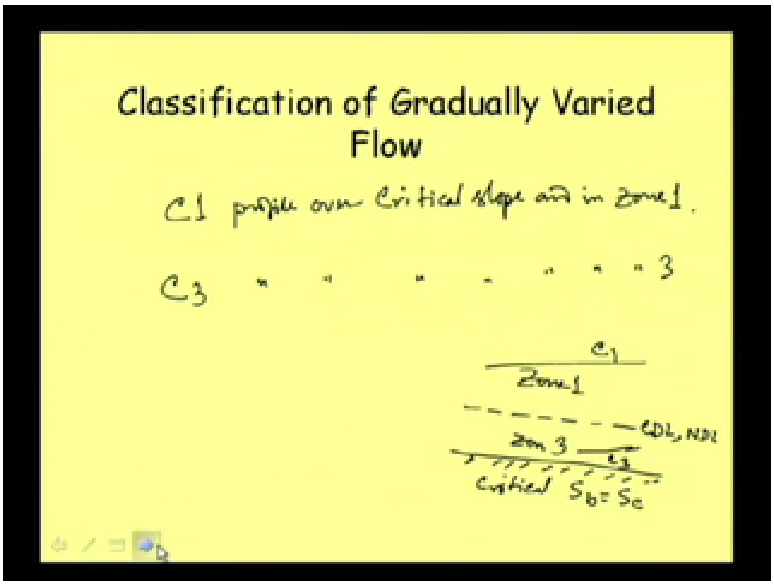


Well, similarly, if we get suppose our slope is steep slope, slope is steep slope, it is like that, by steep slope, we mean that S b that is the bed slope is greater than the critical slope S c, greater than the critical slope S c. And in that case, our critical depth line is suppose this one C D L, then normal depth will be normal depth of flow in a steep slope, will always be less than the critical depth, it will move with a high speed, speed velocity will be higher, but depth will be lower. So, normal depth is falling here somewhere that says normal depth line. And this is here, zone 1 is this one, zone 2 is this one and zone 3 is this one, ok.

So, these profiles named as S 1, so by S 1 what we mean? Any profile lying in the zone 1 and over steep slope, so this profile is S 1, any profile lying here in zone 2 and in say above a steep slope or rather over a steep slope then it is called and zone 2. And this profile will be a draw down profile; this is a rising profile, that part we will be coming later just after completion of this classification. But, let us see at this moment that this of course will be a draw draw down profile and then, if a profile occurs here, in the zone 3 and this will of course be a rising one, that we call as a S 3 profile. So, here we get S 1 that is profile over steep slope, profile over steep slope and in zone 1 and in zone 1 this is S 1.

So, what is S 2? This profile over steep slope again and in zone 2… Well, then what is S 3? That is profile over steep slope an in zone 3, so that way we can classify the gradually varied flow profile occurring over steep slope again into three parts, that is S 1, S 2 and S 3. Well, now we shall see that we could see if it is flatter than critical slope then we are having three types of profile M 1, M 2, M 3, if it is steeper than critical slope, we are getting three types of profile that is S 1, S 2, S 3, but if it is equal to critical depth, then what will happen, let us see that.

(Refer Slide Time: 29:46)



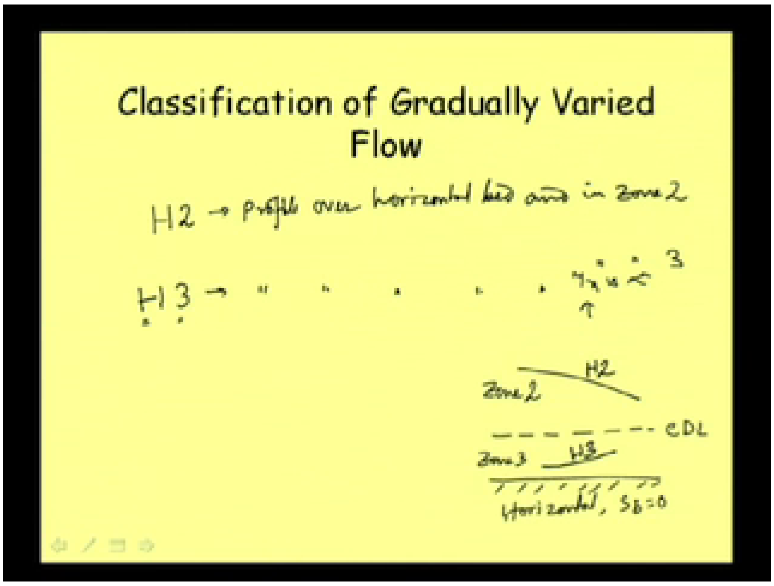
Well, suppose this slope is critical slope, that is critical slope, by critical slope what we mean, that S b, that bed slope is equal to critical slope. And as per definition as per definition we know that by critical slope what we mean that, when uniform flow occur at critical depth, that means uniform flow depth and critical depth are equal. So, here, this is say C D L, critical depth line as well as N D L, as well as N D L. So, here we have how many zones? Because we know that zone 2 is the zone, between critical depth line and normal depth line, but here critical depth line and normal depth line are the same line.

So, we cannot have a zone in between that and that is why zone 2 is not existing over critical slope, zone 2 is not existing. Well, if we still want to name this as zone 2, then this will be just one line and that line is the critical depth line or the normal depth line. And when we talk about classification of gradually varied flow, we cannot give a name to that because this is this line is a uniform flow depth line, it is not a gradually varied flow, it is not varying depth.

So, this line we neither we can give a name to this zone nor we can say this flow. If occurring here is say two profiles or something like that, because it is basically a uniform flow occurring in that line. Well, so here the zone 2 is vanishing and what we have is that this is zone 1 and the flow profile if occurs below these things, this is our zone 2, sorry zone 3, because 2 is not there, zone 3, well. So, when we talk about critical slope, over critical slope we are getting two type of profile, one is called C 1, that is again a rising profile like this, C 1 and another is C 3, that is also a rising profile, that C 3 is also a rising profile.

So, that way we are getting two type of profile here, C 2 does not exist, so C 1 we call that profile over critical slope, profile over critical slope. And in zone 1 and in zone 1 and C 3 will be profile over critical slope and in zone 3, so these two type of profiles we are getting.

(Refer Slide Time: 33:09)



Well, and then let us see what other sort of profile we can have. Say our slope can be horizontal, slope can be horizontal, say it is a horizontal bed, so horizontal means S b is equal to 0, S b equal to 0 and over that of course we can draw critical depth line C D L, if Q is known, then we can always calculate the critical depth. If it is a rectangular channel Q is given, width is given, suppose rectangular channel, then you can calculate Q square by g whole to the power one third, that is giving us the critical depth.

Well and in trapezoidal channel also we can do it, of course it will require trial and error procedure, but anyway you can calculate critical depth. So, that critical depth is the critical depth line, fine. Then what about the normal depth? We have already discussed that part on horizontal channel, over horizontal channel we cannot have normal depth and it will be the normal depth if we say that will be at infinite distance from the bed. So, normal depth line we cannot have, we will say that y n is at infinity.

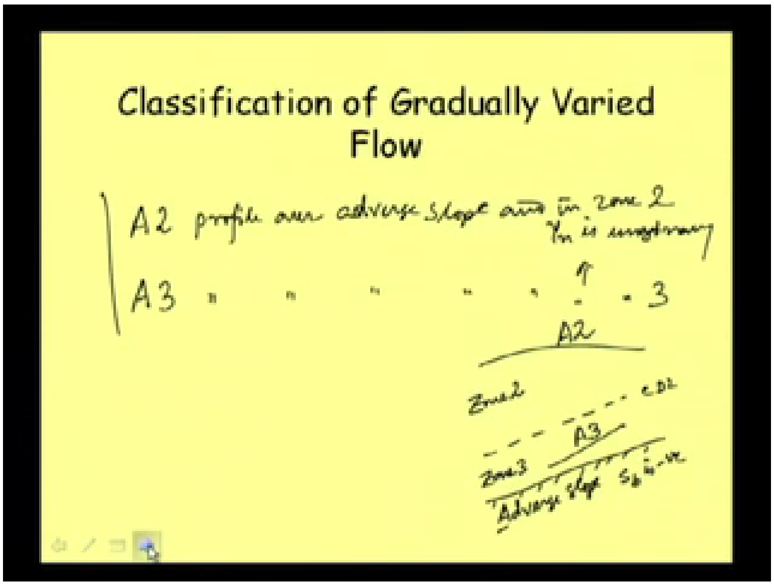
So, now when we try to classify the zone, what we will do, say this zone between bed and the critical depth to or N D L or whichever is lower here, definitely critical depth line is at lower, so this zone will name as zone 3. And the zone between critical depth line and normal depth line, so anything above critical depth line, any portion, any space above critical depth line is lying between critical depth line and normal depth line, because normal depth line is somewhere infinity, so this portion is always lying between critical depth line and the normal depth line. So, as such these particular zones we will name as zone 2.

Now, what about zone 1? Well, if we want to write here zone 1, then we will have to something above critical depth, above above of normal depth. Now, normal depth here itself is at finite distance, so we cannot have anything beyond that and that is why here over horizontal slope we cannot have zone 1 that is why we will be getting here two type of profile. That is for to represent horizontal, we write H, H represent the first letter represent the type of slope, like that earlier also you could see that C represent critical flow and this second digit represent in which zone it is. Similarly, in steep slope S represent the slope and this three digit represent or this two digits or one digit, this represent on which zone it is. Similarly, here M represent mild slope, so first letter always representing the type of bed slope and the second digit is representing in which zone it is.

Now, similarly, this H will indicate that it is over a horizontal bed, it is over a horizontal bed and then if it is in zone 2, we will be writing H 2, so we can write this as a profile over horizontal bed, profile over horizontal bed. And in zone 2, and in zone 2 and in this two zones, second zone profile is a falling profile, that of course will be discussing y and this is H 2. Then, similarly, H 3 that is the horizontal profile over zone 3, that we call as a H 3, profile and that is nothing but the profile over horizontal bed and in zone 3, that is we can call now that profile will be a rising profile H 3.

Well, so over horizontal bed also we can have profile and gradually varied flow profile, well when we are saying as profile here, we are always talking about basically the gradually varied flow profile. So, we can have gradually varied flow profile over horizontal bed and the flow profile occurring above horizontal flow we get two type of profile, one is H 2, another is H 3, well. Let us see if any more classification we can make.

(Refer Slide Time: 38:32)



Well, that is again on adverse slope, well on adverse slope if it is like that, so this is adverse slope, adverse slope means our S b is negative, S b is negative less than 0. Now, here also we can have critical depth line C D L and that y n, the normal depth will be imaginary, normal depth will be imaginary, well when it is imaginary, well that will be somewhere here we do not know. So, you will be writing y n is imaginary.

And as such, as we do not know what is there above critical depth where y n is, so here also just like horizontal slope we will be getting zone 3 is here and that zone will be referring as zone 2, zone 2. And the later that we use for denoting adverse slope is A, so for profiles are concerned, so for profiles are concerned, we will be getting A 2 that will be a falling profile like that.

So, this is A 2 profile and then there will be a rising profile in third zone that we call as A 3 profile well. So, A 2 profile means profile over profile over adverse slope, adverse slope and in zone 2, well, now, we can write another profile that is A 3, means this profile, that is nothing but profile over adverse slope and in zone 3.

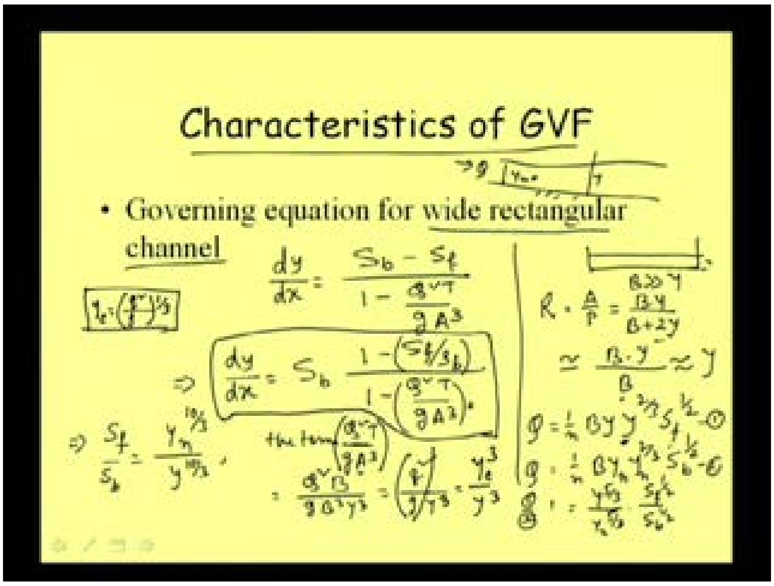
So, now, we can summarize that over different type of bed slope we get different type of profile and so for classification of gradually varied flow profile is concerned, we classify it based on over what type of slope it be and in which zone it is lying. So, that way we are getting M 1, M 2, M 3, then S 1, S 2, S 3 and then C 1 and C 3, C 2 is not existing, because over critical flow N D L and C D L, normal depth line and critical depth line are at the same level, so we are not having zone 2. So, we have profile C 1 and C 3.

Then over horizontal slope we have H 2 and H 3 here, H 1 is not existing the reason is that normal depth y n is at infinite distance and we cannot have any other space above infinity and that is why zone 1 is not existing over horizontal slope or horizontal bed rather I would like to say. Similarly, we have A 2 that is adverse slope zone 2, we have A 2 and A 3 and here also A 1 is not existing, so these are the flow profile that we can have or over any type of slope over any type of slope.

Of course in nature when we see the water surface profile, gradually varied flow profile, then say always we can get combination of these different types of profile, we will always get combination of these different types of profile. I mean, when we get combination, when the bed slope is changing from one slope to another slope, suppose horizontal bed is going then this converting to mild slope, then suppose a mid slope is changing to steep slope, then over different type of profile, different type of slope we are getting different type of profile.

So, it will be a series of profile joining and that way we are getting our flow surface, gradually varied flow surface. Well, so when we try to compute gradually varied flow that will be coming in our next class, we will be discussing about computation of gradually varied flow and there basically we will be discussing how we can compute flow profile in those situations also.

(Refer Slide Time: 43:28)



Well, with this classification of gradually varied flow, knowing the classification now we need to discuss about the characteristic of these different types of gradually varied flow. So, we will now go to characteristic of gradually varied flow, well. And for that purpose, for that purpose for discussing the characteristic of gradually varied flow, I have seen that it become convenient to explain, it is characteristic. Well, by characteristic what we mean characteristic what we mean that a profile whether it is rising or it is falling, that is say one sort of characteristic, then what will happen to this profile if we go to upstream side? That is definitely in nature we will not get a profile for infinite extent on the upstream and downstream, somewhere there will be a limit, say uniform flow is coming then it may get converted to a gradually varied flow.

So, at the upstream end, suppose uniform flow is coming and then it is becoming a gradually varied flow at this junction or say at upstream of the gradually varied flow what will be the characteristic of that particular profile? What sort of shape it will be? Whether it will be say of gradually rising type or whether it is meeting a particular uniform flow line normally or say a synthetically, how these things are happening all those characteristic we shall be discussing, well.

And for discussing those characteristic a let us take the equation of gradually varied flow in a different form, means exactly not in a different form, we will be just taking a different a particular case, that is we will consider wide rectangular channel, because for wide rectangular channel the expression become simple and it become convenient to explain the different characteristic.

So, let us see how we can write the equation of gradually varied flow for wide rectangular channel first. Well, we know that the gradually varied flow equation d y d x is equal to S b minus S f divided by 1 minus Q square T by g A q, that expression we all know, this expression we can write as this implies say d y d x is equal to, if we bring S b common here, then it become 1 minus S f by S b, 1 minus S f by S b and 1 minus Q square T by g A q. Now, these two term S f by S b and this Q square T by g A cube this term, these two term we can express in terms of normal depth. And the depth of flow, other depth of flow at any section and this time, we can define this term, we can define in terms of critical depth and a depth of flow of gradually varied flow.

So, let us just try to do that first. Well, for a wide rectangular channel we know that, well if we do not remember let us just refresh that part. As it is a wide rectangular channel our B is much much greater than y, say depth of flow is suppose y. So, what we can write hydraulic radius R is equal to A by P and this hydraulic radius A by P we can write as area is equal to B into y and perimeter is equal to B plus twice y. Now, if B is much much larger than y, then this twice y, that is B plus twice y in this expression we can neglect, this twice y and this can be written as equivalent to B into y divided by B, of course, this product we cannot neglect. For example, I said at the very beginning, suppose our bed width is 100 meter and in that 100 meter our depth of flow is suppose 1 meter or say 2 meter, depth of flow is 2 meter and bed width is 100 meter, then area is 100 into two depth of flow is 2 meter, so 100 into 2 that will become 200.

So, we cannot neglect two here when it is in product form 100 into 2 is 200. And so far perimeter is concerned, this is say B plus twice y, means 100 is the B B plus 2 into 2 depth is equal to 2 meter, so it is 2 into 2, so this become 4. So, 100, 4, now in place of 100, 4, we can write as 100 that will not make much difference. So, that way we can write it as B into y divided by B, so this part we can neglect and then this is becoming approximately equal to y.

So, with this simplification without creating much error in case of wide rectangular channel we can write the discharge Q is equal to 1 by n, then A R to the power 2 by 3. So, area is equal to B into y, then in place of R to the power 2 by 3 we can write y to the power 2 by 3, this y is basically representing hydraulic radius, this y to the power 2 by 3 and S to the power half.

Now, when we are writing this expression for gradually varied flow, then we know that as it is gradually varied flow at each and every section it will not be uniform flow depth, rather say if in a channel if uniform flow is flowing like that, this is the y n, then somewhere here it will be rising like this, say this is our bed and it is rising like this.

So, at any section this will be y, depth y it is not uniform flow depth, but it is uniform flow depth. And when we write this resistance flow formula, this is nothing but the resistance flow formula, we can write chassis equation, manning's equation all those resistance flow formula and we consider this as valid. And if we remember when we did a derivation for this resistance flow formula basically this S value is coming as S f, it is the friction slope, it is the friction slope, that is, the we are basically interested in finding the slope of the hydraulic head line that is the total energy at one point, upstream and total energy at the downstream point if we join, if we join then we get a line that we call as a energy line. And then slope of that energy line is basically S f and that slope of the energy line actually governed the flow because energy at upstream must be higher than the energy at downstream and then only the flow is occurring, so this governed the flow and that is why this slope is basically coming as S f.

But when we talk about uniform flow, when we talk about uniform flow, then we know the depth of flow is equal at every section, depth of flow is equal at every section and when depth of flow is equal at every section, velocity is also equal at every section. Now, velocity is equal at every section means V square by twice g that is the kinetic heat is also equal at every section and depth of flow equation equal means or pressure heat is also equal at every section.

So, total energy, slope of the total energy line and slope of the bed become equal, that we discuss at the beginning, just to refresh that again we are discussing that part. So, in case of uniform flow our S f that is the friction slope or the energy slope is nothing but equal to the bed slope. So, in general, we can write for any depth this is the expression and of course, here we are making one assumption that the resistance flow formula is valid, that is why we are writing this equation. And then for because discharge is same, same amount of discharge Q is suppose flowing here, now when we write y n then we can write 1 by n B y n, then hydraulic radius for normal depth condition is also y n to the power 2 by 3 and this we can write as S b to the power half.

So, if we write this as equation 1 and this as equation 2, then if we just divide 1 by 2, so dividing 1 by 2 what we will be getting, this is 1 is equal to, so this n n n is getting cancelled, B and B are getting cancelled, this is equal to y to the power 5 by 3, y to the power 5 by 3. So, we can write y to the power 5 by 3 and here it will be y n to the power 5 by 3. And then what is left is S f to the power half and S b to the power half, ok

So, now, again if we write S b bring this side, S f bring this side and if we take square of this one, if we make square of both side, then this expression we can write as from here, let us write it here, this implies that S f by S b S f by S b is equal to y n will be coming here, so y n to the power, earlier it was 5 by 3, now when we are talking square, so it will become 10 by 3, y n to the power 10 by 3 and y to the power 10 by 3.

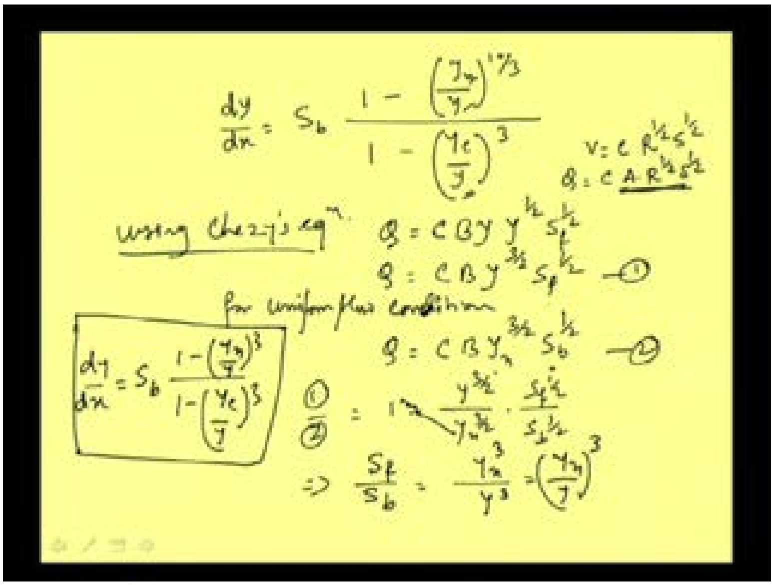
So, this S f by S b term we can write in this form, well this is one expression that we can use to replace this S f by S b term. And then what about Q square T by g A Q, this term if we see, the term Q square T by g A Q, Q square T by g A Q, this we can write as for rectangular channel, we are talking now in terms of wide rectangular channel. So, this T will become B, so this is equal to Q square in place of T we are writing B and g in place of a, we are writing B cube, then y cube. Now, this is equal to so B and B is getting cancel, it is becoming Q square by B square and Q by B that is total discharge per unit width is nothing but unit discharge.

So, we can write Q by B, Q square by B square as small Q square, which represent unit discharge, Q square by g and we have this y, this will become Q square by g and y cube. Well, now, if we just recall our earlier classes, then we did define that critical depth is equal to, for rectangular channel we did define let me write here, we did define that y c critical depth is nothing but Q square by g whole to the power one third.

So, based on that, starting from that, this is for rectangular channel of course and we are talking about wide rectangular channel the same thing. So, Q square by g to the power one third, that means y here we have Q square by g, so Q square by g is nothing but y c cube, well, so this we can write as y c cube by y cube.

Well, that means this S f by S b we can write as y n to the power 10 by 3, y to the power divided by y to the power 10 by 3 and Q square T by g a cube, this term we can write as y c cube by y cube. Then, let us come to this expression, this expression what is our basic equation of our governing equation of gradually varied flow.

(Refer Slide Time: 57:03)



This expression we can write as d y d x is equal to S b into 1 minus y n by y whole to the power 10 by 3 and then 1 minus y c by y whole to the power cube, it is whole cube. Well, now, this expression we are getting by using uniform flow equation or the resistance equation, resistance flow formula as manning’s formula. Now, in place of manning’s formula if we use chassis formula, then again in place of y n by y whole to the power 10 by 3 we will be getting y n by y whole cube.

Let us just see using chassis formula what we can get. Using chassis equation and of course, earlier we are writing this expression using manning’s formula, using manning’s formula we are writing this, using manning’s equation, using manning’s equation we are writing this part. Now, if we write chassis equation then we can write say Q is equal to C, we we remember that chassis formula V is equal to C root over R S, that means R to the power half, then S to the power half and Q is equal to C into area, so V into area basically. So, this part is velocity, so we are writing this velocity in this form and then we are multiplying this by area and just a we are writing here keeping the resistance parameter term separately and other terms related to the shape and the bed slope separately.

Well, so, we can write like that. So, this expression we can write area for wide rectangular channel, we can write B y and this R as we have already explained, R can be approximated as depth in case of wide rectangular channel, so y to the power half and S to the power half. If we write y, that means here not uniform depth, not a uniform depth, then we can write this as S f. And of course, this is equal to C, then B and this is becoming y n y into y to the power half, so it is becoming y to the power 3 by 2 and S f to the power half.

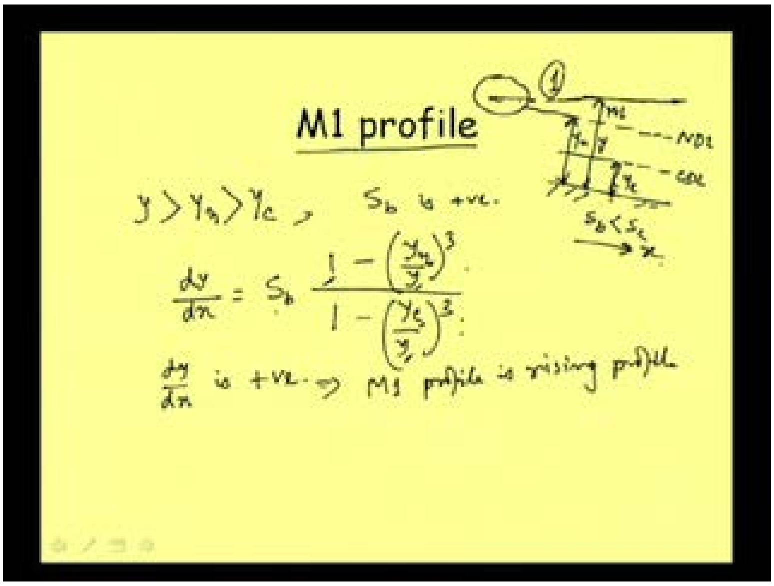
Now, for normal depth condition, for uniform flow condition, uniform flow condition what we can write that Q is equal to say C into B into y n to the power 3 by 2. And as it is uniform flow we are writing here y n and this we are writing as S b, because S b that is the bed slope S b and the normal depth y n, I mean, sorry for normal depth uniform flow case S b is equal to the S f.

Well, so, now, again if we divide 1 by 2 1 by 2 we will be getting 1 is equal to this parts are going out, so this is becoming, first we can square also then y to the power 3 by 2, y n to the power 3 by 2 and S f to the power half, S b to the power half. And our interest is to find out what is S f, this expression basically, our interest is to find out for this expression S f by S b. So, S f to the power half and S b to the power half if we square it out then we will be getting say S f by S b that is equal to, then we will have to square out this part also and bringing this to this side and this to this side, we will be getting y n cube divided by y cube.

So, this expression y n by y n of course, this expression y c by y whole cube, this will remain as it is, y c by y n, this will remain as it is. And this part y n by y whole to the power ten by three, we can write as y n by y whole to the power cube. Of course, 10 by 3 is nothing but almost nearly equal to 3, if we use manning’s equation and using chassis equation we are getting it as cube directly, so the entire expression we can simplify as say d y d x is equal to S b into 1 minus y n by y whole cube divided by 1 minus y c by y whole cube.

So, the expression become as simple as this for wide rectangular channel and using chassis equation, so, now for analyzing characteristic of gradually varied flow, we can use this equation conveniently and that is why we are deriving this equation. Well, now, let us start analyzing the characteristic of gradually varied flow profile. And for this class of course we do not have much time and we will be able to discuss I think the characteristic of one type of profile or the approach that we adopt for understanding characteristic of gradually varied flow profile well.

(Refer Slide Time: 1:03:04)



First, as it is M 1 profile, let us discuss about M 1 profile, so M 1 profile means this is mild slope and here it is C D L line and here it is N D L line, here it is N D L line and our profile is somewhere here. I mean this one is M 1, because this slope is mild, that is S b is less than critical depth that is why it is mild slope and profile is lying in zone 1, this is zone 1, so this is M 1 profile.

Well, so what we are having by getting this sort of setup for M 1 profile is that this is our normal depth y n and this is critical depth y c. So, one point is clear that and depth profile will be lying in the zone 1, it means that depth at any point, suppose depth at any point in this profile is y.

So, what we are getting that y is greater than y n and y n is greater than y c. So, this is the very basic relationship between depth of flow profile, flow profile, means depth of gradually varied flow profile and the uniform flow depth and the critical flow depth. Now, if we use this equation and of course, another parameter S b, bed slope, what we are getting, it is less than critical depth, but it is of course greater than one, mild slope means it is S b is positive, S b is positive.

So, what is our relation that we are getting is d y d x is equal to S b into 1 minus y n by y whole cube and divided by 1 minus y c by y whole cube, this is the relation. Well, with this relation how can we see the characteristic? Well, first we need to know whether the profile will be a rising profile or a falling profile, well.

So, now, let us see that when y n and y this relationship y is greater than y n, so this will be a fraction, this will be a fraction and it is cube will definitely be a fraction, smaller fraction and fraction means it is less than 1. So, 1 minus something less than 1 that will be a positive term, that is our numerator is positive here. And then in the denominator if we see that y c is again less than y, so this will be also a smaller term fraction and it is cube will be smaller than 1 definitely and then 1 minus a smaller than 1 term will be again positive.

So, this ratio will be a positive ratio and S b is positive. So, what we can write that d y d x is positive and this indirectly means that M 1 profile is rising profile, is rising profile. So, now, we can draw very confidently that it will be like this, rising means its depth is increasing in the x direction. In this direction if it is, this is x direction, then depth is gradually increasing, depth is gradually increasing, this y value is increasing in this direction and that way we call this as a rising profile.

Now, when it is raising profile we need to know that what will happen in the downstream and if we just extend it in the upstream side, somewhere it will be meeting normal depth line, it is meeting normal depth line. Now, we are interested to know how this profile will be meeting the normal depth line and that way we will analyze the characteristic what will happen to the downstream side, well. So, this is how we will be approaching to analyze characteristic of different type of profile and that we will be doing in our next class. Thank you very much.