Module 4 (Contd.)

FLUID MECHANICS

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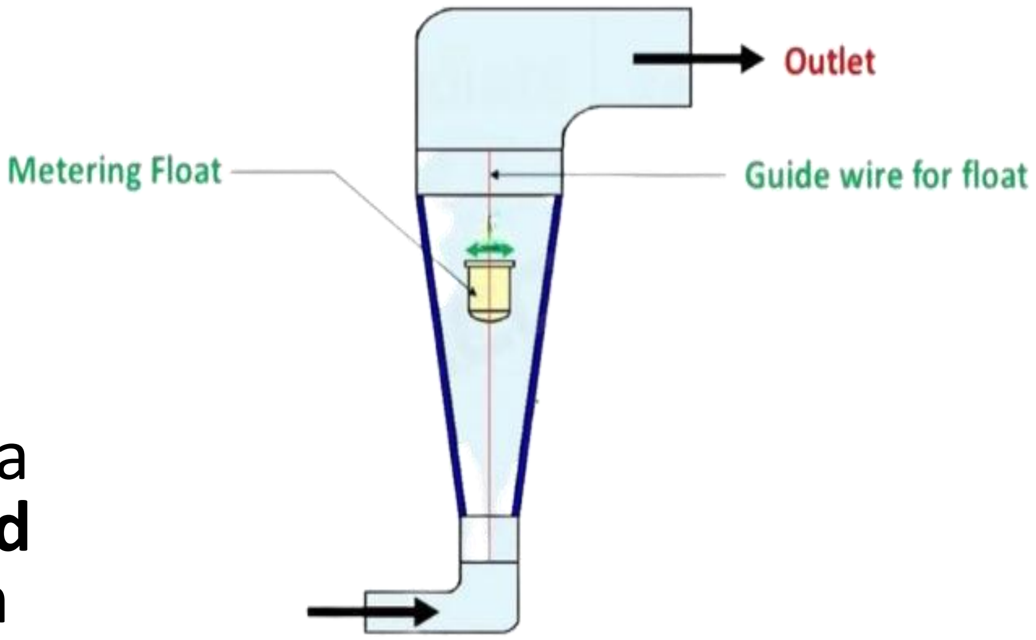
Rotameter

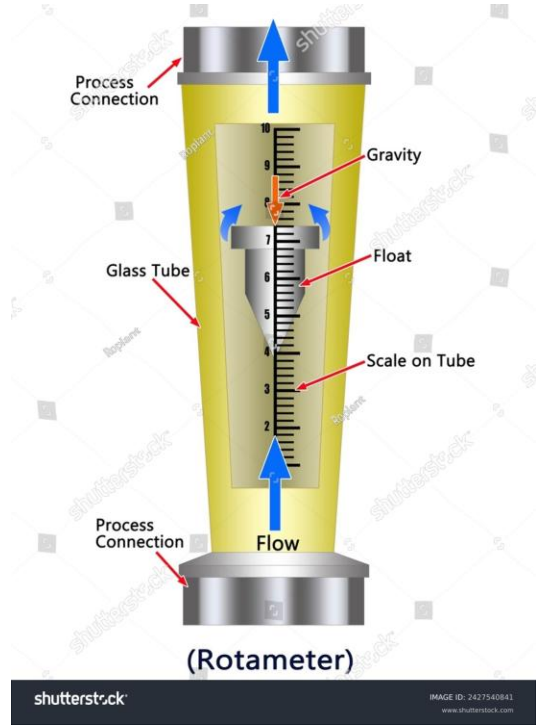
- A **rotameter** is a type of **variable-area flowmeter** used to measure the volumetric flow rate of fluid (liquid or gas) in a closed tube.
- The rotameter consists of a vertically mounted **tapered tube** (widens from bottom to top) and a freely moving **float** inside it.



Working Principle

- When fluid flows upward through the tube, it creates a drag force that pushes the float up.
- As the float rises, the annular area between the float and the inner wall of the tapered tube increases, which reduces the fluid velocity.
- The float reaches a stable position when:
- Upward force due to fluid flow=

Weight of the float (minus buoyant force)



- At this point of equilibrium, the position (height) of the float in the tapered tube corresponds to a specific volumetric flow rate. The higher the float, the greater the flow rate.
- The flow rate is read directly from a calibrated scale, which is either marked on the tube itself or placed adjacent to it, at the point corresponding to the float's position.

- The scale is pre-calibrated to directly display the flow rate, usually in volumetric units like **Liters per Minute (LPM)** or **Cubic Feet per Hour (CFH)**, for a specific fluid (e.g., water or air) at standard conditions.

NOTCHES AND WEIRS

NOTCHES AND WEIRS

- Notches and weirs are both **structures used in open channels to measure** (or control) **the flow rate of water**.
- Both work on the same principle — the flow of water over an opening is related to the **head of water** above the opening.
- They essentially constrict the flow, causing the water level upstream to rise, and this relationship between the water level (head) and the flow rate is known.

Figure: Notch

Concept: Head and Flow

- The fundamental idea for both is that as the water flows over the weir or through the notch, the height of the water above the bottom edge of the opening (called the head, H) is directly related to the volume of water flowing per unit of time (Q).

$$Q \propto H^n$$

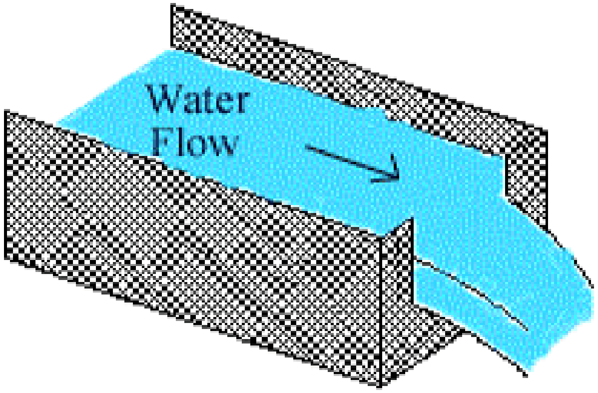
where n is an exponent that depends on the shape of the notch/weir, usually 3/2 for rectangular and 5/2 for triangular).

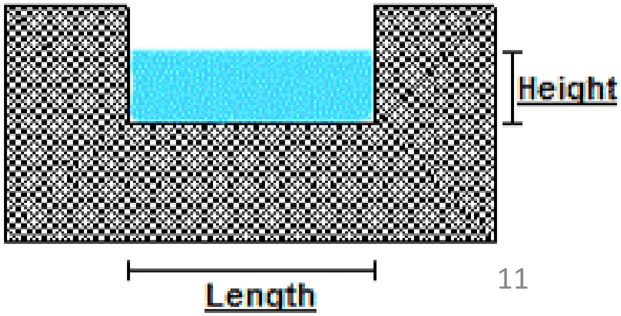
NOTCH

- A **notch** is a sharp-crested opening of a specific shape (like rectangular, triangular, or trapezoidal) cut into the top edge of a plate placed across the channel.
- They are openings, not full-width barriers.
- Used particularly for small to moderate flows in laboratories or small streams.

Key Types:

- **Rectangular Notch:** Simple rectangular opening.
- **V-Notch (or Triangular Notch):** The most common type for low flows, as it provides **greater sensitivity (the head changes more significantly for small changes in discharge).**
- **Trapezoidal Notch:** A combination of a rectangular and two triangular notches.





WEIR

- A **weir** is a barrier, often a wall or embankment, placed across a river or open channel.
- Primarily to **measure flow rate** (discharge) or to **raise the water level** upstream (e.g., for diversion into a canal).
- They usually span the entire width of the channel.

Key Types:

- **Broad-crested weir:** Has a long, flat top (crest).
- **Sharp-crested weir (or Notch):** Has a thin, sharp edge for the water to flow over.

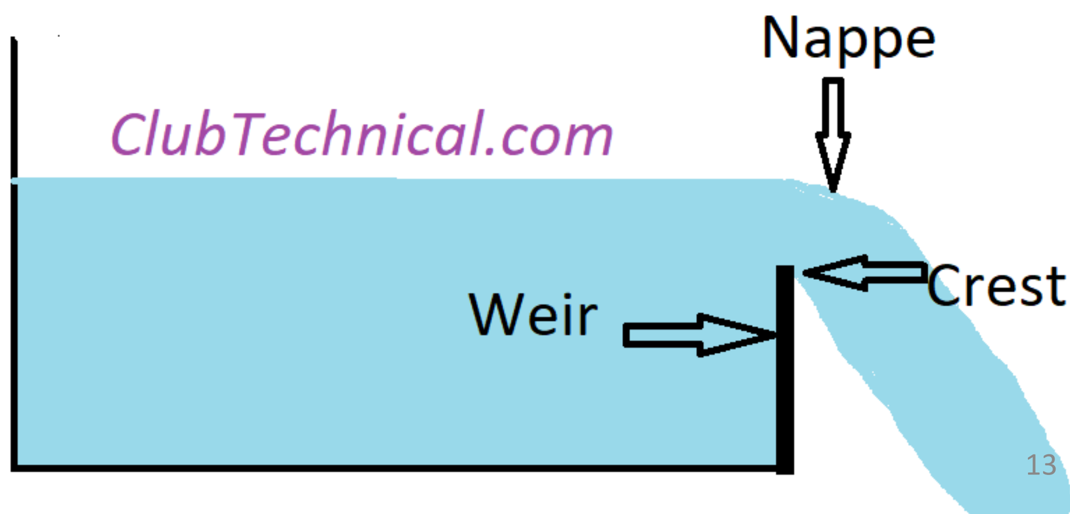
Terminology

Nappe or Vein

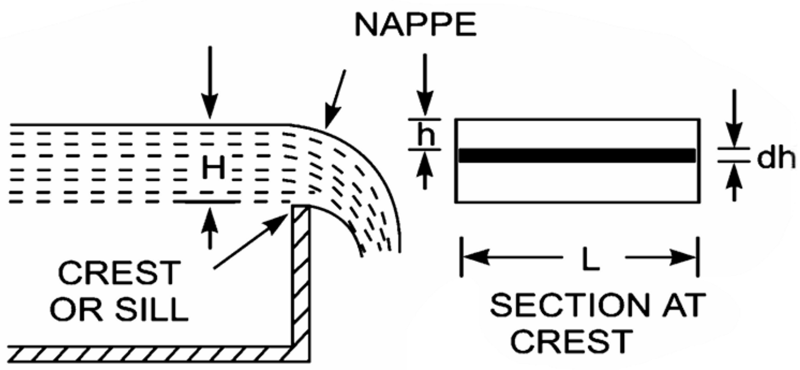
- The sheet of water flowing through a notch or over a weir is called Nappe or Vein.

Crest or Sill.

- The bottom edge of a notch or a top of a weir over which the water flows, is known as the sill or crest.



Discharge through a Rectangular notch / weir



RECTANGULAR NOTCH

Let H = Head of water over the crest

L = Length of the notch or weir

For finding the discharge of water flowing over the weir or notch, consider an elementary horizontal strip of water of thickness dh and length L at a depth h from the free surface of water as shown in Fig.

The area of strip $= L \times dh$

and theoretical velocity of water flowing through strip $= \sqrt{2gh}$

The discharge dQ, through strip is

$$dQ = C_d \times \text{Area of strip} \times \text{Theoretical velocity}$$

$$= C_d \times L \times dh \times \sqrt{2gh} \qquad \ldots(i)$$

where C_d = Co-efficient of discharge.

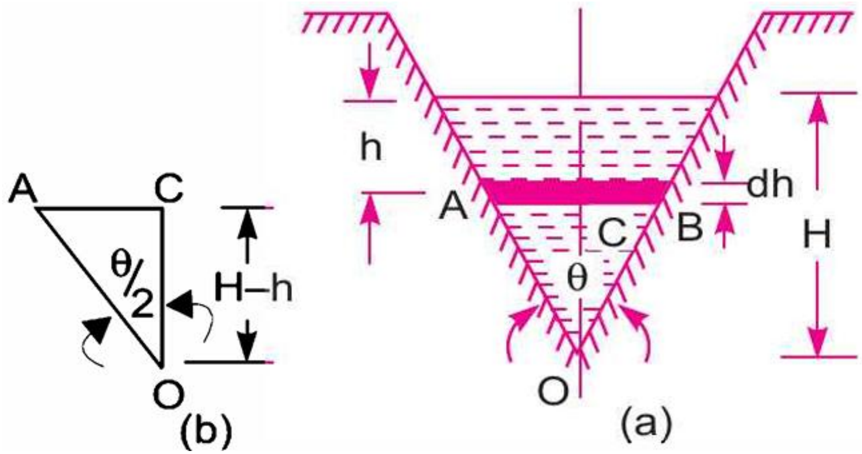
The total discharge, Q, for the whole notch or weir is determined by integrating equation (i) between the limits 0 and H.

$$\therefore \qquad Q = \int_0^H C_d \,.\, L \,.\, \sqrt{2gh} \,.\, dh = C_d \times L \times \sqrt{2g} \int_0^H h^{1/2}\, dh$$

$$= C_d \times L \times \sqrt{2g} \left[\frac{h^{1/2+1}}{\frac{1}{2}+1} \right]_0^H = C_d \times L \times \sqrt{2g} \left[\frac{h^{3/2}}{3/2} \right]_0^H$$

$$= \frac{2}{3} C_d \times L \times \sqrt{2g}\ [H]^{3/2}.$$

Discharge through a Triangular notch / weir



The expression for the discharge over a triangular notch or weir is the same. It is derived as :

Let H = head of water above the V- notch

θ = angle of notch

Consider a horizontal strip of water of thickness 'dh' at a depth of h from the free surface of water

$$\tan\frac{\theta}{2} = \frac{AC}{OC} = \frac{AC}{(H-h)}$$

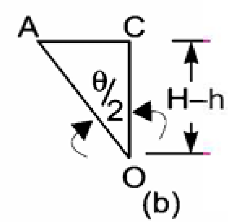


Fig. 8.3

$$\therefore \qquad AC = (H-h)\tan\frac{\theta}{2}$$

Width of strip $= AB = 2AC = 2\,(\mathrm{H}-h)\tan\dfrac{\theta}{2}$

$\therefore$ Area of strip $= 2\,(\mathrm{H}-h)\tan\dfrac{\theta}{2}\times dh$

The theoretical velocity of water through strip $= \sqrt{2gh}$

$\therefore$ Discharge, through the strip,

$$dQ = C_d \times \text{Area of strip} \times \text{Velocity (theoretical)}$$

$$= C_d \times 2\,(H - h)\tan\frac{\theta}{2} \times dh \times \sqrt{2gh}$$

$$= 2C_d\,(H - h)\tan\frac{\theta}{2} \times \sqrt{2gh} \times dh$$

$\therefore$ Total discharge,

$$Q = \int_0^H 2C_d\,(H - h)\tan\frac{\theta}{2} \times \sqrt{2gh} \times dh$$

$$= 2C_d \times \tan\frac{\theta}{2} \times \sqrt{2g}\int_0^H (H - h)h^{1/2}\,dh$$

$$= 2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g}\int_0^H (Hh^{1/2} - h^{3/2})\,dh$$

$$= 2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g}\left[\frac{Hh^{3/2}}{3/2} - \frac{h^{5/2}}{5/2}\right]_0^H$$

$$= 2 \times C_d \times \tan \frac{\theta}{2} \times \sqrt{2g} \left[\frac{2}{3} H . H^{3/2} - \frac{2}{5} H^{5/2} \right]$$

$$= 2 \times C_d \times \tan \frac{\theta}{2} \times \sqrt{2g} \left[\frac{2}{3} H^{5/2} - \frac{2}{5} H^{5/2} \right]$$

$$= 2 \times C_d \times \tan \frac{\theta}{2} \times \sqrt{2g} \left[\frac{4}{15} H^{5/2} \right]$$

$$= \frac{8}{15} C_d \times \tan \frac{\theta}{2} \times \sqrt{2g} \times H^{5/2}$$

For a right-angled V-notch, if $C_d = 0.6$

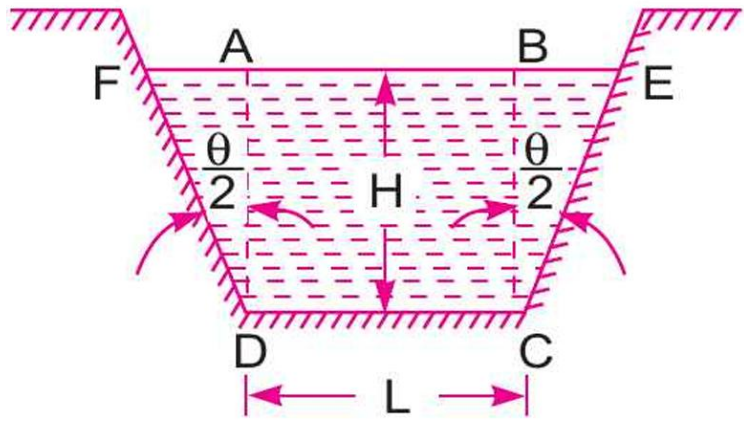
$$\theta = 90°, \quad \therefore \quad \tan \frac{\theta}{2} = 1$$

Discharge,

$$Q = \frac{8}{15} \times 0.6 \times 1 \times \sqrt{2 \times 9.81} \times H^{5/2}$$

$$= 1.417 \; H^{5/2}.$$

Discharge through a Trapezoidal notch / weir



As shown in Fig., a trapezoidal notch or weir is a combination of a rectangular and triangular notch or weir.

Thus, the total discharge will be equal to the sum of discharge through a rectangular weir or notch and discharge through a triangular notch or weir.

Let **H** = Height of water over the notch

L = Length of the crest of the notch

C_{d_1} = Co-efficient of discharge for rectangular portion *ABCD* of Fig.

C_{d_2} = Co-efficient of discharge for triangular portion [*FAD* and *BCE*]

The discharge through rectangular portion *ABCD* is given by

or
$$Q_1 = \frac{2}{3} \times C_{d_1} \times L \times \sqrt{2g} \times H^{3/2}$$

The discharge through two triangular notches *FDA* and *BCE* is equal to the discharge through a single triangular notch of angle θ

$$Q_2 = \frac{8}{15} \times C_{d_2} \times \tan\frac{\theta}{2} \times \sqrt{2g} \times H^{5/2}$$

∴ Discharge through trapezoidal notch or weir *FDCEF* = $Q_1 + Q_2$

$$= \frac{2}{3} C_{d_1} L \sqrt{2g} \times H^{3/2} + \frac{8}{15} C_{d_2} \times \tan\theta/2 \times \sqrt{2g} \times H^{5/2}.$$

Calibration of Flow Measuring Devices

Calibration of Flow Measuring Devices

- Calibration means comparing the reading of a flow measuring device (like a venturimeter, orifice meter, or rotameter)with a known accurate standard or actual discharge.
- It helps to find the error and establish a correction factor or calibration curve.

Purpose of Calibration

- To check the **accuracy** of the instrument.
- To find the **coefficient of discharge (Cd)**.
- To ensure the device gives **reliable and repeatable readings**.
- To correct any **systematic error** in measurement.

Instruments

- The flow device to be calibrated (e.g., Venturimeter, Orifice meter, Rotameter)
- A collecting tank or measuring tank
- A stopwatch
- Measuring scale / point gauge for head difference.
- Manometer (for differential head measurement)

General Procedure

- Set up the flow measuring device in a hydraulic circuit.
- Allow water to flow steadily through the device.
- Measure the differential head (h) using a manometer.
- Collect the discharged water in a tank for a known time (t).
- Find actual discharge (Q_a):

$$Q_a = \frac{A_t \times h_t}{t}$$

- Find theoretical discharge (Q_t): (depends on device).
- **Compute coefficient of discharge:**

$$C_d = \frac{Q_a}{Q_t}$$

Repeat for different flow rates.

Plot calibration curve:

- Q_a vs. √h, or
- C_d vs. Reynolds number (Re)

Calibration Curve

- A graph between actual discharge (Q_a) and $\sqrt{h}$ (head difference).
- Should be a straight line through the origin if the device works properly.
- The slope of the line represents the calibration constant or Cd .

Common Flow Devices Calibrated

Device	Measured Quantity	Calibration Output
Venturimeter	Discharge	Cd vs $\sqrt{h}$
Orifice meter	Discharge	Cd vs $\sqrt{h}$
Rotameter	Flow rate	Actual flow vs Float position
Notches / Weirs	Discharge	Q vs Head (H)

Typical Values of Cd

Device	Typical Cd
Venturimeter	0.97 – 0.99
Orifice meter	0.60 – 0.65
Rotameter	0.90 – 0.98
Rectangular Weir	~0.62