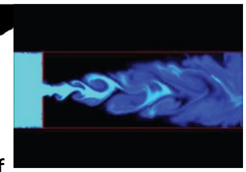
Chapter 8: Flow Through Orifices and Mouthpieces



8.1. INTRODUCTION

This lecture will explore the theoretical and practical aspects of flow through orifices and mouthpieces, highlighting their significance in industrial, environmental, and hydraulic engineering applications.

An **orifice** is an opening in the wall or base of a vessel through which the fluid flows. The top edge of the orifice is always below the free surface (If the free surface is below the top edge of the orifice, becomes a weir).

Topics to be covered

- 8.2. CLASSIFICATION OF ORIFICES
- 8.3. FLOW THROUGH AN ORIFICE
- 8.4. Hydraulic Co-Efficients
- 8.5. Experimental Determination of Hydraulic Co-Efficients
- 8.6. Discharge Through A Large Rectangular Orifice
- 8.7. Discharge Through Fully Submerged Orifice
- 8.8. Discharge Through Partially Submerged Orifice
- 8.9. Time Required For Emptying A Tank Through An Orifice At Its Bottom
- Chapter 9: FLOW OVER NOTCHES AND WEIRS

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8.2. CLASSIFICATION OF ORIFICES

The orifices are classified as follows

1. According to size:

(i) Small orifice: when its dimensions are small compared to the head causing flow.

(ii) Large orifice: if the dimensions are comparable with the head causing flow. The variation in the velocity from the top to the bottom edge is considerable.

2. According to shape

(i) Circular orifice **(ii)** Rectangular orifice, **(iii)** Square orifice **(iv)** Triangular orifice.

3. Shape of upstream edge

(i) Sharp-edged orifice

(ii) Bell-mouthed orifice.

4. According to discharge conditions

(i) **Free discharge orifices**

(ii) **Drowned or submerged orifices:** (*a*) Fully submerged, (*b*) Partially submerged.

8.3. FLOW THROUGH AN ORIFICE

Note. An orifice or a mouthpiece is said to be discharging **free** when it discharges into atmosphere. It is said to be **submerged** when it discharges into another liquid.

$$\frac{p_1}{w} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{w} + \frac{V_2^2}{2g} + z_2$$

But,

$$p_1 = p_2 = p_a$$
$$z_1 = z_2 + H$$

Further, if the cross-sectional area of the tank is very large, the liquid at point 1 is practically standstill and hence $V_1 = 0$

Thus,

$$\frac{V_2^2}{2g} = H$$

or,

$$V_2 = \sqrt{2gH}$$

Equation (8.1) is know as **Torricelli's theorem.**

Note. In the problems of orifices it is covenient to work in terms of *gauge pressures*.

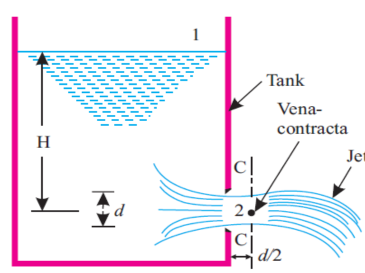

Fig. 8.1. Orifice discharging free.

(p_a = atmospheric pressure)

8.4. Hydraulic Co-Efficients

The hydraulic co-efficients (or orifice co-efficients) are enumerated and discussed below :

- **Co-efficient of contraction, C_c**
- **Co-efficient of velocity, C_v**
- **Co-efficient of discharge, C_d**
- **Co-efficient of resistance, C_r**

8.4.1. Co-efficient of Contraction (C_c)

The ratio of the area of the jet at vena-contract to the area of the orifice is known as **Co-efficient of contraction.** It is denoted by *Cc*.

Let, a_c = Area of jet at vena contract, and a = Area of orifice. Then, $C_c = \frac{a_c}{a}$

The value of *Cc* varies slightly with the available head of the liquid, size and shape of the orifice; in practice it varies from **0.613 to 0.69** but the average value is taken as **0.64.**

8.4.2. Co-efficient of Velocity (C_v)

The ratio of actual velocity (V) of the jet at vena-contract to the theoretical velocity (V_{th}) is known as **Co-efficient of velocity.** It is denoted by *Cv* and mathematically, C_v is given as:

$$C_v = \frac{V}{\sqrt{2gH}}$$

8.4.3. Co-efficient of Discharge

The ratio of actual discharge (Q) through an orifice to the theoretical discharge, (Q_{th}) is known as **Co-efficient of discharge.** It is denoted by C_d.

$$C_d = C_c \times C_v$$

8.4.4. Co-efficient of Resistance (Cr)

The ratio of loss of head (or loss of kinetic energy) in the orifice to the head of water (actual kinetic energy) available at the exit of the orifice is known as **Co-efficient of resistance.** It is denoted by *Cr*.

$$C_r = \frac{Loss\ of\ head\ in\ the\ orifice}{Head\ of\ watera}$$

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Example 8.1. An orifice 50mm in diameter is discharging water under a head of 10 meters. If $C_d = 0.6$ and $C_v = 0.97$, find: ***(i)*** Actual discharge, and ***(ii)*** Actual velocity of the jet at vena contract.

Solution. Diameter of the orifice, $d = 50$ mm $= 0.05$ m

$\therefore$ Area of the orifice, $a = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (0.05)^2 = 0.001963\ \text{m}^2$

Head, $H = 10\text{m}$; $C_d = 0.6$; $C_v = 0.97$

(*i*) Actual discharge

$$C_d = \frac{\text{Actual discharge}}{\text{Theoretical discharge}} = 0.6 \qquad \text{...(Given)}$$

But theoretical discharge = Area of orifice × theoretical velocity

$$= a \times \sqrt{2gH}$$

$$= = 0.001963 \times \sqrt{2 \times 9.81 \times 10}$$

$$= 0.02749\ \text{m}^3/\text{s}$$

$\therefore$ Actual discharge $= 0.6 \times 0.02749$ **= 0.01649 m³/s (Ans.)**

(*ii*) Actual velocity

We know that , $C_v = \frac{\text{actual velocity}}{\text{theoretical velocity}}$

$\therefore$ Actual velocity **=** $C_v \times$ theoretical velocity

$$= 0.97 \times \sqrt{2gH} = 0.97 \times \sqrt{2 \times 9.81 \times 10} = \mathbf{13.58\ m/s}\ \textbf{(Ans.)}$$

Example 8.2.

The head of water over the center of an orifice of diameter 30 mm is 1.5m. The actual discharge through the orifice is 2.55 litres/sec. Find the co-efficient of discharge.

Solution. Diameter of the orifice, $d = 30$ mm $= 0.03$m

$\therefore$ Area, $a = \frac{\pi}{4} \times 0.03^2 = 0.0007068\ \text{m}^2$

Head, $H = 1.5$ m

Co-efficient of discharge, C_d

Actual discharge through the orifice, $Q = 2.55$ litres/sec.$= 0.00255\ \text{m}^3/\text{s}$

Theoretical discharge, Q_{th} = Area of orifice × theoretical velocity.

But theoretical velocity, $V_{th} = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 1.5} = 5.425$ m/s

$\therefore$ $Q_{th} = a \times V_{th}$

$$= 0.0007068 \times 5.425 = 0.004166\text{m}^3/\text{s}$$

Hence, $C_d = \frac{Q}{Q_{th}} = \frac{0.00255}{0.004166} = \mathbf{0.612}$ **(Ans.)**

8.5. Experimental Determination of Hydraulic Co-Efficient
8.5.1. Determination of Co-efficient of Velocity (Cv).

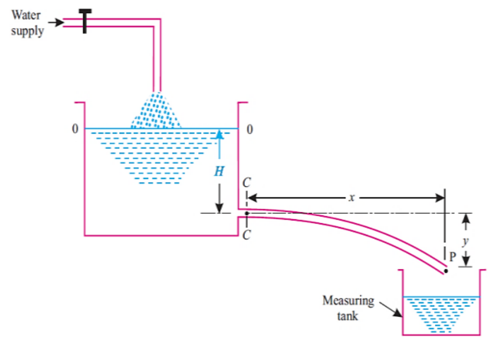

Fig. 8.2. Experiment for hydraulic co-efficients.

$$y = \frac{1}{2} g \times \left(\frac{x}{V}\right)^2 = \frac{gx^2}{2V^2}$$

$$V^2 = \frac{gx^2}{2y} \text{ or } V = \sqrt{\frac{gx^2}{2y}}$$

ity, $V_{th} = \sqrt{2gH}$

ocity,

$$C_v = \frac{V}{V_{th}} = \frac{\sqrt{\frac{gx^2}{2y}}}{\sqrt{2gH}} = \sqrt{\frac{x^2}{4yH}}$$

$$C_v = \frac{x}{\sqrt{4yH}}$$

8.5.2. Determination of Co-efficient of Discharge (C_d)

$$C_d = \frac{Q}{Q_{th}} = \frac{Q}{a \times \sqrt{2gH}}$$

8.5.3. Determination of Co-efficient of Contraction (C_c)

$$C_d = C_c \times C_v$$

8.5.4. Loss of head in Orifice Flow

$$h_f = \frac{V^2}{2g}\left(\frac{2gH}{V^2} - 1\right) = \frac{V^2}{2g}\left(\frac{1}{C_v^2} - 1\right)$$

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Example 8.3. A vertical sharp-edged orifice 120 mm in diameter is discharging water at the rate of 98.2 litres/sec. under a constant head of 10 metres. A point on the jet, measured from the vena contract of the jet has co-ordinates 4.5metres horizontal and 0.54 metre vertical. Find the following for the orifice.
(i) Co-efficient of velocity, **(ii)** Co-efficient of discharge, and **(iii)** Co-efficient of contraction.

Solution. Diameter of orifice, $d = 120 \text{ mm} = 0.12 \text{ m}$

$$\therefore \quad \text{Area of orifice, } a = \frac{\pi}{4} \times 0.12^2 = 0.01131 \text{ m}^2$$

$$\text{Discharge, } Q = 98.2 \text{ litres/sec.} = \frac{98.2}{1000} = 0.0982 \text{ m}^3/\text{s}$$

$$\text{Head, } H = 10 \text{ m}$$

Horizontal distance of a point on the jet from vena contracta, $x = 4.5$ m

$$\text{Vertical distance, } y = 0.54 \text{ m}$$

$$\text{Now theoretical velocity, } V_{th} = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 10} = 14 \text{ m/s}$$

Theoretical discharge,

$$Q_{th} = \text{Area of orifice } (a) \times V_{th}$$
$$= 0.01131 \times 14 = 0.1583 \text{ m}^3/\text{s}$$

(*i*) Co-efficient of velocity, C_v:

$$C_v = \frac{x}{\sqrt{4yH}}$$

$$= \frac{4.5}{\sqrt{4 \times 0.54 \times 10}} = \mathbf{0.968} \text{ (Ans.)}$$

(*ii*) Co-efficient of dischrge, C_d:

$$C_d = \frac{\text{Actual discharge}}{\text{Theoretical discharge}}$$

$$= \frac{0.0982}{0.1583} = \mathbf{0.62} \text{ (Ans.)}$$

(*iii*) Co-efficient of contraction, C_c:

$$= \frac{C_d}{C_v} = \frac{0.62}{0.968} = \mathbf{0.64} \text{ (Ans.)}$$

Example 8.4. A large tank has a sharp edged circular orifice of 930 mm² area at a depth of 3 m below constant water level. The jet issues horizontally and in a horizontal distance of 2.4 m, it falls by 0.53 m, the measured discharge is 4.3 lit/s. Determine coefficients of velocity, contraction and discharge for the orifice.

Solution. *Given :* Area of the orifice, $a = 930$ mm²; $H = 3$ m; $x = 2.4$ m; $y = 0.53$ m;
$Q = 4.3$ litres/sec. $= 0.0043$ m³/s

C_v, C_c and C_d:

Theoretical volocity, $V = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 3}$
$= 7.67$ m/s

Theoretical discharge $= a \times V_{th}$
$= 930 \times 10^{-6} \times 7.67$
$= 0.00713$ m³/s

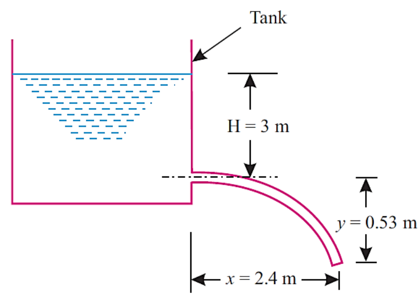

Fig. 8.3

Co-efficient of velocity,

$$C_v = \frac{x}{\sqrt{4yH}} = \frac{2.4}{\sqrt{4 \times 0.53 \times 3}}$$

$= \mathbf{0.952}$ **(Ans.)**

Co-efficient of discharge,

$$C_d = \frac{\text{Actual discharge}}{\text{Theoretical discharge}} = \frac{0.0043}{0.00713}$$

$= \mathbf{0.603}$ **(Ans.)**

Co-efficient of contraction,

$$C_c = \frac{C_d}{C_v} = \frac{0.603}{0.952} = \mathbf{0.633} \textbf{ (Ans.)}$$

8.6. Discharge Through A Large Rectangular Orifice

*When the available head of a liquid is **less than 5 times** the height of the orifice, the orifice is called a **large orifice.*** Consider a large rectangular orifice in one side of the tank discharging water freely into the atmosphere, as shown in Fig. 8.9.

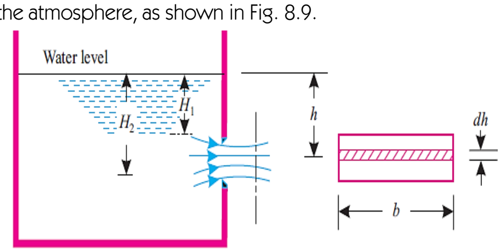

Fig. 8.9. Large rectangular orifice.

- **For small orifice:** $Q = C_d \, . \, a \, . \sqrt{2gH}$ ……….. (*a=b.d were a is the orifice area, b is the width and d is the depth*)
- **For Large orifice:** $Q = \frac{2}{3} C_d \, . \, b \, . \sqrt{2g} (H_2^{\frac{3}{2}} - H_1^{\frac{3}{2}})$

Example 8.13. Find the discharge through a rectangular orifice 3.0 m wide and 2.0 m deep fitted to a water tank. The water level in the tank is 4·0 m above the top edge of the orifice. Take C_d= 0.62.

Solution. Width of the orifice, b = 3.0 m

Depth of the orifice, d = 2.0 m

Height of water above the top of the orifice, H_1 = 4.0 m

∴ Height of the water above the bottom of the orifice, $H_2 = 4 + d = 4 + 2 = 6$ m

Co-efficient of discharge, C_d = 0.62

Discharge through the orifice, *Q*:

Using the relation:

$$Q = \frac{2}{3} C_d \cdot b\sqrt{2g}\,(H_2^{3/2} - H_1^{3/2}) \quad \text{with usual notations}$$

$$= \frac{2}{3} \times 0.62 \times 3.0 \times \sqrt{2 \times 9.81}\left(6^{3/2} - 4^{3/2}\right) = 36.78 \text{ m}^3/\text{s}$$

i.e. $\mathbf{Q = 36.78\ m^3/s}$ **(Ans.)**

8.7. Discharge Through Fully Submerged Orifice

If an orifice has its whole of the outlet side submerged under liquid so that it discharges a jet of liquid into the liquid of the same kind then it is known as **fully submerged** (or *drowned*) **orifice.** Consider a fully submerged orifice as shown in Fig. 8.10.

$$Q = C_d \cdot b \cdot d\,\sqrt{2gH}$$

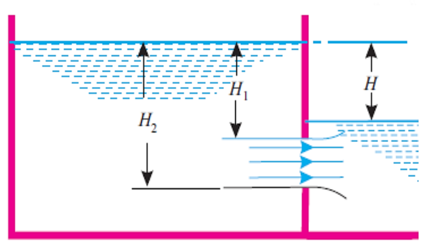

Fig. 8.10. Fully submerged orifice.

Example 8.15. Find the discharge through a totally drowned orifice 1.5 m wide and 1 m deep, if the difference of water levels on both the sides of the orifice be 2.5 m. Take $C_d = 0.62$.

Solution. Width of the orifice, $b = 1.5$ m

Difference of water levels, $H = 2.5$m

Depth of the orifice, $d = 1$ m

Co-efficient of dicsharge, $C_d = 0.62$

Discharge, Q:

Using the relation,

$$Q = C_d \,.\, b \,.\, d\,\sqrt{2gH}$$

$$= 0.62 \times 1.5 \times 1 \times \sqrt{2 \times 9.81 \times 2.5} = 6.513 \text{ m}^3/\text{s}$$

i.e., $\mathbf{Q = 6.513 \text{ m}^3/\text{s}}$ **(Ans.)**

8.8. Discharge Through Partially Submerged Orifice

If the outlet side of an orifice is only partly submerged (or drowned) under liquid then it is known as **partially submerged** (or drowned) **orifice** (Fig. 8.11).

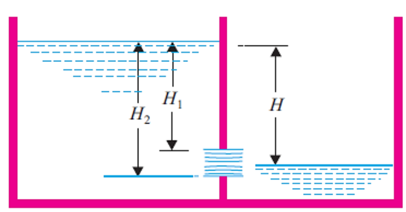

Fig. 8.11. Partially submerged orifice.

$$Q = C_d \,.\, b \,.\, (H_2 - H) \times \sqrt{2gH} + \frac{2}{3} C_d \,.\, b \,.\, \left(H^{3/2} - H_1^{3/2}\right)$$

Example 8.16. A rectangular orifice 1.5 m wide and 1.2 m deep is fitted in one side of a large tank. The water level on one side of the orifice is 2 m above the top edge of the orifice, while on the other side of the orifice; the water level is 0.4 m below its top edge. Calculate the discharge through the orifice if $C_d = 0.62$.

Solution. Width of orifice, $b = 1.5$ m

Depth of orifice, $d = 1.2$ m

Height of water level above the top of the orifice, $H_1 = 2$ m

Height of water level above the bottom of the orifice, $H_2 = 2 + 1.2 = 3.2$ m

Difference of water levels on both the sides, $H = 2.4$ m

Co-efficient of discharge, $C_d = 0.62$

Since the orifice is partially submerged, let us treat the upper portion as a free orifice and the lower portion as a submerged orifice.

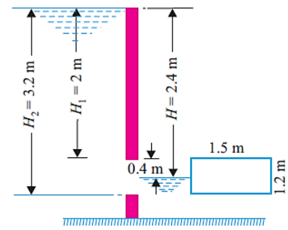

Fig. 8.12

Let, Q_1 = Discharge through the submerged portion, and

Q_2 = Discharge through the free portion.

Using the relation:

$$Q_1 = C_d \,.\, b \,.\, (H_2 - H) \times \sqrt{2gH} \qquad \text{...with usual notations}$$

$$= 0.62 \times 1.5\,(3.2 - 2.4) \times \sqrt{2 \times 9.81 \times 2.4} = 5.1 \text{ m}^3/\text{s}$$

Now, using the relation:

$$Q_2 = \frac{2}{3} C_d \cdot b\sqrt{2g}\,(H^{3/2} - H_1^{3/2}) \qquad \text{...with usual notations}$$

$$= \frac{2}{3} \times 0.62 \times 1.5 \times \sqrt{2 \times 9.81}\,(2.4^{3/2} - 2^{3/2})$$

$$= 2.44 \text{ m}^3/\text{s}$$

The total discharge,

$$Q = Q_1 + Q_2 = 5.1 + 2.44 = 7.54 \text{ m}^3/\text{s}$$

i.e. $Q = 7.54$ **m³/s (Ans.)**

8.9. Time Required For Emptying A Tank Through An Orifice At Its Bottom

Consider a tank, of uniform cross-sectional area, containing some liquid, and having an orifice at its bottom as shown in Fig. 8.13.

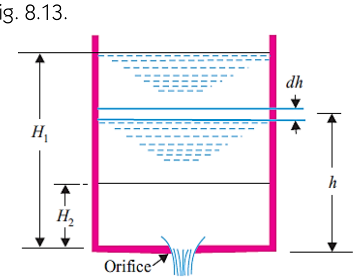

Fig. 8.13 Tank with an orifice at its bottom.

$$T = \frac{2A\sqrt{H_1}}{C_d . a\,\sqrt{2g}}$$

Example 8.17. A circular tank of diameter 3 m contains water up to a height of 4m. The tank is provided with an orifice of diameter 0.4 m at the bottom. Find the time taken by water, (i) to fall from 4 m to 2 m, and (ii) for completely emptying the tank. Take $C_d = 0.6$.

Solution. Dia. of the tank, D = 3m ➔ Area, a = (π/4) × 3² = 7.068 m², Dia. of the orifice, d = 0.4 m

Solution. Dia. of the tank, $D = 3\text{m}$

$\therefore$ Area, $a = (\pi/4) \times 3^2 = 7.068 \text{ m}^2$

Dia. of the orifice, $d = 0.4$ m

$\therefore$ Area, $a = (\pi/4) \times 0.4^2 = 0.1257 \text{ m}^2$

Initial height of water, $H_1 = 4$ m

Final height of water, (*i*) $H_2 = 2$ m (*ii*) $H_2 = 0$

Case I. When $H_2 = 2$ m

Using the relation,

$$T = \frac{2A(\sqrt{H_1} - \sqrt{H_2})}{C_d \cdot a \cdot \sqrt{2g}} \quad \text{...with usual notations}$$

$$= \frac{2 \times 7.068\,(\sqrt{4} - \sqrt{2})}{0.6 \times 0.1257 \times \sqrt{2 \times 9.81}} = \frac{8.28}{0.334} = 24.8 \text{ s}$$

i.e. $T = $ **24.8 s (Ans.)**

Case II. When $H_2 = 0$.

$$T = \frac{2A\sqrt{H_1}}{C_d \cdot a\sqrt{2g}} = \frac{2 \times 7.068 \times \sqrt{4}}{0.6 \times 0.1257 \;\sqrt{2 \times 9.81}} = \frac{28.27}{0.334} = 84.6s$$

i.e. $T = $ **84.6s (Ans.)**

Chapter 9: FLOW OVER NOTCHES AND WEIRS

9.1. DEFINITIONS

- A **notch** may be defined as an opening provided in the side of a tank or vessel such that the liquid surface in the tank is below the top edge of the opening. A notch may be regarded as an orifice with the water surface below its upper edge. It is generally made of metallic plate. It is used for measuring the rate of flow of a liquid through a small channel or a tank
- A **weir** may be defined as any regular obstruction in an open stream over which the flow takes place. It is made of masonry or concrete.
- **A notch is sometimes called as a weir and vice versa**. Weirs may be used for measuring the rate of flow of water in rivers or streams.

9.3. Discharge Over A Rectangular Notch or Weir

Consider a rectangular notch or weir provided in a channel carrying water as shown in Fig. 9·1.

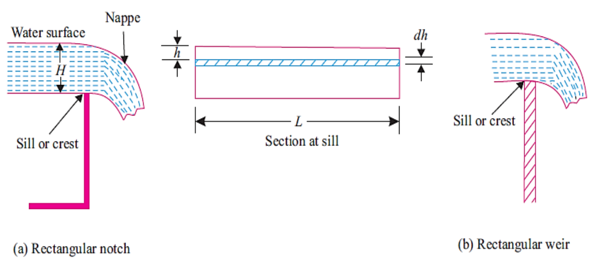

Fig. 9.1. Rectangular notch and weir.

$$Q = \frac{2}{3} C_d . L \sqrt{2g} \left(H^{3/2}\right)$$ (For rectangular weir and notch)

Example. 9.1. A rectangular notch 2·0 m wide has a constant head of 500 mm. Find the discharge over the notch, if co-efficient of discharge for the notch is 0·62.

Solution. Length of the notch, $L = 2{\cdot}0$ m

Head over notch, $H = 500$ mm $= 0{\cdot}5$ m

Co-efficient of discharge, $C_d = 0{\cdot}62$

Discharge, Q:

Using the relation,

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

$$= \frac{2}{3} \times 0{\cdot}62 \times 2{\cdot}0 \times \sqrt{2 \times 9{\cdot}81} \times (0{\cdot}5)^{3/2}$$

$$= \mathbf{1{\cdot}294\ m^3/s}$$ **(Ans.)**

Example. 9.2. A rectangular notch has a discharge of 0·24 m3/s, when head of water is 800 mm. Find the length of the notch. Assume $C_d = 0·6$.

Solution. Discharge, $Q = 0·24\ m^3/s$

Head over notch, $H = 800\ mm = 0·8\ m$

Co-efficient of discharge, $C_d = 0·6$

Length of the notch, L:

Using the relation :

$$Q = \frac{2}{3} C_d \cdot L \times \sqrt{2g}\,(H)^{3/2}$$

$$0·24 = \frac{2}{3} \times 0·6 \times L \times \sqrt{2 \times 9·81}\,(0·8)^{3/2} = 1·267\,L$$

$$\therefore \quad L = \frac{0·24}{1·267} = 0·189\ m \text{ or } 189\ mm$$

i.e. **L = 189 mm (Ans.)**

9.4. Discharge Over a Triangular Notch or Weir

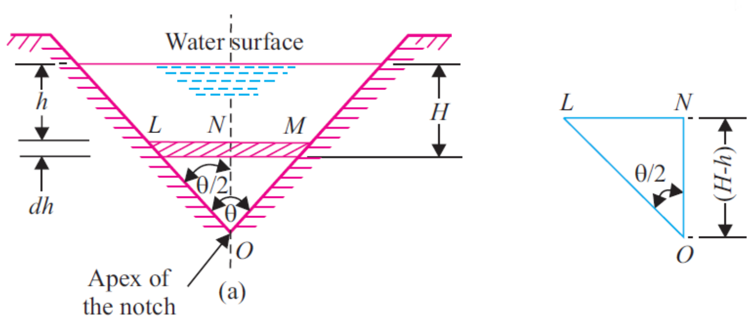

Fig. 9.2. The triangular notch.

$$Q = 2C_d\sqrt{2g}\,tan\frac{\theta}{2}\,H^{5/2}$$

Example 9.3. Find the discharge over a triangular notch of angle 60° when the head over the triangular notch is 0·2 m. Assume Cd = 0·6.

Solution. Angle of notch, $\theta = 60°$

Depth of water, $H = 0{\cdot}2$ m

Co-efficient of discharge, $C_d = 0{\cdot}6$

Discharge, Q:

Using the relation :

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

$$= \frac{8}{15} \times 0\cdot6 \times \sqrt{2 \times 9\cdot81} \times \tan\frac{60°}{2} \times (0\cdot2)^{5/2}$$

$$= \frac{8}{15} \times 0\cdot6 \times 4\cdot429 \times 0\cdot577 \times 0\cdot01788$$

$$= \mathbf{0\cdot01462\ m^3/s}\ \textbf{(Ans.)}$$

Example 9.4. During an experiment in a laboratory, 0·05 m^3 of water flowing over a right angled notch was collected in one minute. If the head of the sill is 50 mm calculate the co-efficient of discharge of the notch

Solution. Discharge, Q = 0·05 m^3/min = 0·000833 m^3/s, Angle of notch, $\theta = 90°$

Head of the sill, H = 50 mm = 0·05 m

Co-efficient of discharge, C_d:

Using the relation:

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

$$0\cdot000833 = \frac{8}{15} \times C_d \times \sqrt{2 \times 9\cdot81} \times \tan\left(\frac{90°}{2}\right) \times (0\cdot05)^{5/2}$$

$$= \frac{8}{15} \times C_d \times 4\cdot429 \times 1 \times 0\cdot000559 = 0\cdot00132\, C_d$$

$$\therefore \quad C_d = \frac{0\cdot000833}{0\cdot00132} = \mathbf{0\cdot63}\ \textbf{(Ans.)}$$

Summary

This lecture covers the fundamental principles of fluid flow through orifices and mouthpieces, which are essential components in hydraulic and pneumatic systems. It explains the differences between orifices (small openings in a wall or vessel) and mouthpieces (extended orifices), detailing their applications in flow measurement and control.

Key topics include:

- **Types of Orifices:** Based on shape, size, and discharge conditions (e.g., sharp-edged, submerged, or weir-type).
- **Flow Equations:** Application of Bernoulli's equation to determine velocity and discharge through orifices using the coefficient of discharge, velocity, and contraction.
- **Mouthpieces:** Their role in modifying flow behavior, increasing efficiency, and reducing energy losses.
- **Experimental and Practical Applications:** Use in industries for metering, pressure regulation, and fluid transport.