The 20th week

Measuring flow in open channels (weirs)

Broad-Crested and Sharp-Crested Weirs

Weirs are overflow structures that alter the flow so that:

1. Volumetric flow rate can be calculated,

2. Flooding can be prevented, or

3. Make a body of water more navigable

Types of Weirs:

Main Types of Weirs

1. Sharp-Crested
    a. Rectangular
    b. Triangular
    c. Trapezoidal

2. Broad-Crested
    a. Rectangular

Sharp- vs. Broad-Crested Weirs

SHARP-CRESTED WEIR	BROAD-CRESTED WEIR
Critical depth (yc) occurs off the crest of the weir	Critical depth (yc) occurs at the crest of the weir
Usually used to: 1. Measure the discharge of smaller rivers and canals 2. Change water elevation of smaller rivers and canals	Usually used to: 1. Measure the discharge of larger rivers and canals 2. Change water elevation of larger rivers and canals

Sharp-Crested Weir

There are three main types of sharp-crested weirs:

1.Rectangular—Measure Discharge and Change Water Elevations

2.Triangular—Measure Discharge

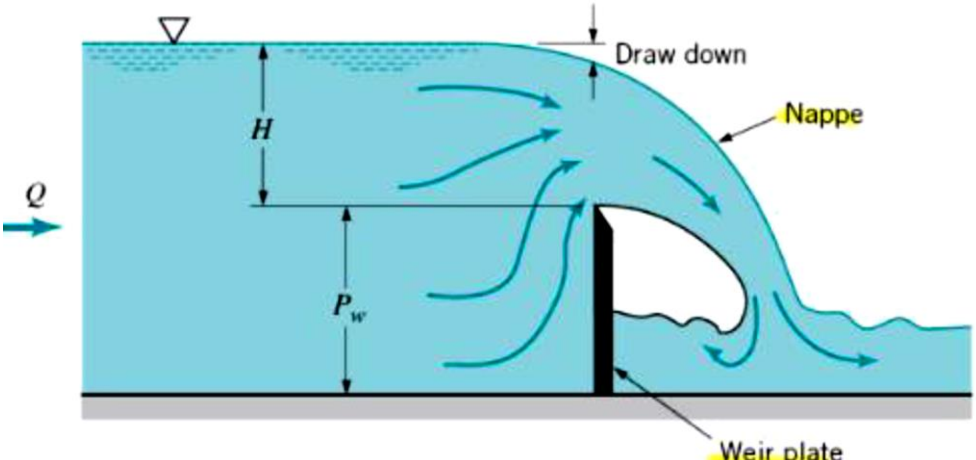
3.Trapezoidal—Measure Discharge and Change Water Elevations with Large Head

Sharp-crested weirs are usually used for smaller rivers and canals.

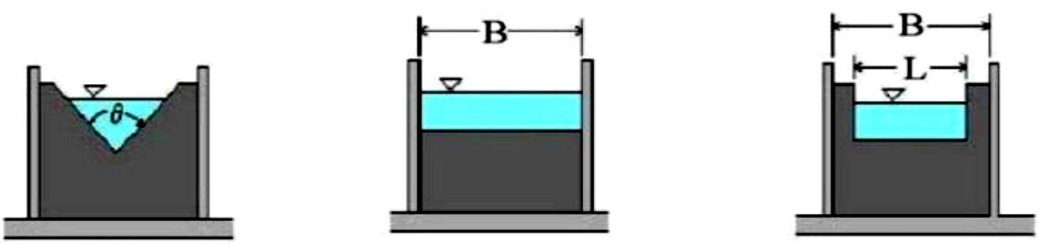
Sharp crested weirs differ from broad crested weirs due to the detached water surface falling away from the downstream edge of the structure, known as a free-falling nappe

▪The flow surfaces at the top and bottom of the nappe are exposed to the air and at atmospheric pressure

▪A nappe that clings to the weir must be avoided in order to improve the accuracy of the weir discharge calculation



sharp-crested weir



v notch weir | suppressed rectangular | contracted rectangular

Sharp-Crested Weir Rectangular/Suppressed Discharge

▪Rectangular and suppressed weirs have the same general discharge equation (below), but differing weir lengths that the water flows over

$$Q = \frac{2}{3} C_D \sqrt{2g}\, BH^{3/2}$$

▪$C_D = 0.602 + 0.083H/P$

- Where:
- Q (m^3/s) is the volumetric flow rate over the weir
- C_D is the discharge coefficient usually ranging from 0.60 to 0.62
- H (m) is the head over the weir(from the weir crest to the upstream water surface)
- P (m) is the height of the weir plate
- B (m) is the width of the contracted notch (rectangular), or the width of the channel (suppressed)

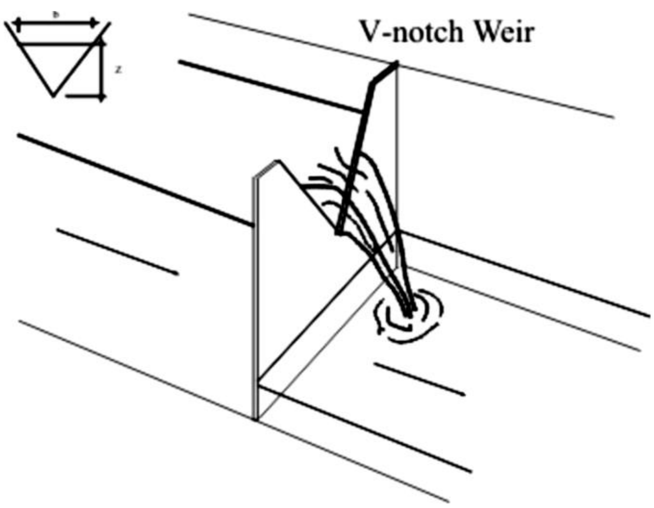
▪g is the acceleration of gravity (9.81 m/s^2)

Sharp-Crested Weir V-Notch (Triangular)

▪Used in cases of small discharge

- Best weir to measure discharge in an open channel

▪Highest accuracy when measuring flow rate (usually +/-2%)

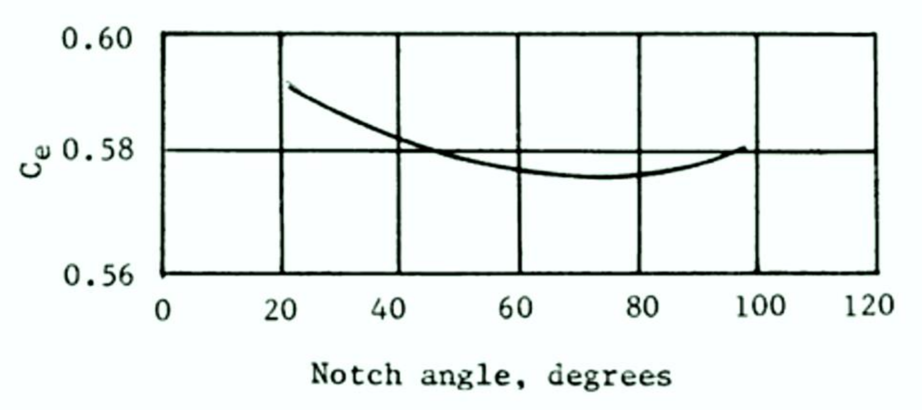


Sharp-Crested Weir V-Notch (Triangular) Discharge

Calculating discharge across a V-Notch weir is more complicated:

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

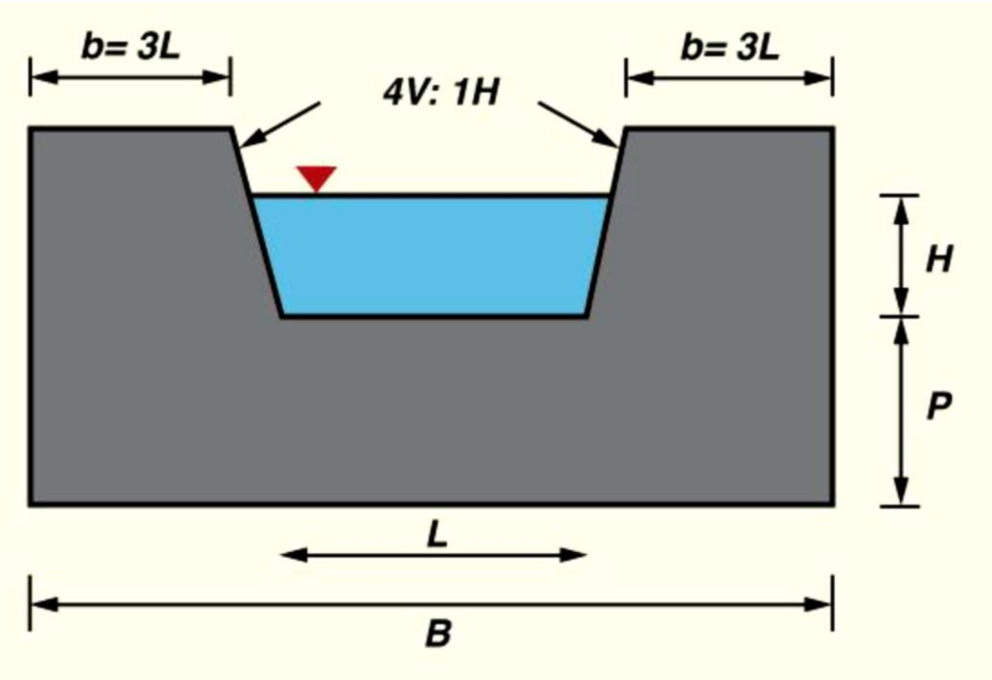
Where:



- Q (m^3/s) is flow over V-Notch weir
- Ce, can be found using the graphs to the right
- *H*(m) is the head flowing through the notch
- θ(degrees) is the notch angle
- g is the acceleration of gravity(9.81 m/s^2)

<u>Sharp-Crested Weir (Trapezoidal)</u>

- These weirs are trapezoidal shaped with notch side slopes of 4:1 (vertical:horizontal)
- Combination of a rectangular and triangular weir
- These weirs are commonly used for irrigation
- Used when discharge is too great for a rectangular weir



- Discharge for a trapezoidal Weir is calculated as follows:

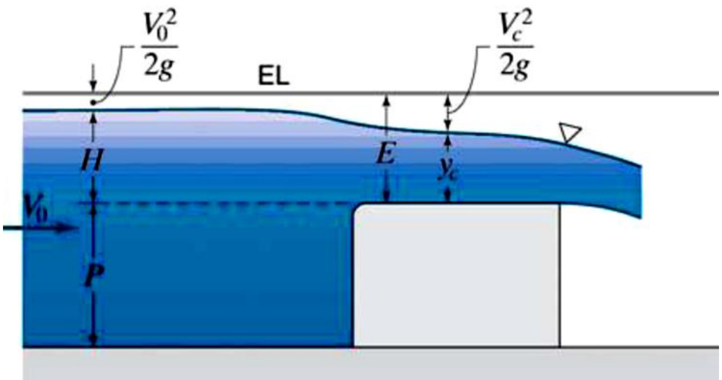
$$Q=3.367LH^{3/2}$$

- Contractions in the free-flowing nappe occur in non-suppressed weirs because water travelling along the faces of the weir cannot instantaneously “turn” around the corners of the weir plate

- A weir is fully contracted if B>4H and partially contracted if 0<B<4H

- The presence of contractions requires a discharge correction factor, but trapezoidal weirs are designed so that no correction is required

Broad-Crested Weir



- Typically sturdier than sharp-crested weirs

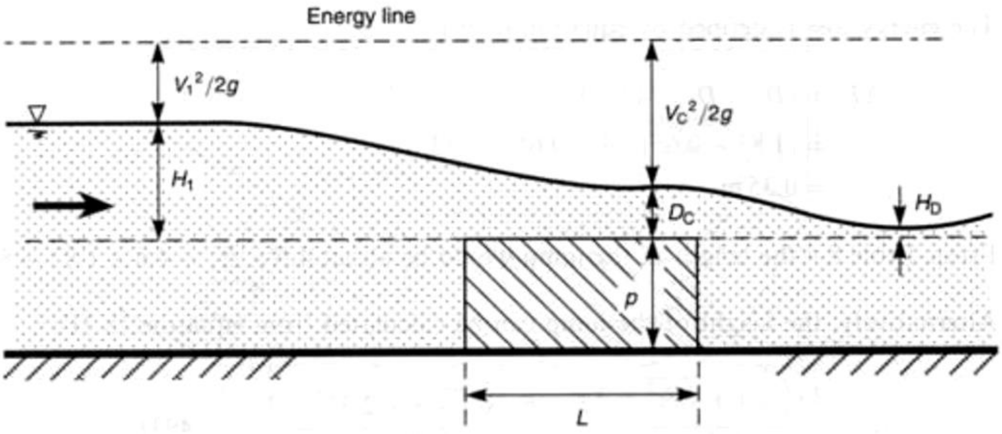
- Used in medium to large size rivers and canals (sturdier)

- Used as a flow measurement and water level regulator

- Necessary for flow to be in subcritical range—ensures smooth water surface

Broad-Crested Weir Discharge

Flow over a broad-crested weir is highly dependent on the weir’s geometry.
Simply discharge can be calculated as follows
$Q= C\,L\,H^n$



Where:

Q = Volumetric flow rate

C = Constant for the specific weir structure

L = Width of the weir

H = Height of water head upstream in relation to the weir's crest

n = structure variant (usually 3/2 for a horizontal weir)

The equation above can also be used for sharp-crested weirs if the design constants are known

Ex. 1

The head on a rectangular weir that is 60 cm high in a rectangular channel that is 1.3 m wide is measured to be 21 cm. What is the discharge of water over the weir?

Solution

1. Flow coefficient

$$K = 0.40 + 0.05\frac{H}{P} = 0.40 + 0.05\left(\frac{21}{60}\right) = 0.417$$

2. Discharge

$$Q = K\sqrt{2g}LH^{3/2} = 0.417\sqrt{2(9.81)}(1.3)(0.21^{3/2})$$
$$= 0.23\ m^3/s$$

Ex.2

It is proposed to use a notch for measuring the water flow from a reservoir. It is estimated that the error in measuring the head above the bottom of the notch could be 1.5mm. For a discharge of $0.3m^3/s$, determine the percentage error, which may occur, using a right-angled triangular notch with coefficient of discharge of 0.6.

For a V-notch, $$Q = \frac{8}{15} C_d . H^{\frac{5}{2}} \sqrt{2g} \tan\left(\frac{\theta}{2}\right)$$

Taking , $C_d = 0.6 \text{ and } \theta = 90^0$ $$Q = \frac{8}{15} \times 0.6 \times H^{\frac{5}{2}} \times \sqrt{2 \times 9.81} \tan\left(\frac{90}{2}\right) = 1.417 H^{\frac{5}{2}}$$

When $Q = 0.3 m^3/s \;\; H = 0.5374 m$

Now $$\frac{\partial Q}{\partial H} = \frac{5}{2} \times 1.417 \times H^{\frac{3}{2}} = \frac{2.5Q}{H}$$

Or, $$\frac{\partial Q}{Q} = \frac{2.5 \partial H}{H} = \frac{2.5 \times 0.0015}{0.5374} \times 100 = 0.7\%$$

Example 3

A rectangular channel 6m wide carries 168 lits/min at a depth of 0.9m. What height of a rectangular weir must be installed to double the depth? Discharge coefficient of weir may be taken as 0.85.

Solution :

The discharge for a broad crested weir is given by,

$$Q = 1.7 C_d L_w . \left(H + \frac{V_a^2}{2g} \right)^{\frac{3}{2}}$$

Here, $Q = 168 m^3/min = 2.8 m^3/s$; $L_w = 6m$; $C_d = 0.85$

Then,

$$H + \frac{V_a^2}{2g} = \left(\frac{Q}{1.7 C_d L_w}\right)^{\frac{2}{3}} = \left(\frac{2.8}{1.7 \times 0.85 \times 6}\right)^{\frac{2}{3}} = 0.47m$$

The depth of the flow required = $2 \times 0.9 = 1.8m$

The velocity of approach is given by,

$$V_a = \frac{Q}{6\times1.8} = \frac{2.8}{6\times1.8} = 0.26\,\mathrm{m/s}$$
$$h_a = \frac{V_a^2}{2g} = 0.0034\mathrm{m}$$
$$H = 0.47 - 0.0034 = 0.4666\mathrm{m}$$

Height of the broad crested weir = 1.8 – 0.4666 = 1.3334m.

Ex. 3

A rectangular weir 0.75 m high and 1.5 m long is to be used for discharging water from a tank under a head of 0.5 m. Estimate the discharge (i) when it is used as a suppressed weir (ii) when it is used as a contract weir. Use Rehbock equation for estimating C_d in both cases.

Data:

Weir height (P) = 0.75 m

Width of weir (B) = 1.5 m

Head (H) = 0.5 m

Formulae:

$$C_d = 0.605 + \frac{1}{1000H} + \frac{0.08H}{P}$$

H and P in meter

Suppressed weir

$$Q = C_d \frac{2}{3} B\sqrt{2g}H^{3/2}$$

Contracted weir

$$Q = C_d \frac{2}{3}(B - 0.1nH)\sqrt{2g}H^{3/2}$$

Where n = number of contractions

Q = flow rate

Calculations:

i. Suppressed weir:

C_d = 0.605 + 1 / (1000 x 0.5) + 0.08 x 0.5 / 0.75 = 0.66

Q = 0.66 x (2/3) x 1.5 x $(2 \times 9.812)^{0.5}$ x $0.5^{3/2}$ = **1.034 m^3/sec**

ii. Contracted weir

Q = 0.66 x (2/3) x (1.5 - 0.1 x 2 x 0.5) x $(2 \times 9.812)^{0.5}$ x $0.5^{3/2}$ = **0.965 m^3/sec**

Example - Discharge Over A Rectangular Weir

Problem

A weir of 8m long is to be built across a rectangular channel to discharge a flow of $9m^3$ /s. If the maximum depth of water on the upstream side of weir is to be 2m, what should be the height of the weir ? Adopt C_d = 0.62.

Given,

- L = 8 m
- Q = 9 m^3 /s
- Depth of water = 2m
- C_d = 0.62

Let, H = Height of water above the sill of the weir.

So, the discharge over the weir,

$$Q = \frac{2}{3} C_d . L \sqrt{2g} (H)^{\frac{3}{2}}$$

$$\therefore 9 = \frac{2}{3} \times 0.62 \times 8 \sqrt{2 \times 9.81} (H)^{\frac{3}{2}} = 14.65 H^{\frac{3}{2}}$$

$$\Rightarrow H^{\frac{3}{2}} = \frac{9}{14.65} = 0.614$$

$$\Rightarrow H = 0.72m$$

Therefore height of weir should be = 2.0 - 0.72 = 1.28 m

Height of weir = 1.28 m

Example - Discharge Over A trapezoidal Weir

Water is flowing over a **trapezoida** weir of 4 meters long under a head of 1 meter. Compute the discharge, if the coefficient of discharge for the weir is 0.6.

- Given,

- L = 4m
- H = 1m

- C_d = 0.62

We know that the discharge over the Cippoletti weir,

$$Q = \frac{2}{3} \times C_d.L\sqrt{2g} \times H^{\frac{3}{2}}$$
$$\Rightarrow Q = \frac{2}{3} \times 0.62 \times 4 \times \sqrt{2 \times 9.81} \times 1^{\frac{3}{2}}$$
$$\Rightarrow Q = 7.32 \times 1 = 7.32m^3/s$$

Solution

Discharge = 7.32 m^3 /s

Example - Discharge Over A Narrow Crested Weir

Problem

A narrow-crested weir of 10 meters long is discharging water under a constant head of 400 mm. Find discharge over the weir in liters/s. Assume coefficient of discharge as 0.623.

Workings

Given,

- L = 10 m
- H = 400 m = 0.4 m
- C_d = 0.623

We know, the discharge over the weir,

$$Q = \frac{2}{3}C_d.L\sqrt{2g}(H)^{\frac{3}{2}}$$
$$\Rightarrow Q = \frac{2}{3} \times 0.623 \times 10 \times \sqrt{2 \times 9.81}(0.4)^{\frac{3}{2}}$$
$$\therefore \Rightarrow Q = 18.4 \times 2.53 = 46.55\ m^3/s = 4655\ liters/s$$

Example - Discharge Over A Broad Crested Weir

Determine the maximum discharge over a broad-crested weir 60 meters long having 0.6 m height of water above its crest. Take coefficient of discharge as 0.595. Also determine the new discharge over the weir, considering the velocity of approach. The channel at the upstream side of the weir has a cross-sectional area of 45 sq meters.

- Given,

- L = 60 m
- H = 0.6 m
- C_d = 0.595
- A = 45 m^2