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CERTIFICATION COURSES

NPTEL

Irrigation and Drainage

Lecture No:11 Irrigation Water Conveyance

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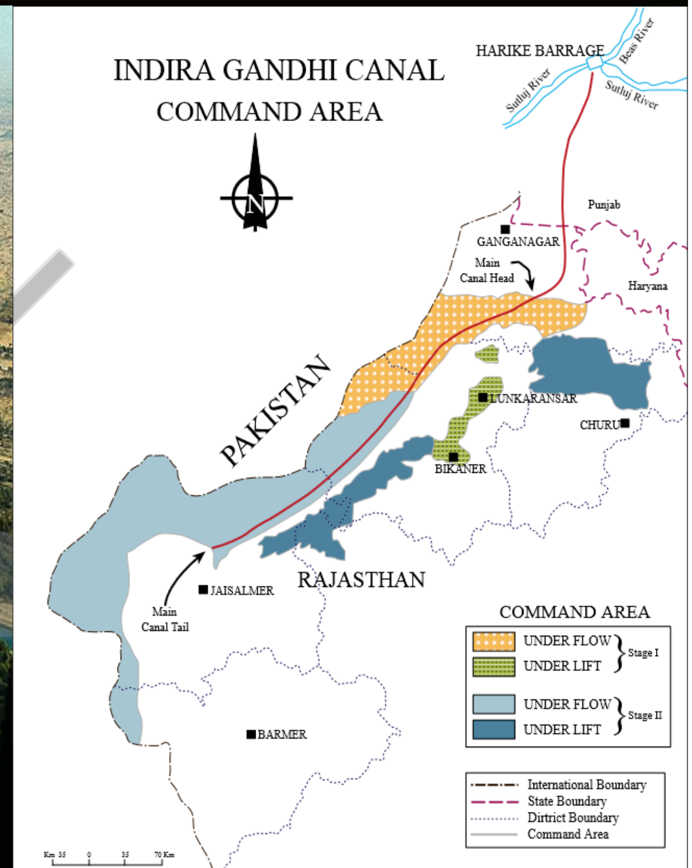
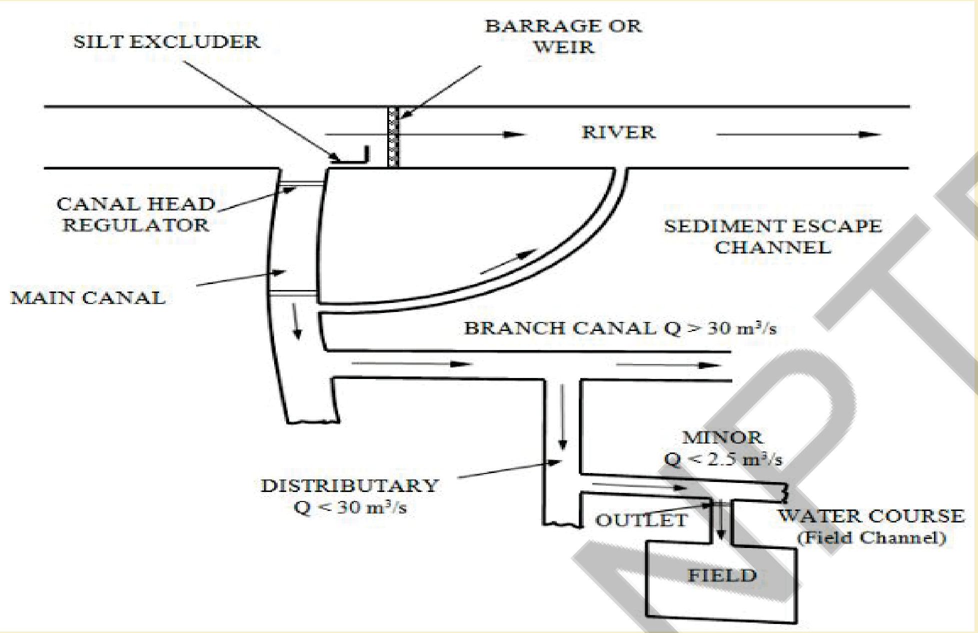
Aerial view of Indira Gandhi Canal, Rajasthan

- ✓649 km long main canal
- ✓Carry water from Satluj and Beas rivers of Punjab
- ✓Rajasthan Feeder
- ✓Fully lined masonary canal



Canal System Layout



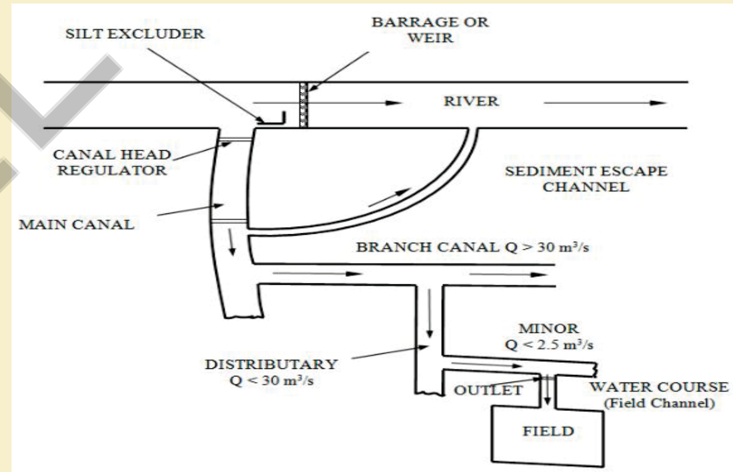
Conveyance of irrigation water from head works at a reservoir, weir or barrage

Components

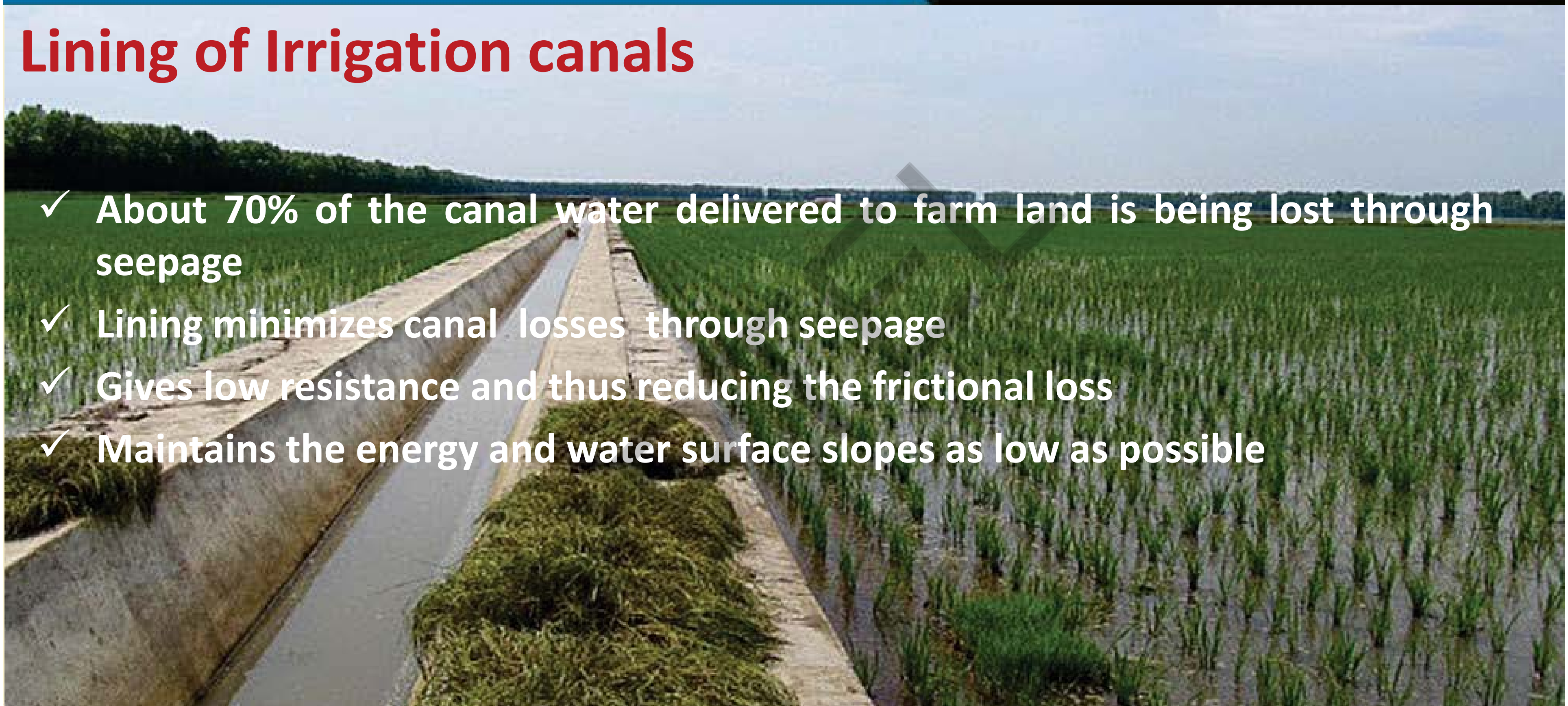
- ✓Open Channels/canals
- ✓Pipelines
- ✓Conveyance Structures
  - ✓Diversions & Pumps
  - ✓Headgates, Wasteways, Division Boxes, Turnouts
  - ✓Water Measurement Devices
  - ✓Check & Grade Control Structures
  - ✓Flumes, Siphons & Culverts

Canal Water Supply

- ✓ Water supply is according to the crops planned in the command area
- ✓ Canal system has to be designed for maximum expected demand
- ✓ Canal layout is important as it should ensure smooth channel flow by gravity
- ✓ Headwork regulates the flow into a canal at the diversion structure
- ✓ Main canal intakes directly from the river (not for direct irrigation)
- ✓ Main canal acts as a feeder channel to the branch canals, or branches
- ✓ Branch canals generally carry a discharge > 5 m^3/s and acts as feeder channel to major distributaries



Lining of Irrigation canals



- ✓ About 70% of the canal water delivered to farm land is being lost through seepage
- ✓ Lining minimizes canal losses through seepage
- ✓ Gives low resistance and thus reducing the frictional loss
- ✓ Maintains the energy and water surface slopes as low as possible

Canal Lining

1. Concrete lining:

- ✓ Best suited for main canals
- ✓ High initial cost
- ✓ long life and minimum maintenance
- ✓ A thickness of about 5 to 12 cm and stable side slopes between 1.5H: 1V to 1.25H: 1V are adopted

Canal Lining

2. Shotcrete lining:

- ✓ Cement mortar ratio of 1:4. Generally laid in a thickness of about 3.5 cm.
- ✓ Wire mesh reinforcement is clamped to the channel surface before applying shotcrete.
- ✓ Convenient for lining small sections, for repair of old linings, and for placing linings around curves or structures.

Canal Lining

3. Brick or burnt clay tile/ precast concrete tile lining:

- ✓ Top layer is generally laid in 1:3 cement mortal over 15mm thick layer of plaster in 1:3 cement plaster
- ✓ Does not require skilled mason or rigid quality control
- ✓ More labour intensive and generates employment potential

Canal Lining

4. Boulder Lining

- ✓ Suitable where stones of required specification are available in abundance locally
- ✓ Used for lining the earthen canal cross-section
- ✓ To reduce the resistance to flow, a 20 to 25 mm thick cement plaster is provided as a finishing surface

Canal Lining

5. Earth linings:

- ✓ ***Stabilized earth linings:*** stabilized using either clay or by adding chemicals
- ✓ ***Loose earth blankets:*** Fine grained soil
- ✓ ***Compacted earth linings:*** about 15 percent clay is spread and compacted
- ✓ ***Buried bentonite membranes:*** constructed by spreading soil-bentonite mixtures and covering it with gravel or compacted earth
- ✓ ***Soil-cement lining:*** cement and sandy soil are mixed and then compacted at optimum moisture content

Canal Lining

6. Plastic Lining

- ✓ The Low Density Polyethylene (LDPE), Polyvinyl Chloride (PVC), High Molecular High Density Polyethylene (HDPE), Linear Low Density Polyethylene (LLDP) etc., are the plastics used for canal lining.
- ✓ Plastic films are: Light in weight, impermeable to liquids and gases, chemically inert, flexibility, resistance to microbiological attacks, ease of transportation and installation etc.
- ✓ Burrowing by rodents is a menace.

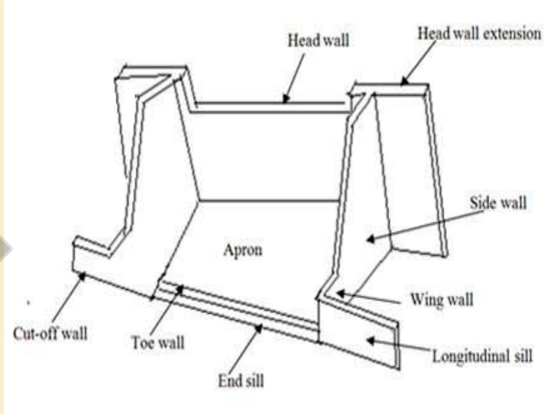
Water Conveyance Structures

These structures help channels or pipelines to cross roads, depressions, high spots, drainage channel etc.

1. Drop structures :

Components –Head wall, headwall extensions, side wall, wing walls apron, longitudinal sills, end sills, and cutoff walls.

- ✓ Constructed when ground surface is of steep slopes
- ✓ Open structures and pipe drop structures

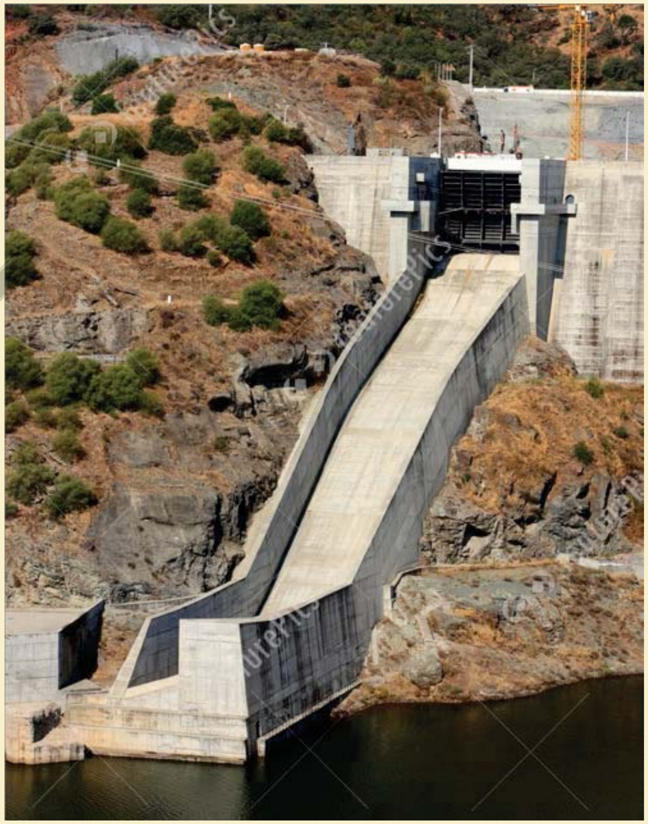


Drop in irrigation channel

Water conveyance structures

2. Chutes:

- ✓ In steep slopes, a series of open drop structures are replaced with chute spillways to reduced the construction cost
- ✓ It consists of –inlet, steeply slope channel and an outlet
- ✓ It is made up of concrete or masonry structure



Water conveyance structures

3. Channel crossing

- ✓ Aids channels in cross roads, depressions, high spots, drainage channel and obstructions.
- ✓ Inverted siphon, Culvert, and flume are some channel crossing structures

Diversion Structures

These structures divert irrigation water from field channel to the border, check basin or furrows

1. **Check gate:** It raised the upstream water level so that water can be easily diverted to field

2. **Portable check dams:** Used to raised the water surface in the channel to facilitate easy irrigation at discharge < 60 l/s: made of metal, canvas or plastic.

Diversion structures

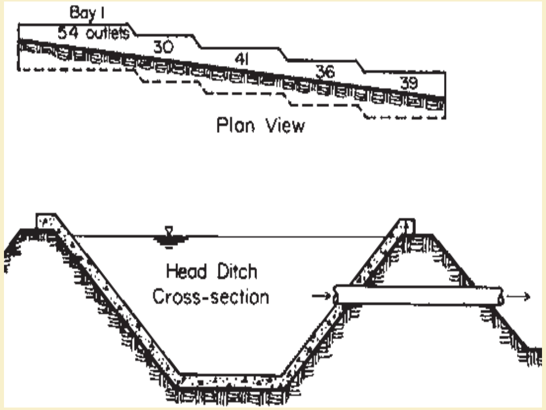
3. Turnouts:

used to convey irrigation from distribution channel to field supply ditch or from ditch to field

4. Spiles:

are short pieces of bamboo, concrete, burnt clay or rigid PVC pipes to convey water from field to furrow, border or check basin

Bamboo Spiles



Spiles

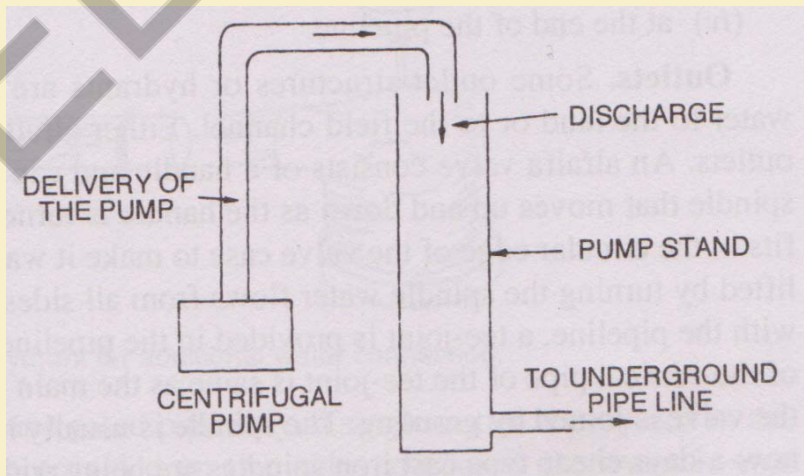
Structure for pipeline

Pipeline require certain structure at specific position for proper flow and control of discharge.

1. Pump stand :

Pump stand is used for

- ✓ Convey the flow of the pump into the pipe by maintaining the required head
- ✓ Ensure full flow in the pipe line
- ✓ Prevent pipe damage from excessive pressure

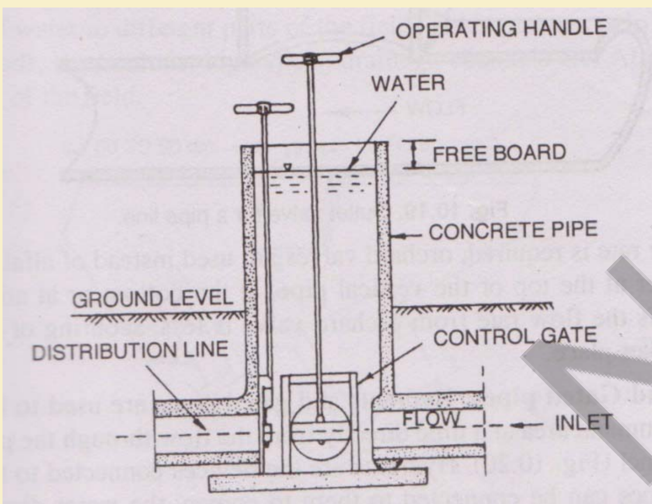


Pump stand of an under ground pipe line

Structure for pipeline

2. Gate stands:

Used to control the flow when the branch line takes off from the main line in different direction



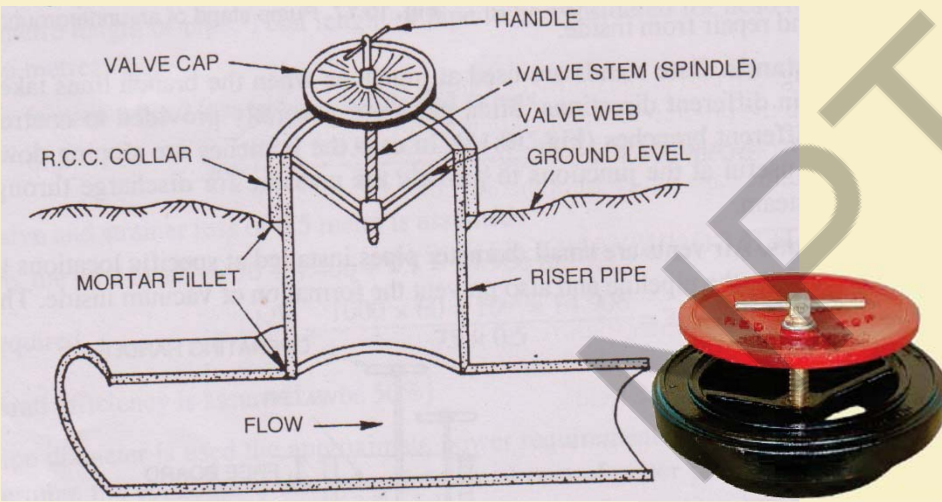
3. Air vent:

Small diameter pipes installed at specified locations to release any entrapped air and vaccum formation

Structure for pipeline

4. Outlets:

- ✓ Are required at regular intervals to deliver water to the field channel
- ✓ Alfalfa valves



5. Hydrant and gated pipes

Used for irrigating a particular portion of the command area directly from the flow through pipe without the use of any field channel.

Diversion structures

5. Siphon tubes: used to convey water to individual furrow, basin or border by passing over the field embankment and irrigate through siphoning

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Irrigation and Drainage

Lecture No:12 Irrigation Channel Design

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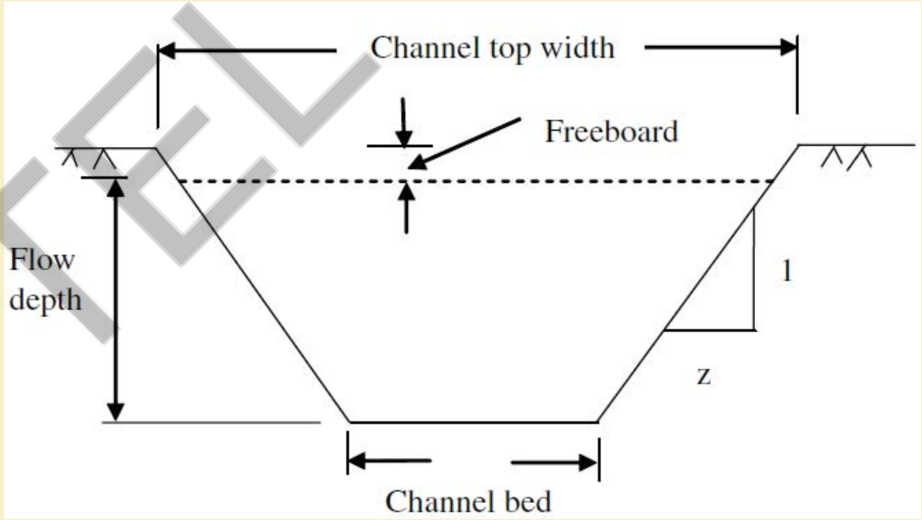
Open Channel Flow of Irrigation Water

Main Parameters

- ✓ Top width (T)
- ✓ Freeboard
- ✓ Channel bed (b)
- ✓ Side slope (S)
- ✓ Wetted perimeter (P):
- ✓ Hydraulic radius (R) $= \frac{A}{P}$



Open Channel Flow

Calculation of Velocity (V) of Flow in Open Channel

- ✓ **Chezy's Equation** $V = C\sqrt{RS}$
- ✓ **Manning's Equation** $V = \frac{1}{N} R^{2/3} S^{1/2}$

Where, V = velocity of flow (m/s); R = hydraulic radius of the flowing section (m); S = Channel slope, in m per m; C = Chezy's constant, which varies with surface roughness and flow rates, N = Manning's roughness coefficient

$$C = \frac{1}{N} R^{1/6}$$

Channel type/lining type	N value
Concrete	0.011–0.013
Stone masonry	0.03–0.042
Soil cement	0.02–0.025
Bare soil	0.02–0.023
Vegetative waterway[a]	0.15–0.35

[a]For medium, dense, and very dense grass, N should be 0.15, 0.25, and 0.35, respectively.

Manning's roughness coefficient for different channels

Hydraulic Design of Open Channel

Maximum Discharge Through a Rectangular Channel

Area of flow, $A = b \times d$

Discharge, $Q = A \times V = AC\sqrt{RS}$ (since V = C√ RS)

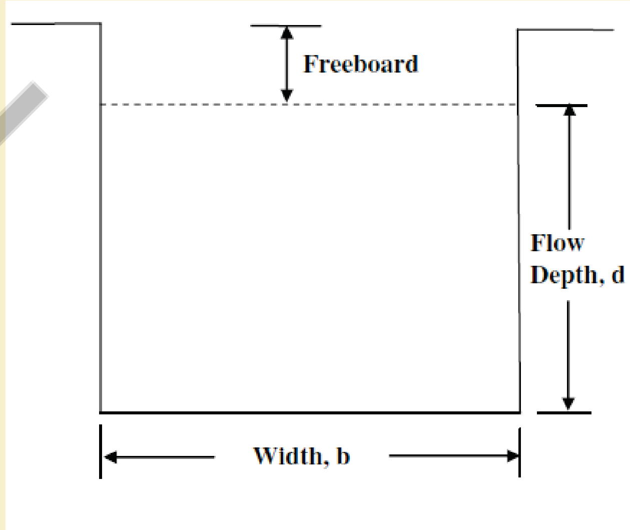
Wetted perimeter, P = b + d + d = b + 2d

$$P = A/d + 2d \quad (\text{since } b = A/d)$$

$$\frac{dP}{dd} = -\frac{A}{d^2} + 2 = 0 \quad \text{or} \quad \frac{A}{d^2} - 2 = 0$$

$$\text{or } A = 2d^2 \text{ or } b = 2d$$

The hydraulic radius, $R = \frac{A}{P} = \frac{bd}{b+2d} = \frac{2d \times d}{2d+2d} = \frac{2d^2}{4d} = \frac{d}{2}$



Hence, for the maximum discharge conditions, $b = 2d$ and $R = d/2$

Hydraulic Design of Open Channel

Maximum Discharge Through a Trapezoidal Channel (side slope = $\frac{1}{z}$)

Area , $A = (d \times b) + 2\left(\frac{1}{2} \times d \times zd\right) = bd + zd^2 = d(b + zd)$ or $\frac{A}{d} = b + zd$ or $b = \frac{A}{d} - zd$

Discharge, $Q = A \times V = AC\sqrt{RS} = AC\sqrt{\frac{A}{P}S}$

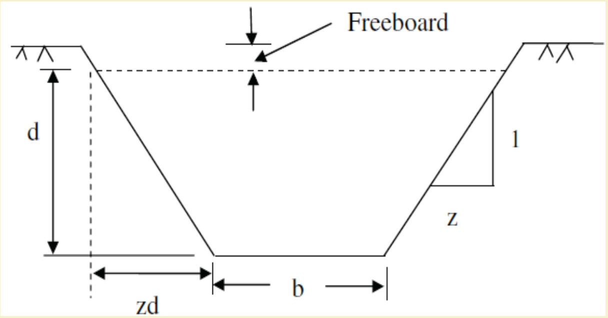
We know, $P = b + 2\sqrt{z^2d^2 + d^2} = b + 2d\sqrt{z^2 + 1}$ or $P = \frac{A}{d} - zd + 2d\sqrt{z^2 + 1}$

P will be minimum when, $\frac{dP}{dd} = 0;$

$\frac{dP}{dd} = -\frac{A}{d^2} - z + 2\sqrt{z^2 + 1}$ or $\frac{A}{d^2} + z - 2\sqrt{z^2 + 1} = 0$

or $\frac{d(b+zd)}{d^2} + z = 2\sqrt{z^2 + 1}$ or $\frac{(b+2zd)}{d} = 2\sqrt{z^2 + 1}$

or $\frac{(b+2zd)}{2} = d\sqrt{z^2 + 1}$



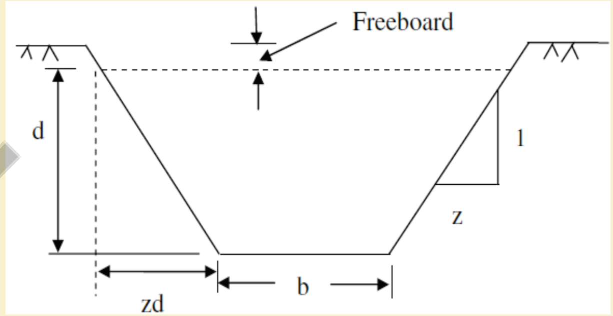
Hydraulic Design of Open Channel

$\frac{(b+2zd)}{2} = d\sqrt{z^2+1}$

½ Top width of water = single sloping side

Incase of hydraulic radius,

$$R = \frac{A}{P} = \frac{d(b+zd)}{b+2d\sqrt{z^2+1}} = \frac{d(b+zd)}{b+(b+2zd)} = \frac{d(b+zd)}{2(b+zd)} = \frac{d}{2}$$



For maximum discharge or maximum velocity,

$\frac{b+2zd}{2} = \frac{T}{2} = d\sqrt{z^2+1}$ (the sloping side is equal to half of the top width, T)

$R = \frac{d}{2}$ (hydraulic radius is half of flow depth)

Hydraulic Design of Open Irrigation Channel

Example 12.1:

Determine the velocity of flow and discharge capacity of an unlined canal branch on a grade of 1 m in 800 m having depth of flow 1.5 m, bottom width 0.80 m, and side slope 1:1.

Solution: Depth of flow, d = 1.5 m; Bed width, b = 0.8 m; Canal bottom slope, $S = \frac{1}{800}$= 0.00125

Side slope, 1:z = 1 : 1

Channel is unlined, assume roughness coefficient of Manning's formula, N = 0.023

Area, $A = (bd + zd^2) = (0.8 \times 1.5) + 1 \times (1.5)^2 = 3.45\, m^2$

Wetted perimeter, $P = b + 2d\sqrt{1+z^2} = 0.8 + 2 \times 1.5\sqrt{1+1^2} = 5.042\, m$

Hydraulic radius, $R = \frac{A}{P} = \frac{3.45}{5.042} = 0.684$

Velocity, $V = \frac{1}{n} R^{2/3} S^{1/2} = \frac{1}{0.023} \times (0.684)^{2/3}$ ×√0.00125 = 1.193 m/s **(Ans.)**

Discharge, $Q = AV = 3.45 \times 1.193 = 4.116\, m^3/s$ (**Ans.**)

Hydraulic Design of Open Irrigation Channel

Example 12.2:

Design an earthen channel of trapezoidal section for the following conditions:

Discharge Q = 2m^3/s ; Slope of the channel bed, $S = \frac{1}{1200}$; Side slope, z :1 = 1.3:1; Manning's n = 0.02

Solution: For most economical trapezoidal section, $\frac{(b+2zd)}{2} = d\sqrt{z^2+1}$ and $R = \frac{d}{2}$

$\frac{(b+2zd)}{2} = d\sqrt{z^2+1}$ or $b + 2.6d = 2d\sqrt{1.3^2+1}$ or $b = 0.68d$

Now, area, $A = d(b + zd) = d(0.68d + 1.3d)$ $or, A = 1.98d^2$

Discharge, $Q = AV = A \times \frac{1}{n} R^{2/3} S^{1/2}$ Putting the values,

$$2 = 1.98d^2 \times \frac{1}{0.02} \times \left(\frac{d}{2}\right)^{2/3} \times \left(\frac{1}{1200}\right)^{1/2}$$

Hydraulic Design of Open Irrigation Channel

or $d^{8/3} = 1.11 \; or \; d = 1.04 \, m$

Then, $b = 0.68d = 0.7072$ m

Assuming a freeboard of 20% of flow depth, depth of channel would be

$$d_c = 1.04 \times 1.20 = 1.248 \, m \approx 1.25 \, m$$

Top width $= b + 2zdc = (0.7072 + 2 \times 1.3 \times 1.25) = 3.957 \, m$

Channel bed width, d = 0.7072 m

Flow depth, d = 1.04 m

Depth of channel = 1.25 m

Top width = 3.957

Side slope = 1.3:1(H:V) Ans.

Pipe flow of irrigation water

- ✓ **Equations describing fluid flow are based on three fundamental laws of physics.**
  - ✓ **Conservation of matter (or mass)** - states that matter cannot be created or destroyed, but it can be converted e.g., by a chemical process
  - ✓ **Conservation of energy-** energy cannot be created or destroyed, but can be converted from one type to another e.g., potential energy may be converted to kinetic energy or pressure energy.
  - ✓ **Conservation of momentum** - a moving body cannot gain or loss momentum unless an external force acts upon it.
- ✓ **Theories of Hydraulics and Fluid Flow**
  - ✓ Pascal's Law
  - ✓ Continuity Equation/Conservation of Mass
  - ✓ Bernoulli's Equation/Energy Equation

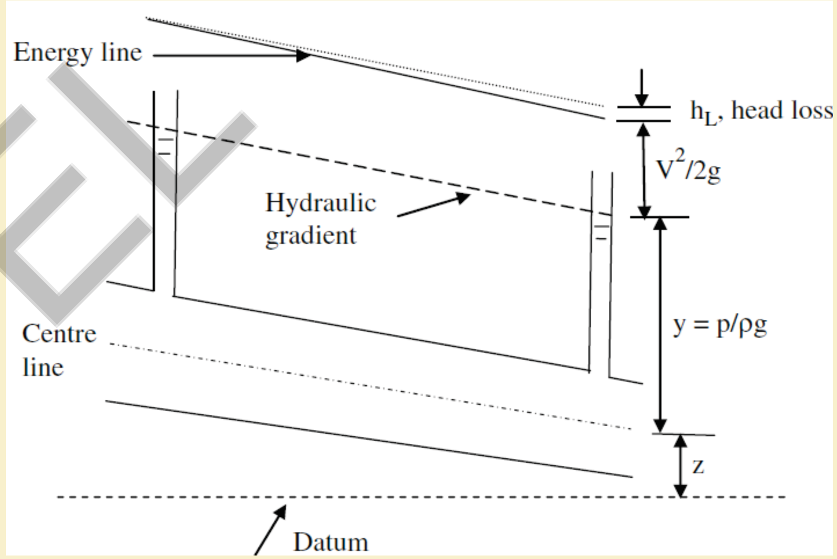
Hydraulic and Energy Grade Line for Pipe Flow

- ✓ Total Energy line
- ✓ Hydraulic grade line
- ✓ Types of Flow in Pipe – Reynolds Number

$$Re = \frac{\rho V d}{\mu}$$

Where ρ = density of fluid (kg/m^3) V = mean fluid velocity (m/s); d = diameter of the pipe (m); μ = coefficient of viscosity of the fluid (kg/m/s)

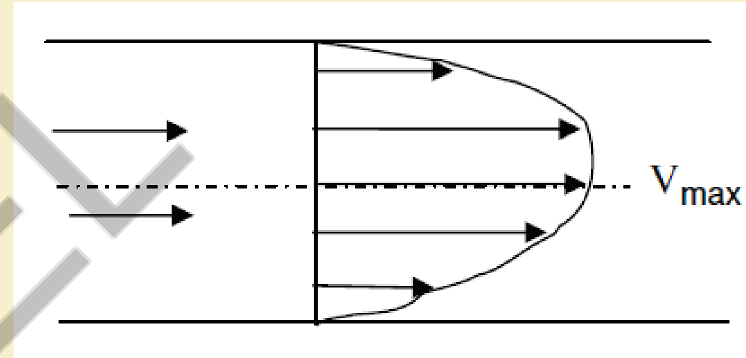
- ✓ Laminar flow : $Re \leq 2{,}100$.
- ✓ Transition flow : 2,100 < Re >4,000
- ✓ Turbulentflow >4,000



Hydraulic and Energy Grade Line for Pipe Flow

- ✓ **Velocity Profile of Pipe Flow**
  - ✓ Velocity is zero at the surface and maximum at the center of the pipe
- ✓ **Head Loss in Pipe Flow**
  - ✓ Major head loss - friction in the pipe
  - ✓ Minor head loss- change in diameter, change of velocity in bends, joints, valves, and similar items
  - ✓ **Darcy-Weisbach** equation for head loss

$$h_f = F\frac{L}{D}\frac{V^2}{2g}$$



Where h_f = head loss due to friction (m)
F= friction factor (Darcy's friction coefficient)
L = length of pipe (m)
V = velocity of flow (m/s)
g = acceleration due to gravity = 9.81 m/s^2
D = inner diameter of the pipe (m)

Hydraulic and Energy Grade Line for Pipe Flow

Example 12.3:

Determine the head loss due to friction in an irrigation pipe having 150 m length and 25 cm diameter. The velocity of flowing water in the pipe is 2.0

Solution: Head loss according to Darcy-Weisbach formula

$$h_f = F\frac{L}{D}\frac{V^2}{2g}$$

V = 2.0 m/s

Assuming F = 0.025 (as of cast iron)

$$hf = 0.025 \times \frac{150}{0.25} \times \frac{2^2}{2 \times 9.81}$$

$$= 3.058\, m\ of\ water\ \boldsymbol{Ans}.$$

Designing Pipe Size for Irrigation Water Flow

- ✓ **Selection of pipe size should be based on the following:**
  - ✓ Hydraulic capacity (discharge) requirement
  - ✓ Head loss, and
  - ✓ Economy
- ✓ **Pipe size based on hydraulic capacity can be found as**

$$A = \frac{Q}{V}$$

Where A = cross-sectional area of the pipe (m^2) $A = \pi D^2/4$, that is, $D = \sqrt{\frac{4A}{\pi}}$

Q = discharge (m^3/s); V = permissible velocity of flow (m/s)

Designing Pipe Size for Irrigation Water Flow

- **Selection of pipe size should be based on the following:**
  - Hydraulic capacity (discharge) requirement
  - Head loss, and
  - Economy
- **Pipe size based on hydraulic capacity can be found as;** $A = \frac{Q}{V}$

Where A = cross-sectional area of the pipe (m2)$A = \pi D^2/4$, that is, $D = \sqrt{\frac{4A}{\pi}}$

Q = discharge (m^3/s); V = permissible velocity of flow (m/s)

- **Calculate the head loss per unit length** and also for the whole irrigation farm
- **Compare the prices of the pipes and extra cost** for head loss for the entire life, choose the least cost
- one.

Designing Pipe Size for Irrigation Water Flow

Example 12.4:

Compute the size of best quality cast-iron pipe that will carry 0.03 m^3/s discharge with a head loss of 2 m per 1,000 m.

Solution: We know $h_f = F\frac{L}{D}\frac{V^2}{2g}$

$$Q = 0.03\, m^3/s$$

For $L = 1000\, m, hf = 2\, m$

$$V = Q/A = Q/(\pi D^2/4)$$

Thus, 2 = $0.023 \times \frac{1000}{D} \times \frac{(0.03)^2}{(\pi D^2/4)^2} = 0.023\ \frac{1000\times 16\times (0.03)^2}{\pi^2 \times D^5}$

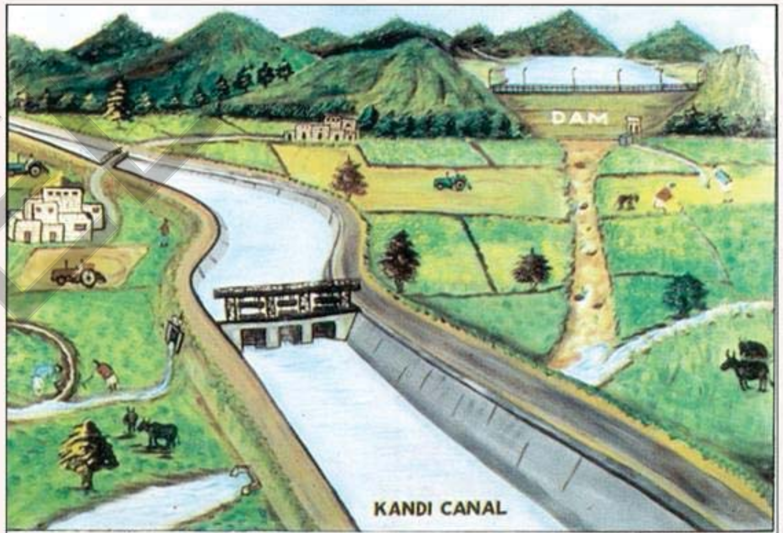
Or, $D^5 = 0.016779$ Or, $D = 0.4415m = 44.15\ cm$

Hence, pipe diameter = 44.15 cm (Ans.)

Canal Irrigation Scheduling

- ✓ **Aim of a canal system -** to provide irrigation water at the **right time** in the **right amount** and at the **right place**.

- ✓ **Canal scheduling types:**
  - ✓ **Rigid (predetermined) schedules –**
    - ✓ improve irrigation efficiencies in areas where operators are new to irrigation technology
  - ✓ **Flexible (modifiable) schedules –**
    - ✓ free access of a flexible system could be misused.



Artistic view of Kandi Area development

Canal Irrigation Scheduling

- ✓ **Rigid Schedule Irrigation Systems**
  - ✓ Canal is operated continuously at a constant flow rate
  - ✓ Flow rate 15 to 30 L/s; frequencies 7 to 14 days; and durations of 8, 12, or 24 hrs
  - ✓ Relatively low capital investment
  - ✓ Cause improper timing, excess irrigation and runoff, prevent effective use of rainfall, create conflicts over water, and potentially inhibit good farm management
  - ✓ Low water use efficiency
- ✓ **Flexible Control Irrigation Systems**
  - ✓ Water is supply as desired with flexibility in frequency, rate, and duration
  - ✓ Flexible schedules are expensive
  - ✓ Optimizing farming operations and maintaining sustainable irrigated agriculture.
  - ✓ Large irrigation systems are available to irrigate each crop when needed

Canal Irrigation Scheduling

1. Warabandi (Rigid Schedule)

- ✓ Wara is ‘turn’ and bandi means ‘fixation’
- ✓ Water distribution is performed by turns based on a predetermined irrigation schedule (day, time and duration)
- ✓ The upper tier is operated by state agency
- ✓ The lower tier is managed by an institution of cultivators having their land under that outlet.
- ✓ Greater social acceptance as there is an in-built mechanism for equity and efficiency
- ✓ **Limitation**-Equitable distribution of water to tail end farmer is not possible due to seepage losses in the serving length of the channel.

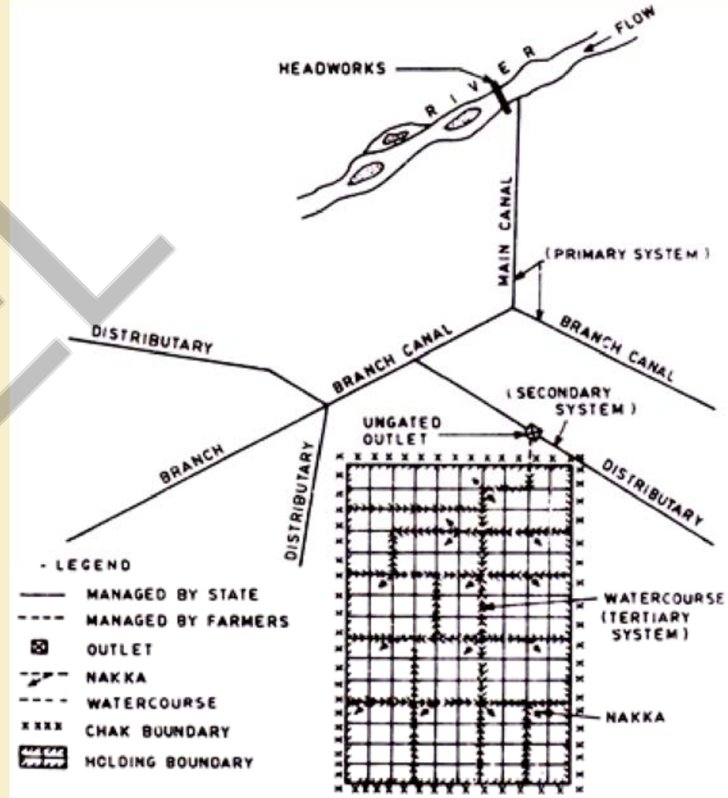


Fig. 1.1 Warabandi system

Canal Irrigation Scheduling

2. Shejpali (Rigid Schedule)

- ✓ Practiced in the State of **Maharashtra** and **Gujarat**.
- ✓ Priority is given to the tail-end farmers and serving the head-end farmers last
- ✓ Solved the tail-end problem of Warabandi system
- ✓ Farmer is required to apply for irrigation water right for a particular crop over a particular area each season
- ✓ **Limitation**-trail end deprivation, which results due to inequity in water supply between head-end and tail-end farms

3. Block System

- ✓ Practice in the western Maharashtra
- ✓ The state enters into a 6 to 12 year agreement with a group of farmers to provide a fixed quantity of water for a particular crop pattern
- ✓ The farmers in the block are required to pay for the volume of water delivered as measured by the irrigation agency
- ✓ Block system is also devised to encourage investment in sugar

Canal Irrigation Scheduling

5. Assured Irrigation Area (Rigid Schedule)

- ✓ Practiced in the state of Bihar
- ✓ Water is allocated to the assured irrigation area within each surface irrigation system
- ✓ Water is sufficient to bring the crop to maturity
- ✓ Extra water is allotted to the probable irrigation area within the system
- ✓ Assured irrigation area farmers are billed each season
- ✓ Probable irrigation area are billed following their applications for water

6. Land Classification

- ✓ Practice in the state of Bihar and the southern states of Tamil Nadu and Kerala
- ✓ Surface irrigation water is allocated according to land classes
- ✓ Entire land in an irrigation command area is classified with regards to 'rights to irrigation water'
- ✓ Certain key aspects of operating irrigation schedules are decided at meetings chaired by District Collectors

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Irrigation and Drainage

Lecture No:13 Measurement of Irrigation Water: Open channel

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Basic Terminologies and Hydraulic Principles of Flow Measurement

- ✓ **Flow Rate or Discharge**

  The quantity of fluid flowing per second through a channel or pipe. It is usually expressed in m^3/s or L/s.

- ✓ **Velocity of Approach**

  The velocity with which water approaches/reaches the flow measuring device

$$V = Q/Area\ of\ flow$$

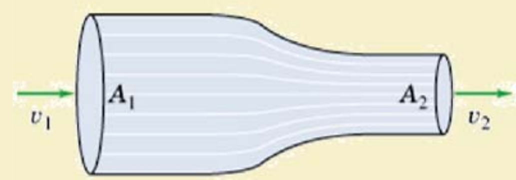
Basic Terminologies and Hydraulic Principles of Flow Measurement

✓ **Continuity Equation**

The quantity of fluid flowing per second through a conduit at all the cross-section is constant (considering no loss from the system or gain outside the system).

$$Q = A_1V_1 = A_2V_2$$

Where A and V are the area and velocity, respectively.



✓ **Fluid Pressure: Pascal's Law**

A fluid at rest (static) or in motion (dynamic) exerts pressure on its surface. In a static fluid, the intensity of pressure at a point is equal in all directions, i.e., $P_x = Py = Pz$

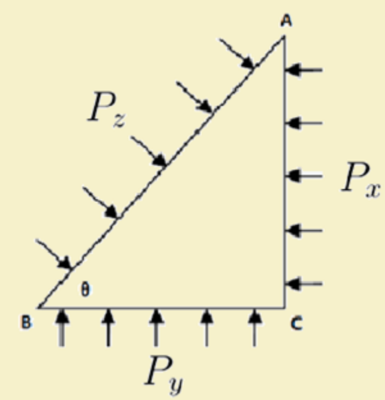


Fig: Element of liquid

Basic Terminologies and Hydraulic Principles of Flow Measurement

- ✓ **Steady and Unsteady Flow -** In an open channel flow, if the velocity (V), depth of flow (h), and flow rate (Q) do not change with time, the flow is termed as steady flow, else it is an unsteady flow. For Steady flow;

$$\frac{dV}{dt} = 0,\ \frac{dh}{dt} = 0,\ \frac{dQ}{dt} = 0,\ \text{and Unsteady flow;}\ \frac{dV}{dt} \neq 0,\ \frac{dh}{dt} \neq 0,\ \frac{dQ}{dt} \neq 0$$

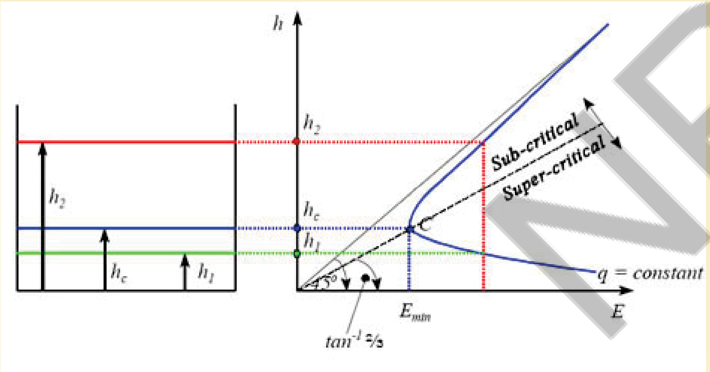
- ✓ **Bernoulli's Equation –** states that in a steady flow of an incompressible fluid, the total energy at any point of the fluid is constant. Bernoulli's equation for non viscous fluid between two points of a flowing path can be written as:

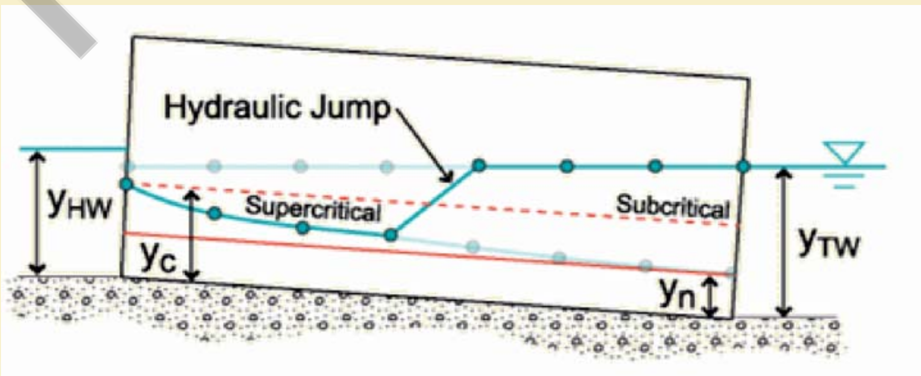
$$P_1 + \frac{V_1^2}{2g} + Z_1 = P_2 + \frac{V_2^2}{2g} + Z_2$$

Where P is the pressure head; $\frac{V^2}{2g}$ is the kinetic head; Z is the elevation head.

Basic Terminologies and Hydraulic Principles of Flow Measurement

- ✓ **Specific energy** – is defined as the energy per unit weight of fluid. It is given by: $E = h + \frac{V_1^2}{2g}$
- ✓ **Critical depth (h_c)** is the depth of flow when the specific energy is minimum and velocity of flow at critical depth is known as critical velocity.
  - o Critical flow is defined in relation to Froude number (FN)= $\frac{V}{\sqrt{gD}}$
  - o i.e., FN = 1, the flow is critical; FN<1, the flow is subcritical, and if FN>1, the flow is super-critical. In other





Types of Flow Measuring Devices

- ✓ Broadly categorized as follows:
  - Volumetric measurements,
  - Area - Velocity methods,
  - Tracer methods (dilution)

- ✓ The tools or devices used for measuring water flow can be categorized as follows:
  - **Volumetric flow measuring devices** – notch, weirs, flumes, venturimeter, orifice meter, magnetic meter, ultrasonic meter,
  - **Velocity measuring devices** - current meter, pitot tube, float, etc
  - **Water level (height) measuring devices** - staff gauge, meter scale, water level sensor, ultrasonic water level sensor, etc.

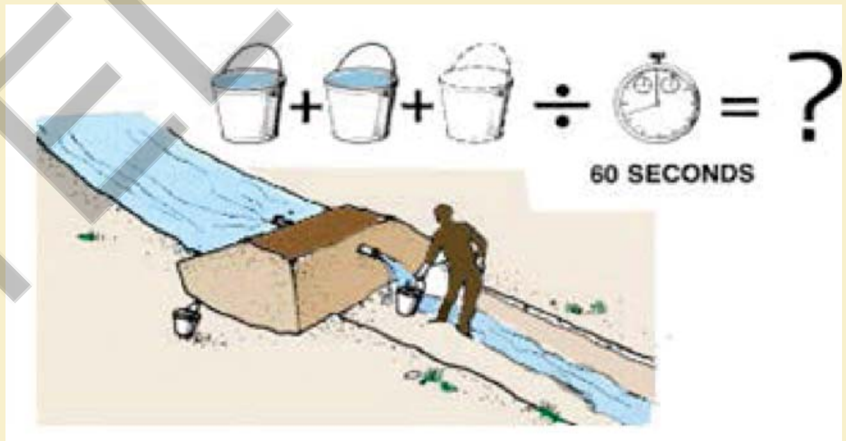
Types of Flow Measuring Devices

Volumetric Measurements

- ✓ Flow rate through a small opening is collected for a particular time period, and then measured the volume of the collected water to obtain the flow rate,

$$Q = \frac{\text{volume of water collected}}{\text{time required}}$$

- ✓ This approach is not suitable for large discharge or open channel flow.



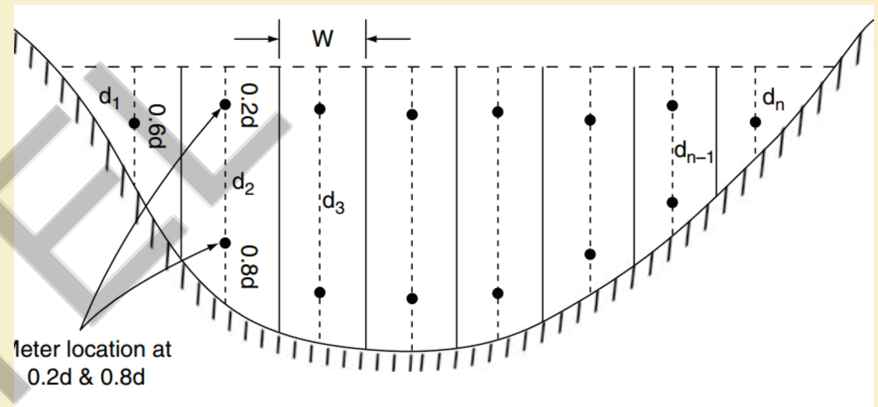
Types of Flow Measuring Devices

Area–Velocity method

- ✓ Involves measurement of velocity of flow (V) and area of the flowing stream (A). Flow rate (Q) is calculated as:

$$Q = A \times V$$

- ✓ For irregular cross-sections, velocity measurements are be made at depth of **0.2d and 0.8d** (for two-point method) or at **0.6d** depth (for one-point method)



The discharge at each strip (ΔQ):

$$\Delta Q = \left(W \times \frac{d_1 + d_2}{2}\right) \times \frac{V_{0.2d} + V_{0.8d}}{2}; \text{ or}$$

$$= W \times \frac{d_1 + d_2}{2} \times V_{0 \cdot 6d}$$

Total discharge $Q = \sum \Delta Q$

Types of Flow Measuring Devices

Tracer Method

- ✓ Suitable for field measurements without installing fixed structures
- ✓ A substance (tracer) in concentrated form is introduced into the following water and allowed to thoroughly mix
- ✓ The concentration of the tracer is measured at a downstream section.

Types of Flow Measuring Devices

Tracer Method

Conservation of mass equation:

$$Q_0 \times C_b + q \times C_1 = (Q_0 + q) \times C_2$$

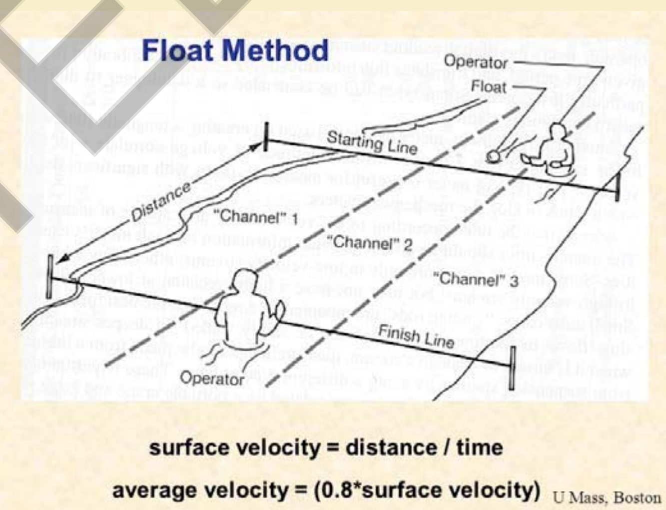
$$Q_0 = \frac{q\ (C_1 - C_2)}{C_2 - C_b}$$

Where, Q_0= flow rate of the stream, q= injection rate of concentrated tracer in the stream, C_b=background tracer concentration in stream, C_1= concentration of tracer in the prepared solution, C_2= concentration of tracer in the downstream water.

Measurement of velocity

Surface float consists of material that can float

- Time taken by floats(t) to travel a certain distance (L) is measured and surface velocity is calculated as: $V_s = L/t$:
- Then, mean velocity of flow$= 0.8 \times V_s$



Measurement of velocity

Current meter : A current meter is used to measure velocity at several points

Stream velocity measured at 0.2 and 0.8 of depth of channel for higher depths
In case of shallow depths, 0.6 of the depth

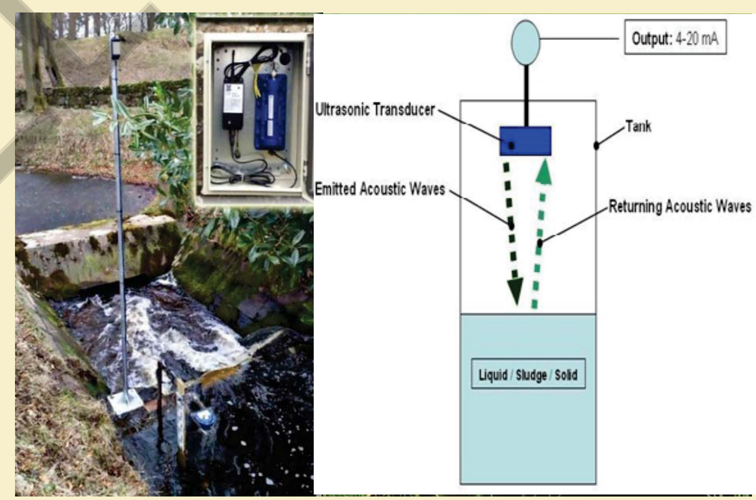
$$Discharge = Flow\ cross\_section\ X\ flow\ velocity$$

Measurement of Water Depth

Staff Gauge

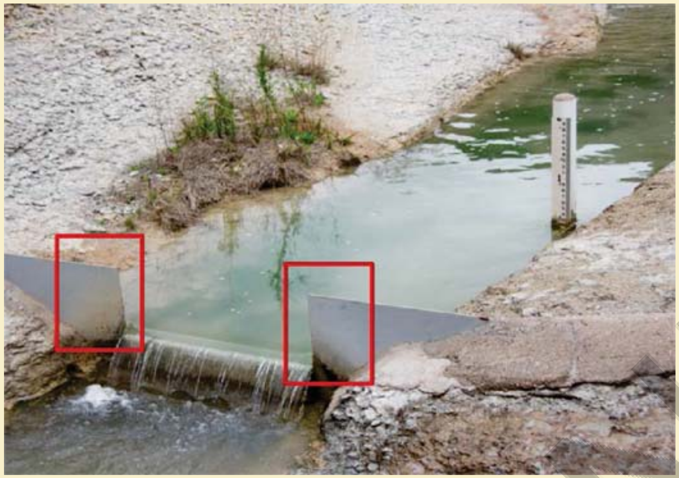
water level sensor

Ultrasonic water level sensor



Measuring Structures

Classification of Notches



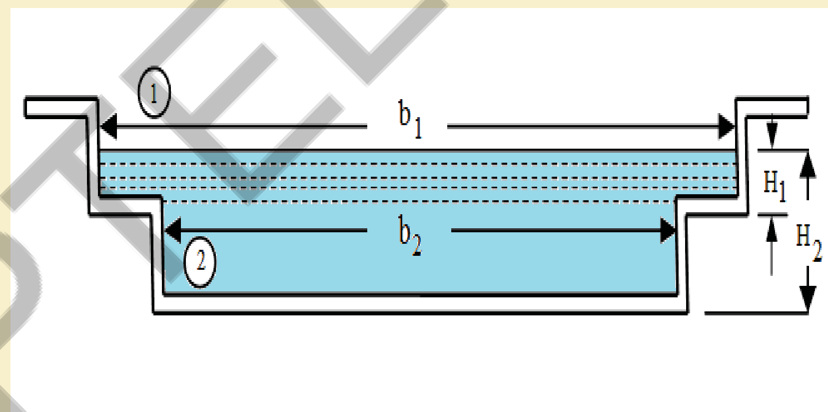
Rectangular notch

Triangular notch

Measuring Structures

Classification of Notches

Trapezoidal notch

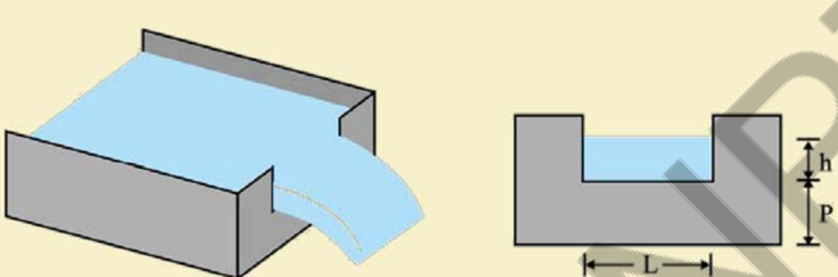


Stepped notch

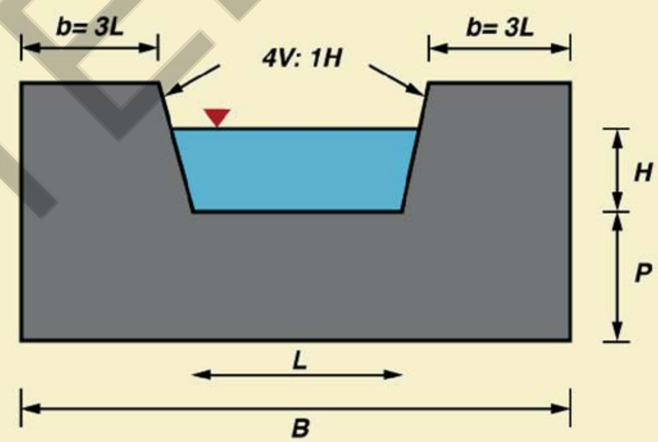
Measuring Structures

Classification of Weirs

1. According to shape of opening



Rectangular weir

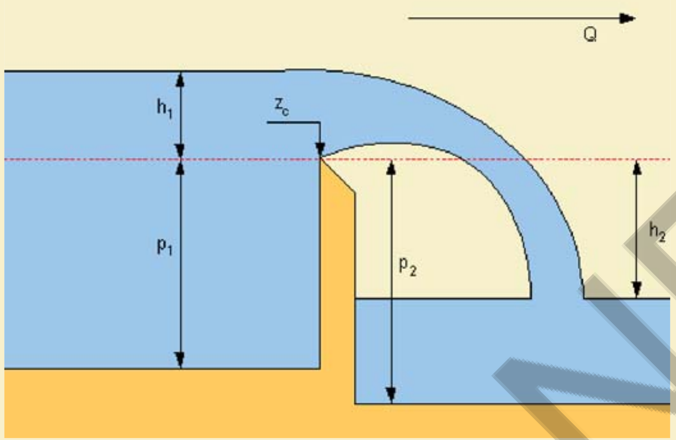


Cipoletti weir

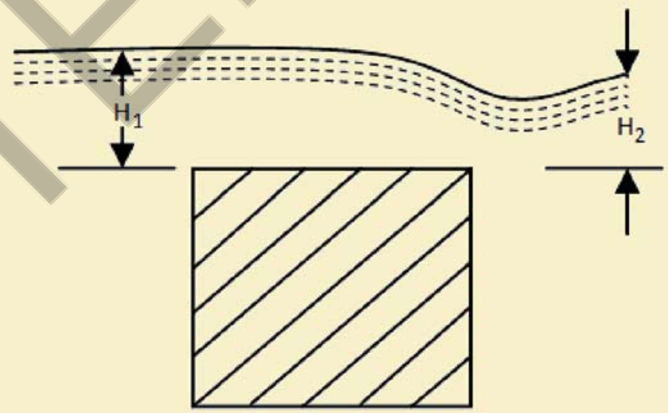
Measuring Structures

Classification of Weirs

2. According to Nature of Discharge



Regular weir

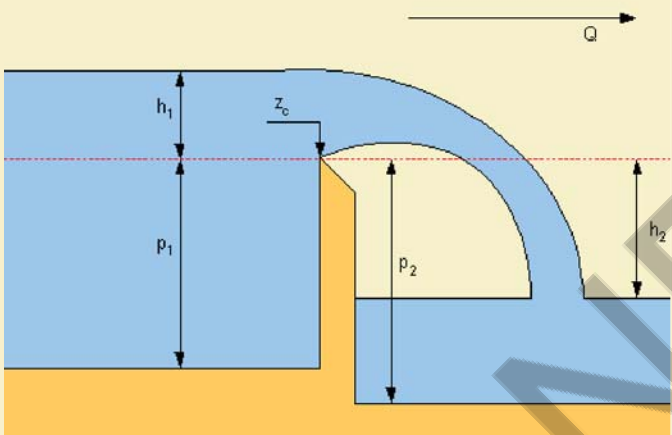


Submerged weir

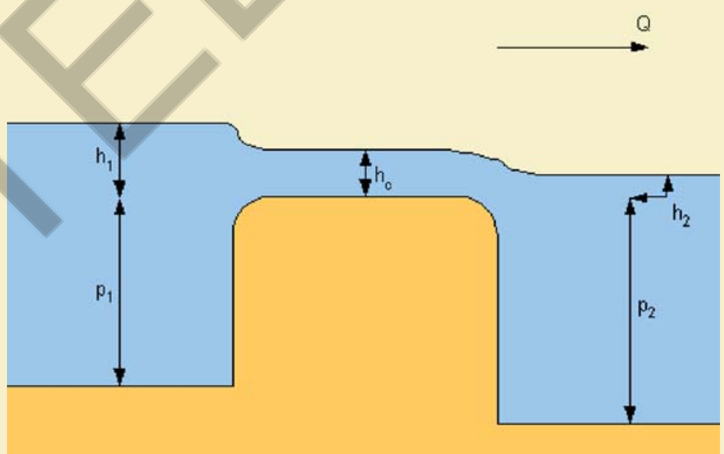
Measuring Structures

Classification of Weirs

3. According to Width of Weir



Narrow crested weir (h_1> 4 x width of weir)

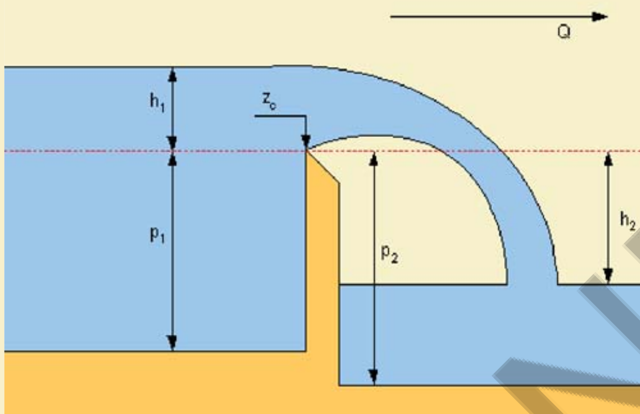


Broad crested weir

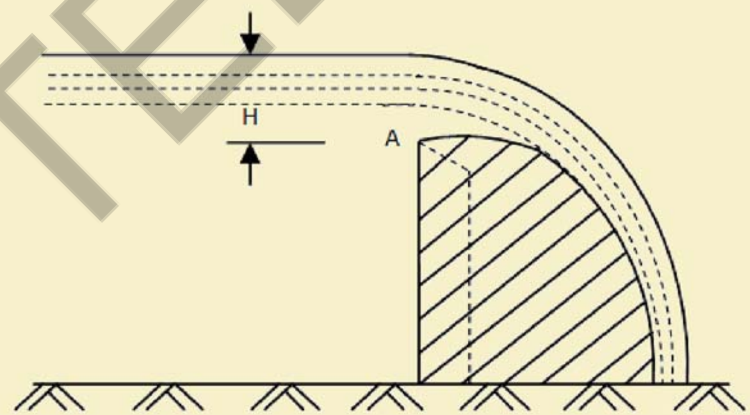
Measuring Structures

Classification of Weirs

4. According to nature of crest



Sharp crested weir (thickness <h_1/2)

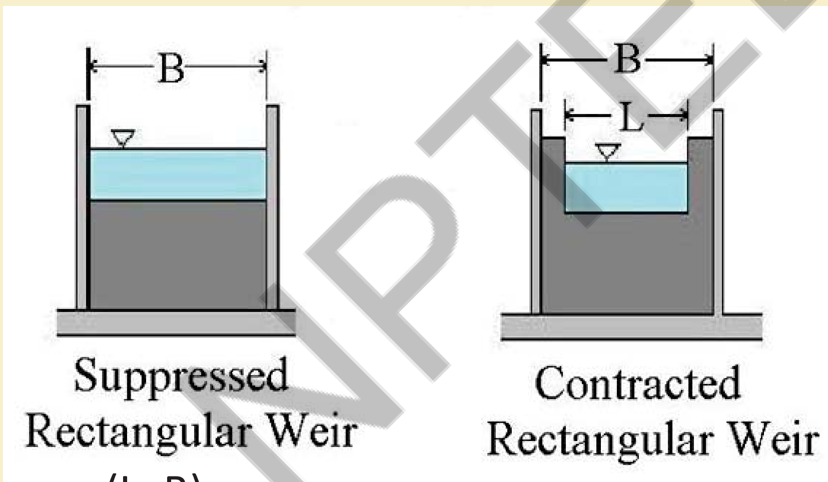


An Ogee weir (max. rise from A is 0.115*H, then follows a parabola)

Measuring Structures

Classification of Weirs

5. According to Effect of the sides on the emerging nappe



(L=B)

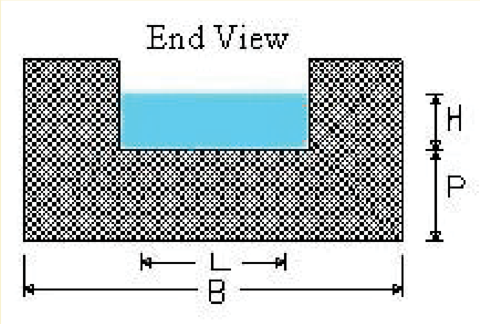
(L<B)

Measuring Structures

Measuring Discharge from a rectangular weir

- ✓ Consider an elementary horizontal strip of water thickness ***dh*** and length ***L*** at a depth ***h*** from the water surface.
- ✓ Area of strip = L x dh
- ✓ Theoretical velocity of water = $\sqrt{2gh}$
- ✓ Therefore, discharge through strip = $C_d \times L \times dh \times \sqrt{2gh}$

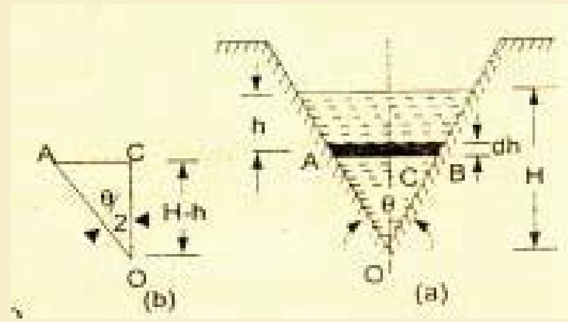
  Where C_d = coefficient of discharge
- ✓ By integrating above equation with limits 0 to H we can get the total discharge Q=$\int_0^H \left(C_d \times L \times dh \times \sqrt{2gh}\right)$
- ✓ Finally discharge over the weir $Q = \frac{2}{3} C_d \times L \times \sqrt{2g} \times \mathrm{H}^{3/2}$
- ✓ Contracted rectangular weir $Q = \frac{2}{3} C_d \times (L - 0.2H) \times \sqrt{2g} \times \mathrm{H}^{3/2}$



Measuring Structures

Measuring Discharge from a triangular weir

- ✓ Consider an elementary horizontal strip of water of thickness ***dh*** at a depth ***h*** from the water surface.
- ✓ Area of strip = dh x 2AC = 2 (H-h)tan(θ/2)dh
- ✓ Theoretical velocity of water = $\sqrt{2gh}$
- ✓ Therefore, discharge through strip = C_d2 (H−h)tan(θ/2)dh$\sqrt{2gh}$
- ✓ By integrating above equation with limits 0 to H we can get the total discharge Q=$\int_0^H\left(2C_d \right.$ (H−h)tan(θ/2)dh$\left.\sqrt{2gh}\right)$
- ✓ Finally discharge over the weir $Q=\frac{8}{15}C_d\times$ tan(θ/2) $\times\sqrt{2g}\times \mathrm{H}^{5/2}$
- ✓

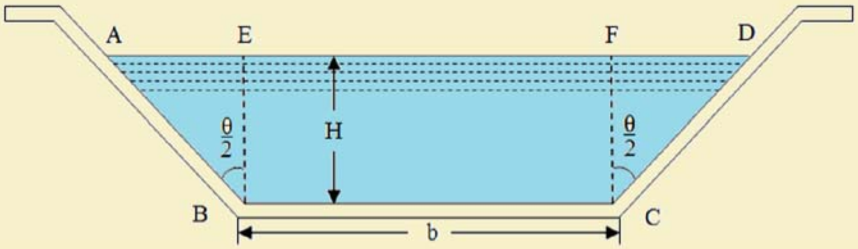


Measuring Structures

Measuring Discharge from a Trapezoidal/Cipoletti Weir

- ✓ Trapezoidal shape has a rectangular and triangular shapes
- ✓ Cipoletti weir has side slopes 1:4 (horizontal: vertical)
- ✓ The discharge over **a Trapezoidal** weir
- ✓ $Q = \left(\frac{2}{3} C_d \times L \times \sqrt{2g} \times H^{3/2}\right) + \left(\frac{8}{15} C_d \times \tan(\theta/2) \times \sqrt{2g} \times H^{5/2}\right)$

Where, Q = discharge, L/s; L= length of crest, cm H = head over the weir, cm, C_d = Coefficient of discharge, g= acceleration due to gravity



Problem 13.1:

A rectangular notch has a discharge of 0.24 m^3/s, when head of water is 800 mm. Find the length of notch. Assume C_d=0.6.

Solution:

Given, Q = 0.24 m^3/s, H = 800 mm = 0.8 m, C_d = 0.6

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

$$0.24 = 0.67 \times 0.6 \times L \times \sqrt{2 \times 9.81} \times 0.8^{\frac{3}{2}}$$

$$L = 0.189\ m$$

$L = 189\ mm$ **(Ans.)**

Problem 13.2:

Find the discharge over a triangular notch of angle 60^0, when head over triangular notch is 0.2m. Assume C_d=0.6

Solution:

Given, $\theta = 60^0$

$H = 0.2$ m

$C_d = 0.6$

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

$$= \frac{8}{15} \times 0.6 \times \sqrt{2 \times 9.81} \times \tan\frac{60}{2} \times 0.2^{\frac{5}{2}}$$

$= 0.0146\, m^3/s$**(Ans.)**

THANK YOU

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Irrigation and Drainage

Lecture No: 14 Measurement of Irrigation Water: Pipes

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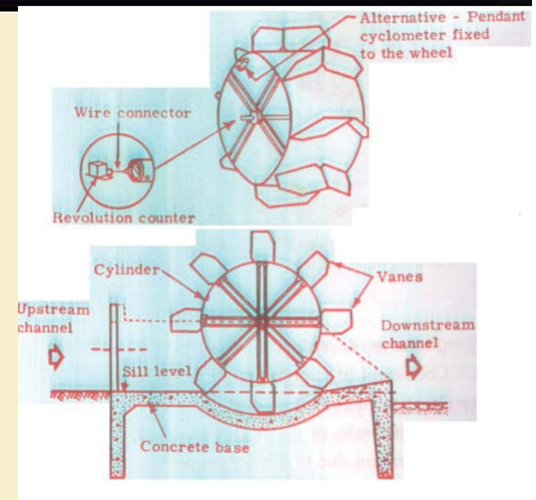
Dethridge Meter

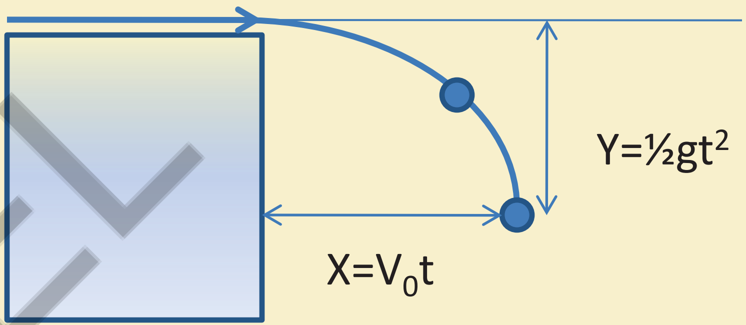


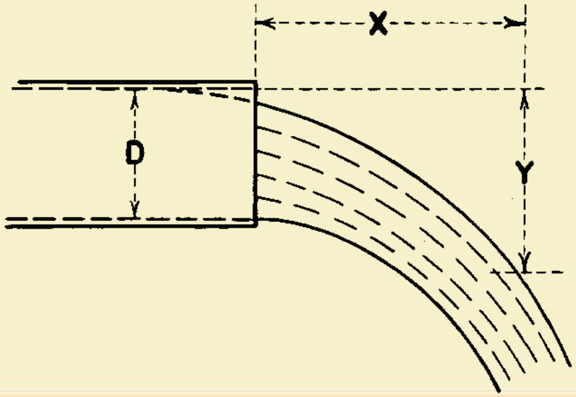
- ✓ Named after J S Dethridge of Australia
- ✓ It consists of a drum on an axle, with eight v-shaped vanes fixed to the outside.
- ✓ It sits laterally across a channel and is turned by water flow
- ✓ A short concrete outlet formed to provide only minimum clearance
- ✓ The meter provides direct discharge measurement corresponding to number of revolution by the counter

Trajectory Meter

- ✓ For a full pipe flow falling on a horizontal surface, the distance 'Y' that water falls in time 't', is $Y = \frac{1}{2}gt^2$
- ✓ The horizontal distance $X = V_0 t$
- ✓ Combining the equations (substitute for t)

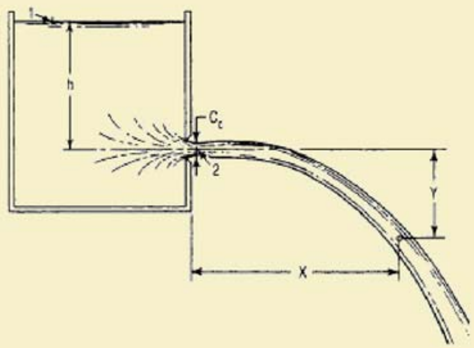
$$V_0 = \sqrt{(\frac{1}{2} gX^2/Y)}$$
$$Q = C\,A\,V_0 = C\,(\pi/4)D^2\sqrt{(\frac{1}{2} gX^2/Y)}$$

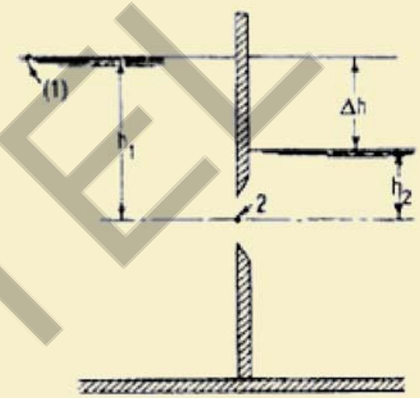




Orifice Meter

✓ Orifices are usually circular or rectangular openings.





https://www.engineeringcivil.com/flow-through-orifices.html

Free flow case: $Q = Cd.Cv.A.(2gH)0.5$

Submerged case: $Q = Cd.Cv.A.(2g(h1 - h2))0.5$

Where, Cd(0.6 to 0.8) is the coefficient of discharge, Cv(=1) is the coefficient of velocity

Example 14.1:

Determine the discharge of a 4-in. diameter end-cap orifice on a 6-in. diameter pipe if C = 0.7 and the head on the orifice is 12 in.

Solution

Given,

C = 0.7, $A = \pi \times r^2 = 3.142 \times (2 \times 2.54)^2 = 81.08$ cm^2

g = 981 cm/s^2

h = 12 inches = 30.48 cm

$$Q = Cd.A.(2gH)0.5$$

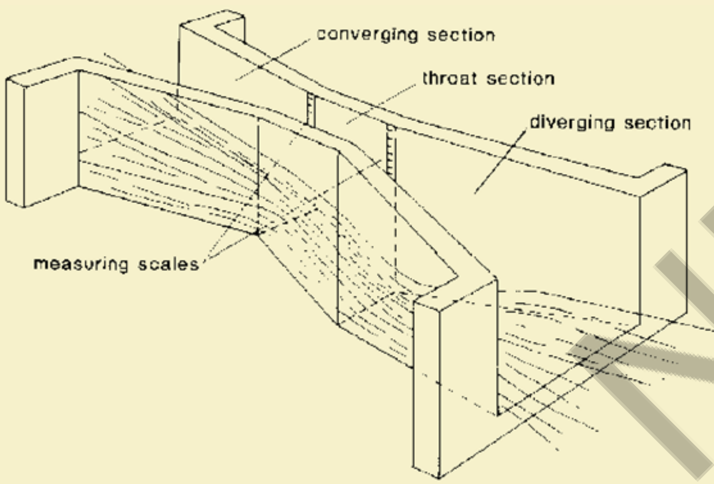
$$= 0.7 \times 81.08 \times (2 \times 100 \times 30.48)^{0.5}$$

$= 22636.56\ cm^3/s$

$= 0.02\ m^3/s$ **(Ans.)**

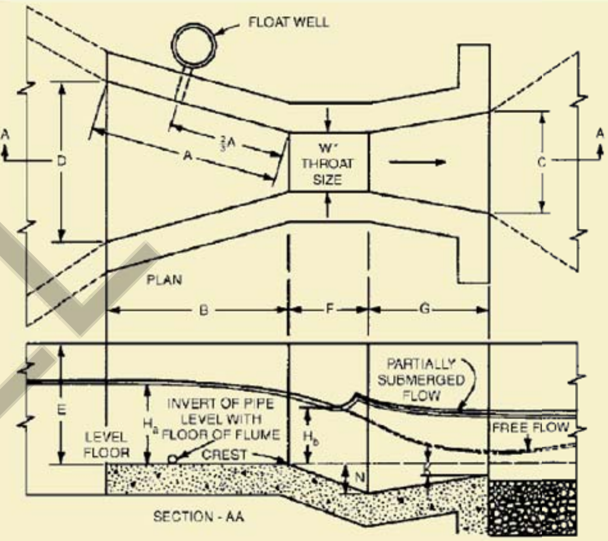
Parshall Flume

- ✓ Flumes are shaped open channel flow sections for measuring up to 1500 million gal/day (5.7 million m^3/day).



Parshall flume

- ✓ Designated by throat width
  - o Measure 0.01 cfs (0.28 lps) with 1 inch flume
  - o Measure 3000 cfs (84950.5 lps) with 50 foot flume
- ✓ Dimensions are standardized for each flume
- ✓ Relate H_a (or H_a and H_b) to discharge with rating equation, or consult appropriate chart



http://saba.kntu.ac.ir

W	A	2/3 A	B	C	D	E	F	P	K	N	R	T
1"	1'2 9/32"	9 17/32"	1"2"	3 21/32"	6 19/32"	1'8"	3"	2'1"	3/4"	1 1/8"	1 3/4"	3/16"
2"	1'4 5/16"	10 7/8"	1'4"	5 5/16"	8 13/32"	9"	4 1/2"	2'6 1/2"	7/8"	1 11/16"	1 3/4"	3/16"
3"	1'6 3/8"	1'1/4"	1'6"	7"	10 3/16"	2'0"	6"	3'0"	1"	2 1/4"	2 1/2"	3/16"
6"	2' 7/16"	1'4 5/16"	2'0"	1'3 1/2"	1'3 5/8"	2'0"	1'0"	5'0"	3"	4 1/2"	2 1/2"	3/16"
9"	2'10 5/8"	1'11 1/8"	2'10"	1'3"	1'10 5/8"	2'6"	1'0"	5'4"	3"	4 1/2"	2 1/2"	3/16"
1'0"	4'6"	3'0"	4'4 7/8"	2'0"	2'9 1/4"	3'0"	2'0"	9'4 7/8"	3"	9"	2 1/2"	1/4"
1'6"	4'9"	3'2"	4'7 7/8"	2'6"	3'4 3/8"	3'0"	2'0"	9'7 7/8"	3"	9"	2 1/2"	1/4"
2'0"	5'0"	3'4"	4'10 7/8"	3'0"	3'11 1/2"	3'0"	2'0"	9'10 7/8"	3"	9"	2 1/2"	1/4"
3'0"	5'6"	3'8"	5'4 3/4"	4'0"	5'1 7/8"	3'0"	2'0"	10'4 3/4"	3"	9"	2 1/2"	5/16"
4'0"	6'0"	4'0"	5'10 5/8"	5'0"	6'4 1/4"	3'0"	2'0"	10'10 5/8"	3"	9"	2 1/2"	3/8"

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Parshall Flumes

Flow occurs under two conditions

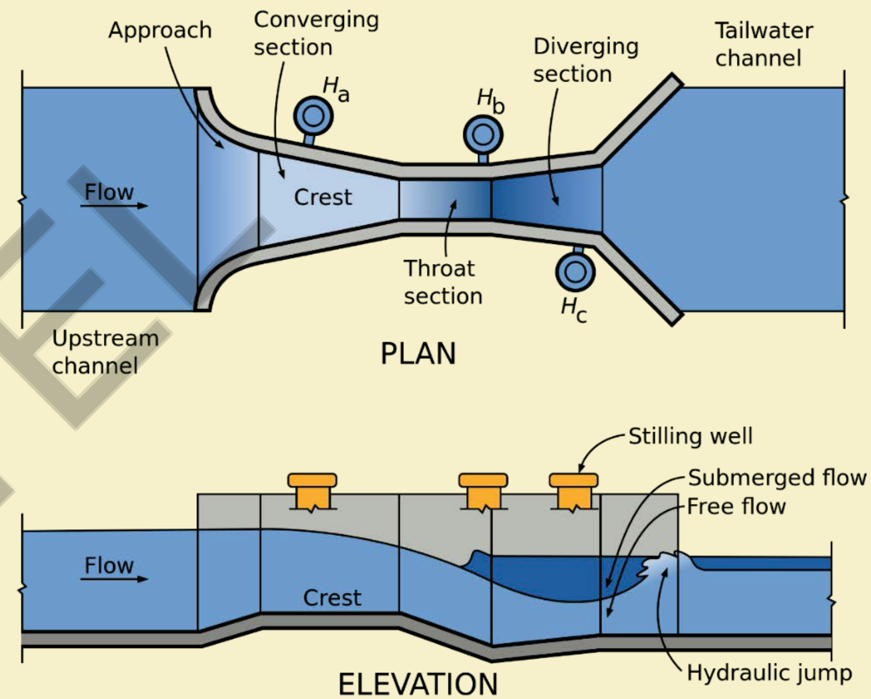
✓ **Free flow**

- o Requires only 1 head reading (H_a)
- o $Q = C H_a^n$

  Where H_a measuring head, C is the coefficient and n is the exponent

✓ **Submerged flow**

- o 2 head readings (H_b and H_a) required
- o 50% submergence (H_b/H_a) on 1 to 3 inch flumes
- o 60% submergence for 6 to 9 inch flumes
- o 70% submergence for 1 to 8 ft flumes
- o 80% submergence on ≥ 8 feet flumes
- o After 90% submergence, flume is no longer effective



https://en.wikipedia.org/wiki/File:Parshall_Flume.svg

Pipeline Flow Measuring Devices

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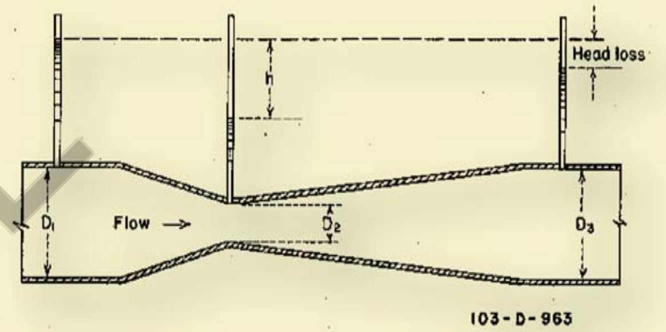
Venturi Meter

Common differential head meter

- Differential pressure meter
- Also used to inject chemicals into an irrigation system
- Discharge is measure as (C_d = 0.97)



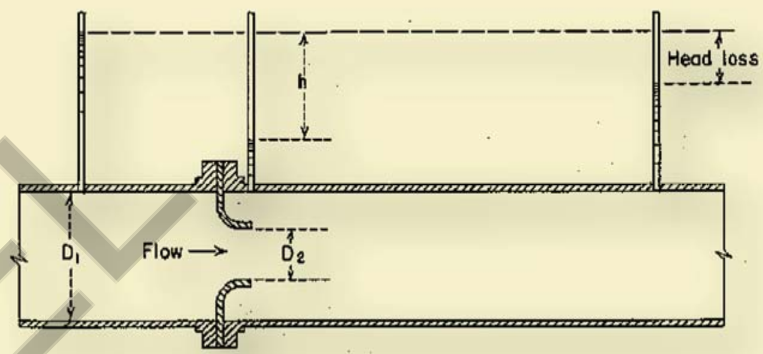
$$Q = C_d A_1 \sqrt{\frac{2gH}{\left(\frac{D_1}{D_2}\right)^2 - 1}}$$

where A_1 is the upstream cross-sectional area of the pipe (use nominal diameter given in the Apparatus section), H is the difference in pressure head measured on the inside and outside of the bend, D_1 is the upstream pipe diameter and D_2 is the diameter in the throat (see Apparatus section).

Nozzle Meter

Simplified form of venturi meter

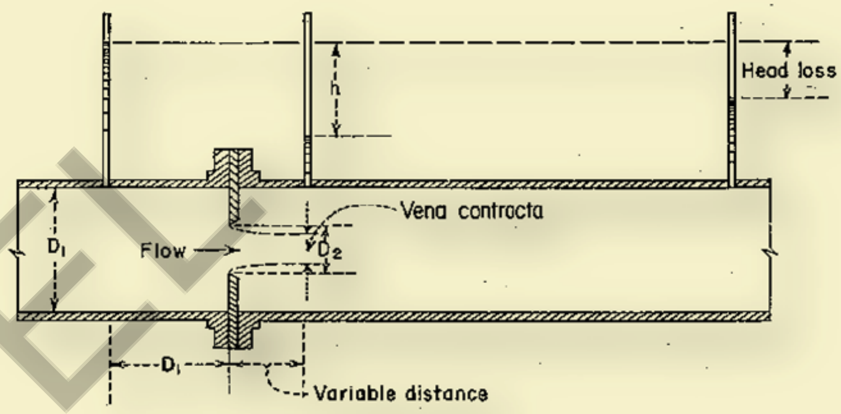
- Gradual downstream expansion of venturi is eliminated
- Higher head loss than venturi
- Not used extensively in irrigation
- Discharge equation is same as Venturi meter

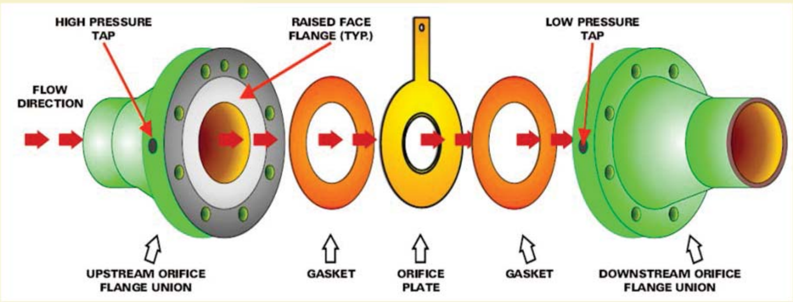


Orifice Meter

Another differential pressure meter

- Often used for measuring well discharge
- Also used to measure chemical injections
- Requires long straight pipe lengths
- Full pipe flow required
- Limited discharge ratio
- Discharge equation identical to Venturi (C_d = 0.66)





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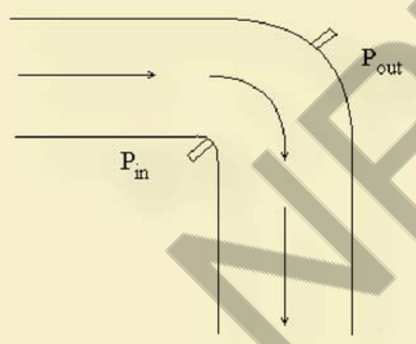
Elbow Meter

- ✓ Works on the principle that when liquid travels in a circular path, centrifugal force is exerted along the outer edge
- ✓ Measure pressure difference between inside and outside of an elbow



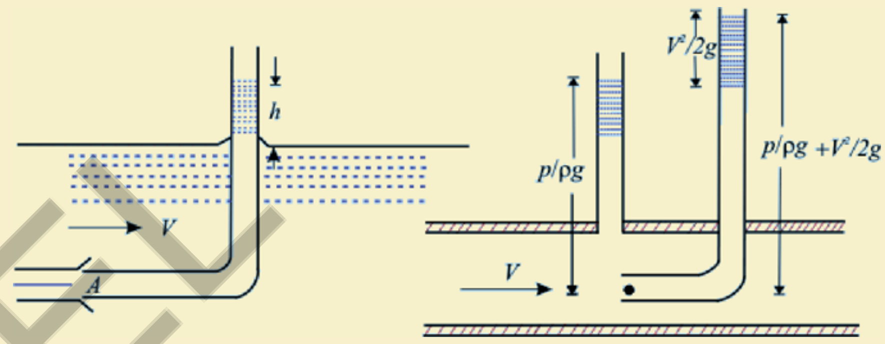
Propeller Meters

- ✓ Multiple blades that rotate on horizontal axle
- ✓ Basically operate on Q=AV principle
- ✓ Usually have totalizer plus instantaneous discharge display
- ✓ Accuracy can be ±2-5% of actual flow
- ✓ Must be installed to manufacturer's specifications for accurate measurement
- ✓ Must have full pipe flow

Pitot Tube

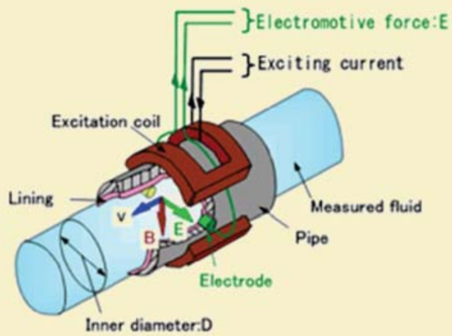
Pitot Tube Velocity Measurements

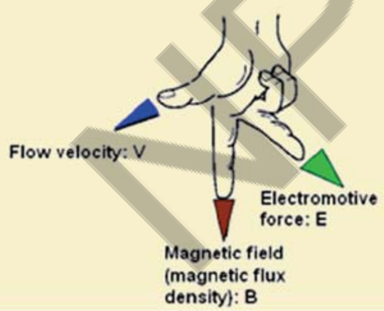
- Right angle bend inserted with horizontal leg pointed upstream and parallel to flow
- Senses both velocity and pressure head
- works based on the differential pressure created by the flow.
- The velocity, V, is obtained as: $V = \sqrt{2gh}$
- Where h = depth of pitot tube from the water surface

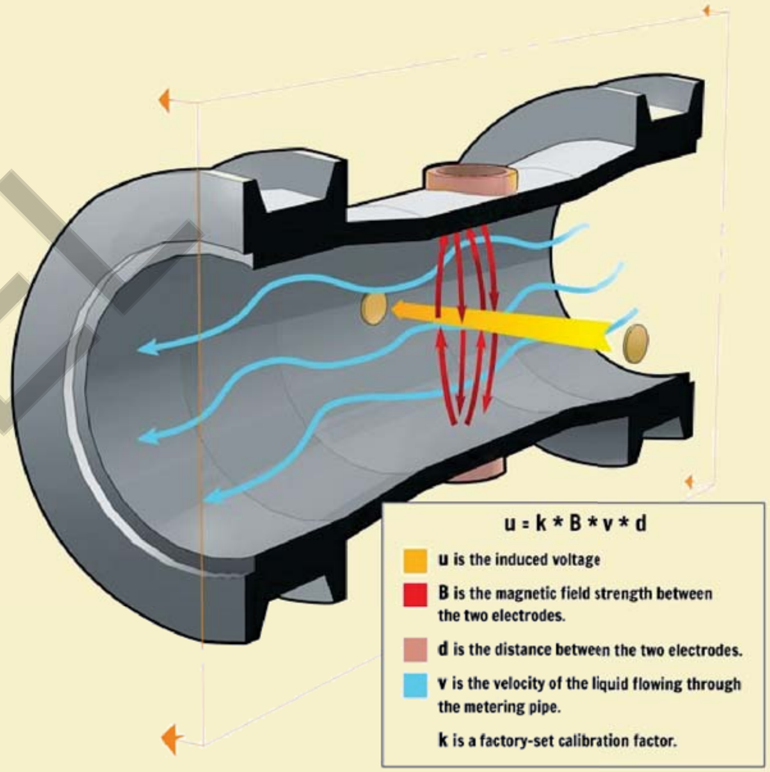


Magnetic Flowmeters

- ✓ Use the principle (Faraday's Law) that voltage is induced in an electrical conductor moving through a magnetic field. Conductor is flowing water
- ✓ For a given field strength, the magnitude of the induced voltage is proportional to velocity



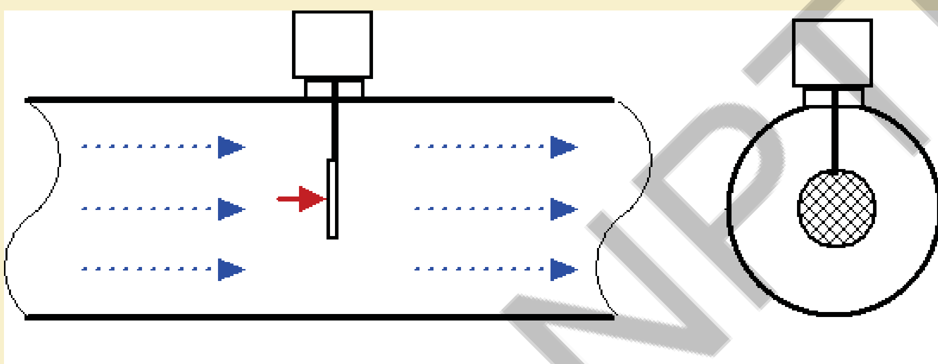


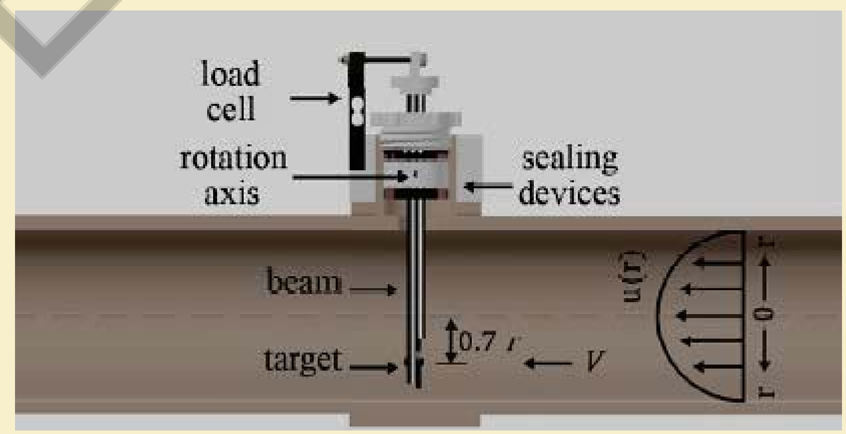


Deflection Meters

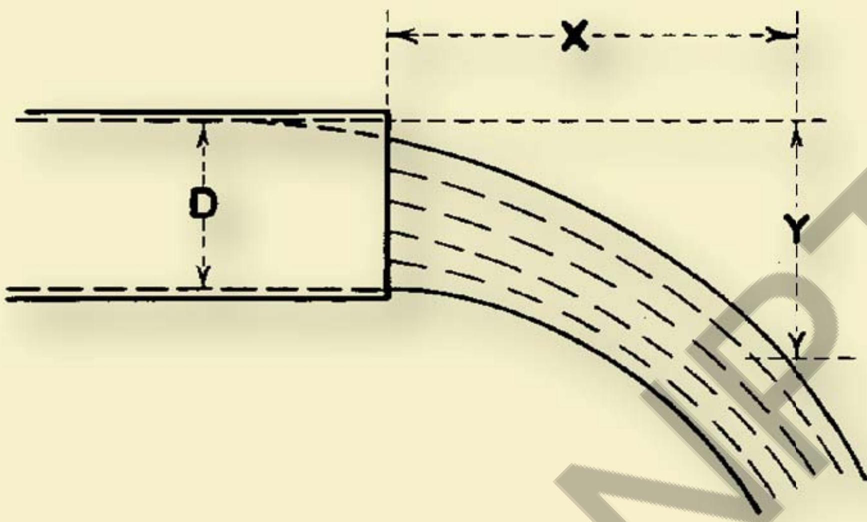
– Vane or plate projecting into flow and a sensing element to measure deflection.

– Calibrated to indicate flow in desired units

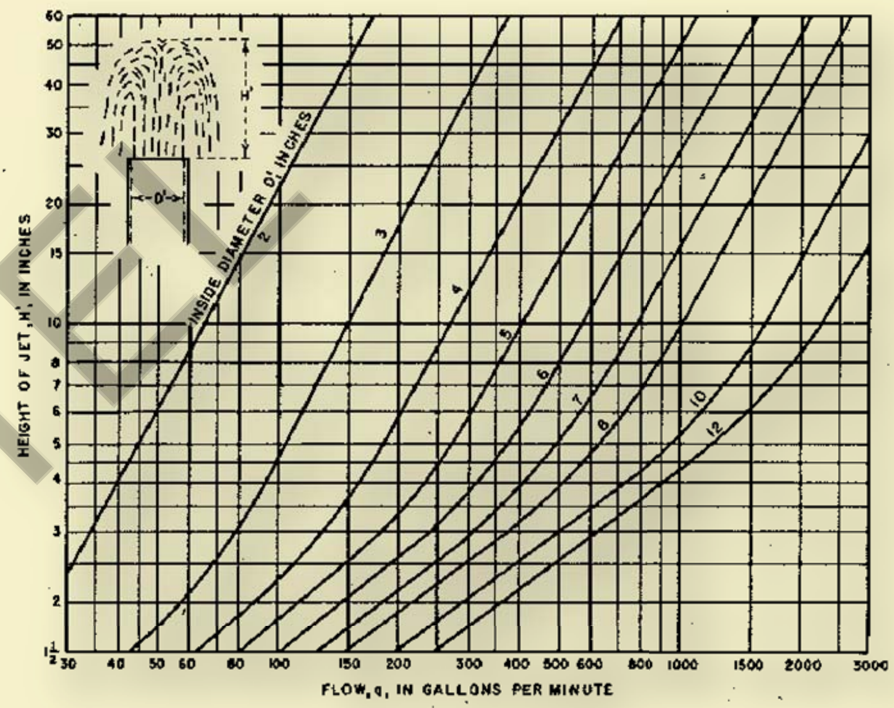




Trajectory Method



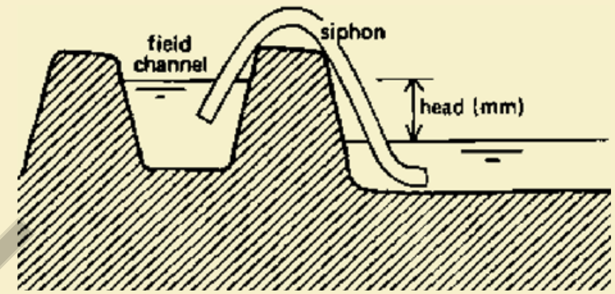
Horizontal pipe

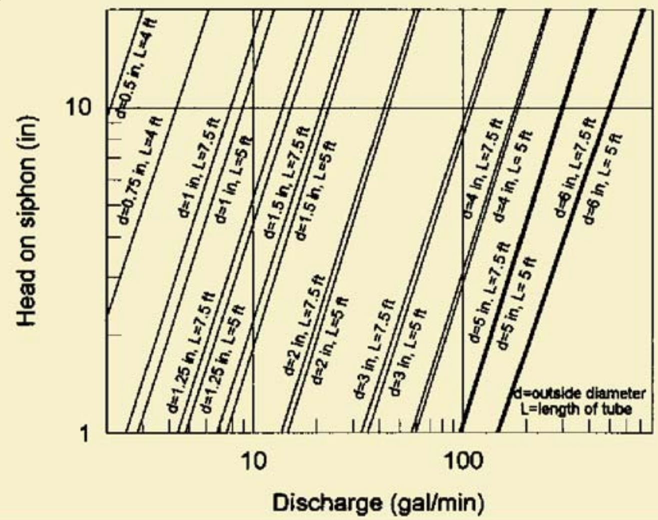


Vertical pipe

Siphon Tubes

- Estimate discharge based on head, diameter, and length of siphon tubes
- Accuracy ±10-15%
- Provides an in-field method of estimating flow





THANK YOU

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NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Irrigation and Drainage

Lecture No:15 Tutorial: W3

Dr. DAMODHARA RAO MAILAPALLI

AGRICULTURAL AND FOOD ENGINEERING DEPARTMENT

IIT KHARAGPUR

Loss of energy in pipe flow

Energy losses

Major energy losses: This is due to friction.

- **Darcy-weisbach formula**

$$h_f = \frac{4 \times f \times L \times v^2}{2 \times d \times g}$$

$$f = \frac{16}{R_e} \text{ for } R_e < 2000 \text{ (viscous flow)}$$

$$= \frac{0.079}{R_e^{\frac{1}{4}}} \text{ for } R_e \text{ varying from 4000 to } 10^6$$

$$R_e = \frac{v \times d}{\mu}$$

- **Chezy's formula**

$$V = C\sqrt{mi}$$

$m = \frac{A}{P}, i = \frac{h_f}{L}$

Where, h_f=loss of head due to friction, f=co-efficient of friction which is function of Reynolds number, L=length of pipe, v=mean velocity of flow, d=diameter of pipe, g=acceleration due to gravity, A=area of cross-section of pipe, P=wetted perimeter of pipe, C=chezy's constant, i=loss of head per unit length of pipe.

Loss of energy in pipe flow

Minor Energy losses: This is due to

- **Sudden expansion of pipe**

$$h_e = \frac{(V_1 - V_2)^2}{2g}$$

- **Sudden contraction of pipe**

$$h_c = 0.5\frac{V_2^2}{2g}$$

- **Entrance of pipe or exit of pipe**

$$h_i = 0.5\frac{V^2}{2g} \text{ or } h_o = 0.5\frac{V^2}{2g}$$

- **An obstruction in pipe**

$$h_{ob} = \frac{V^2}{2g}\left(\frac{A}{C_c(A-a)} - 1\right)^2$$

- **Bend in pipe**

$$h_b = \frac{kV^2}{2g}$$

Where, V_1= velocity at entrance, V_2= velocity at exit

Loss of energy in pipe flow

Exercise W3.1:

Find the head loss due to friction in a pipe of diameter 300 mm and length 50m, through which water is flowing at a velocity of 3 m/s using i) Darcy formula and ii) Chezy's formula for which C= 60. Take kinematic viscosity (μ)for water =0.01 stoke.

Solution:

d= 300 mm = 0.30 m, L=50 m, v =3 m/s, C = 60, μ =0.01 stoke = 0.01 cm^2/s = 0.01×10^{-4} m^2/s

i) Darcy formula

$$h_f = \frac{4 \times f \times L \times v^2}{2 \times d \times g}$$

$$R_e = \frac{V \times d}{v} = \frac{3 \times 0.3}{0.01\times10-4} = 9 \times 10^5$$

$$f = \frac{0.079}{R_e^{\frac{1}{4}}} = \frac{0.079}{(9 \times 10^5)^{1/4}} = 0.00256$$

Loss of energy in pipe flow

$h_f = \frac{4 \times 0.00256 \times 50 \times 3^2}{2 \times 2 \times 9.81} = 0.7828\, m$ **(Ans.)**

ii) Chezy's formula

$$V = C\sqrt{mi}$$

$$m = \frac{d}{4} = \frac{0.30}{4} = 0.075\, m$$

$$3 = 60\sqrt{0.075 \times i}$$

$$i = 0.0333$$

$$i = \frac{h_f}{L}$$

$$0.0333 = \frac{h_f}{50}$$

$h_f = 1.665$ m **(Ans.)**

Exercise W3.2:

A rectangular channel having bed slope of 0.05% and Manning's roughness coefficient of 0.01 carries a discharge of 5 m^3/s. If the channel is designed as the most economical section, the width of the channel in meter will be ___________ **(GATE 2017)**

Solution:

Given, S = 0.05% = 5×10^{-4}, n = 0.01, $Q = 5$ m^3/s

$$Q = A \times V$$

$$A = Width\ (b) \times Depth(d)$$

$$V = \frac{1}{n} \times \left(\frac{A}{P}\right)^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

$$Q = b \times d \times \frac{1}{n} \times \left(\frac{b \times d}{2d + b}\right)^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

For most economical channel section $d = \frac{b}{2}$

$$Q = b \times \frac{b}{2} \times \frac{1}{n} \times \left(\frac{b \times \frac{b}{2}}{2 \times \frac{b}{2} + b} \right)^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

$$5 = \frac{b^2}{2} \times \frac{1}{0.01} \times \left(\frac{b}{4}\right)^{\frac{2}{3}} \times 0.0005^{\frac{1}{2}}$$

$$5 = \frac{b^{\frac{8}{3}}}{5.03} \times 2.23$$

$b = 2.48$**(Ans.)**

Exercise W3.3:

A steady discharge of 60 m^3/s is passing through a trapezoidal irrigation channel with a bottom width of 5 m, bed slope of 0.01% and Manning's roughness coefficient of 0.025. The conveyance of the channel in m^3/s is______.**(Gate 2015)**

Solution:

Given, Q = 60 m^3/s, S_f= 0.01% =0.0001

$$Q = A \times V$$

$$Q = A \times \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}, = K \times S^{\frac{1}{2}} \text{ ; where } K = \text{conveyance of the channel} = A \times \frac{1}{n} R^{\frac{2}{3}}$$

$$Q = K \times \sqrt{S_f}$$

$$60 = K \times \sqrt{0.0001}$$

$K = 6000$ m^3/s **(Ans.)**

Exercise W3.4:

A 50 g/L solution of a tracer was discharged into a stream at a constant rate of 20 mL/s. At a downstream section, the tracer was completely mixed and attained an equilibrium concentration of 10 parts per billion. Assuming the background concentration as zero, the stream discharge is **(Gate 2008)**

Solution:

Given, C_1= 50 g/L

C_2= 10 ppb = .00001 g/L

C_b= 0 g/L

q= 20 mL/s = 20×10^{-6} m^3/s

$$Q_0 = \frac{q(C_1 - C_2)}{C_2 - C_b}$$

$$Q_0 = \frac{20\times10^{-6} \times (50 - 0.00001)}{0.00001 - 0}$$

$Q_0 = 99.99$ m³/s **(Ans.)**

Exercise W3.5:

The discharge through a 90^0 V notch for a head of 0.5 m and coefficient of discharge of 0.6. **(GATE 2007)**

Solution:

Given, H = 0.5 m, $C_d = 0.6$, $\theta = 90^0$

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

$$Q = 0.6 \frac{8}{15}\sqrt{2 \times 9.81}\, tan\frac{90}{2} 0.5^{5/2}$$

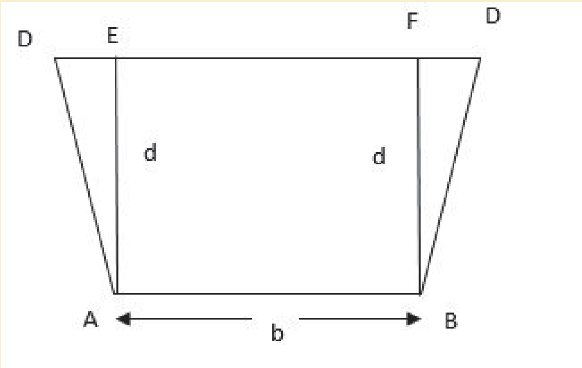
$$Q = 0.32 \times 4.42 \times 1 \times 0.176$$

$Q = 0.25 m^3/s$ **(Ans.)**

Exercise W3.6

A trapezoidal channel of 0.5 m bottom width 1:1 side slope in carrying water at a depth of 0.4 m. If the channel slope in 1 in 400 and roughness co-efficient is 0.02, find the mean velocity. **(ARS 2007)**

Solution:



Given, B = 0.5 m, Z = 1:1, d = 0.4 m, n=0.02

$S = (1/400) = 2.5 \times 10^{-3}$

$V_m = ?$

$$T = b + 2d = 0.5 + 0.8 = 1.3\, m$$

$$A = \frac{1}{2}\, d\, (b + b + 2d)$$

$$A = \frac{1}{2}\, 0.4\, (0.5 + 0.5 + 2 \times 0.4); = 0.36\ m^2$$

$$Wetted\ perimeter\ (p) = b + \sqrt{2}\, d$$

$$= 0.5 + 1.1312 = 1.6312 \text{ m}$$

$$Hydraulic\ Radius\ (R) = \frac{A}{P} = \frac{0.36}{1.6312} = 0.221 \text{ m}$$

$$Minimum\ Velocity\ (V_{min}) = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

$$= \frac{1}{0.02}\, 0.221^{\frac{2}{3}} (2.510^{-3})^{\frac{1}{2}}$$

$= 0.9 \text{ m } S^{-1}$ **(Ans)**

Thank You!!

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