



Wollo University
Kombolcha Institute of Technology

Department of Hydraulic and Water Resources
Engineering

Lecture on Hydraulic Structures-II (HWRE-3132)
(For G₃-HWRE)

Course Description

Objective:

- *Provide students with construction and design principles of dam appurtenant structures like:*
 - *Dam Outlet Works,*
 - *Spillways, Energy Dissipation*
 - *Dam Safety: Instrumentation and Surveillance,*
 - *Diversion Head Works,*
 - *Cross Drainage and Drop Structures*

Outcome :

- *After completion of this course students will be able to*
 - *Design dam appurtenant structures*
 - *Have knowledge on Dam Safety: Instrumentation and Surveillance*
 - *Design weirs and barrages on permeable foundations*

Contents

1. Dam Outlet Works

- 1. Introduction*
- 2. Hydraulics of Outlet Works*
- 3. River Intakes*

2. Spillways and Energy Dissipation

- 1. Spillways*
- 2. Energy Dissipation on Spillways*
- 3. Stilling Basins*
- 4. Plunge Pool*
- 5. Energy Dissipation at bottom outlets*

3. Gates and Valves

4. Dam Safety: Instrumentation and Surveillance

5. Diversion Works

- 1. Design of Weirs and Barrages on Permeable foundation*
- 2. Bligh's theory, Lanes theory and Khosla's theory*
- 3. Intakes*

6. Cross-Drainage and Drop Structures

- 1. Aqueducts and Canal inlets and Outlets*
- 2. Culverts, bridges and drips*
- 3. Drop Structures*

References:

- ▶ *Novak, Moffat, Nalluri & Narayanan (1996) Hydraulic Structures, 2nd Ed. Chapman & Hall.*
- ▶ *Davis & Sorrensen, “Hand Book of Hydraulics”, 3rd Ed. 1984 Reissue*
- ▶ *Varshney, R.S, “Hydropower Structures”, Nem Chand & Bros, Roorkey 2001*
- ▶ *Garg, S.K., ”Irrigation Engineering And Hydraulic Structures” Khanna Pub. Delhi, 2000*
- ▶ *Arora, K.R. “Irrigation, Water Power and Water Resource Engineering”, St. Pub. Delhi 2001*

Mode of Evaluation

Tentative Assessment

- ***Quiz***5%
- ***Mid exam***.....25%
- ***Project work***..... 20%
- ***Final exam***.....50%
- ***Total***100%

Minimum 75% of Attendance !!!

Chapter-One *Dam Outlet Works*



1. Dam Outlet Works

1.1 Introduction to Dam out lets

- **Outlet works-** are hydraulic structures used to convey water from a reservoir to a point downstream of a dam.
- It serves to regulate or release water impounded by a dam.
- It may release incoming flows at a retarded rate, as in the case of detention dam; divert incoming flows into canals or pipelines, as in the case of diversion dam; or release stored waters at such rates as may be dictated by downstream needs, evacuation considerations, or a combination of multi-purpose requirements.
- In certain instances the out let works of a dam maybe used as **a service spillway** in conjunction with an auxiliary or secondary spillway.

1.2 Classification of Outlet Works

□ **Outlet works structures** can be classified according to their purpose, their physical and structural arrangement, or their hydraulic operation.

a) *Classification according to purpose*

- **River outlets** -Empties directly into the river for river flow requirements
- **Canal outlets** -Discharges into a canal
- **Flood control** -To evacuate storage in anticipation of flood inflows
- **Emergency drawdown**- To empty the reservoir to permit inspection

.....classification of outlet works

- *Additional spillway capacity- The structure can serve as both an outlet works and a spillway.*
- *Diversion during construction*
- *Control of sedimentation of reservoirs- By draining out sediment-laden water*
- *Power production, Irrigation, public water supply, etc.*

b) Classification according to the type of waterway

- *Open channel waterway*
- *Closed conduit waterway, or*
- *Closed waterway in a conduit or in tunnel*

c) According to its hydraulic operation

- *Gated or ungated*
- *Pressure flow (for a closed conduit) - for part or all of its length or*
- *Free flow waterway (for closed conduit)*

1.3 Capacity of Outlets

- ❑ *Outlet work controls- are designed to release water at specific rates, as dictated by downstream needs, flood control regulation, storage consideration, or legal requirements.*
- *Determination of the proper outlet capacity where **flood control** is a major function is dependent on the following factors.*
 - *Magnitude of design flood for the project*
 - *Reservoir storage capacity required for control purposes & spillway capacity*
 - *Downstream channel capacity.*

***Note:** For efficient and adequate flood control, channel improvement should be made to increase the capacity*

.....capacity of outlets

- *Irrigation outlet capacities* are determined from reservoir operation studies and must be based on a consideration of a critical period of *low runoff* when reservoir storages are low and daily irrigation demands are at their peak.
- *Determines the minimum irrigation outlet capacity.*
- If an outlet is to serve as *a service spillway*, the required discharge for this purpose may fix the outlet capacity.
- For *emptying the reservoir for inspection or repair*, the volume of water to be evacuated and the allotted emptying period may be the determining conditions for establishing the minimum outlet capacity.
- *The inflow into the reservoir during the emptying period must be considered*
- *The capacity at low reservoir level should be at least equal to the average inflow expected during the maintenance or repair period.*

.....capacity of outlets

- ❑ *The size of an outlet conduit for a required discharge varies **inversely** with the available head for producing the discharge.*
- *The relationship is expressed by the following equation:*

$$H_T = K_2 * Q^2 / a^2$$

Where:

H_T = *The total available head for producing flow,*

Q = *The required outlet works discharge,*

a = *The required area of the conduit,*

K_2 = *Coefficient*

.....capacity of outlets

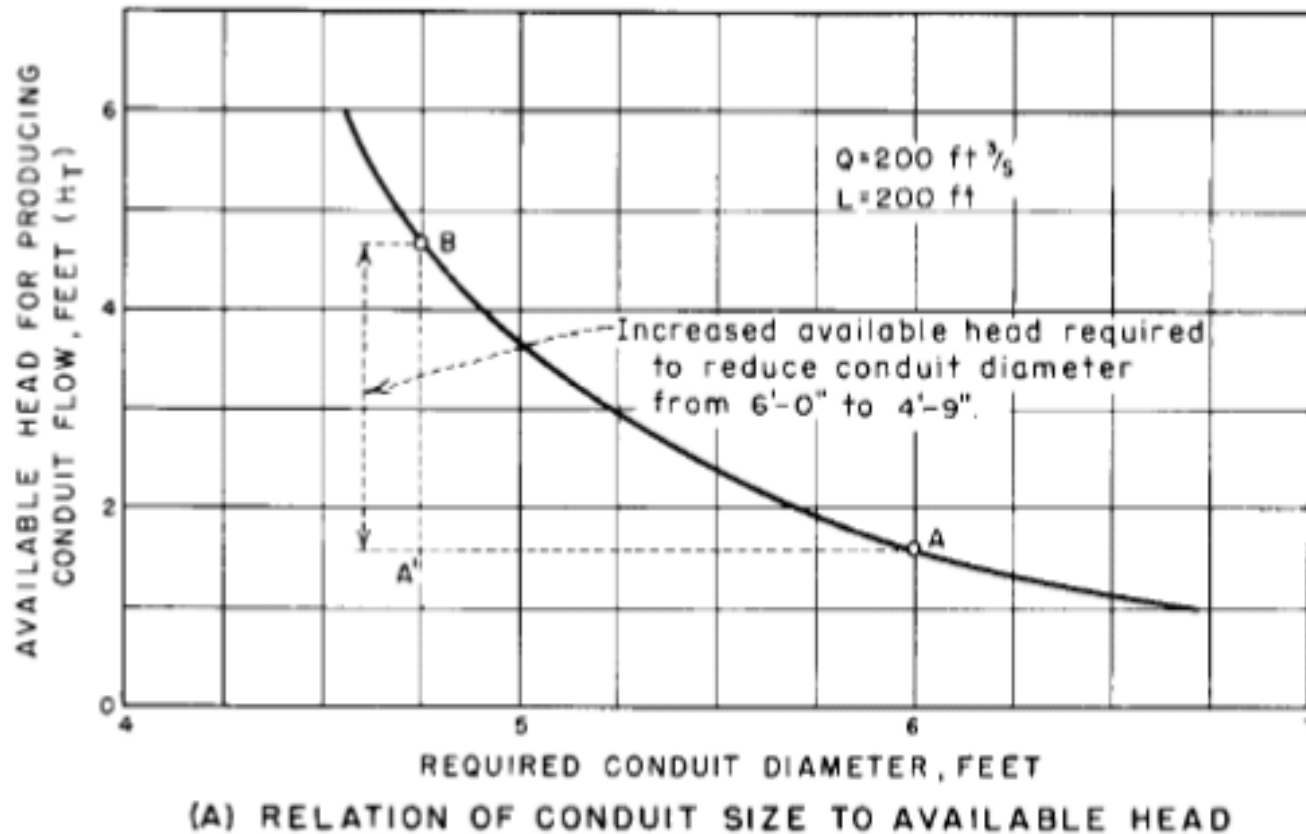


Figure 1.1: Example of variation of conduit diameter with head

1.4 Positions, Alignment and Arrangement of Outlet Works

- ***Below minimum reservoir operating level;***
 - *In order to attain the required discharge capacity*
 - *To provide head for effecting outlet works flows*
- ***Outlet works for **small detention dams** are generally constructed **near riverbed level** since permanent storage space, except for silt retention, is ordinarily not provided.***
- ***For **dams impounding water** for irrigation, domestic use, or other conservation purposes, the outlet works must be placed **low enough** to draw the reservoir down to the bottom of the allocated storage space.***

1.5 Layout of Outlet Works

- *The topography and geology of the site may have a great influence on the layout selection.*
- *Cut-and-cover conduit type of outlet works, while at other sites either a cut-and-cover conduit or **a tunnel** can be selected.*
- *Unfavorable foundation geology, such as deep overburdens or inferior foundation rock, will **obviate** the selection of a tunnel scheme.*
- *On the other hand, sites in **narrow canyons** with **steep abutments** may make a tunnel outlet the only choice.*

1.6 Arrangement of Outlet Works

- *For a Low Dam-* an open channel or a cut-and-cover structure placed at the dam abutment;
- *For a low Earthfill Embankment-* a closed-type structure might be used
- *For Higher Earthfill Dams-* through, under, or around the dam as a cut-and-cover conduit or through the abutment as a tunnel.
- *For a concrete dam-* through the dam as a formed conduit or a sluice, or as a pipe embedded in the concrete mass.
- *Intakes and terminal devices can be attached to the upstream and downstream faces of the dam.*
- *Often the outlet is formed through the spillway overflow section, using a common stilling basin to dissipate both spillway and outlet flows.*

.....arrangement of outlet works

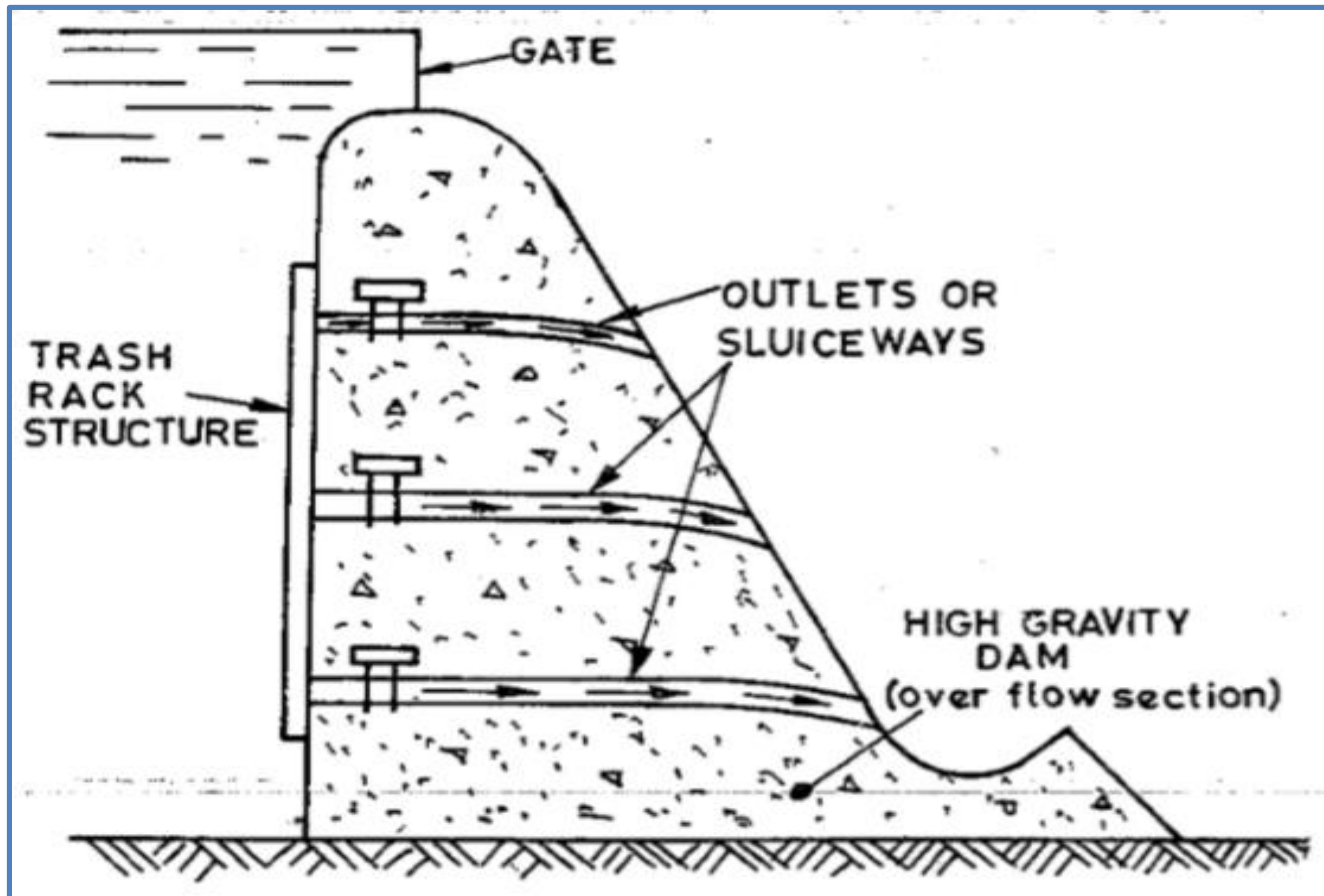


Figure 1.2: Typical outlet arrangements through a concrete gravity dam

.....arrangement of outlet works

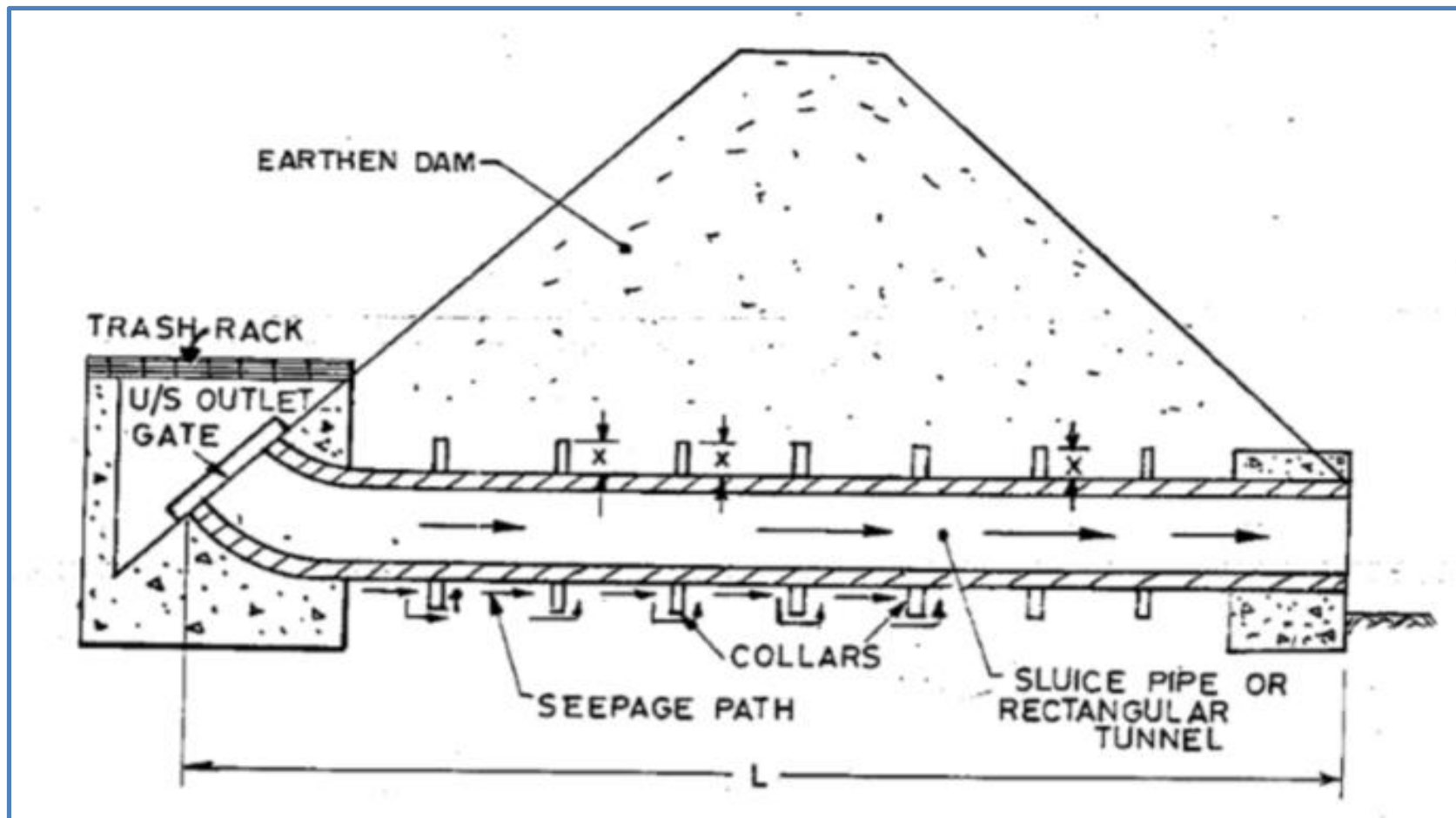
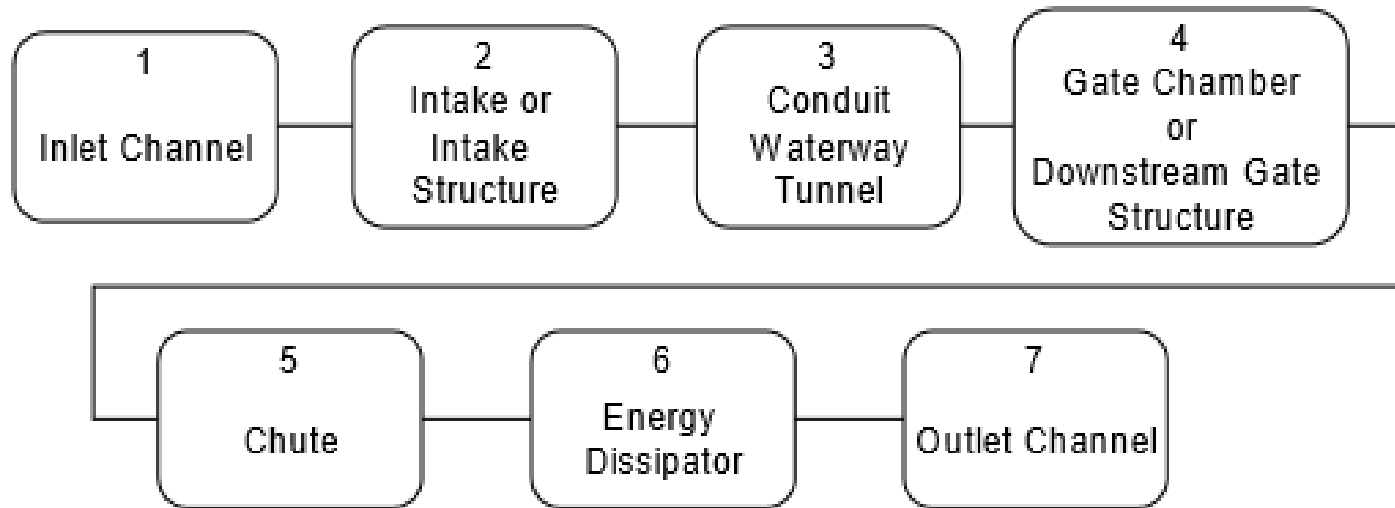


Figure 1.3: Typical outlet arrangements through an earth dam

1.7 Components of Outlet Works

- ❑ **An outlet work consists of all or some of the following components.**



- **Conveyance - (1), (3), (5), (7)**
- **Control - (2), (4)**
- **Energy dissipation - (6)**

1.7.1 Inlet and Outlet Channels

- *Inlet channels* are primarily associated with bottom-level intakes.
- Are extremely **vulnerable to clogging** with sediment and material from unstable excavated and natural slopes.
- *Outlet channels* must be properly designed to protect them against excessive erosion or deposition of eroded materials.
- Greater channel stabilization may be required for outlet releases than for spillway releases because of:
 - The longer periods of operation of the outlet,
 - Normal outlet releases are closer to maximum design releases.

1.7.2 Intake Structures

- ❑ **Intakes** are positioned with respect to various reservoir levels:
 - ✓ *Lowest level for reservoir evacuation*
 - ✓ *The bottom of active storage*
 - ✓ *The bottom of flood control storage*
 - ✓ *The temperature and DO level (selective withdrawal)*
 - ✓ *The sediment deposition level*
 - ✓ *Or some other specified operating level*
- **Intake structure** supports **trash racks, fish screens and bypass devices**, and accommodates the **control device** (gates and valves).
- **Conduit Entrance**- **rounded or bell-mouthed** to reduce hydraulic entrance losses
 - ✓ **Square-Edged Entrance**- causes separation of flow (the consequent danger of cavitation).

..... intake structures

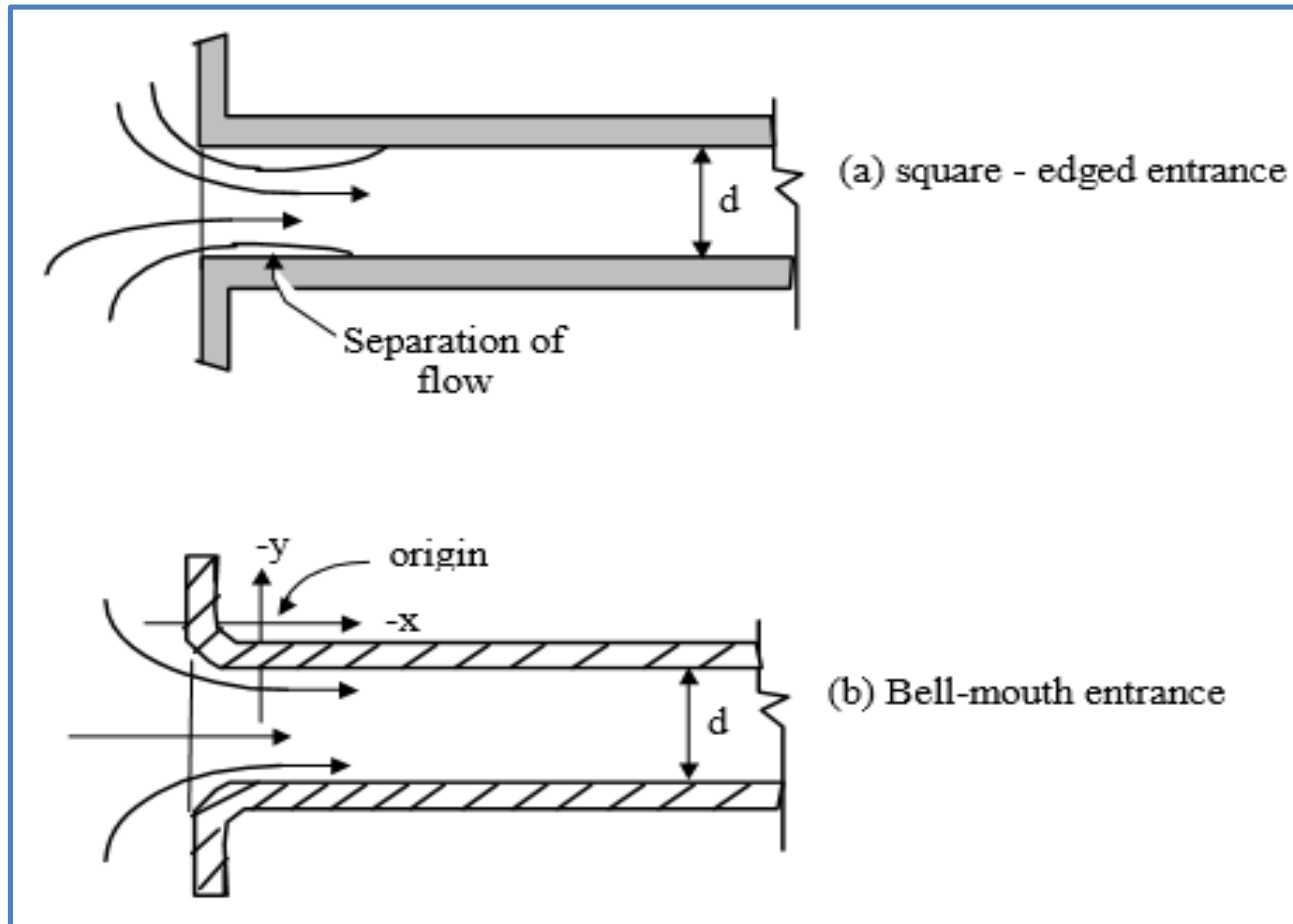


Figure 1.4 Entrance shapes

1.8 Hydraulics Of Outlet Works

- ❑ *The **hydraulics** of outlet works usually involve either one or both of two conditions of flow:*
 - ***Open channel (or free) flow**- Based on the principle of steady non-uniform flow conforming to the law of conservation of energy.*
 - ***Full conduit (or pressure) flow**- based on pressure flow, which involves a study of **hydraulic losses** to determine the total heads needed to produce the required discharges.*
- ❑ ***Cavitation** is an important factor that must be considered in the design of high velocity outlet works.*

1.8.1 Open Channel Flow In Outlet Works

- The flow will be similar to that in **open channel spillway**.
- When **unsubmerged radial or slide gates** are used, discharge through the control with the gates completely raised will be **open crest flow** given by the following equation.

$$Q = CLH^{3/2}$$

Where,

Q = Discharge,

C = A variable coefficient of discharge,

L = Effective length of crest,

H = Total head on the crest, including velocity of approach head, h_v .

.....open channel flow in outlet works

- *When an outlet flow is controlled by partly open surface gates, or where top-seal radial gates or submerged radial gates control the flow, sluice flow will result. Discharges for such flow is given by:*

$$Q = \frac{2}{3} \sqrt{2gCL} (H_1^{3/2} - H_2^{3/2})$$

Where,

H_1 and H_2 - The total heads to the bottom and top of the orifice, respectively.

C- Coefficient, will differ with different gate and crest arrangements.

.....open channel flow in outlet works

- In instances where there is **high tailwater** due to canal water surfaces or to downstream influences in the streambed, the control openings may be **partly or entirely submerged**. For such conditions the discharge through the control will be in accordance with submerged **orifice or tube flow** and can be compiled the equation:

$$Q = CA\sqrt{2gH}$$

Where,

A = Area of the opening

H = Differential head causing flow, i.e. the difference between the upstream and downstream water levels,

C = Coefficient of discharge for submerged orifice or tube flow.

1.8.2 Pressure Flow in Outlet Conduits

- If a control gate is placed at some point *d/s* from the conduit entrance, that portion above the control gate will flow under pressure.
- For flow in a closed pipe system, *Bernoulli's equation* can be written as follows:

$$H_T = h_L + h_v$$

Where,

H_T - The total head needed to overcome the various head losses to produce discharge,

h_L - The cumulative losses of the system

..... pressure flow in outlet conduits

- *The above equation can be expanded to list each loss, as follows:*

$$H_T = ht + he + hb + hc + hex + hg + hf + hv$$

Where, ht = trash rack losses,

he = entrance losses,

hb = bend losses,

hc = contraction losses,

hex = expansion losses,

hg = gate or valve losses,

hf = friction losses, and

hv = velocity head exit loss at the outlet.

1.9 Losses in Outlet Works

- a) Conduit Losses- Caused primarily by the frictional resistance to flow along the conduit walls.*
- b) Friction Losses- For flow in large pipes, the Darcy-Weisbach formula is often employed to determine the energy losses due to frictional resistances of the conduit as follows:*

$$h_f = flv^2/2gD$$

Where, f-is the friction loss coefficient

- *This coefficient varies with the conduit surface roughness and with the Reynolds number.*

.....*losses in outlet works*

c) **Trash rack Losses-** *The loss will depend on the bar thickness, depth, shape and spacing;*

$$h_t = k_t * V_n^2 / 2g$$

Where, $k_t = 1.45 - 0.45(a_n/a_g) - (a_n/a_g)^2$

K_t = *the trashrack loss coefficient,*

a_n = *the net area through the rack bars,*

a_g = *the gross area of the rack & supports,*

V_n = *the velocity through the net trashrack area*

➤ **Where maximum loss values are desired, assume that 50% of the rack area is clogged**

.....losses in outlet works

d) **Entrance Losses**- The loss of head at the entrance of a conduit is comparable to the loss in a short tube or in a sluice.

➤ If H is the head producing the discharge, C is the coefficient of discharge, and a is the area, then;

$$Q = Ca\sqrt{2gH}, \text{ and } V = C\sqrt{2gH} \text{ or } H = V^2 / (C^2 * 2g)$$

➤ Since H is the sum of the velocity head h_v and the head lost at the entrance, h_e , equation above may be written as:

$$V^2/2g + h_e = V^2 / (C^2 * 2g), \text{ Or } h_e = ((1/C^2) - 1) * V^2/2g$$

$$\text{Then: } k_e = ((1/C^2) - 1)$$

➤ Published literature gives an **entrance coefficient of 0.50** for a square edged entrance and **0.23** for a slightly rounded entrances.

.....losses in outlet works

e) **Bend Losses-** The bend loss, excluding friction loss, for a circular conduit is a function of **bend radius, pipe diameter** and **deflection angle of the bend**.

f) **Transition Losses-**

(i) **Contraction:** The loss of head is approximately equal to:

$$h_c = k_c (v_2^2 - v_1^2) / 2g$$

➤ Where k_c varies from **0.1** for gradual contractions to **0.5** for abrupt contractions.

(ii) **Expansion:** The loss of head, h_{ex} , will be approx. equal to:

$$h_{ex} = k_{ex} (v_1^2 - v_2^2) / 2g$$

➤ The coefficient k_{ex} varies with the flare angle. It increases from **0.12** for **50** flare angle to **1.0** for a flare angle of **500**.

.....losses in outlet works

- g) Gate slot losses-** The loss coefficients for beveled slots are **0.005** for each pair of gate slots.
- When gate slot losses are **not included** in the intake (entrance) loss, a value of **0.01** is recommended for each pair of slots to account for **the effects of roughness**.
- h) Exit losses-** As there is no recovery of velocity head, where the release from a pressure conduit freely discharges, the velocity head loss coefficient k_v is equal to **1.00**.

Assignment On Outlet Works

- 1) *What is meant by a dam sluice (outlet) ? Why are such sluices necessary in dam construction?*
- 2) *Show with neat sketches, the provision of sluiceways in:*
 - i) *An earth dam*
 - ii) *A concrete gravity dam*
- 3) *Write short notes on:*
 - i) *Components of outlet works*
 - ii) *Trash Racks*
 - iii) *D/t head losses in a conduit pressure flow*

THANK YOU !!!



WATER IS LIFE!

NO DROP OF WATER WOULD JOIN THE SEA WITH OUT BENEFITING THE MAN!