Hydraulics

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Module No. # 04

Gradually Varied Flow

Lecture No. # 05

Computation of Gradually Varied Flow

Friends, today we will continue on the topic of gradually varied flow. We shall be discussing, one of the most important topics of gradually varied flow, that is the computation of gradually varied flow, which will be requiring in our almost day-to-day life. When we talk about engineering life, means in computation of hydraulic engineering in many project, we required this computation of gradually varied flow. We will be taking up that particular topic today. Let us recapitulate, what we have discussed till now on gradually varied flow before going to the computation of gradually varied flow.

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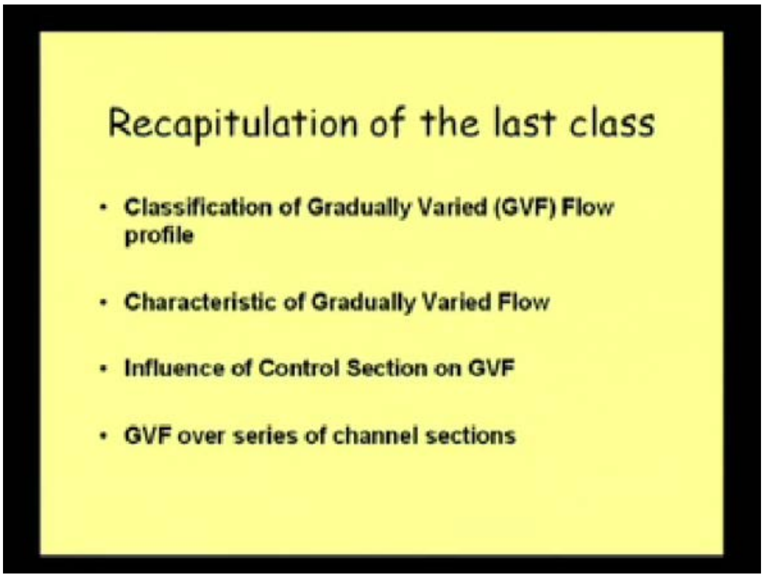

Well, we have discussed till now is classification of gradually varied flow, that we have discussed very elaborately. Then, we did discuss the characteristic of different types of gradually varied flow. For each of the different types, we did discuss how their characteristic varies. Then, we have discussed another important point, that is, the control section. How the control section influences the gradually varied flow? I mean, when it is subcritical flow, then we know that control will be under downstream side. When it is supercritical flow, then we know that control will be on the upstream side. Any disturbance created at upstream will influence the flow in case of supercritical flow and any disturbance created at downstream, will be influencing the flow, if it is subcritical.

So, that sort of discussion we have done. Then, we again could see that how the flow profile forms over a series of channel. That means, connecting channel, but with different slope in nature, actually this will be a continuous channel, but the slope will be changing from point to point, that is what actually we get in practical field. We hardly get a slope, which is uniform all through the channel reach. So, that way, we will be getting channel where the slope will keep on changing. So, that sort of channel when we are getting, then how flow profile is performing, so that part also we did discuss in the last class.

Now, with this introduction to gradually varied flow, we shall be moving on to computation of gradually varied flow. Well, by computation of gradually varied flow, what we really mean? We can just in a systematic way, say that computation of flow depth of gradually varied flow profile at any section of a channel that can be regarded as computation of gradually varied flow. Then, we know that gradually varied flow, I mean when we are talking about computation of gradually varied flow, what are the things we are covering in this particular discussion, that we must know that.

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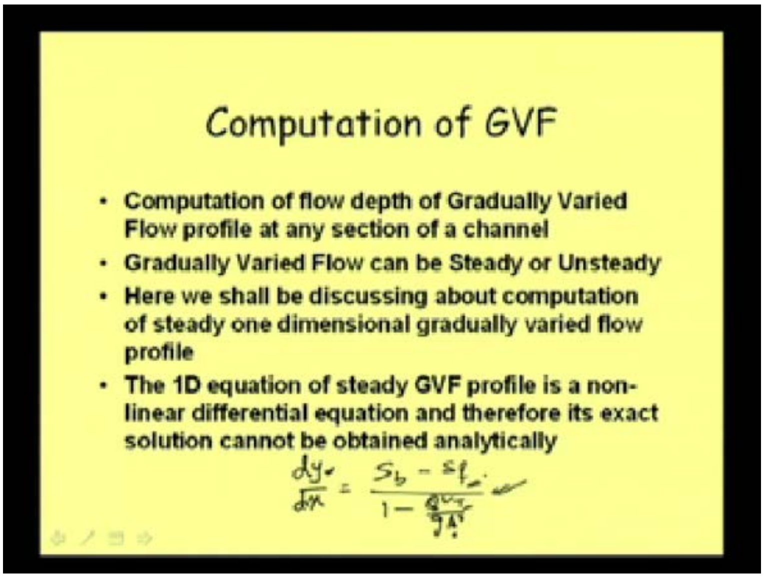

We know that gradually varied flow can be steady and as well as, it can be unsteady also. Now, in this particular topic, we shall be discussing on computation of steady gradually varied flow. We are not talking about unsteady situation. That will take up in general, when we will be discussing the unsteady flow.

Well, then again when we talk about any flow system, then we can have one-dimensional flow and two-dimensional flow. Here, of course, when we are talking about gradually varied flow computation, we are meaning solution of the governing equation of one-dimensional gradually varied flow equation. So, we have already derived the one-dimensional governing equation of gradually varied flow and we will see that how this equation can be solved. When we refer to our earlier equation, if I just write down here, it was like this that dy dx is equal to S b minus S f divided by 1 minus Q square t by gA cube. So, when we are writing this equation, then this particular equation is of non-linear type because this dy dx is on the right hand side. We are not getting this as a function of x. Only, this is rather a function of y because S f that is the friction slope or say, top width or here, all these are basically function of y. If it is non-prismatic channel, then only we will talk about that. These things are also varying with x, if it is a prismatic channel. All these are pure function of y.

So, that way, what we are getting that right hand side of this equation is function of y and that is why, this equation is a non-linear differential equation. We cannot get a direct analytical solution of that. It is difficult and that is why, we go for different approaches for solving this particular equation. That is why, in gradually varied flow solution, solution of gradually varied flow equation rather for obtaining the gradually varied flow profile, we go for different method. All those methods of course, give us approximate solution as we cannot get it analytically. At any point, exact solution we cannot get. So, these are all approximate solution. So, these solutions, we can list in this form.

You can just refer to the slide, that is, first method which is popular is called direct step method. Well, then we will discuss about this in detail of course. Then, we have another method that we call standard step method. What is the basic difference between these two methods? Well, here just to initiate, we can say that in direct step method, we divide the entire flow profile into some steps and then we solve. These steps, that is, say distance or length of the entire flow profile, we divide it into some smaller length, but this smaller length is not fixed. That we get after computation only.

First, we will assume that this is the depth. Then, we will be getting what the corresponding distance for this particular depth. So, that way, the distance or the small segments that we will be getting are not of fix length. In standard step method, here also we divide the entire flow profile into small segments and then we solve, but here, we first divide the channel into our required small section. If we want that, we want to make it very small, we will make very small. If you want to make that little bigger, we will make it bigger.

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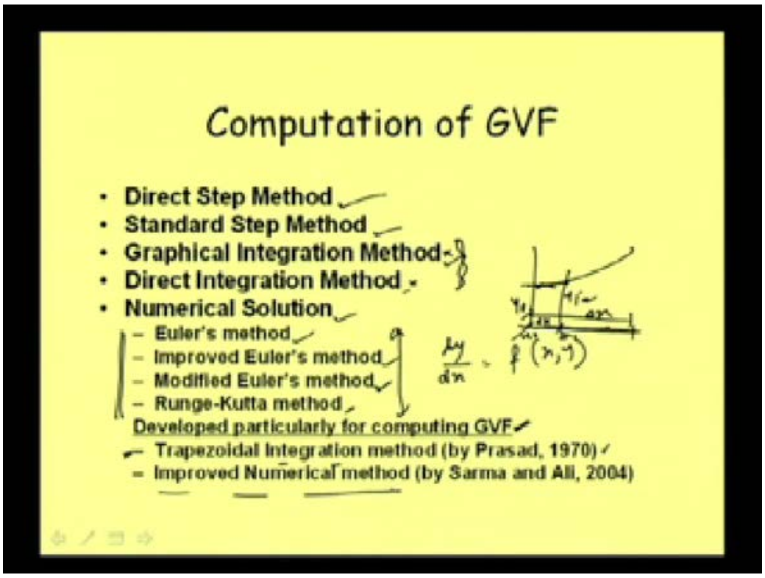

Well, now why we will make it smaller or bigger section? This has definitely something to do with the assumption that we are making in deriving the equation and in solving the equation. So, that will be coming later. Then, we had some graphical integration method. Graphically, we can integrate this equation and we can get a solution for that. Then, we have direct integration method. This direct integration means, in fact, for some of the value, we will be using some table and then, we will get a solution for this particular equation.

In fact, several approaches were there for using this direct integration method. Different people started and they gave different ways of solving it by using table and chart. Nowadays, these two methods are just becoming a historical importance because nowadays, we have computer and we can go for lot of other advantageous techniques for solving, rather than taking recourse to some graphs, rather than taking recourse to some tables. People do not go for those solutions. We go for some solutions which we can have using computer programming.

So, that means, that these methods are nowadays becoming almost absolute and we do not use. That is why in our discussion, we will not be discussing these methods. Then, we will be discussing the method numerical solution. Well, that means, apart from standard step method and direct step method, we will be talking about numerical solution. In fact, this direct step method and standard step method is also one kind, where we put some numerical value and we get the solution, but by numerical solution, what we mean for solution of differential equation in general, several numerical methods have been developed.

So far, I am just listing some of those which are generally used. That one is called Euler’s method which was used earlier. Then, of course, when it was found that this method is not giving very accurate result, then improved Euler methods was used or it came. Then, again to improve upon that modified Euler method has been suggested and then, Runge-Kutta method. As we know, that this is a very popular numerical method, the fourth order Runge-Kutta method. This gives very accurate solution for gradually varied flow profile.

So, that way, these are of course, general numerical methods that give solution for any differential equation of the type that dy dx is a function of say, x and y. Then, any of these methods can give us solution. Of course, I am just naming a few only here. There are several methods. Then, of course, for solution of gradually varied flow, particularly I mean these methods. Out of these methods, solution for gradually varied flow, this was trapezoidal integration method. This is nothing, but of course, modified Euler method and that was applied by Prasad in 1970, first for solution of gradually varied flow. That is why, I am just putting it under a different heading that develop, particularly for computing gradually varied flow ok.

Then, always we find that there are some drawbacks in these numerical methods, particularly in numerical method, we based on a known value at a particular point. Suppose this is the curve. If we know a particular value at this point, say initial value, then based on the value here x 1, we compute the value at x 1. What will be y 1? Suppose, y 1 is known, we calculate y 1. This is, say initial value problem sort of things, we are getting this one here and we are trying to solve this one. In numerical method, we calculate these values for a small value of, say delta x. This delta x, if we keep very small, then almost all these numerical methods what I have stated here, will give accurate result.

Now, if this delta x value is increased, suppose delta x. We are taking very large like that, this is our delta x. Then, some of these methods will give erroneous result and some of these may still give correct result, but now the main problem is that, what should be our delta x. Then, we could see that for computation of gradually varied flow as the flow profiles are very large and then, people may wish to put delta x to be when, suppose, it is a 6 kilometer. Then, people may feel that, let us keep delta x as 10 meters.

Someone may feel that let us keep delta x as 100 meter and in that process, when we are using a computer program, if we give some delta x value, this will give us a solution, but there may be some error introduced in it. So, we tried to develop another method which can give us correct result, even if our delta x is significantly large well. So, that method we named as improved numerical method. Well, about all those methods, we will be discussing briefly under this particular topic.

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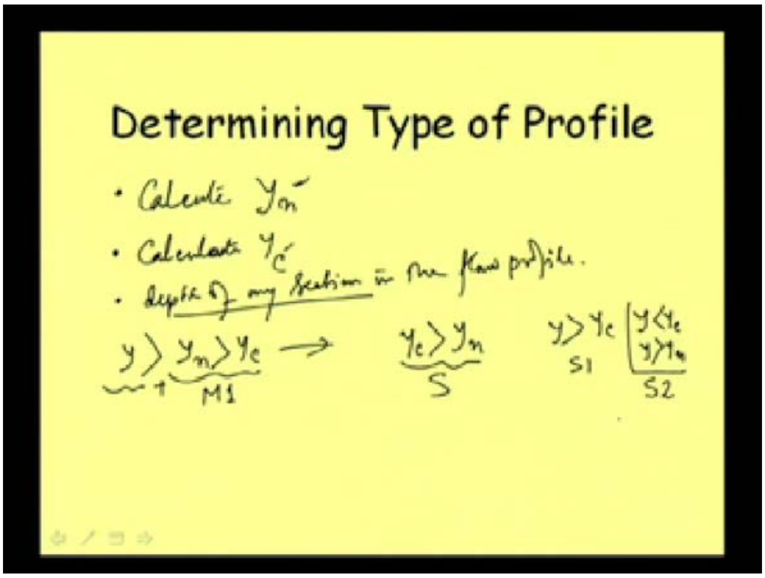

Well, now when we talk about computation of gradually varied flow, our first approach is to determine the type of profile. So, how to determine the type of profile? That is our first step. So, a problem once it is given, then first what we should do as a step. First, calculate Y n. That is first we should calculate normal depth, then we should calculate critical depth Y c. For normal depth calculation, we know that computation of normal depth we have already covered. So, we are not discussing this here. Similarly, for calculation of critical depth that also we have covered already. So, we are not discussing it here, but we know that we need to calculate Y n and Y c.

Then, based on the statement of the problem or based on what we are observing in the field or say, situation we are expecting, suppose a dam is there. We know that dam height is something or say a weir is there. We know that weir height is something. So, the flow profile will have to cross, that means, what will be the depth of the flow profile at any section that we must know. So, that way, first we need to determine the type of profile.

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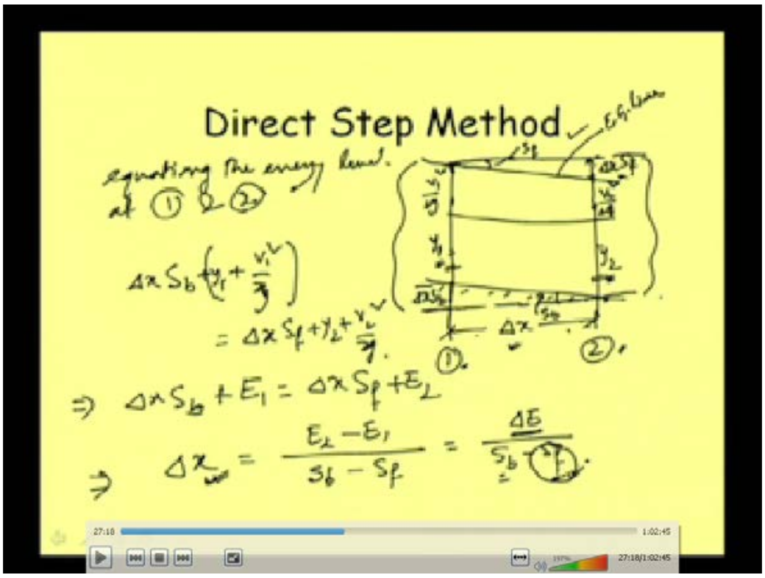

Then, we can move for solution of that particular profile and for solution, first let us discuss this direct step method. Well, this direct step method is a very simplified approach for solving gradually varied flow and is very popular because it can solve the profile almost correctly. If our channel is prismatic and for a channel in nature, we can many a time assume that to be prismatic, if the variation of width is not that much within that portion. Well, let us see what the very basic theory of direct step method or how these are used. Well, let me draw a channel portion. Say, this is the bed and suppose, this is the flow profile and I am drawing this as y 1 and this is, say y 2.

Now, let me consider the datum to pass through the downstream point this and let this distance, we are considering a small segment. This is what actually, basically drawn is a small segment of the profile. Entire profile is quite large; say we are considering a small segment. Well, that we are giving as delta x and this slope is nothing, but bed slope S b. Then, there will be velocity. So, say V square V 1 square by twice g and that will lead to total head somewhere here and here. Say, V 2 square by twice g, this will lead to total head here.

I am not considering alpha that is the velocity coefficient here, but anyway, this is the energy gradient line. This line is called energy gradient line and slope of this line is nothing, but S f. Now, if I draw this line in this direction, extend this horizontal line, then we will be getting that this much is nothing, but the loss and we can write this as delta x into Sf. Similarly, say this particular extent, what we can write if this is the delta x and Sb is there. So, this distance will be delta x into S b.

So, the energy level between two sections we can write in this form here we are of course, considering the loss part in the form that this is delta x into Sf. It is coming and we are considering the loss is only due to the frictional loss and that is what we are getting here. Energy slope is also like that. We are drawing this is the energy gradient line. Well, now if we just write the relation between the section 1 and 2, what we can have that is total if you see this is also horizontal line and that is also horizontal line.

So, this part is equal to, I mean from here to here is equal to from here to here. So, we can write equating the energy level at 1 and 2. Basically, we are equating energy level means loss part also we are including here. That is why we are talking. Otherwise this energy level here is definitely higher than energy level here. Energy level upstream will be higher than energy level at downstream, but we are writing this delta xS f here. So, what we can write that delta xS b plus Y 1 plus V 1 square by twice g is equal to delta xS f plus y 2 plus V 2 square by twice g. Well, now we know that 1 very popular expression for y 1 plus v square by twice g that is nothing, but specific energy. So, we can write this as this implies that delta x into S b in plus the specific energy E 1 is equal to delta xS f plus the specific energy at E 2.

Well, now from that, what we can have our target is to find out, what is the delta x. When y 2 is the depth here and y 1 is the depth here at upstream. So, I mean knowing the y 1, suppose we want to know what y 2 is, then we know that at what distance this y 2 will be. So, that way, we are trying to derive one relationship between these distances. We want to find out in terms of the known parameter at this and at downstream, at upstream and downstream. So, let us write it as delta x. Now, we can write delta x is equal to say E 2 minus E1divided by S b minus S f. So, this indicates that this is equal to; you can write the energy loss delta E divided by this is equal to S b minus S f. So, from this expression, this because this delta E is the basically energy difference between this upstream and downstream point and S b is the bed slope and S f is the friction slope.

Now, one point here is very important, that although we are talking about S f, this S f at the section 1 and section 2 will not be same. It will not be same value, but we can compute this S f using Manning’s roughness formula or Chevy’s roughness formula, but whatever way we calculate, in fact, we will be getting two different value of S f for section 1 and section 2. So, what S f will be using for computing the delta x, that is one important point and that delta, then for computing this delta x. In fact, we should use the S f as the average S f between the section 1 and section 2.

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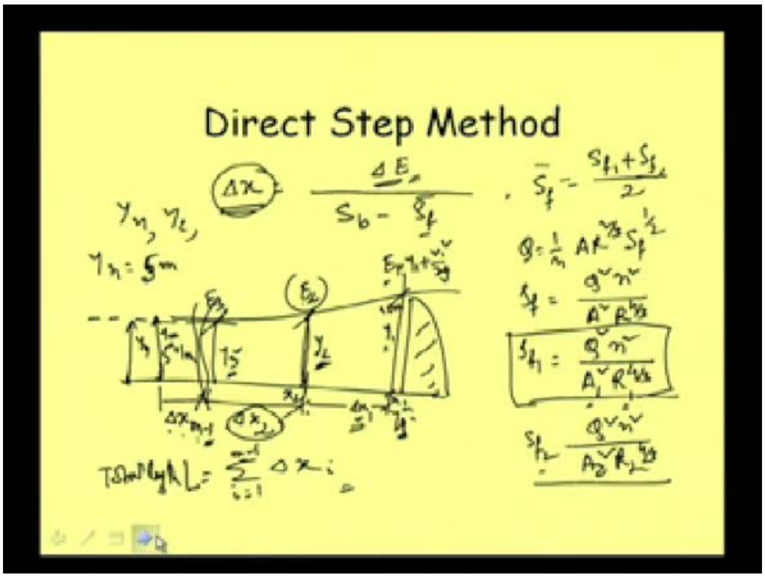

So, how we can write that delta x is equal to delta E divided by S b minus S f bar this. What S f bar is equal to S f1 plus S f2 divided by 2. Now, what is S f1 that we can write, say Q is equal to 1 by nAR to the power 2 by 3 S f to the power half that we can write. So, what is S f? That we can write as Q square n square divided by A square R to the power 4 by 3. So, knowing the value of depth at a particular section, say S f1 means averaging Q is fixed. Of course, Q square and n, if we consider n to be, say constant for any depth or for any section, suppose roughness is not changing significantly, then we can consider this to be constant and then area that will depend on depth.

So, if I talk about A section 1, then this will be A 1 square and hydraulic radius again, it will be R 1 to the power 4 by 3. So, this way we can calculate putting everything for section 1. We can calculate this particular value and then S f2; we can calculate everything like Q square n square A 2 square R to the power 4 by 3. Now, what it indicate? Now, if we want to calculate this delta x, we must know, similarly for energy calculation also, suppose energy difference calculation, we need to calculate Y 1 plus V 1 square by twice g.

Similarly, energy at the level 2 or section 2 will be Y 2 plus V 2 square by twice g. So, we need to know the information about a particular section. So, what is done, say if we want to calculate gradually varied flow, say this is the flow profile. Now, we have calculated first Y n and Y c and then, we know that this depth is known say Y 0. So, we know this control section depth. So, we have got this value. Now, what we can do from this known value? Initially, we know one value and from this known value, what we can do? We can calculate this S f1, say then I am writing this as 1. Say, from this, we can calculate this S f1 and we can calculate this Y 1 plus V 1 square by twice g means E 1 we can calculate. Then, we actually do not know E 2 and S f2. That we do not know.

So, what we assume that first we want to calculate the delta x, but we do not know where this delta x will be, but let us assume that the depth Y 2 will be the depth. So, we need to calculate now and of course, from our knowledge of gradually varied flow knowing the Y n and Y 2, we must know whether the flow profile will be rising or falling. We definitely know if it is in zone 2, it will be a falling profile. If it is in zone 1, it will be a rising profile. If it is in zone 3, it will again be a rising profile. So, that part we know. Now, from that suppose, we know that it is a rising profile and that way, if this depth is Y1, then we can say let us consider we will compute our delta x for a depth Y 2 which is at upstream.

So, this Y 2 we are considering from our side. We want to know what will be the delta x or that at what distance from Y 1 that is x1. Suppose this one and this is, suppose x 2, at what distance from x 1, this x 2 will be which correspond to depth Y 2. So, taking this Y 2 as our known parameter, we are calculating S f2 and we are calculating E 2. So, everything we are calculating and then, we are calculating what is our delta x. So, once we calculate delta x, say let us put this delta x as delta x 1.

So, what we have got after calculation, say Y 2. For Y 2, we are getting this is delta x 1 that means, our purpose is served that we know that our Y 1 depth is at x 1, then after delta x 1 distance our Y 2 depth will be that. We want to know, if we want to plot the profile also. Now, we can plot up to this point, but then again we can calculate the next depth is, suppose Y 3. So, that also we will be first considering from our side and we will try to calculate delta x 2. Well, delta x 2 means the other things are all remaining same. Now, we know Y E2. So, E 3 we need to calculate. That means, this difference between E 2 and E 3 will be our delta E.

Then, we can calculate S f2 here means S f3 we can calculate. That means, just following the same procedure that we have adopted for computing from here to here, we can now knowing this Y 2, we can compute this distance delta x 2 which will correspond to another depth that we are considering from our side Y 3. So, this way we are calculating delta x 2. If it is m 1 profile, suppose from our first, we are calculating what is Y n and Y c and we are getting this is m 1 profile, then we know that this profile will be extending up to normal depth Y n. So, we can keep on computing this one.

Suppose, this Y n value is we know that Y n is equal to suppose our 10 meter or that is 5 meter and this depth is suppose 10 meter, then we will keep on computing our depth, our distance by reducing the depth. To what extent we will compute that because we know that this profile will be coming up to 5 meter where Y and depth is. So, we can take our last depth which is little higher than Y n may be 5.1 meter.

So, last depth, suppose we are taking Y. Let me write as Y m. Suppose, the last depth we have taken m number of section and last depth we are taking after breaking this part. Last depth we are taking, suppose this is delta xm minus 1 because for each of the pair, we are getting 1 delta x for Y m number. We are getting, say our pair we are getting m minus 1 pair. So, this last extend will be delta x m minus 1 and then we are getting a distance here.

So, if we sum up the all this delta x summation of all delta x, so this delta x i is starting from say 1 to m minus 1. If we do that, what we are getting is the total length of the profile l. We can get like that and at different distance, what will be the depth that we are already calculating like this. So, this is what the procedure for calculating gradually varied flow profile in direct step method I have shown. If it is m 1 profile, how we can compute? If it is m 2, the same procedure we need to follow and we can just calculate ok.

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Now, let us see this application of direct step method I have already explained and perhaps, I mean further explanation is not required at this level.

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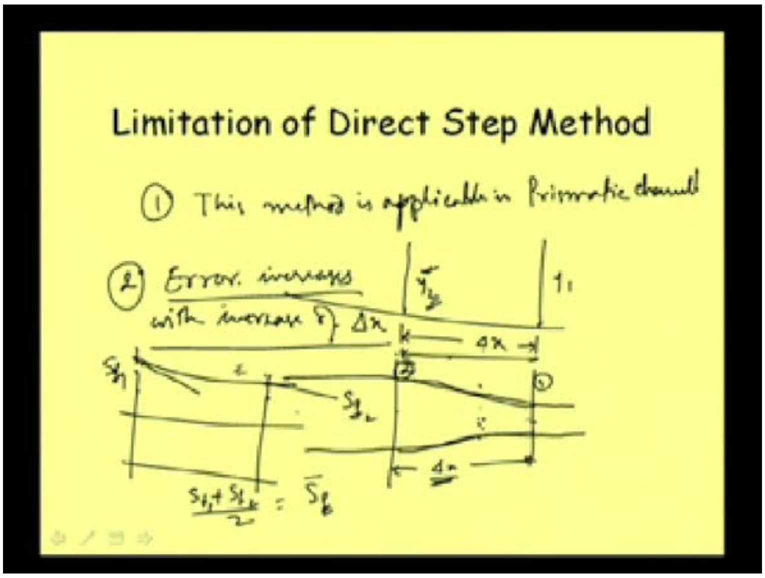

So, we have seen that how we can compute a gradually varied flow profile using direct step method, but this method has some limitations. Well, what are those limitations, we must know. Otherwise, we will end up applying this method into a situation where actually this method is not applicable and we may end up in error. So, let us see what the limitations of this particular method are.

First, I must say that this method is applicable only in prismatic channel. Why? Well, this is one limitation of this method. The reason is that say when we are calculating, say Y 1 is known, we are calculating Y 2. Rather, we are not calculating Y 2. We are assuming Y 2 and then, we are calculating this delta x and the equation what we are using the governing equation. Basically, there itself we made one assumption that the channel is prismatic. Now, when we are applying that equation and we are solving for delta x, so we do not know beforehand what is the length of this delta x. After taking this Y 2, we are calculating this delta x.

Now, it may happen that channel is, suppose plan view of the channel is like this, when we have say, Y 1 at this section 1 and then we took Y 2 because we do not know. We thought that Y 2 may be somewhere here and that is why we thought that this part is prismatic and then more or less prismatic. Then, we thinking in that line, we took the Y 2 value and we started computing the delta x, but when we finally computed the value of delta x, we are finding that delta x is coming here and we do not have any control on that. That is why, basically we have computed from 1 to 2. This depth we have computed, but in the process as we did not know the delta x beforehand, we have ended up in computing this between two sections between which we cannot at all consider the channel to be prismatic. This is a non-prismatic type. So, what calculation we are doing this will be definitely erroneous. So, this is one limitation and second limitation is of course, there second limitation is that error increases with increase of delta x with increase of A with increase of delta x.

So, this is an error which is common for any sort of, I mean numerical methods and here also, it is say when delta x is very large, then this error is there. Error increases, why because say actual flow profile is, well let me draw another diagram here. Say, in between we are using suppose the flow profile is or the energy slope line may not be straight. Suppose, energy slope line is like this, energy slope line is this. Well, this is not the flow profile. Flow profile is somewhere here. This is suppose the actual energy slope line between these two points and then what we are doing that we are calculating energy slope at this point Sf1 and we are calculating energy slope at this point say S f2. Then, we are taking average of this 2S f1 plus S f2 divided by 2. We are taking average of this 2 and that we are taking as S f bar. Well, that S f bar is being used for computing the gradually varied flow.

Now, this will be valid when this change of slope between this point and that point is not that large. Whatever we are taking, we can, suppose average value is representing the change of slope between this point and that point more correctly, then only it is applicable. Otherwise, this will end up in giving some error. We do not know actually in this particular computation, we do not know what our delta x distance is beforehand. So, after calculation only, we are getting this delta x distance and as such, how much will be this part that is our S f1, S f2. How much this will change and how this error will introduce that we are do not know beforehand.

So, this method is having this sort of limitation always. You should take the Y 1 and Y 2 in a way that is Y 1 that is next value of Y 2 in a way that our delta x become small and that of course, will have to have some experience based on the type of profile. Based on the shape of the profile, we need to decide how much we can reduce the next Y 2 value, if it is a rising profile. If it is a falling profile, how much we should increase this.

So, that way, this needs some understanding and if we find that delta x is becoming very large, that means, we should know that we are introducing some error. We can again redo the entire work putting smaller value of change in depth that is say, if I say delta Y is the change in depth, then from Y 1, we should reduce Y 2 by a very smaller value. We should see whether our delta x is reducing or not. That way, we should calculate. Well, these are the measure limitations of direct step method and because of these limitations, particularly this standard step method came.

Well, what is the basic difference between direct step method and the standard step method? This is that in standard step method, we can decide our delta x. We can fix the delta x and then, we calculate the Y. Of course, here one disadvantage is that as we are fixing our delta x and as the equation says that we cannot have directly the value of Y. It will require iterative procedure. Trial and error will be required in calculating the depth Y 2 corresponding to the depth delta, corresponding to the distance delta x.

So, that is what one limitation is, but with having lot of computational facility, now all high speed computer that cannot be considered as limitation. Iteration can always be done quickly now. Well, just to say about the very basic theory of this particular standard step method, now you can concentrate into the slide. What we can do, say we can write the energy equation between two sections, say section 1 and section 2. We can write the energy V 1 square by twice gV 2 square by twice g. These are there we have. Then, energy gradient line and this is bed slope is there. Then, there are definitely some losses in between.

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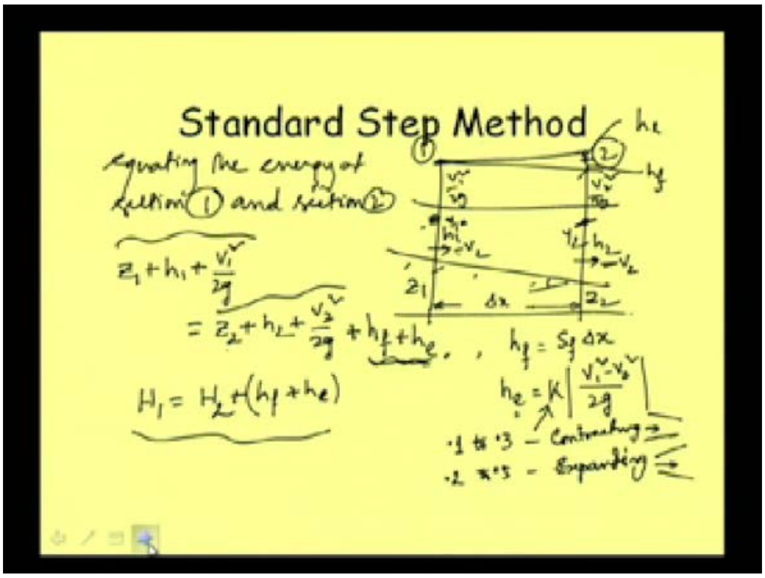

Well, now that part. Now, we can write as say energy level at upstream side, say equating the energy at section 1 and section 2. What we can write that Z 1 plus h 1 plus V 1 square by twice g that is equal to Z 2 plus h 2. Well, here for depth, we have written h. No problem. Earlier, I was writing Y here. Anyway, it is already written h. We have written anyway Z 2 plus H 2 plus V 2 square by twice g, but definitely these two energy cannot be equal because loss part we need to add here. In this part, we are adding two type of loss. One loss is due to friction, say S f. That is S f from the friction slope itself we can directly get this S f. That is our, if the distance is very small delta x, then we can get the friction slope S f multiplied by delta x.

Apart from that friction loss, there are some other types of losses also as in between there may be the deformation. If there are some changes in the channel pattern velocity is also dropping. Suppose, significantly from V 1 here, V 2 here and then because of that change in velocity, there may be another kind of loss that we called as Eddy loss. That is why that loss is also added here as he.

Well, that is why this particular method that is a standard step method has another advantage of using this for a non-prismatic channel also because this sort of Eddy loss are prominent or important in case of non-prismatic channel. If the channel is expanding or if the channel is contracting, then this sort of Eddy loss are important or significant, but if it is a prismatic channel, then this Eddy loss is not that significant unless there are lot of turbulence and other.

That is why in direct step method that was also another reason, why we cannot apply it to, I mean non-prismatic channel; there we did not consider this Eddy loss. Now, what is hf that we can write? If this distance is delta x, then we can write this as S f into delta x. Then, what is he? Head loss, I am not drawing here. I can draw a horizontal line where this will be and total loss we can divide it into two parts. One is say this part is hf and that is another part which is he, then eddy loss. That eddy loss can be written as some factor K. Then, of course, V 1 square minus V 2 square divided by twice g. So, whether velocity is more here, less here does not matter. We need to get the difference. So, that way, this expression can be used for Eddy loss and then hm.

Experimentally, it was studied and it was found that this K value we can use as 0.1 to 0.3 for a contracting channel. If the channel is contracting in the downstream direction that is like this, flow is going like that, then we can use this value between 0.1 to 0.3. Of course, what it should be whether it should be 0.1 or 0.3 that will depend on your experience, but anyway we can take in between and then it is 0.2 to 0.5 for expanding channel. It is used like this for expanding channel that is when channel is expanding like that, that means, it is clear that this Eddy loss will be more when a channel is expanding rather than in contracting. So, that part is very obvious from this particular value and this point we need to take care.

Now, of course, still in standard step method we generally do not prefer to go for a non-prismatic channel all along, but still wherever necessary we go. Then, in that case, if some expanding portion is coming, then we can use this he value. There we can calculate this value. Then, from this equation, what we are getting if we write this as the H 1 head h 1 plus, say this as the head H 2. Sorry, this is equal to we can write this is equal to H 1 equal H 2 plus the loss S f plus h e. That we can put under bracket. Well, now using this relation, how we can calculate the Y 1 and Y 2? That is our required point that is suppose, if it is Y 1, we want to calculate Y 2 or say this is Y, sorry this is Y 1 and we want to calculate Y 2, then how we can do that. This can be other way also. We can have Y 1 here known things and we can calculate Y 2.

Of course, here one important point is there. If we are computing from the downstream side to the upstream side that is of course important. If we are computing from downstream side to the upstream side, say our first known point is at downstream and unknown point at upstream, then this S f plus he that is loss will have to deduct from here, then only we will be getting this value head at here. So, that way we can use a plus minus sign and we can write it accordingly.

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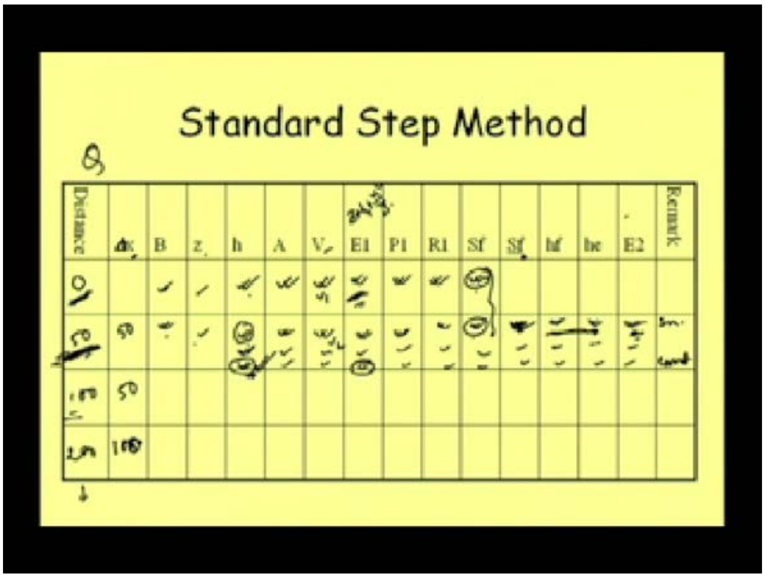

Well, to have some better understanding, how we actually calculate. Use the standard step method that we can see through this table. You can refer to the table here. We have one advantage. Let me just take this slide and let me show you, say distance means how we can do it. Distance means, say our starting point is 1, then we are continuously computing the profile, say first distance is 52nd distance.

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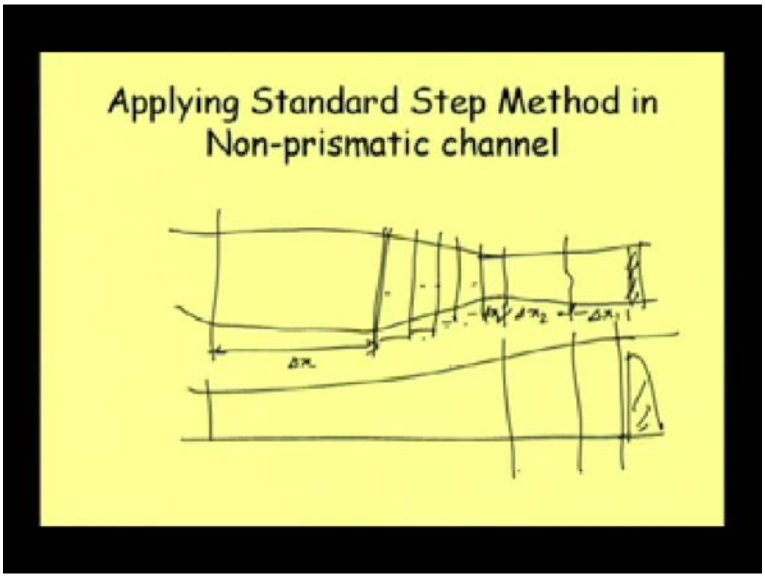

May be 100 increasing by 50, but a next distance, there is no restriction. That we suppose, find that next distance we will take 200, then there is a gap of 100 between and here is a gap of 50. Here, also a gap of fifty it does not matter. So, distance at any point we can calculate. Now, based on this distance, we will have to decide what is our small delta x or dx. That is we are getting, we could write it as delta x also say this is, for this part actually we are writing dx is equal to 50 from here, 150 we are getting this is just 50. Then, for this 150 to 100, this is again 50. Then, from 100 to 200 that is, basically 100.

So, this way we can write the delta x. Then, we can put what is our bed width b. So, again if it is a non-prismatic 1, then bed width here from 1 to 50 and bed width here may be different. So, that way, we can write the bed width value. I am not putting any value here. Then, similarly z based on the bed slope and this distance, we can find out what is the rise of the bed or what is the fall of the bed that z value we can write. So, z 1 z 2, all these we can write like this. Then, suppose at a first point, we know the h value. So, that is I am giving double mark, mean this is for this known value, we can calculate area. Then, once we calculate area, then if our Q, it is we are doing for a particular Q.

So, this velocity is also known. So, when we know these things, that we know the h and v, then we can calculate this energy at section 1 that is h 1 plus B 1 square. Say, that we can calculate h plus V square. If I do here, V 1 square by twice g that we can calculate here. So, this is known. Then, from all these values, we can calculate what the perimeter is at this point. We can calculate what the hydraulic radius is at that point because area and perimeters are known. Then, we can calculate S f friction slope as I have shown already by using Manning's formula. We can calculate the friction slope, but what will be the Sf bar that we cannot calculate at this point. Then, we will come to this table. This line again. Then, for this delta x, we are calculating this b value. Well, this is basically z plus. Just 1 minute here. This energy means actually we are talking about this z plus h 1 plus B 1 square by twice g.

Similarly, this E 2 is also because z value, we have calculated here. Then, for this part, we will be putting again the B value and z value, then h value. What we are rising, how much we are rising that we will be putting here. Then, h area we know, V we know. This part we can always calculate and then, coming here, we will be calculating the S f bar. How this S f we are calculating here? The S f we are calculating here between this 1 point and 50 point. We are calculating both the S f. So, this S f bar will be basically average of these two values. So, combining this, we are calculating the S f bar. Then, we can calculate S f, the friction loss.

Once, we get the S f bar, then we can calculate the friction loss S f bar into delta x that we can calculate. Then, once we know the V 1 and V 2, here this our V 1 and this is our V 2. The V 1 and V 2, we can calculate what is the energy loss. Then, if we sum up these values, Sf he, then here what is our z 1. Then, z and h and V square by twice g. All these things will give us the calculated value of E 2. Now, as per our relation that E 1 should be equal to E 2, of course, as I was telling already that if suppose E 2 value is, we are calculating for a upstream section, if this value we are calculating for a upstream section, then we should see that whether this value minus these two values is equal to this particular value or not. That we need to check or if say E 2 is at, I mean if E 1 is at in the proper direction that is actually it is in the upstream and this is in the downstream. Then, we can calculate in the same way what we are doing, but say if E 2 is that mean the second section.

Suppose, this 50 is at upstream, you just try to see this point if this 50 distance it at upstream of 1. Then, only we should do E 2 minus this part and then, we should check whether it is equal to this 1. If 50, is at downstream of 1, then this way, we should check whether this is equal to that. If it is not matching, then we should consider another h value because this h value, we are assuming this h value and then, we should consider another h value. Then, we can calculate all these values again and then, we can try checking this value.

In a comment, we can write whether it is correct or not. Say, first is incorrect, then second we are checking. It may be again incorrect. Then, we will go for another trial and finally, after some trials, we will be getting, suppose it is correct value that means, we take that for 50 days distance. This is this h. What we are taking is the correct h. So, then we will go for the next 100 and we will follow the same procedure and the energy E 1 will take this one corresponding to the ultimate h. What we are getting as the correct and we will keep on computing and this process will follow. Then, we will be getting the depth at different section. These sections are already known.

Now, when we talk about the applying standard step method in non-prismatic channel, what is the advantage? Say, our channel is like this. Suppose, the channel is like this and then, it is like this. Now, our profile can be this one, say this is the profile we are getting giving a barrier here and because of this barrier, flow profile is forming like this. Suppose, it is m 1 profile, but we want to compute it.

So, what we will do? We can take our section here, then another section we can take here and then we can take another section here. So, now, our sections are like this. We are computing this is our delta x 1, this is delta x 2. That way, what delta x we are taking that we know beforehand that these are our delta x and we decide that this part to this part, we cannot take this portion. Say, more or less we can consider this to be prismatic.

So, let us take this delta x 3 and then, these are expanding quickly. Although, we use a factor k for computing Eddy loss, but still, it is better to make a smaller section when it is significantly expanding. So, we can have other assumption that we had for prismatic channel and that can be valid for this part. So, that we are considering as a smaller part. Then, we are calculating from here to here. Suppose, this is more or less prismatic and we are dividing it by our own way like that.

So, this distance can be much larger. That way, we can compute our profile from here to here considering different delta x as per our wish, so that we can have a better solution and a more accurate solution. What the only problem is that we need to go for little bit of trial and error and with a computer program, this can be very easily overcome. So, that cannot be considered as a big problem. So, this direct step method and standard step method were developed long back and then, people are using and of course, nowadays with the development of high speed digital computer, we go for numerical methods.

In this particular class, we will not be going for all those different types of numerical methods, but still we will be discussing some of the very preliminary aspect of numerical methods. How error get introduced in numerical method to overcome those errors, how we can use different types of numerical method that we will be discussing. With giving a brief introduction to the numerical method for computing gradually varied flow, we will be moving on to rapidly varied flow.

So, we hope in the next class, we will be covering these numerical methods. Then, we will be moving on to the, I mean rapidly varied flow. Of course, before that, we will have to take up some numerical problem giving example of practical situation. Thank you very much.