Hydraulics

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Module No. # 01

Introduction to Open Channel Flow

Lecture No. # 04

Velocity and Pressure Distribution in Open Channel Flow

Friends, so we shall discuss today about one very important aspect of open channel flow; that is, say velocity at different point, flow will always be different - how to tackle that particular issue? Because when we will do our computational work, then we do this as a single velocity in most of the cases. Now, how to tackle that particular problem?

Similarly, say when we talk about pressure at a particular point, say we know that when the fluid is in static condition, then we know what the pressure is at a particular point, but when the fluid will be in motion, then whether the pressure at that particular point or at any point will be similar to that of the condition of the static or whether there will be difference. So, that way, the pressure variation within the flow or the velocity variation within the flow is an important aspect and that we will be discussing today.

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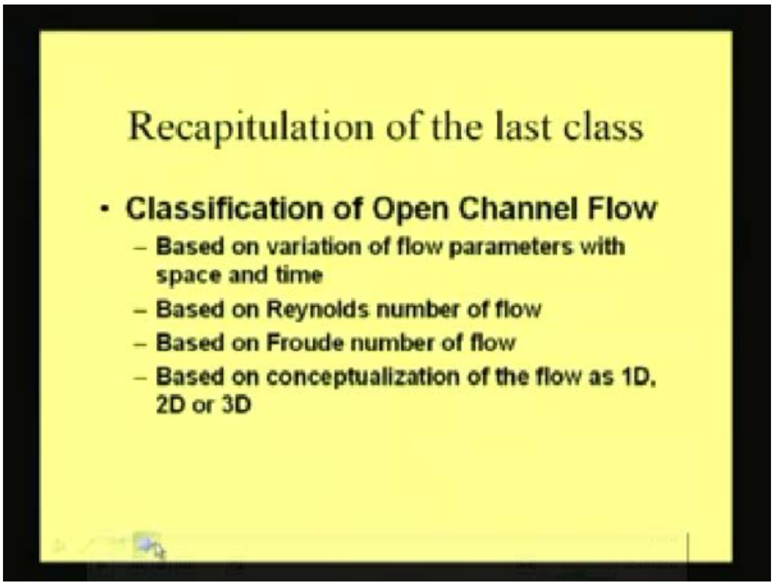

Well, before going to that particular aspect, let me just summarize what we did in our last class. Recapitulate the last class, that is, see we did about classification of open channel flow and we could see that we can classify open channel flow on different basis. Based on variation of the flow parameters with space and time, we can do classification. Then, we can do classification variation or based on the Reynolds number of flow. That way, we classify the flow as a laminar turbulent or between laminar and turbulent like transition.

Then, we can classify it based on Froude number, that is, again the classification based on the concept of specific energy. Then, we do this as say whether the flow is critical flow, it is sub-critical flow or it is supercritical flow. So, that way, we classify the flow, and then we did, of course, classification based on how we conceptualize the flow, that is whether we conceptualized the flow as one-dimensional, as two-dimensional and as three-dimensional, and for what sort of situation, we need to consider a flow as one-dimensional; for what situation, we need to take this as two-dimensional; for what situation we need to take that as three-dimensional. So, those aspects we did discuss.

We could see that uniform flow, steady flow all are different type of flow, but in all these sorts of flow, one important point is that, say when we were talking about velocity, we were writing a single velocity term, that is say change of velocity or partial variation of velocity with respect to x or distance.

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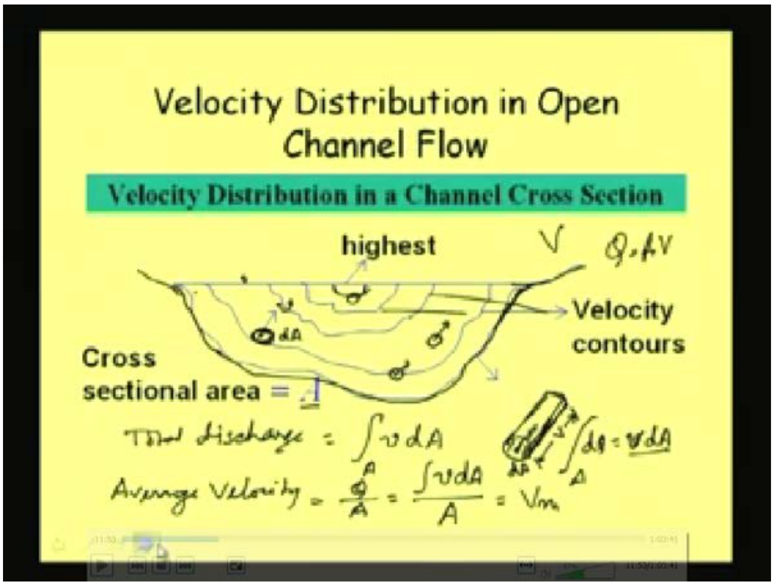

When we were talking, then we were writing it as del v del x or with respect to time, del v del t. That means, we were writing a single velocity term, but in a channel, in reality, the velocity in the entire section will not be same. Let us refer to this particular slide. See velocity distribution in open channel flow, and first, let me talk about velocity distribution in a channel cross section. Suppose, let me take a pen here, say this is a channel section we are talking about, and say this is our channel section, and water level is flowing at this height. Now, that flow velocity in the entire section will not be same.

Suppose, if we draw a velocity contour, means line indicating equal velocity, if we draw, then perhaps we will be getting a line like this. That means, this line is indicating that velocity along this line will be same and then these are called velocity contour. All these lines we are drawing, velocity contour here. All these lines are basically velocity contour we are drawing and this is the channel section or we can call this the boundary channel bed and the cross section area of this channel. Total cross section area of this entire channel section is say A. Well, now let us consider a small channel, small elementary area, say dA. Well, say the flow velocity in that small elementary area bv, through this small elementary area bv, then when we talk about flow velocity here, it is v. If I take another section here, another small elementary area, then here may be some other velocity. It is flowing here. It will be another velocity like that. Here it will be another velocity.

So, at different point, the flow velocity will be different. Probably, it is a common understanding that in a river channel, if we observe normally the maximum velocity, we get in the middle of the river, and when you come to the side, the flow velocity decreases. This is because when the flow is moving on the side, very near to the bank, the resistance of the bank wall and up to certain extent, this resistance become more significant, similarly from this side, similarly from bed.

So, this flow velocity will be of lower level than this flow velocity. This will be of higher level. This velocity will be high. This velocity will be gradually coming lower and lower and here, at the bed, velocity will be almost negligible. So, for that sort of velocity distribution we normally get. So, now, when we talk about average velocity, say one single term v, we are using all the time now. What this v can be? Well, so what is the discharge flowing through this elementary area A? What will be the discharge flowing through this elementary area A?

Well, as the velocity of, let me draw a small elementary area here and let me just show it like that. Say, it is moving with the velocity v, then as the flow velocity is v. So, discharge means flow in unit time, the quantity of flow that is moving in unit time. So, in this cylindrical or whatever may be the exact say, but say more or less cylindrical. Then, as the velocity is v, then in unit time how much distance this flow will be moving? That will be moving through a distance of v because velocity means that distance travelled per unit time.

So, in unit time, it is moving a distance v and then the sectional area is, say dA. So, how much total volume that has passed through this particular portion in unit time, that is the basically discharge flowing in time in unit time. So, that will be that Q. If I write a small q indicating that small discharge flowing through this elementary area or say, I can write dQ. Also, say this dQ, that is, basically equal to the dA. That is basically equal to v into dA, v into dA because this is the volume of this particular cylindrical shape. May not be exactly cylindrical, but this particular shape.

So, this dQ is equal to v into dA. This much is the discharge flow. Now, if I consider that all these elementary area, this sort of discharge is flowing, then total discharge flowing through the entire section we can get by integrating it over the area. So, that total discharge flowing through the section, we can get integrating. This area means say integration of over the entire area, we can write v d A. This v is small, v of course, we are indicating that this is small v and this is what the total discharge. Then, we know that discharge is equal to area into velocity Q is equal to area into velocity.

So, when we talk in terms of average velocity, then we can write that average velocity is equal to that Q by the entire sectional area. This is what the entire sectional area. So, Q by entire sectional area means we can write that integration of v d A divided by the entire sectional area. So, that way, we can calculate the average velocity. This is referred as say v mean velocity v m. In most of the case, we write v m or v average. Well, so that way, we can calculate the average velocity vm. When in reality, we have different flow velocity at different point and this aspect is important for different purposes like for calculating energy and calculating momentum.

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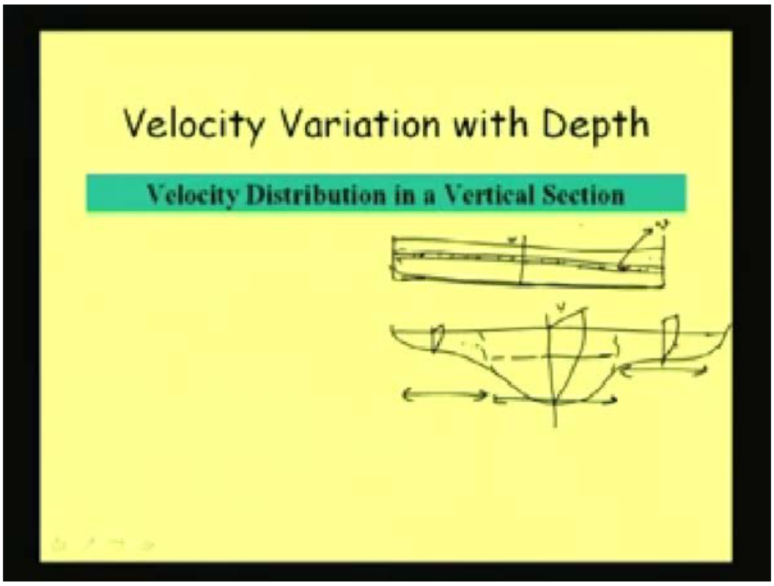

We will come to that in a later point. Now, this sort of velocity variation is in a natural channel, but suppose, our channel is very wide like this. Say, it is a very wide channel, then what is there influence of these sides will be to some extent, up to that much and this much. Then, if I have the flow depth of this much, then we will find that this influence will be very much negligible after certain distance and then we can consider that the variation of velocity width wise. That means, say what is the velocity here and here, there may not be that much of difference. Then, we can assume that velocity variation across the section in the lateral direction is say negligible and we can consider that this entire strip is flowing with a velocity v.

However, that velocity variation in the depth direction cannot be neglected because this bed is in touch with entire water and this will be significant. This will influence the flow velocity and significant change of velocity will be there in the vertical direction. So, in that case, we talk about say velocity variation with depth. Here, we are not considering that the velocity is varying across the channel, also in the lateral direction of course. Suppose, we have a channel like this, then when we have a channel like this, we can again just assume it like that in this portion. Our velocity is varying along the depth and across the section say velocity variation is negligible, but along the depth, the velocity variation is there, that is here. It is suppose, larger velocity here, it is smaller velocity and in this portion also. Again, we can consider that variation of velocity in the lateral part is small, but there is a variation of velocity, here in the vertical direction.

Now, what is the basic need of considering three separate sections? Because the variation of velocity in the lateral direction between this portion and that portion, that is the velocity average. Velocity between this portion and that portion or between say this portion and that portion we cannot consider as same or say similar, because this will be much lower because the depth is lower. The resistance from the bed will be more here. The resistance from the bed will be less.

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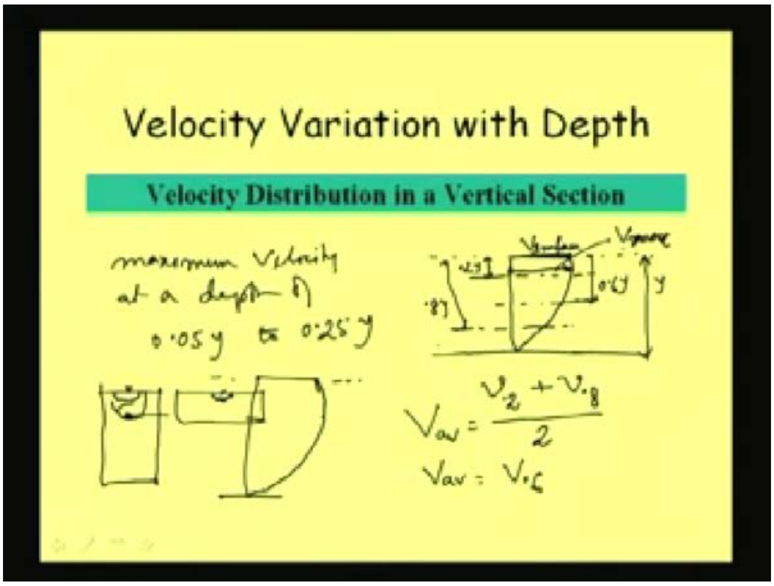

So, that way we sometimes consider that vertical velocity of variation we consider and that again, part by part here. What is the vertical variation? So, we need to know that velocity distribution in a vertical section and then, let me show you how we consider the velocity variation in a vertical direction, vertical section. Well, that of course, we will vary from section to section, but still some of the typical section, we can just observe say this is the velocity diagram.

If I draw, suppose here. It is this much and then it is coming down like this. Let me not show the entire surface. We are just showing that velocity diagram here and then, what will be the average velocity in this particular part. In this particular part, say this is depth, this much is y depth, and this much is y. Normally, what is done? We will find that depth from here if I come say 0.2y. Suppose 20 percent of the depth we are considering here and say from here, we can consider 0.8y. Of course, we can take at 0.6y like that. At different point, we can measure the velocity.

Now, the velocity, if we measure at 0.2y, if I just write a notation here that v point 2 meter depth and if we measure the velocity at 0.8 meter depth. Then, if we take the average of these two velocities, then this we can refer as average velocity. That we can refer as average velocity. So, we can say that average velocity is equal to velocity at 0.2 depth plus velocity at 0.8 depth divided by 2. Many a time, it becomes too lengthy when we take measures in two different sections. So, rather than that, we do another way that average velocity is equal to, say velocity measured at a depth of 0.6. That is also that done.

Many a time, again based on the surface velocity, what is the velocity at the surface v. Surface say, we sometimes take a percentage of this surface velocity as the average velocity. Now, it is interesting to note one fact that the velocity at the surface is, of course, not the maximum velocity. Generally, maximum velocity we get at some lower depth here. Say velocity is maximum; we get maximum velocity not at the surface, but at a lower depth. From some observation, an experimental observation as well as field observation, it was found that maximum velocity we get maximum velocity at a depth of say 0.05y to 0.25y.

So, at this depth we get the maximum velocity. So, velocity diagram in if I draw more accurately, it will be like that. It is coming like that. Of course, this will depend on many other factors like that and if we just consider a narrow channel, then you will find that. Suppose, this is the surface and then our velocity diagram will be like this. You can find that maximum velocity is occurring in a more lower portion, but if it is a wide channel like this, it will be more towards surface. This is more lower. This is first surface like that considering different aspect. We can just have some idea where we can have maximum velocity and that way, we can just see what should be the average velocity or what we should take as average velocity for our computational work.

Well, then regarding these velocity variation that we have seen, that there will be velocity variation and we can have average velocity. We can compute the average velocity in a way, but then as we are using this average velocity for our computational work, we will always introduce some error in the computational process means say energy will be required in many of our computation. We will be requiring computation of momentum. We will be requiring computation of energy and when these are calculated in terms of the average velocity, then definitely we are introducing some error in the computation of energy or momentum.

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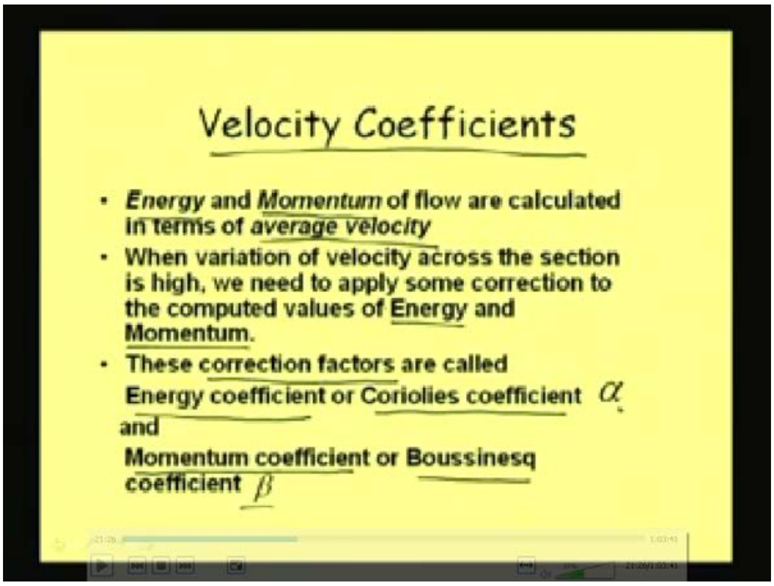

When this error will be moved, when the variation of velocity across the section is very high, then this error will be moved. In that situation, we need to apply some correction to the computed value of energy and momentum. Well, so these correction factors that we apply for getting the corrected value of energy and momentum are called energy coefficient or Coriolies coefficient alpha and for the correction that we apply from momentum that we call as momentum coefficient or Boussinesq coefficient beta. These coefficients in general, we call as velocity coefficient because these coefficients are coming because of variation of velocity. So, we call this as velocity coefficients in general. Well, now let us discuss what we mean by energy coefficient alpha energy coefficient alpha?

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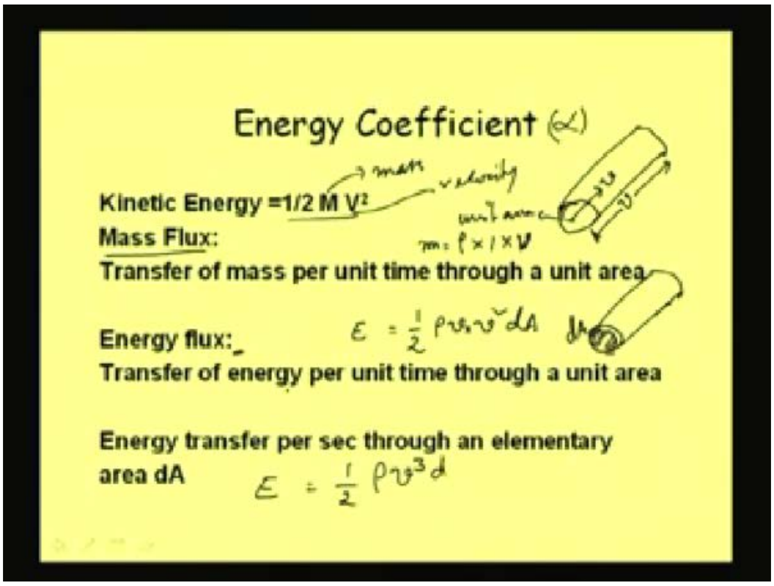

Well, then before going to this energy coefficient alpha, let me just explain how we do calculate the kinetic energy. Well, this expression is probably known to all of us, that is kinetic energy is equal to half MV square, where m is the mass and this V is the velocity. Again, these velocity we can have average velocity or for a small elementary area. If we do, we can take individual velocity at that particular point. So, the expression is half of mass into velocity square.

Well, then in case of flowing fluid, what will be the mass of a particular quantity. If it is in static, we can say that it is total mass is how much say we can know, but when the fluid is flowing, then we need to use a term that we call as flux. Basically, what we mean by mass flux? It is the transfer of mass per unit time through a unit area, say if I consider a unit area, suppose this is unit area, then transfer of mass through this unit area. Say if it is flowing with a velocity V just like that we did drawn earlier, then in unit time, the distance travels will be V in unit time. Then, this area is also one say unit mass.

So, in unit time means one second. Suppose, through this unit area, well let me write it as unit area. So, through this unit area, how much mass is flowing? What is the total volume flowing? It is 1 into V into V is the total volume flowing. Then, what will be the mass? If I multiply it by rho, then it will become the mass. So, mass is equal to, you can say that this is equal to rho V. Well, then how much is, then let me talk about the energy flux that we can describe as transfer of energy per unit time through a unit area. So, mass flowing is rho V mass flowing is rho V, then what will be the energy flowing.

So, energy flowing is equal to half of the mass. So, energy flowing is equal to half of the mass rho V and V square, again AV square half of the mass into V square. So, that is the energy flux, but energy flowing, if now I talk about a small elementary area dA. Suppose, my area is not unity, but it is dA, then what will be the mass flowing? What is the energy flowing? We will have to multiply by dA. So, energy transfer through a unit area d through A area, dA elementary area, dA in unit time minute per second that we call as energy is equal to half of rho into V into V square into dA.

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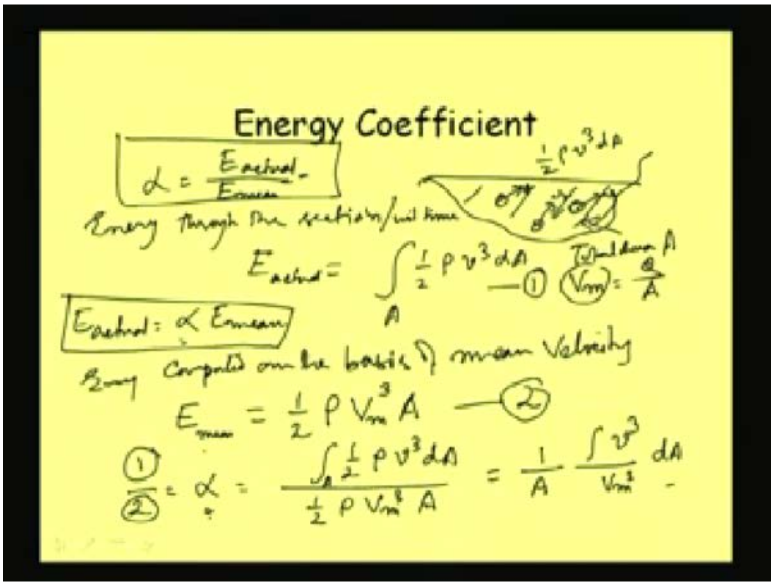

So, we can write that energy is equal to energy transfer from per second through an elementary area dA. We can write as half of rho VQ into dA half of row VQ into dA. Well, now that means, through this small area if I take a section like that as we did discuss through this small area, what is the energy flowing? That we can have that half of rho VQ into dA that we are getting, then what will be the energy passing through d? The entire section that we can get, say energy through the entire section, of course, when we are talking about through the entire section, we are talking regarding per unit time, that is equal to integration of this half of rho VQ into dA integration of this over entire area.

Let me write this energy as xl because why, I am writing xl because that we are talking about the energy calculated on the basis of small elementary area where the velocity here, may be V here. It will be different, say V 1 like that different velocity will be there at different point. We are considering this variation of velocity and then we are calculating, so that we are writing this as x l energy x l. Now, let me take, say this total area is suppose A and the average velocity or mean velocity V m is again Q by the total area. So, this is the mean velocity. Now, if I calculate the energy in terms of the average velocity, then how we can write the energy? Again, the same thing, that is, the energy computed on the basis of say on the basis of mean velocity if I do, then I can write it at E energy computed on the value basis of mean velocity. So, I am writing E mean, say this is equal to half of say rho, then I will put here mean velocity V m cube half of mean velocity V m cube.

Well, half of rho into V m cube into the total area as we are integrating the area. So, that way, we can get the E based on the basis calculated on the basis of mean velocity. Then, if I put this as equation 1 and if I put this as equation 2, then the equation 1 by 2 will give me the value of the energy coefficient alpha. So, energy coefficient alpha, we can write as integration of half of rho V cube. This is small v cube dA integrated over the entire area divided by half of rho mean velocity Q into the total area.

Then, this expression we can simplify into, suppose we consider that the fluid density remain same in the entire cross section, this is not changing, that is the flow fluid is incompressible. In that case, we can just cancel this rho. We can bring common and outside the integration sign and then, we can simplify it in a way that 1 by A. Then, integration of say v cube and here, it is V m cube by dA into dA. So, in this form also we can write this is getting cancelled. So, we can write as 1 by A integration of V cube by V m cube into dA.

So, this will be the expression for velocity coefficient alpha. So, once we calculate the, that means from this, what we are finding? What basically is alpha representing? That it is the E actual divided by E calculated on the basis of mean. So, energy coefficient alpha, we can write as, let me just highlight here energy coefficient alpha. We can write as energy calculated actual means based on the different velocity and energy calculated on the basis of mean velocity. So, when we calculate the energy on the basis of mean velocity, then actual energy we can get as E actual is equal to alpha into E mean velocity.

So, we did not bother. Once we know this alpha value, then we need not bother about the different velocity what is been flowing. So, if we know the average velocity, then we can very well calculate the energy as half MV square again for the entire area. If we make the energy calculation or energy expression on the basis of average velocity, then we can very well write. Then, we can multiply this by the alpha value to get the actual velocity say for the entire cross section you know the average velocity V and you know the area sectional area.

So, energy flowing per unit time on the basis of entire cross section, if we say on the basis of entire section, then it will be again half MV square. If I write half and mass will be, say area into V m, that is what the mass flowing and then, V m square again. So, it is equal to say half of area into V m cube. So, this is what we are getting and then what will be energy? Actual with the correction or corrected energy or we will write corrected energy E actual is equal to alpha into this part half of a V m cube. So, this way, we can use this energy coefficient alpha and then can get the corrected energy well. Then, similarly, we can have momentum coefficient.

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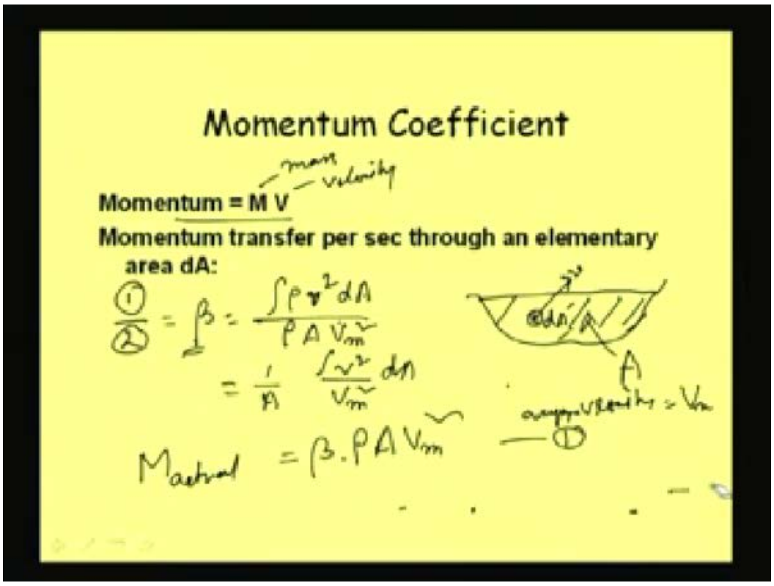

Well, in the momentum also, what we mean by momentum? Momentum is nothing, but mass into velocity. This is what the mass and this is what the velocity again. So, momentum transfer per second through an elementary area dA that we can write as say mass will be again, let me draw this figure here and say this is a small elementary area dA. Then, what is the volume flowing in unit time. That will be the dA into the velocity into the dA. If the velocity is V, velocity into dA multiplied by rho, this volume into density, that become the mass and then, again multiplied by the velocity. This becomes momentum.

So, this is equal to nothing, but rho V square into dA. So, V square rho V square into dA. So, in the similar pattern, the velocity, also momentum flowing through the entire section, if we want to get, we can show momentum through the entire section. This is equal to integration of rho V square dA over the entire area and that we can call as, say momentum actual. Then, if I calculate the momentum on the basis of this sectional area A, entire sectional area, and average velocity is V m, then again I can write that.

What is the momentum? Momentum is calculated on the basis of mean velocity. This is of mean velocity that we can write as again m into V. So, mass flowing is equal to say density into the volume area into velocity V m. Again, another V m will be coming. This part is mass. So, this is equal to like that and that we can write as rho A m V m square. So, this is what the momentum when we calculate in terms of the average velocity.

So, again if I write as equation 1 and this if I write as equation 2, so equation 1 by 2 will give me, let me rub this part. So, equation 1 by 2 will give me the correction factor which we call as momentum coefficient beta and that is equal to integration of rho V square dA. That is small v indicating velocity at different point divided by rho capital AV m square. So, that way, we get the expression again. Here, if we consider again that this density can be considered as constant considering that it is say, not compressible. The fluid is incompressible, then we can write this as rho. Rho we can cancel and you can write 1 by A, and integration of V cube. Sorry, it will be V square. I am wrong here. It will be V square, the integration of V square dA by V m square fine.

So, this is how we can calculate this momentum coefficient. Earlier, we have seen that the velocity coefficient alpha we can calculate using this velocity coefficient and momentum coefficient. Similarly, here also for finding the actual momentum, when we have already calculated it in terms of the average velocity momentum is calculated from the average velocity terms. Then we can get the actual momentum is equal to, let me now change this one and we can write that actual momentum is equal to this momentum coefficient beta into rho A into V m square. So, this way, we can calculate it.

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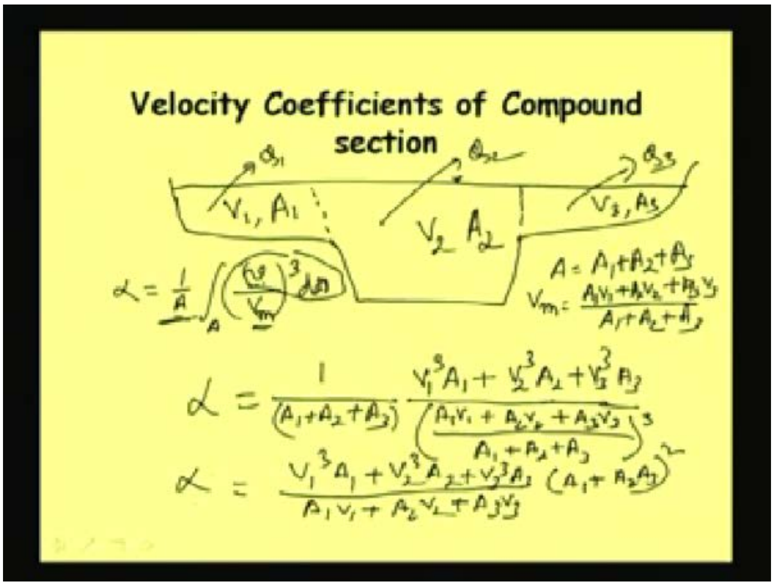

So, another situation where say suppose a compound channel is there. Compound channel means it is like that ok. So, in this compound channel flow depth is suppose this much and errors explaining earlier, say here. Variation of velocity may be within this part is variation of velocity in the lateral direction in this part, may be not that much significant. So, we can consider that vertically also, suppose, we can consider that, this velocity is suppose V, and suppose this is V 1, V 2 and this is V 3 here. We are making some approximation that in this segment, in this sub-area, we are considering a single velocity. Now, the area here, we are marking that this area is say V 1, this is A 2 and this is A 3. Well, then for this sort of area also, this sort of section rather than going for integration, we can do simple summation of this part. We can write an expression for momentum coefficient and velocity coefficient.

So, velocity I mean momentum coefficient and energy coefficient. So, say energy coefficient alpha. So, this alpha is equal to, as we know that it can be expressed as 1 by A and integration of V. Earlier, we were writing V minute V average velocity cube separately, but as it is constant. So, we can bring it within integration also. There is no harm. So, we can write V by V cube. This is the elementary velocity or velocity of the elementary area and then dA, but here in our case, in a compound channel, it will be, say V 1, V 2, V 3 like that, this one. So, what we can write down, total area is nothing, but here, say A 1 plus A 2 plus A 3 and of course, there can be several segments. We can go up to many segments. Well, then what is the mean velocity, say V m. What will be the mean velocity here? We know that the discharge we can calculate as area into velocity.

So, what will be the total discharge flowing? It will be say V 1, V 1 plus A 2, V 2 plus A 3, V 3. These are the discharge, small discharge Q 1, Q 2, Q 3 like that. Suppose, Q 1 is the discharge through this part, Q 2 is the discharge through this part, Q 3 is the discharge through that part, then this will indicate that summation of Q 1 plus Q 2 plus Q 3 and that will give us the total discharge Q.

So, this is divided by the entire area A 1 plus A 2 plus A 3. So, this is our mean velocity. So, this expression alpha, we can write directly as say first one by, for this area we will write as A 1 plus A 2 plus A 3. Then, integration is not required here. So, what we will do is the individual velocity cube into the individual small area. So, here our small area is A. So, what we can write, say V 1 cube into A 1 plus, we are making summation V 2 cube into A 2 plus V 3 cube into A 3. So, this term is being written in this form and that this V is actually nothing, but mean velocity. So, we can write in this form, that is V 1, V 1 plus A 2, V 2 plus A 3, V 3 divided by A 1 plus A 2 plus A 3, but this entire thing, we need to put under cube because this is V m cube. So, this is we are putting like that.

So, finally, what we can write that expression for alpha in a compound channel this V 1, A 2, A 3 is there and there is V 1, A 2, A 3 cube. So, what we can write that this we can write like, first let me write this one say V 1 cube, A 1 plus V 2 cube A 2 plus V 3 cube, A 3 divided by say V 1, V 1 plus A 2, V 2 plus A 3, V 3. Then, this will go to the top. So, this we can write as say A 1 plus A 2 plus A 3 whole square. This is getting cancelled and it is remaining square. So, this will be the expression for velocity coefficient alpha in case of compound channel.

Similarly, we can have an expression for momentum coefficient also in a simplified way for a compound channel. Well, after getting these different points regarding momentum coefficient and velocity coefficient and we need to know about some values. Well, these are some values.

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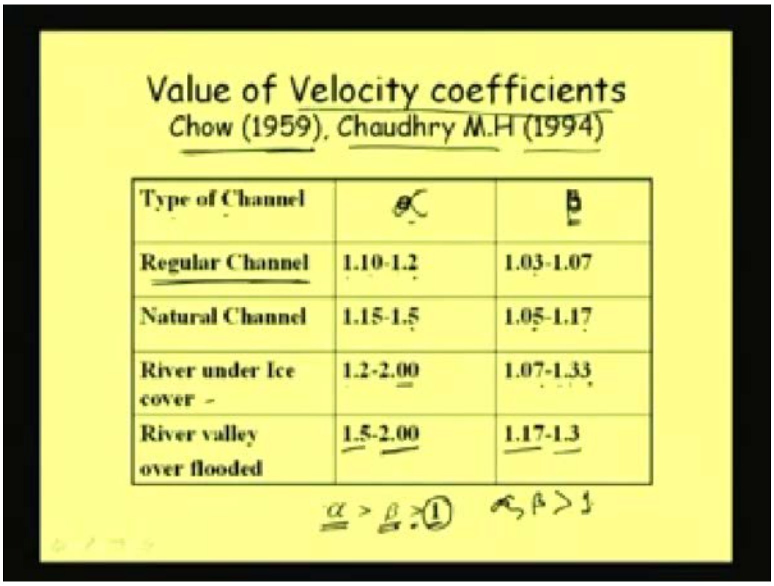

This, there is a typing mistake. This should be alpha because of the font and this should be beta. Well, now value of velocity coefficient, it is 1. Point is very much clear that once we know the value of velocity coefficients, whether it is alpha or beta, I mean if you know the alpha value, then by using the average velocity if we calculate energy, we can get it corrected by multiplying that average multiplying the energy by that alpha value. So, similarly if we calculate the momentum on the basis of the average velocity, then we can get the corrected momentum by multiplying this computed momentum with the beta value.

So, we need to know what is alpha and beta. Fortunately, some scientists conducted experiment and in the books also some standard value for these velocity coefficient are available. You can refer to this slide. The value of velocity coefficients and this was originally given by Chow and Hanif Chaudhry. He compiled in 1994 in his book and so, I am just putting it from there. There is that type of the channels say for regular channel, you are getting that alpha value varies from 1.10 to 1.2, very close to 1 and beta value varies from 1.03 to 1.07. If it is a natural channel, of course, you can always have question, that is natural channel can be again of different type.

Yes, it can be of different type, but of course, that is why there is a range and you need to have some experience for choosing a value between these ranges for a natural channel. There will be some differences, but in general, say for natural channel, we can have it for where the range from 1.15 to 1.5. Similarly, the beta value, we can have say 1.05 to 1.17, then this is a very peculiar case that river under ice cover in a very cold country. We can get this sort of situation that varies from 1.2 to 2. The alpha value and the beta value vary from 1.07 to 1.33.

Well, then river valley over flooded means with a flood plain. When we have a river valley, then suppose in flooding situation, this can be at over flooded, then we can get typical this compound channels sort of things also. For those situations, we consider the alpha varies from 1.5 to 2 and then beta varies from 1.17 to 1.3. These values of course, this is just to have some idea regarding the typical value of alpha and beta. One point is clear from all these values that alpha is always greater than beta and these are always greater than 1. This condition that alpha is greater than beta this is one aspect, then whether alpha or beta, these are always greater than 1.

So, what it means? We know that when we calculate, that is to get the actual energy flowing to a particular section in per unit time, this is obtained by the energy calculated on the basis of average velocity, then multiplied with this alpha. Similarly, momentum multiplied by beta. So, actual value will be always higher than the computed value, actual energy. Suppose, we talk about this will be higher than the value computed on the basis of average velocity. So, this is what is more significant.

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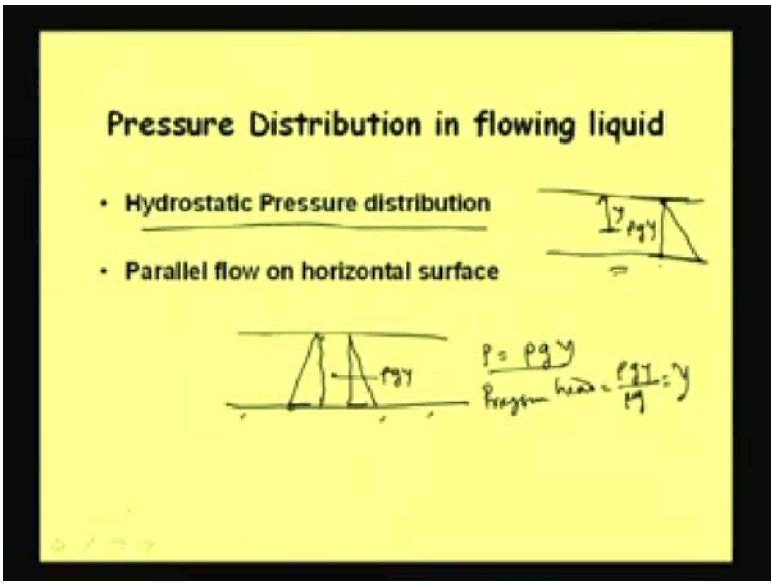

These are all about the variation of velocity. How we take care by using some correction factors, by using some coefficients to have the actual energy and actual momentum? Well, after that we are moving on to the pressure distribution in flowing liquid. Well, before that we have already studied what is hydrostatic pressure, distribution hydrostatic pressure distribution. Suppose, a water depth is here, then at any depth y, our pressure is equal to say rho into g into y. That we know very well.

So, it is proportional to the depth. Hydrostatic pressure is like this. Here, it will be 0 and here, it will be, suppose total depth based on the total depth, the value will be and we can get a pressure distribution like this. Well, now whether in a flowing fluid, whether when the water is flowing, whether we will be getting the same pressure distribution, that is more important.

So, first, let us consider a parallel flow on horizontal surface, say this surface is horizontal and we are having a parallel flow means stream lines are parallel and this is going like that. Then, pressure at any point will be, in fact, suppose, when we talk about pressure, what will be the pressure from this side and that side? One is that, this weight of this is acting at this point, we are getting a pressure, that is equal to rho gy, but what will be the pressure from this side and that side. If I talk, suppose, some pressure will be there from this side and that side, in this direction. If it is a horizontal surface and a parallel flow is, that is a uniform flow sort of things is flowing like that, then pressure from this side and that side will be identical. There will be no significant effect of this pressure on the total pressure.

So, we will be getting the pressure as rho gy and if we talk in terms of pressure head, if we talk in terms of pressure head as we did discuss earlier, it will be say p by rho g. So, it will be y pressure head is y. Well, let me write it fully say rho gy by rho g. So, this will be equal to y. So, that means when the flow is occurring on a horizontal surface and flow is parallel, then parallel with the bed. Then we are getting say pressure head is similar to our pressure is similar to the static pressure condition. So, that pressure we call as hydrostatic pressure.

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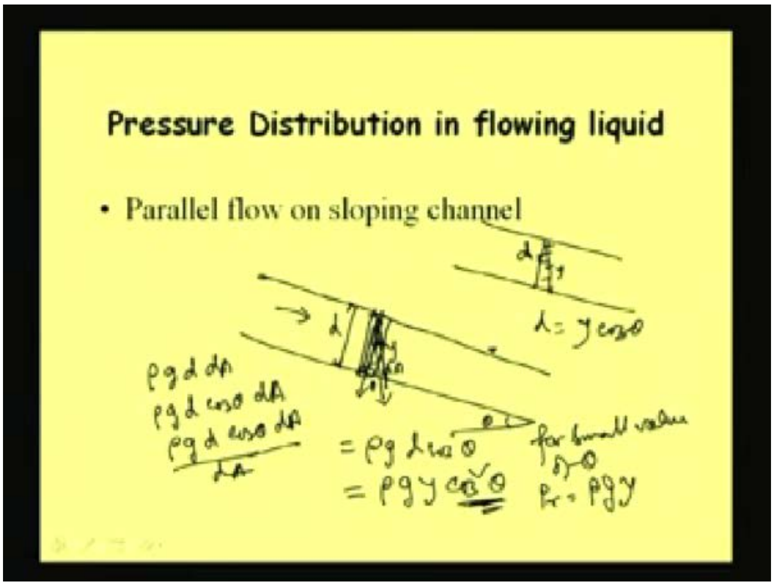

When the channel is not horizontal, whether it has a slope like this and flow is, of course parallel. In earlier case, it was a horizontal channel and there were no slope, but here the flow is parallel, but it has a slope theta. Then, what will be the pressure? At any point, suppose, if I talk about this bed and say this is the depth d, then if I consider a elementary area dA, again if I consider a elementary area dA, then what will happen. The weight of this liquid column, I am drawing a section. I mean taking a section perpendicular to the flow direction. So, this is d, say this height is t, I am taking ok.

Depth means, it is not exactly depth, but the depth of section, if I say depth, then this will be vertical. Now, this will be weight of this flow fluid will be dA into d the mass. So, this will be the mass and then weight is actually rho g and d into dA. This weight will be acting in this direction. So, what will be the force in this direction? That angle is also theta. So, this will be, say rho g d cos theta into dA. This will be the force acting in this direction.

So, what will be the pressure? This divided by dA. So, it will be rho gd cos theta into divided by dA. This is the area. So, this pressure will be equal to rho g d cos theta. So, this is the pressure we are getting in this direction. Now, if I write it in terms of y, say y is the depth, suppose if I take a vertical line, this is the depth y. Generally, for practical purpose what we do? We measure the depth because in a particular point, we understood, we talked about the vertical depth. So, we are getting the depth y.

So, what will be the value of this d in terms of y because depth angle is also, let me draw a fresh figure. If I take this as the y and this as the v, then this yd is nothing, but equal to y cos theta. So, what we will be getting, this we can write in terms of y as rho gy cos square theta. So, this will be the expression for pressure at any point. Accordingly, this y will be varying with different depth, we are getting different pressure and we can draw a pressure diagram in that line, but when this theta is very small value of theta, this cos theta become 1.

So, cos square theta, we can just neglect and then we are getting this is equal to for small value of theta. We can have this pressure is equal to rho gy means, again it is hydrostatic pressure. So, when the theta is small, then only we can consider this to be hydrostatic pressure. Otherwise, not otherwise, we need to multiply it by cos square theta.

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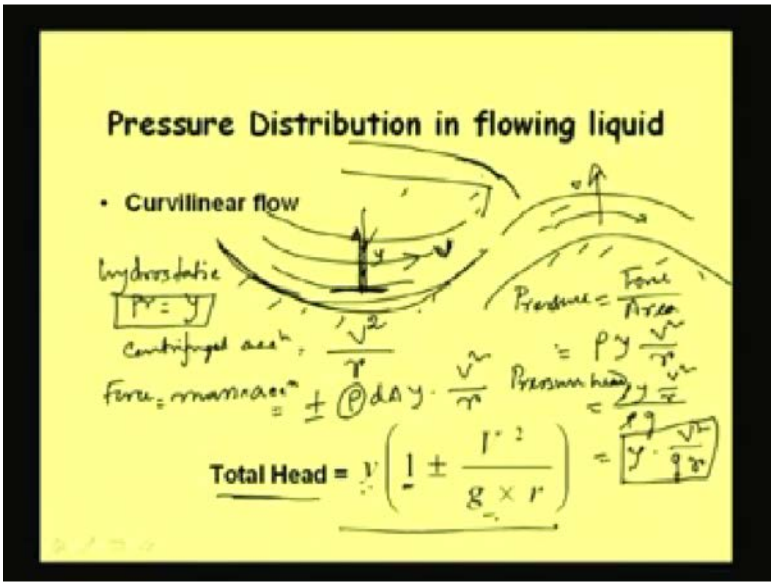

Let me see another case. If the flow is occurring in a curvilinear way, may be the flow is, suppose this is the channel bed and flow is going like this. This is the surface, but when this sort of flow is occurring or it can be the other way also, say this is the bed, this is the bed and the flow is moving like this. This can be portraying. Now, what will be the pressure? At any level, suppose if I talk at this level, what will be the pressure? As we know, let me write the pressure head at this point. Suppose, this is this depth is y, then just hydrostatic pressure will be y. First is that hydrostatic pressure will be y.

Now, whether this only this hydrostatic pressure will be acting there or something else will be there. Hydrostatic pressure will be y as we have seen, but this flow is not parallel. It is moving in a curvilinear way. Now, apart from this hydrostatic pressure, we are getting because of the weight of the fluid that we have already discussed, but apart from the weight of the fluid, here another force is acting. When something is moving in a curvilinear way, then this fluid is subjected to one acceleration and that we call that centrifugal acceleration.

Suppose, if it is moving with a velocity V, then it will be that centrifugal acceleration will be equal to say V square by r. What is that r? It is v square by r. This r is the radius of curvature. What is the curvature? Of this particular flow part, this is what the acceleration and we know that how much at this point, this part of flow is moving. So, what is the mass? If we see, then we can write that. Suppose, this small area is gA, then additional force what is acting is equal to, force is equal to mass into acceleration, that is, extra acceleration. Whatever we have, the earlier force we got due to gravitational acceleration, but this is due to this curvilinear flow.

So, this is equal to you can write, say rho into this. If delta A is the area rho into delta A into y, this is the volume and this is y. This is the mass multiplied by the density. So, we are getting mass into say v square by r. So, this expression, we are getting for this extra additional force. Now, when the flow is in a convex way, then it will be acting in the downward direction. When the flow is over a concave phase, concave channel, then it will be in the outward direction.

So, that is why, this we can write as this force is equal to mass into acceleration. You can put a plus minus sign because it can be plus or it can be minus. Well, then from this here, if we say this is the force, then pressure will be, we will have to divide it by the area. So, it will be pressure is equal to, you can write pressure is equal to force by area pressure is equal to force by area. So, this we can write as if we divide this term by area, this will become rho y. Then, v square by r rho y v square by r and then when we write in terms of head, head is equal to again pressure. Pressure head will be equal to say per unit weight.

So, unit weight means, we need to divide it by rho g. So, it will be rho y square by r divided by rho g. So, this rho rho getting cancelled, y by gv square by r. So, this will be an additional pressure. Now, if we combine this and that, now let me combine this pressure hydrostatic pressure which is coming due to weight of the fluid. Then, this pressure that let me write it more clearly that this is equal to say y into v square by g into r. This we can write like that.

So, if I combine this and that then we are getting total head is equal to y. I am bringing this y and y common. So, this remains one. This y for hydrostatic and then, v square by g r, this is for this centrifugal force. So, that way for a curvilinear flow, we can get this total head in this expression, that is y is equal to 1 plus minus v square by g r. So, in our various computational works, when the flow is moving in a curvilinear way, it is not necessary that always will have a curvilinear path like this. I mean curvilinear channel like this. Sometimes, we can have in a straight channel also. Suppose, there is a fall as I was drawing and water is falling like this, then this part, there is a curvature. So, the hydrostatic pressure cannot be considered here or if we consider the hydrostatic pressure, that means, we are making some assumption and there is a scope of error.

So, if you become clear about that part, then we can go ahead. We know that what mistake or what sort of error can be introduced there. Well, with this, let me conclude this discussion. Today, we have discussed about, say how we can make use some correction factor for taking care of the variation of velocity within the flow section. Then, of course, we have discussed how the pressure in the flowing fluid can be different from the hydrostatic pressure. Of course, for some of the very simple situation of parallel flow, we can consider hydrostatic pressure, but for curvilinear flow, for a flow in a very steep channel, the pressure is not exactly like that of hydrostatic pressure. We need to make some correction there.

So, with all this basic information of open channel flow, we hope we will be able to go in the next class for discussing the governing equation. How? This flow now can be expressed in terms of some equation. Well, thank you very much. Hope to meet you in the next class. Thanks.