

Lab Experiment 9 Weir Flow

Objectives:

- To demonstrate the use of *sharp crested weirs* for discharge measurement in open channels;
- To experimentally determine *weir coefficients* for rectangular and V-notched patterns; and
- To compare the experimental coefficients with values reported in the literature

Background:

The measurement of water flowing in open channels is important in many aspects of our society. For example, water flowing in rivers and streams must be monitored to assure adequate water supplies for residential and industrial uses. In agriculture, water is often conveyed to farmers in open channels for irrigating fields, and such allocations are strictly controlled. It is also important to measure water flow during flooding events for water level prediction in order to avoid property damage and loss of life.

Most methods for measuring water flow in open channels involve placing an “obstruction” in the channel that extends from one channel boundary to the other. Water backs up and then spills over or through the obstruction. Large obstructions, which are capable of measuring open channel flow in rivers, are called *dams*¹. In smaller streams and canals we use *weirs* to measure water flow, which are smaller and more structurally simple. Weirs are the most common method of measuring flows in open channels, and they are widely applied in both the field and the laboratory. They will be the focus of today’s laboratory experiment.

Weirs used for the purposes of flow measurement are most often *sharp crested*, so that the water “springs” clear of the notch (**Fig. 9.1**). The two most common shapes of weirs are *rectangular* and *V-notched* (**Fig. 9.2**). As might be expected, the V-notch weir is better suited for measurement of low flow rates since the head increases more rapidly in proportion to the discharge. Most V-notched weirs are designed with a vertex angle of 90 degrees.

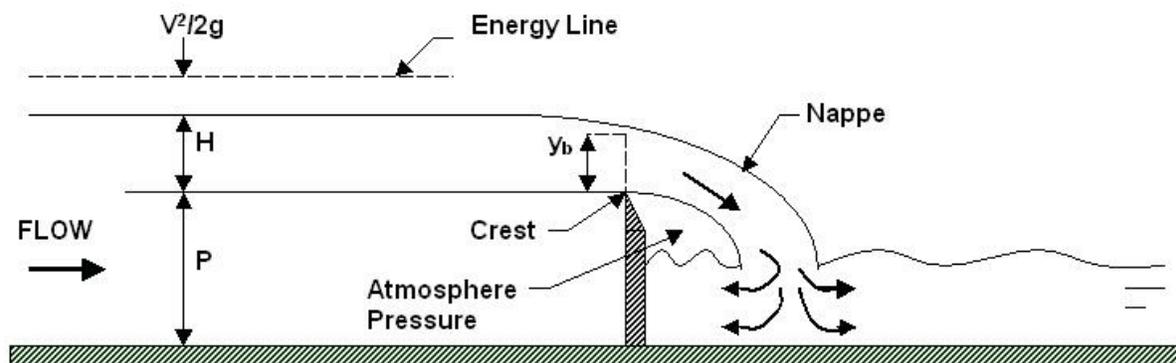


Fig. 9.1 – Flow Over a Sharp-Crested Weir

¹ Although dams are useful for measuring water flow, their principal purpose is water storage or impoundment.

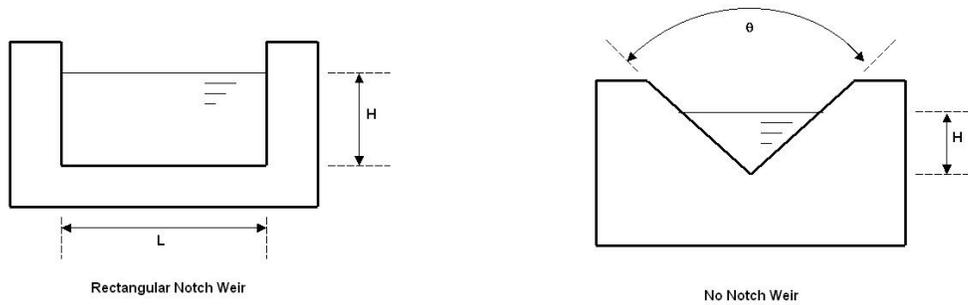


Fig. 9.2 – Common Weir Geometries

The analysis of water flow over a sharp crested weir is at best a exceedingly complex problem, and a rigorous analytical solution is not possible. We will therefore make certain simplifying assumptions in order to solve the problem. It will be assumed that:

- The fluid is incompressible
- The fluid friction is negligible.
- The flow is irrotational.
- The flow is steady and two-dimensional.
- The fluid velocity upstream of the weir very small relative to the velocity of the water passing over the weir and can be neglected.

We begin with a fundamental equation that relates the flow rate, the width of weir, and the depth of water passing over the weir. From considerations of continuity and Bernoulli's Theorem, the generic weir equation may be written as

$$Q = C L H^n \quad \text{Eq. 1}$$

where : Q = flow rate over the weir (L^3T^{-1})

C = coefficient of discharge, also known as the *weir coefficient* (dimensions vary)

L = length of weir over which water flows (L)

H = depth of water (head) behind the crest of the weir, measured a minimum distance of $4 y_b$ back from the "brink" of the weir (L)

n = an empirical exponent (dimensionless)

The values of C and n depend on the geometry and construction details of the weir, *so they are best determined by field or laboratory experiment*. The values of C and n are empirical constants for a particular design of weir, and they define the *working equation* for the weir.

Experimental analysis of a weir begins by expressing Eq. 1 in logarithmic form as

$$\log Q = \log C + \log L + n \log H \quad \text{Eq. 2}$$

This simplifies to

$$\log Q = n \log H + \log C L \quad \text{Eq. 3}$$

Note that Eq. 3 has the familiar form of a linear equation, $y = mx + b$, so the values C and n can be evaluated by plotting measured value of Q (ordinate) and H (abscissa) on a log-log plot. A best fit straight line is then drawn through the data. The exponent n is determined by measuring the slope of the line using a simple linear scale. In order to evaluate C , we extend the line to a value of $H = 1$ (i.e., $\log H = 0$). At this point then Eq. 3 reduces to $Q = C L$, so that C is calculated by $C = Q/L$.

When evaluating a V-notch weir it is necessary to modify Eq. 1 by eliminating the length term. Thus, the generic expression for a V-notch weir is

$$Q = C H^n \quad \text{Eq. 4}$$

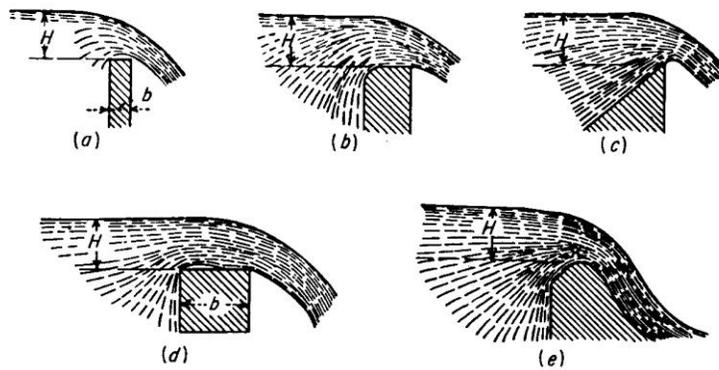
From analytical considerations it can be shown that the exponent n should have the following theoretical values:

$$\text{For rectangular notch weirs} \Rightarrow H^{3/2}$$

$$\text{For V-notch weirs} \Rightarrow H^{5/2}$$

The values of C are sensitive to the geometry and scale of the particular weir (i.e., 0.1 m vs. 1 m vs. 10 m).

In practice, weirs can have a wide variety of designs, although the fundamental principle remain the same: place an obstruction in the channel and develop a relationship between water depth and flow rate. For example, with narrow-crested weirs the shape of the surface of the crest greatly affects the form of the *nappe*. The cross sections and nappe form for five types of narrow-crested weirs are shown in **Figure 9.3**, as an illustration.

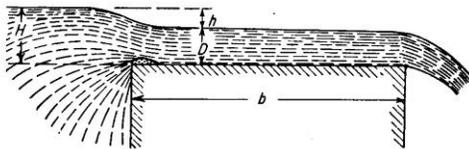


(a) narrow square-edge; (b) rear-edge rounded; (c) sloping rear faced; (d) medium square-edge; and (e) "ogee" crest weir.

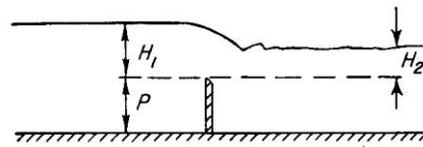
(from L.C. Urquhart, *Civil Engineering Handbook*, 4th Ed. McGraw-Hill, 1959)

Fig. 9.3 – Cross Sections of Various Narrow-Crested Weirs

Another weir variant is the *broad-crested weir* shown in **Figure 9.4 (a)**. With this type of weir the depth of the water remains constant over the majority of the extra-wide crest. It is also possible to use weirs where the downstream side of the weir is partially under water, which is known as a *submerged weir* or *drowned weir* (**Figure 9.4 (b)**).



(a) Broad-Crested Weir



(b) Submerged or Drowned Weir

(from L.C. Urquhart, *Civil Engineering Handbook*, 4th Ed., McGraw-Hill, 1959)

Fig. 9.4 – Other Weir Variants

Equipment:*Part 1 – Rectangular and V-Notch Weir – F1 Hydraulics Bench*

F-1 Hydraulics Bench
 Stilling Baffle and Delivery Diffuser
 Rectangular Weir Plate
 V-notched Weir Plate
 Micrometer Hook and Point Gauge
 Graduated Measuring Vessel
 Stop Watch

Part 2 – Unknown Weirs and Hydraulic Jump - C4 Flume

C4 Multi-Purpose Teaching Flume (5 meter)
 Two Weirs of Unknown Type

Procedure:**Part 1 – Rectangular and V-Notch Weir – F1 Hydraulics Bench**

1. Remove the micrometer hook and point gauge from the F1 bench and examine it carefully. Make some practice readings. Demonstrate to the instructor that you understand how to use it.
2. Install the rectangular notch weir plate, stilling baffle, and delivery nozzle.
3. Establish the initial datum depth by positioning the depth gauge so that the tip at the end of the hook portion is against the back center of the weir plate.
4. Adjust the depth gauge so that the tip of the gauge is even with the bottom of the notch in the weir plate. Record the value on the gauge. This is the zero datum for H.
5. Move the depth gauge to a position approximately 10 cm behind the weir plate.
6. Power on the F1 Hydraulics Bench and slowly open the flow control valve until water just begins to flow over the brink of the weir. Make sure that the nappe of the water springs clear of the plate. Allow at least two minutes for the water level to stabilize.
7. Now adjust the depth gauge to coincide with the water surface. The hook point gauge is capable of high accuracy readings if you exercise care in its use. Record your value of H.
8. Now measure the flow rate Q using a 5-liter measuring vessel and a stop watch. Calculate the flow rate.
9. Now you are going successively increase the flow over the weir in increments making at least three more measurements for a total of four, repeating the above procedure. The highest reading should be about 0.25 inches below the top of the weir plate. Record the water depth and flow rate for each level.
10. Plot your results on the provided log-log paper to regress the values of weir coefficient C and exponent n. Use the procedure described in the “Background” section above.
11. Now install the V-notch weir plate in the F1 Bench.
12. Repeat all of the above steps, except it is recommended with the V-notch weir that you begin with the highest flow rate first (~0.25 inch below top of plate) and then work your way downward.
13. Plot your results for the V-notch weir on the provided log-log paper to regress the values of weir coefficient C and exponent n. Use the procedure described in the “Background” section above.

Part 2 – Unknown Weirs and Hydraulic Jump - C4 Flume

1. Power on the C4 Flume.
2. Carefully examine the two unknown weirs and identify their type.
3. Sketch and label the structures and the water flow patterns along the length of the flume.
4. Adjust the flow rate and observe the effect on the flow patterns. Now adjust the slope and observe the effect.