Fluid Mechanics and Its Applications
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Lecture 10A
Open-channel Flow

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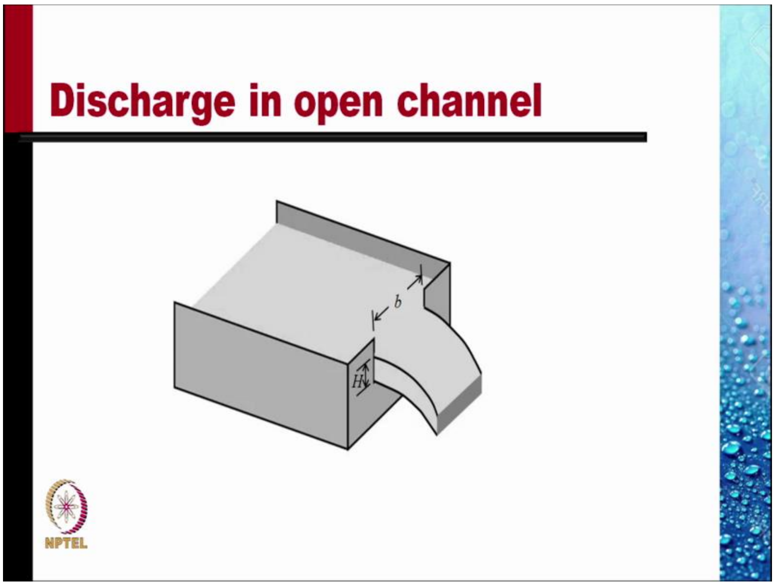

Let us do another application of Bernoulli equation and this time to open channel flow. This picture shows a channel in which a liquid is flowing. There is an obstruction in the channel and in this obstruction, a cut-out has been made of width b. The liquid flows out of that cutout says that it is till a height H above the crest of the cutout. We will calculate the flow rate based on the value H and b.

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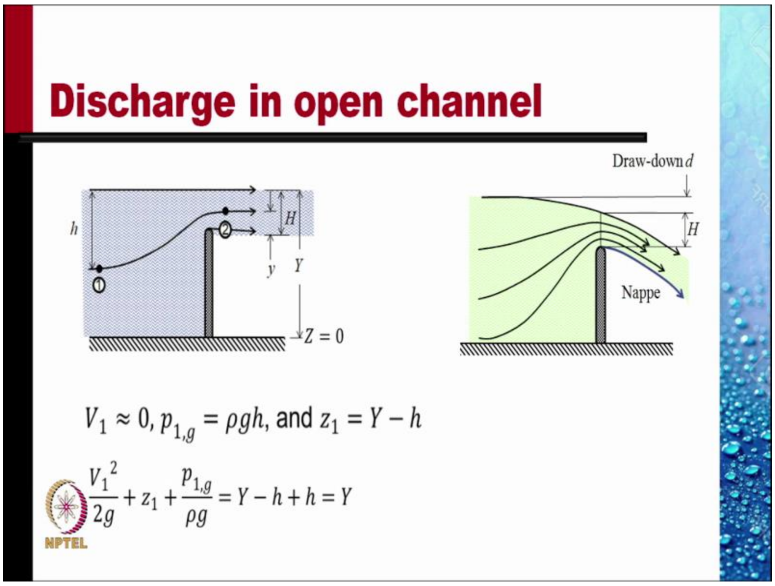

This is a typical picture of streamlines in such a flow. It would be quite complicated if you analyze like this. So we make a model. Let us assume that this no draw-down and the liquid is coming out of the jet which is horizontal. Let us consider a streamline within this flow from 1 to 2. We assume that the width of the channel and height in the main channel is much larger than the height in the flow over the obstruction.

So, the velocity at point 1 can be considered to be much lower than the velocity at point 2. V_1 is approximately 0. The pressure at point 1, if the velocities there are much smaller, then the pressure distribution vertically within the main channel can be considered to be hydrostatic. So that the gauge pressure at point 1 can be written as $\rho g h$. The elevation z_1 is capital $(Y-h)$, where Y is the total height of the flow in the channel, and h is the depth of point 1 from the free surface.

Since, the pressure below the jet and above the jet are both atmospheric, it is fair to assume that the pressure at point 2 is atmospheric. And then the Bernoulli equation is written simply as $\frac{V_1^2}{2g}+z_1+\frac{p_{1,g}}{\rho g}$ is equal to $(Y-h+h)=Y$. This is the evaluation or point 1.

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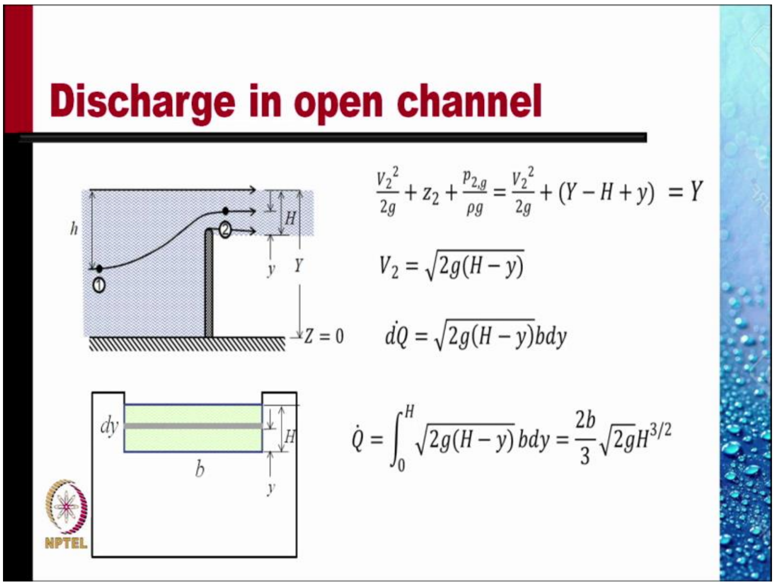

This would be also be at the second point. equal to the velocity there is $\frac{V_2^2}{2g}+(Y-H+y)$, and so, this would give you a capital Y as evaluated before. So, this gives you $V_2=\sqrt{2g(H-y)}$. This is the velocity at point 2. It varies with y, the location of the point within the jet. This value is maximum when $y=0$. That is, at the bottom most point in the jet coming out. And this is minimum when $y=H$. We can assume the velocity there was 0.

We can find the discharge by considering the flow rate through this jet of width b, height H. We consider a small slice of thickness dy at height y. We have obtained the velocity V_2 here. So discharge through this slice is $dQ = V_2 bdy$, and to find out the total discharge, we integrate this from $y = 0$ to $y = H$. And we find this to be $\frac{2}{3}b\sqrt{2g}H^{3/2}$.

So, if I know b and if I can measure the value of H, the height up to which the liquid flows above the crust of this obstruction, we can find out the flow rate. This is a method used in the actual field measurements of the flows through channels.

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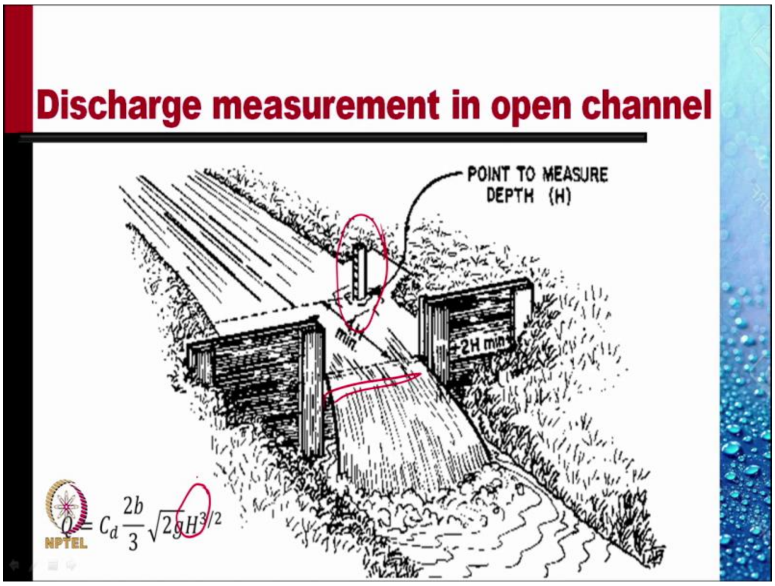

For example, in this channel with the obstructions, a vertical scale is erected so that the 0 of this coincides with the base of the cutout here in this obstruction. So with water flowing there, we measure the level. And this measurement is H. If we know the width b, using this equation, $\dot{Q} = C_d \frac{2}{3} b\sqrt{2g}H^{3/2}$, we can measure the discharge rate.

C_d is called the discharge coefficient. And this discharge coefficient is actually a factor of ignorance. The lot of assumptions that were made in deriving this formula. So Cd is an experimentally determined coefficient that corrects for the assumptions.

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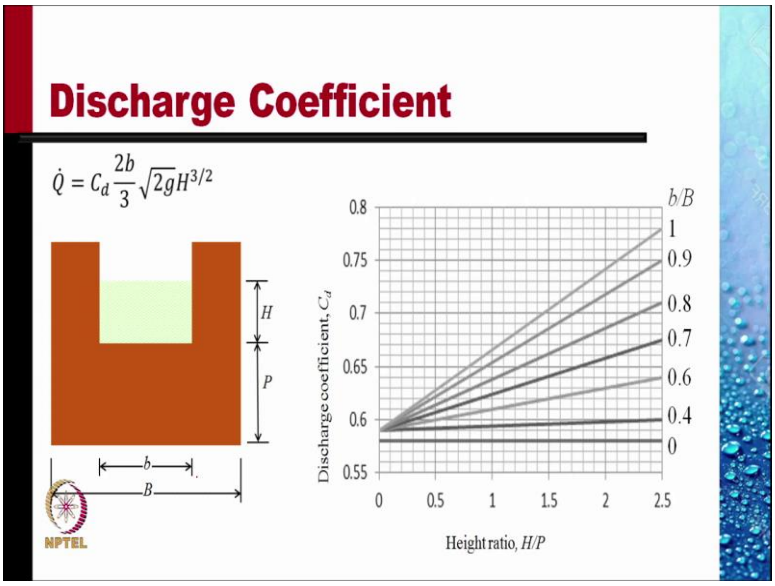

For natural channel, the C_d varies with the height ratio H/P and the width ratio of b/B in this manner. So for each such measuring weir that we can construct we have a calibration chart, a discharge coefficient chart and by measuring H and b and finding from this the discharge coefficient, we can find out the actual discharge. This is only one design of a measuring ware for the flow.

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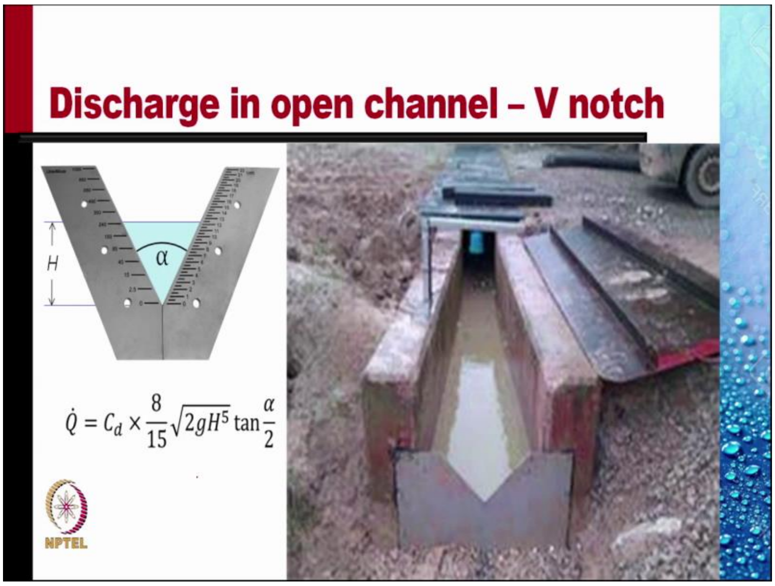

We can have a triangle weir like shown in this picture. We can do exactly similar calculations and we can find out that the flow rate in this case is given by $C_d \times \frac{8}{15}\sqrt{2gH^5}\tan\frac{\alpha}{2}$, where α is the angle of the Vee through which the flow takes place.

This weir plate has been directly calibrated into discharge rate. Here the flow rate is proportional to $H^{5/2}$ as against $H^{3/2}$ in the rectangular notch that we saw in the last example.

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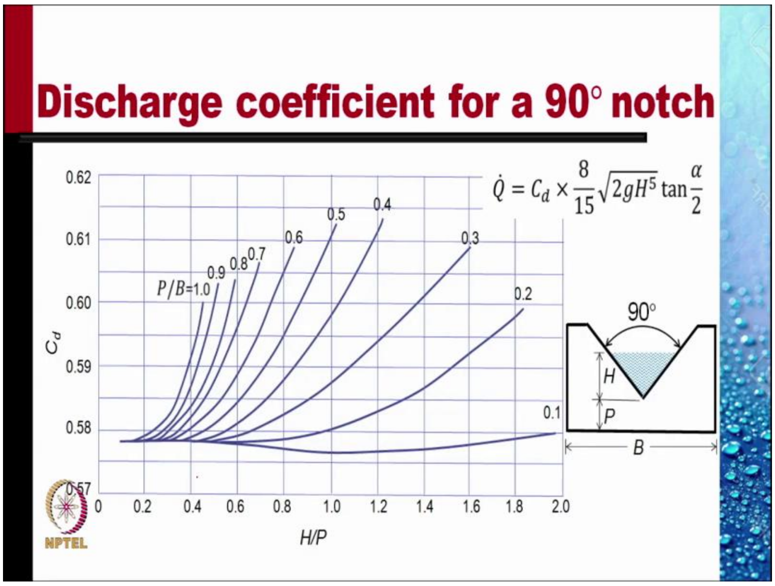

These are the typical discharge coefficients for a 90 degrees notch.