# HYDRAULIC STRUCTURES FOR CHANNELS

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# INTRODUCTION

Hydraulic structures in channels have three main functions:

- measuring and controlling discharge
- controlling water levels
- dissipating unwanted energy.

Hydraulic structures are also very useful for getting rid of unwanted energy. When water flows down dam spillways it can reach speeds of 60 km/h and more and is capable of doing a lot of damage. Hydraulic structures are used to stop such high speed flows and dissipate the kinetic energy by creating **hydraulic jumps**.

So a **hydraulic structure** may be used for *discharge measurement*, and at the same time may be performing a *water level control function* and *dissipating unwanted energy*.

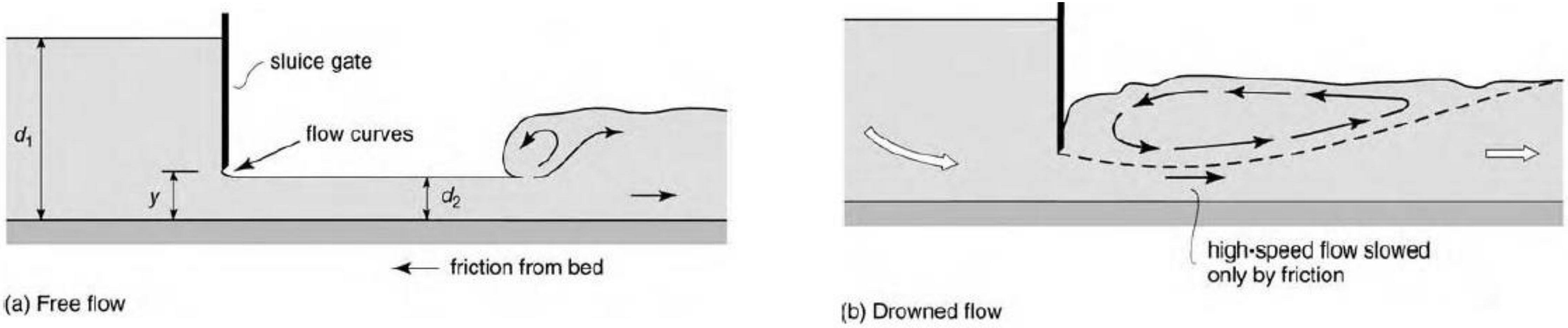
From the point of view of measuring discharge and controlling water levels, there are only **two types of structure**:

1) Some structures allow water to flow through them and these are called *orifice structures*.
2) Others allow water to flow over them and these are called *weirs or flumes*.

Hydraulically, they behave in quite different ways and so each has certain applications for which they are best suited. The energy dissipating function can be attached to both of these structure types.

# ORIFICE STRUCTURES

In practice, **orifice structures** have fixed or movable gates rather than just a simple opening. The sluice gate is a good example of this type of structure. The flow under the gate is very similar to orifice flow but not quite. First, the flow contracts only on its upper surface as it goes under the gate and second there is additional friction from the bed of the channel.




7.3 Orifice structures.

# ORIFICE STRUCTURES

So to find a formula for discharge for this structure the orifice formula is a good starting point, but it needs modifying. The formula for discharge from an orifice is:

$$Q = a\sqrt{2gh}$$

Modifying this for a sluice gate:

$$Q = C_d a\sqrt{2gd_1}$$

Where *Q* is discharge ($m^3/s$); *a* is area of gate opening ($m^2$); $C_d$ is a coefficient of discharge; $d_1$ is the water depth upstream of the orifice (m), *a is* area of the gate opening.

# *FREE AND DROWNED FLOW*

The **sluice gate** example shows the flow freely passing under the gate with a *hydraulic jump* downstream. The **downstream depth *d2*** has no effect on the **upstream depth *d1***. This is referred to as *free flow* and the formula quoted above for calculating discharge is based on this condition.

In some circumstances the **jump** can move upstream and drown out the gate and is referred to as *drowned flow* (Figure 7.3b). The flow downstream may look very turbulent and have the appearance of a jump but inside the flow the action is quite different. There is very little turbulent mixing taking place and the super-critical flow is shooting underneath the sub-critical flow. This high speed jet is not stopped quickly as it would in a jump but slows down gradually over a long distance through the forces of friction on the channel bed. This flow can do a lot of damage to an unprotected channel even though the water surface may appear to be quite tranquil on the surface. *Under drowned conditions the formula for discharge* must be modified **to take account of the downstream water level** which now has a direct influence on the upstream water level.

# WEIRS AND FLUMES

Weirs and flumes are both overflow structures with very different characteristics to orifices. Many different types of weirs have been developed to suit a wide range of operating conditions, some comprise just a thin sheet of metal across a channel (*sharp-crested weirs*), whereas others are much more substantial (*solid weirs*).

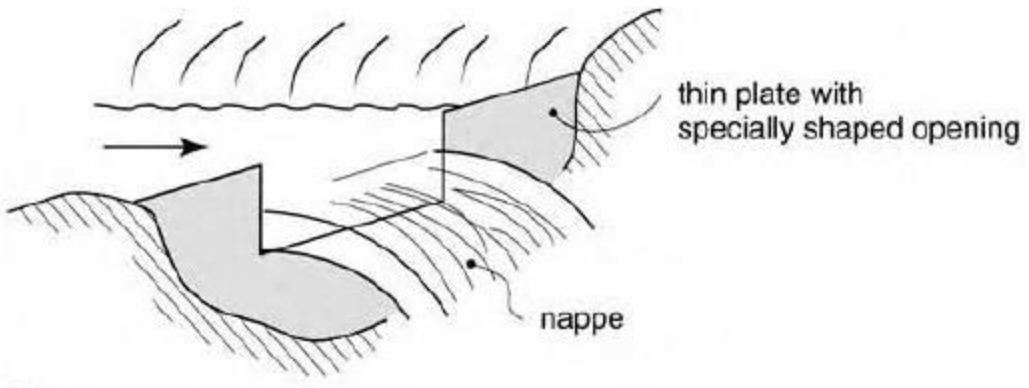
Both are based on the principle of changing the energy in a channel and using the energy and continuity equations to develop a formula for discharge based on depth (pressure) measurements upstream.

But **solid weirs** rely on an energy change which is sufficient to make the flow go **through the critical point**. Because of this they are sometimes called ***critical-depth structures***.

**Sharp-crested weirs** do not have this constraint – but they do have others.

# SHARP-CRESTED WEIRS

Sharp-crested weirs are used to measure relatively small discharges . They comprise a thin sheet of metal such as brass or steel (sometimes wood can be used for temporary weirs) into which a specially shaped opening is cut. **By measuring the depth of water above the opening**, known as the **head on the weir**, the discharge can be calculated using a formula derived from the energy equation. There is a unique relationship between the **head on the weir** and the **discharge** and one simple depth measurement determines the discharge.




(a)

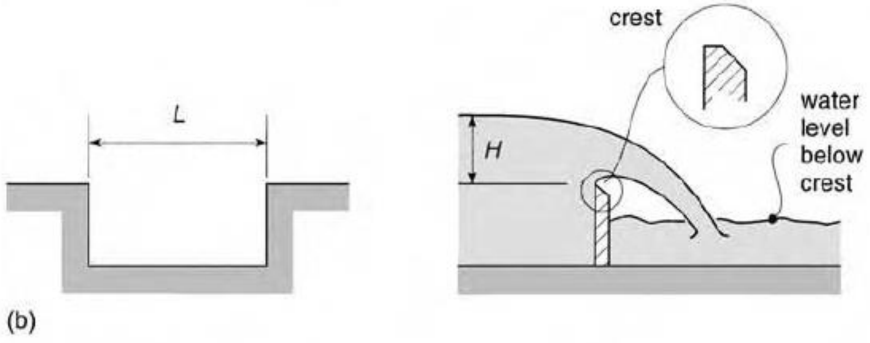
# 1) RECTANGULAR WEIRS

This weir has a rectangular opening (Figure 7.4b). Water flows through this and plunges downstream. The overflowing water is often called the *nappe (водосливная струя)*. The discharge is calculated using the formula:

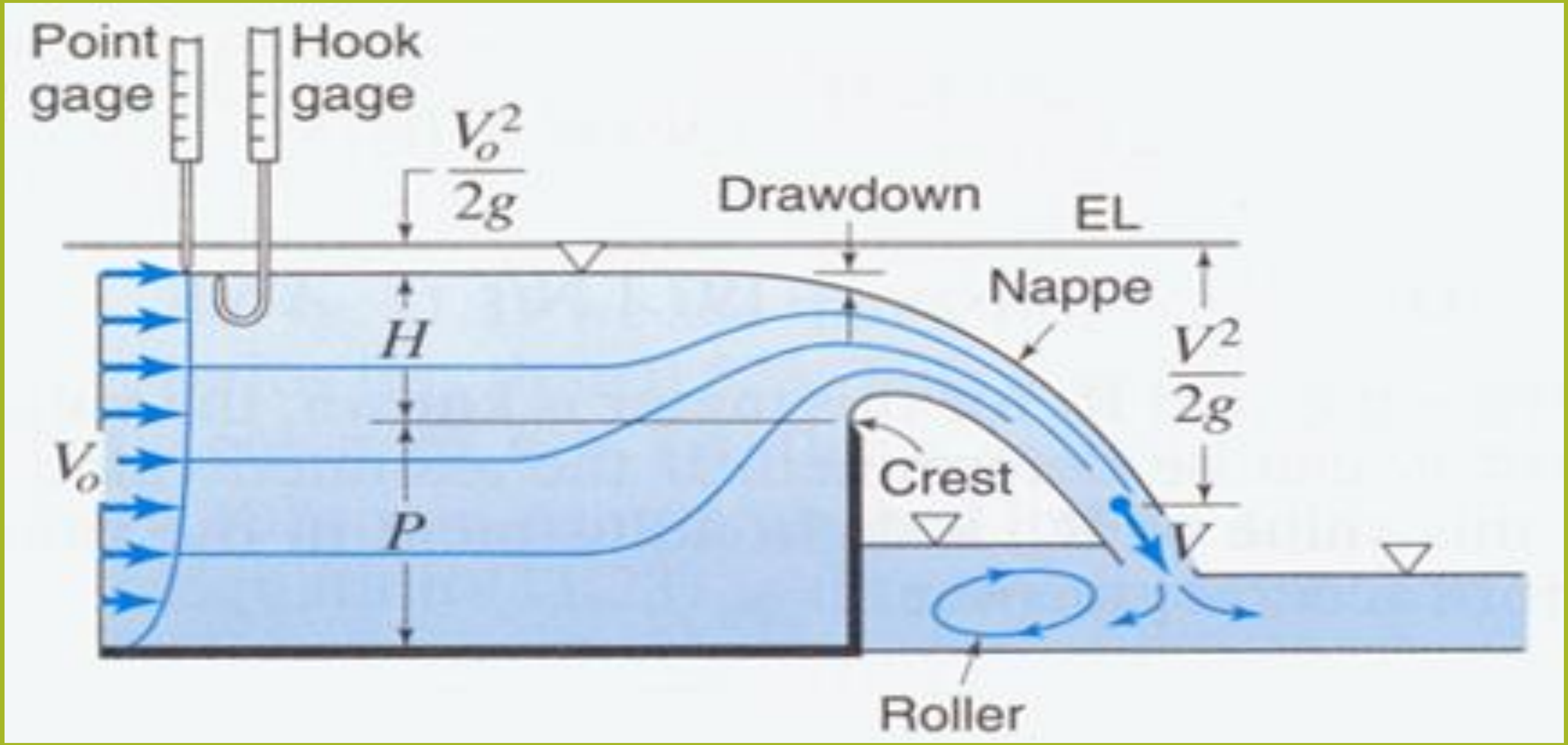
$$Q = \frac{2}{3} C_d L \sqrt{2g}\, H^{1,5}$$

where *Cd* is a coefficient of discharge; *L* is length of weir (m); *H* is the head on the weir measured above the crest (m).

*Cd* allows for all the discrepancies between theory and practice.



# Definition Diagram and Analysis of Sharp-Crested Weirs




Drawdown at crest is typically ~0.15 *H*

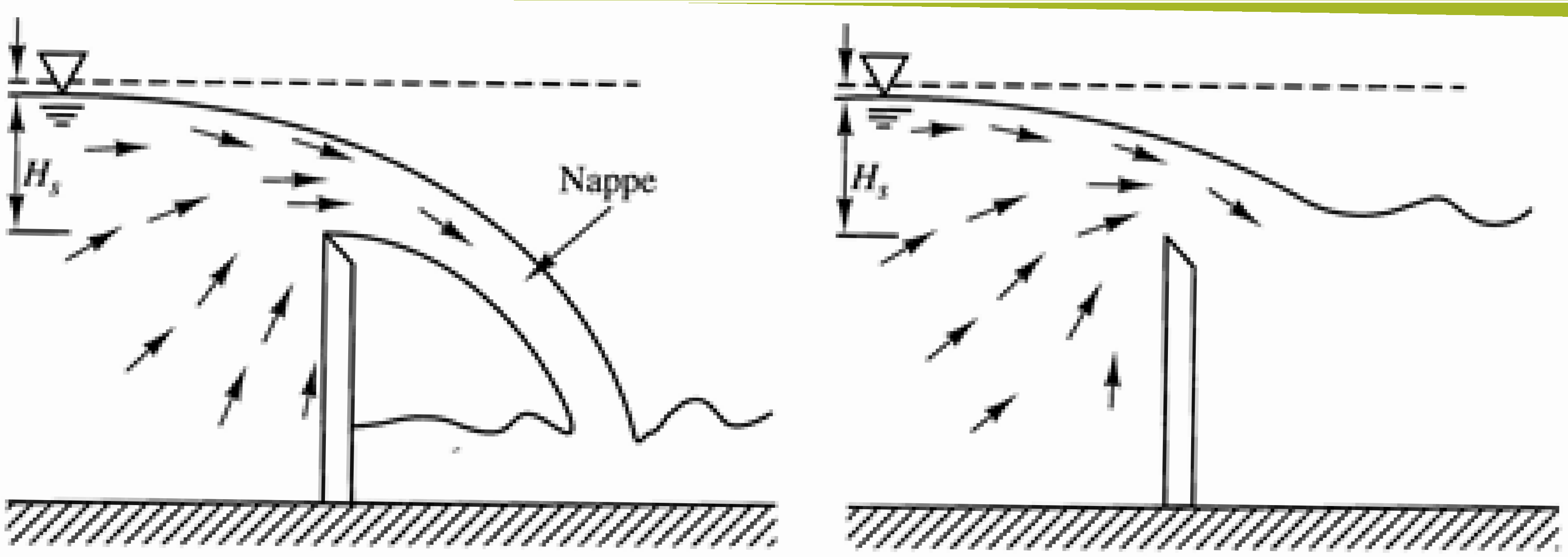
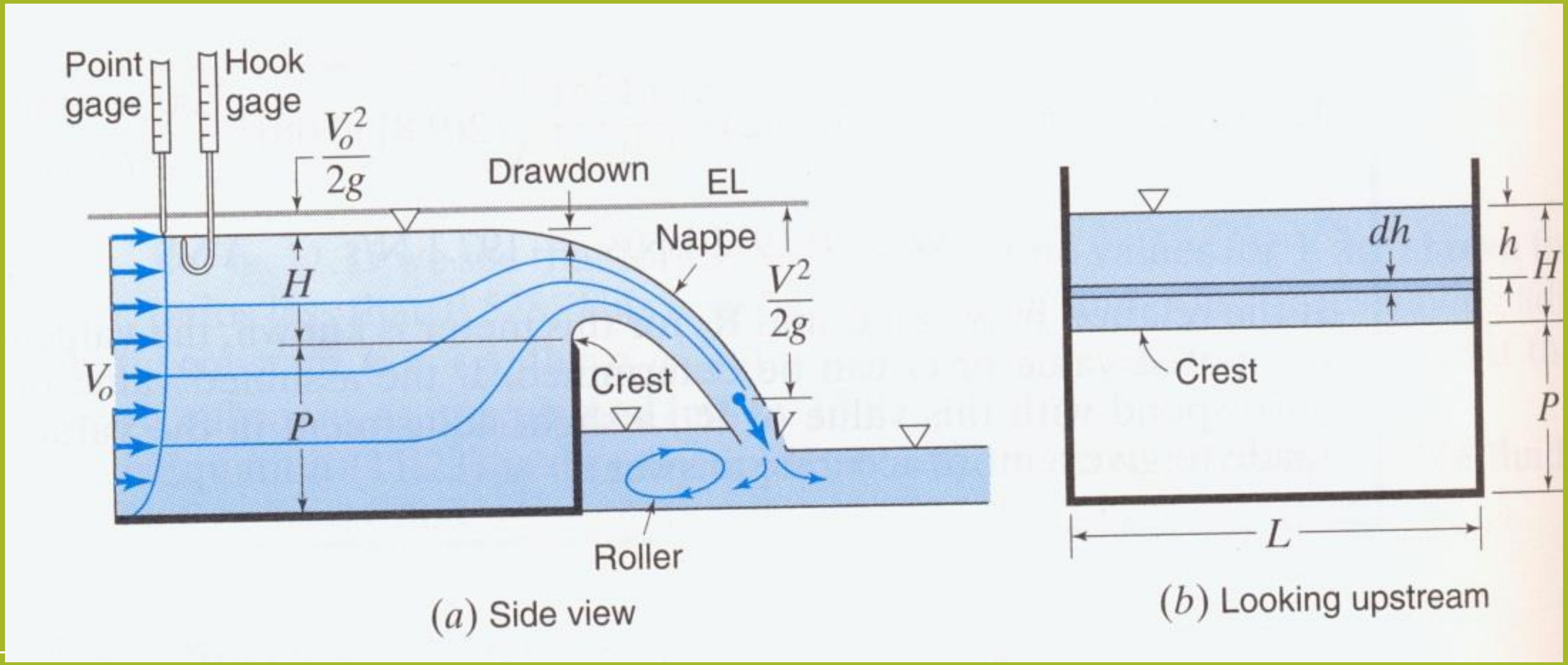



**Figure 8.8 (a)** Flow over sharp-crested weir (free-falling nappe and submerged flow)

Nappe entrains air underneath it and can collapse onto the downstream side of the weir; following analysis assumes that this does not occur (can ventilate this area to assure an air space)

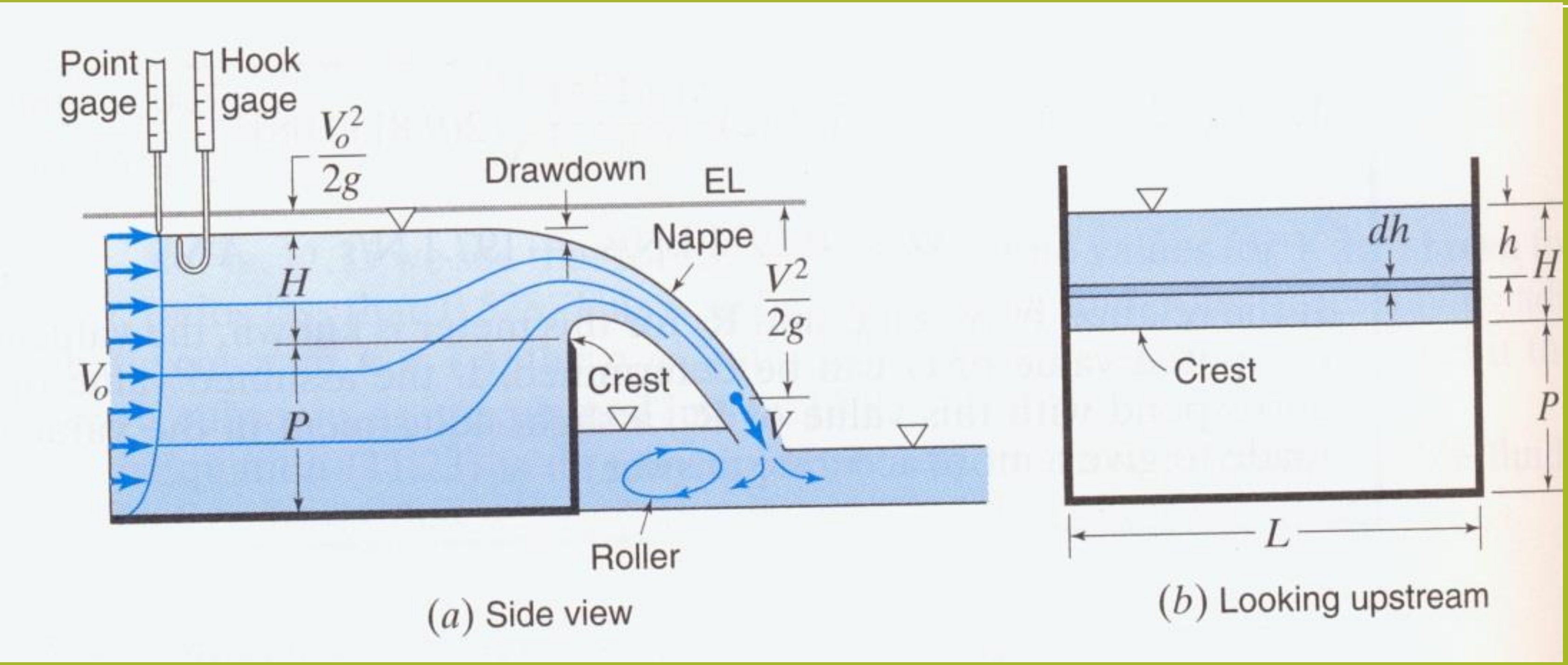



Consider thin layer *dh* in plane of weir in a rectangular channel. Assuming $V^2 >> V_o^2$ and negligible frictional headloss, $V=(2gh)^{0.5}$, so (replacing *L* by *b*):

$$dQ = bdh\sqrt{2gh}$$

$$Q = b\sqrt{2g}\int_0^{H_C} h^{1/2}dh = \frac{2\sqrt{2g}}{3}bH_C^{3/2}$$

where $H_C$ is the distance from the crest of the weir to the water surface at that location.




Measurements of the water surface elevation above the weir crest are typically made upstream of the weir, where the water surface has not been significantly affected, and this value of *H* is used instead of $H_C$ in the calculation. To account for this and other approximations, an empirical coefficient is added to the equation:

$$Q = \frac{2\sqrt{2g}}{3} C_{w,rect} b H^{3/2}$$

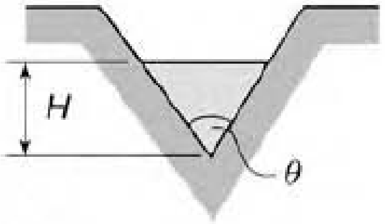
$C_w$ can be approximated by $0.611+0.075(H/P_w)$ and is typically in the range 0.64-0.70.

# 2) VEE-NOTCH WEIRS

This weir has a triangular shaped notch and is ideally suited **for measuring small discharges** (Figure 7.4c). If a rectangular weir was used for low flows, the head would be very small and difficult to measure accurately. Using a **VEE weir**, the small flow is concentrated in the bottom of the **VEE** providing a reasonable head for measurement. The discharge is calculated using the formula:

$$Q = \frac{8}{15} C_d \sqrt{2g} \tan\left(\frac{\theta}{2}\right) H^{2,5}$$

where $\theta$ is the angle of the notch.

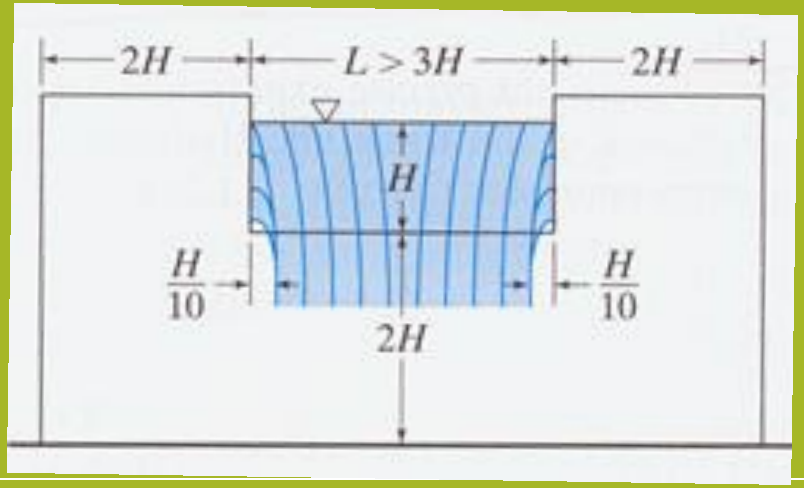



(d)

7.4 Sharp-crested weirs.

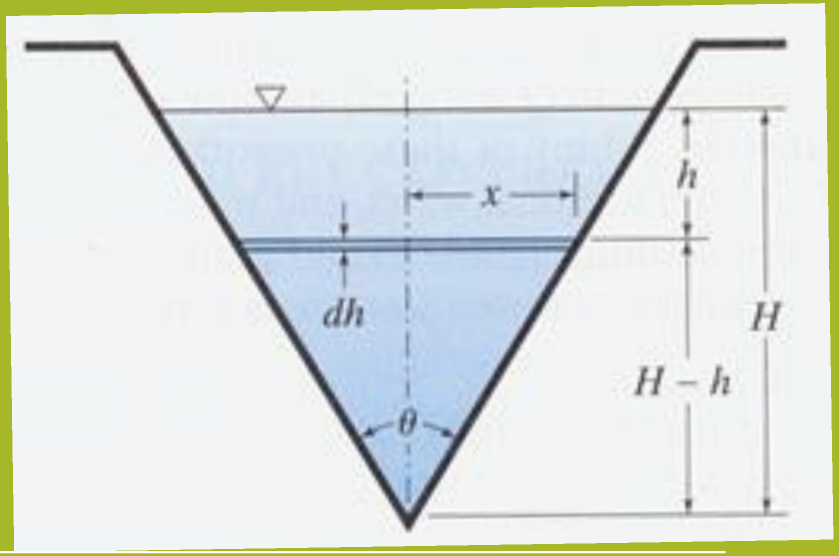
(c) Photograph of a V-shaped weir

# Other Common Shapes for Sharp-Crested Weirs




Contracted weir

Weir can totally block part of the channel width, in which case the channel is **contracted**.




V-notch or Triangular weir

V-notch weir useful if low flows are of interest, since they could cling to the plate of a rectangular weir. For V-notch weirs:

$$Q = C_{w,V-notch}\frac{8}{15}\tan\left(\frac{\theta}{2}\right)\sqrt{2g}H^{5/2}$$

$C_{w,V\text{-}notch}$ typically ~0.6

# *SOME PRACTICAL POINTS*

There are several conditions that must be met for these weirs to work properly.

1. Flow over the weir must be open to the atmospheres so that the pressure around it is always atmospheric.

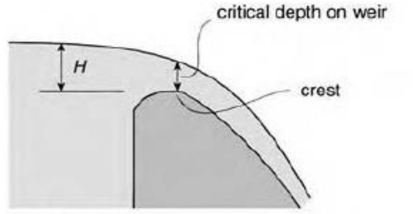
2. The weir crest must always be set above the downstream water level. This is the *free flow* condition for sharp-crested weirs. If the downstream level rises beyond the crest, it starts to raise the upstream level and so the weir becomes *drowned*. Another word that is used to describe this condition is *submerged flow*. **The formula no longer works when the flow is drowned** and so this situation must be avoided by careful setting of the weir crest level.

3. The head *H* must be measured a few metres upstream of the weir to avoid the draw-down effect close to the weir.

**Sharp-crested weirs** can be very accurate discharge measuring devices provided they are constructed carefully and properly installed. However, they can be easily damaged, in particular the sharp crest. **For this reason** they tend to be unsuited for long-term use in natural channels but well suited for temporary measurements in small channels, in places where they can be regularly maintained and for accurate flow measurement in laboratories.

# SOLID WEIRS

These are much more robust than sharp-crested weirs and are used extensively for flow measurement and water level regulation in rivers and canals.



(a) Solid weir

All solid weirs work on the principle that the flow over the weir must go through the critical depth.

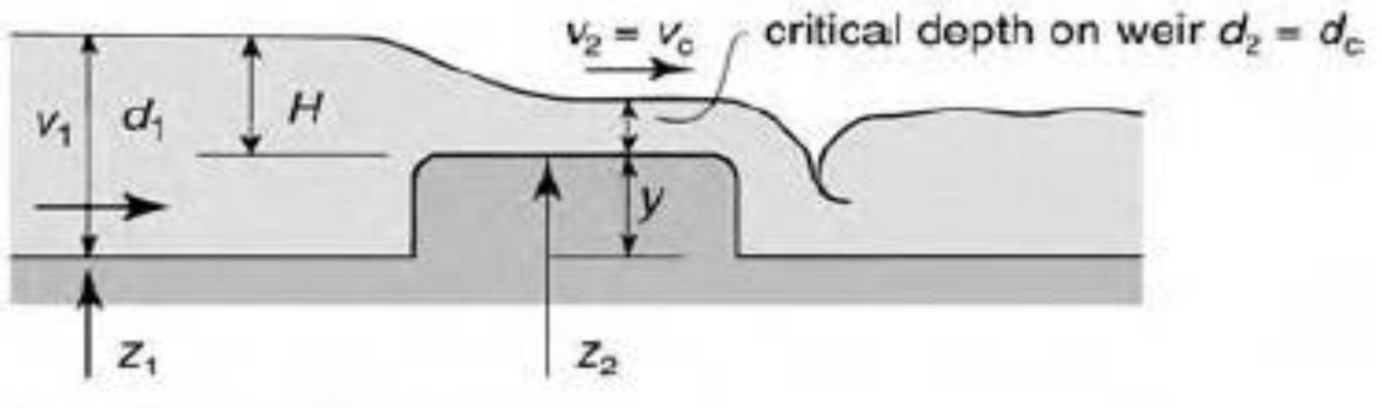
The formula links the channel discharge (*Q*) with the upstream water depth *measured above the weir crest* (*H*).

$$Q = CLH^{1.5}$$

where *C* is weir coefficient; *L* is length of the weir crest (m); *H* is head on the weir measured from the crest (m). As there is some draw down close to the weir, the **head** is usually measured a few metres upstream where the water level is unaffected by the weir.

# SOLID WEIRS: 1) *Broad-crested weirs*

These are very common structures used for flow measurement. They have a broad rectangular shape with a level crest rounded at the edge (Figure 7.5b).



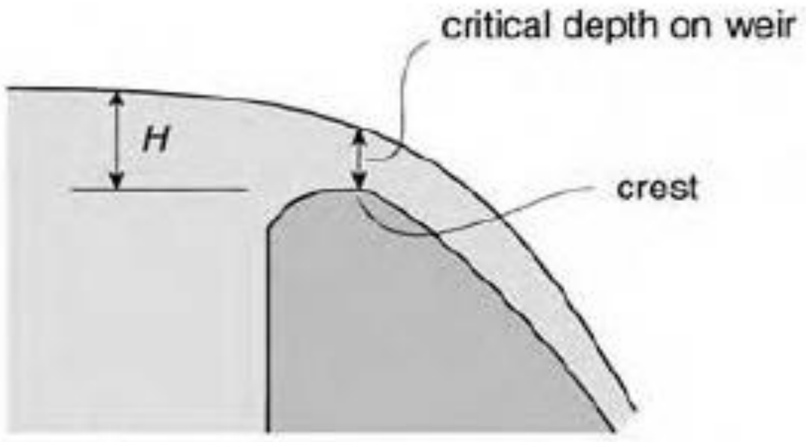
(b) broad-crested weir

The value of *C* for a broad-crested weir is 1.6 and so the formula becomes: $Q = 1.6\, L\, H^{1.5}$

One disadvantage of this weir is the region of dead water just upstream. Another is the **head loss** between the upstream and downstream levels. Whenever a weir (or a flume) is installed in a channel there is always a **loss of energy** particularly if there is a **hydraulic jump** downstream. This is the hydraulic price to be paid for measuring the flow.

# SOLID WEIRS: 2) *Round-crested weirs*

Weirs of this kind are commonly used on dam spillways (Figure 7.5a). The weir profile is carefully shaped so that it is very similar to the underside of the falling nappe of a sharp crested weir. By constructing a weir to the dimensions given in their publications, the discharge can be measured accurately using their *C* values (usually between 3.0 and 4.0).



(a) Solid weir

$$Q = CLH^{1.5}$$

# DISCHARGE MEASUREMENT.

Weirs, flumes and orifices can all be used for discharge measurement. But weirs and flumes are better suited to measuring discharges in rivers when there can be large variations in flow.

Weirs and flumes not only require a simple **head reading** to measure discharge but they can also pass large flows without causing the upstream level to rise significantly and cause flooding.

Orifice structures too can be used for flow measurement but both upstream and downstream water levels are usually required to determine discharge. Large variations in flow also mean that the gates will need constant attention for opening and closing.