Arba Minch Water Technology Institute

Faculty of Water Supply and Environmental Engineering

Course title; Hydraulics Structure II

Course code; WSEE 3162

Target groups; 3rd year WSEE students

Academic year; 2019/20

Semester II

Instructor; Zelalem A.

Course Objectives & Competences to be Acquired

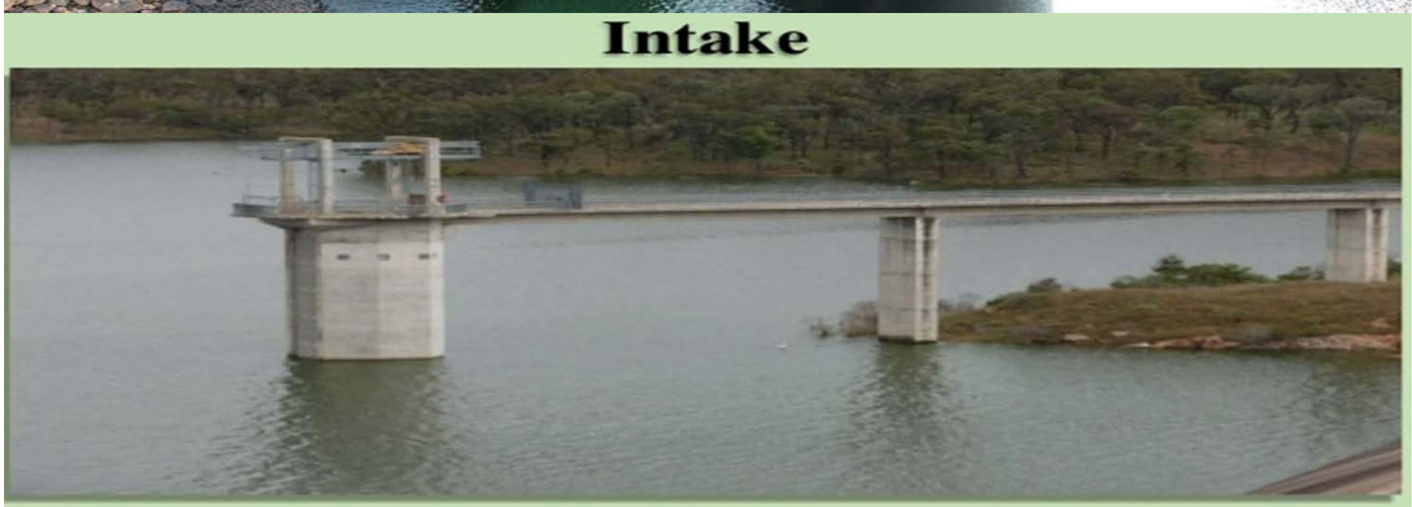
- As the students are equipped in the first course of this module with the knowledge of what Dams & Reservoirs are, this course will make the students know about designs of Over-flow structures, Diversion-tunnels, Diversion-channels, and Coffer-Dams.
- By the end of the semester, students should be confident enough to tackle problems pertaining to Hydraulic-Structures.

Course Contents

- Types and design principles of the following structures
  - ✓Spill-ways:
  - ✓Stilling basin and Intake structures:
  - ✓River diversion works:
  - ✓Design of Weirs on Permeable foundations:
  - ✓Head-works, Locks and Gates

CHAPTER ONE

Intake Structures and Dam bottom Outlets



1.1. INTRODUCTION

- Among the general **hydraulic structures**, the most significant are the **spillway** and **outlet works** which, almost without exception, are constructed in every hydraulic scheme with a dam.
- The **spillway structures** have the task of evacuating flood waters from the reservoir at an assigned maximum level of the headwater and conveying them downstream in a safe manner.

Cont..

- Most of the water, which is stored in a reservoir for **irrigation** ,**water supply** or **power penetration purposes**, is stored below the spillway crest level.
- The **spillway** is provided at **normal pool level**, such that the floods are discharged safety above the spillway. But, in order to draw water from the reservoir as and when needed, for irrigation, water supply, power generation etc.

Cont….

- It is absolutely necessary that **outlet works** are provided either through the body of the dam or adjacent to it through some hillside at one end of the dam.
- The opening a pipe or tunnel provided for this withdrawal of water is known as a **dam out let**.

Cont..

- The construction and position of the bottom outlet depend on
  - the type of the dam
  - the purpose of the reservoir
  - the quantity and depositing of silt

1.2. Intake structures

what is an intake structure ?

- The basic function of intake structure is to help in safely withdrawing water from the source and then to discharge this water in to the withdrawal conduit, through which it reaches water for **irrigation** ,**water treatment plant** or **power penetration purposes**.
- It is constructed at the entrance of the withdrawal conduit and there by protecting it from being **damaged/clogged by ice ,debris** .
- Some times from reservoirs where gravity flow is possible, water is directly transmitted to the treatment through intake structure.

Cont….

The following points must be considered while **designing** and **locating** the **intake structures**.

- The source of supply must be considered including the wide fluctuation in water level.
- Intake surroundings should be considered. For example depth of water around intake.
- Characteristics of bottom, navigation requirements, the effect of floods and storm to the structure and scouring in the bottom are also considered.

Cont..

- The location with respect to the sources of pollution is also considered.
- The frequency of floating materials such as ice, vegetation is considered.
- **Intake capacity** must be large enough to meet the requirement of design discharge.

Function of Intakes

- The main function of intakes is to provide highest quality of water from source.
- To protect pipes and pumps from damaging or clogging by wave action, floating bodies and submerged marine.

Intake for water supply

- The main function of the intakes for **water supply** is to collect water from the surface source and then discharge water so collected, by means of pumps or directly through bottom outlets to the treatment plant.
- For safe operation of gate, approach velocity at the gate opening must be <1.5 m/s

Cont.…

- When **intakes** are selected for a **water supply**, it should be located;
  - Where the best quality of water available so that water is purified economically in less time.
  - At site there should not be heavy current of water, which may damage the intake structure.
  - Where the intake can draw sufficient quantity of water even in the worst condition, when the discharge of the source is minimum.

Cont..

- The site of the work should be easily approachable without any obstruction
- As far as possible the intake should be near the treatment plant so that conveyance cost is reduced from source to the water works

Types of intakes

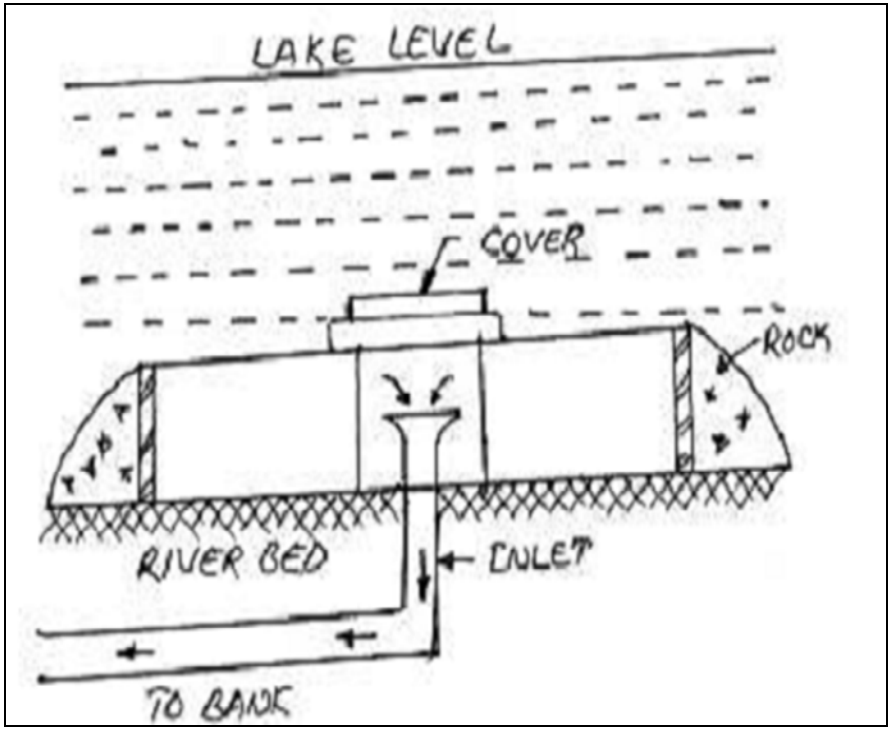
- Depending upon the source, the intakes may be of the following types.
  - ❑Lake Intake
  - ❑Reservoir Intake
  - ❑River Intake
  - ❑Canal Intake

Lake intake

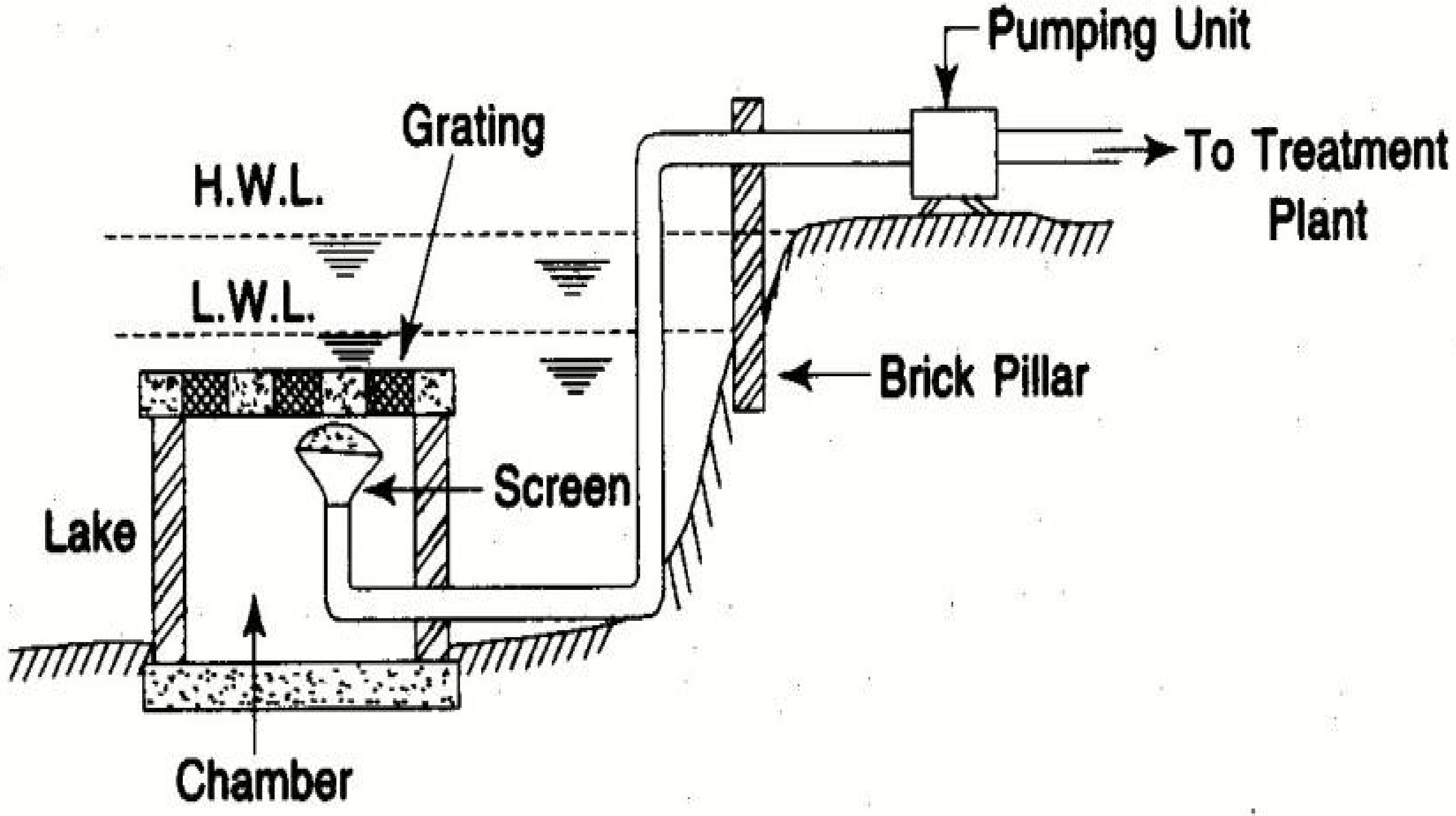
- **Lake intake:** For obtaining water from lakes mostly submersible intakes are used
- These intakes are constructed in the bed of the lake below the water level; so as to draw water in dry season.
- Advantages;
  - no danger from the floating bodies
  - no trouble due to ice

Dis-advantages

- They are not easily approachable for maintenance.



Cont..



Pumping Unit
Grating
To Treatment Plant
H.W.L.
L.W.L.
Brick Pillar
Screen
Lake
Chamber

River intake

- They are generally constructed for withdrawing water from almost all rivers.

✓ They can be classified in to two types

1. twin well type of intake structure
2. single well types of intake structure

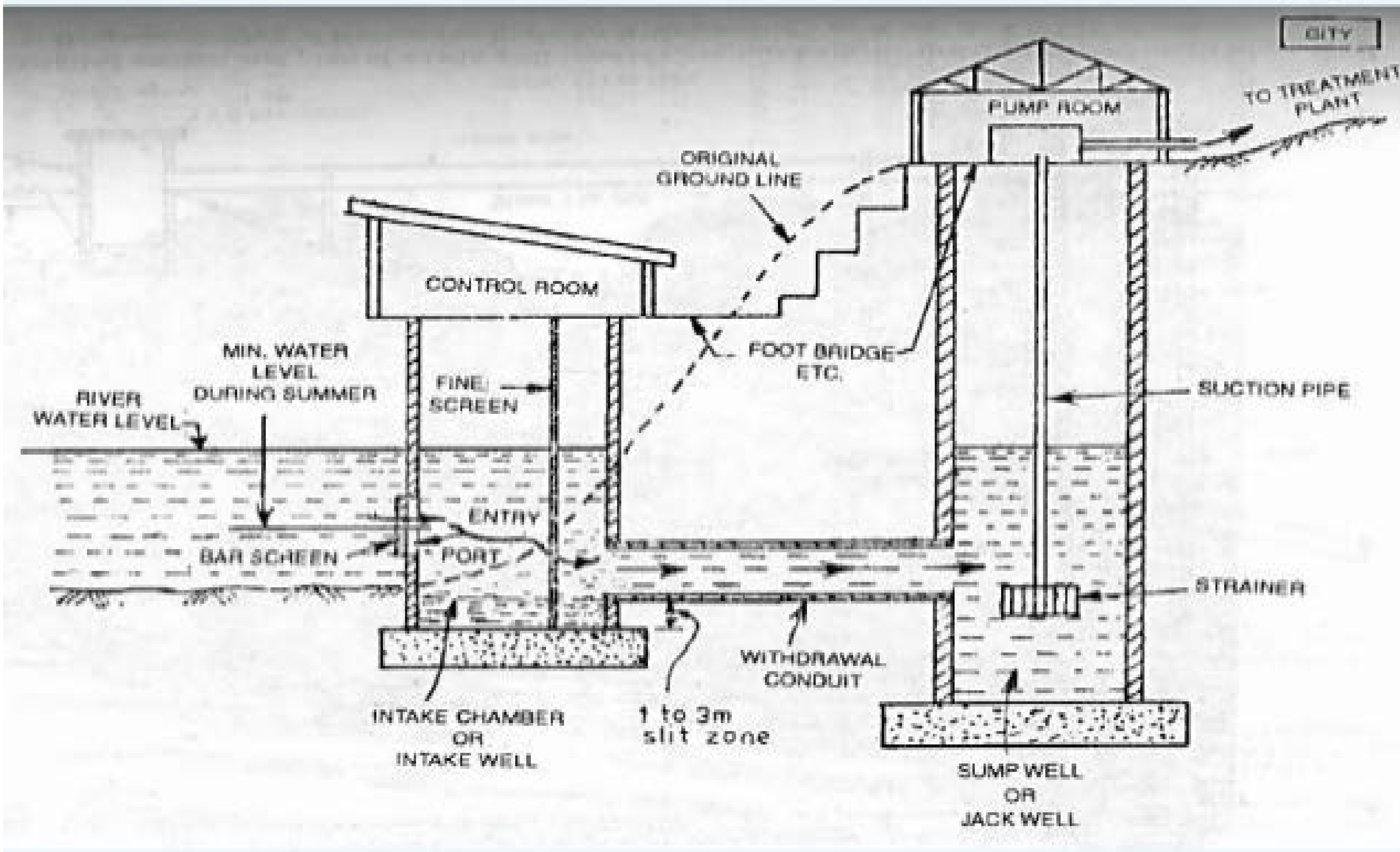
Twin well type of intake structure

- The are constructed on almost all types of rivers, where the river water hugs the river bank.
- A typical river in take structure consists of 3 components .

  a) An inlet well

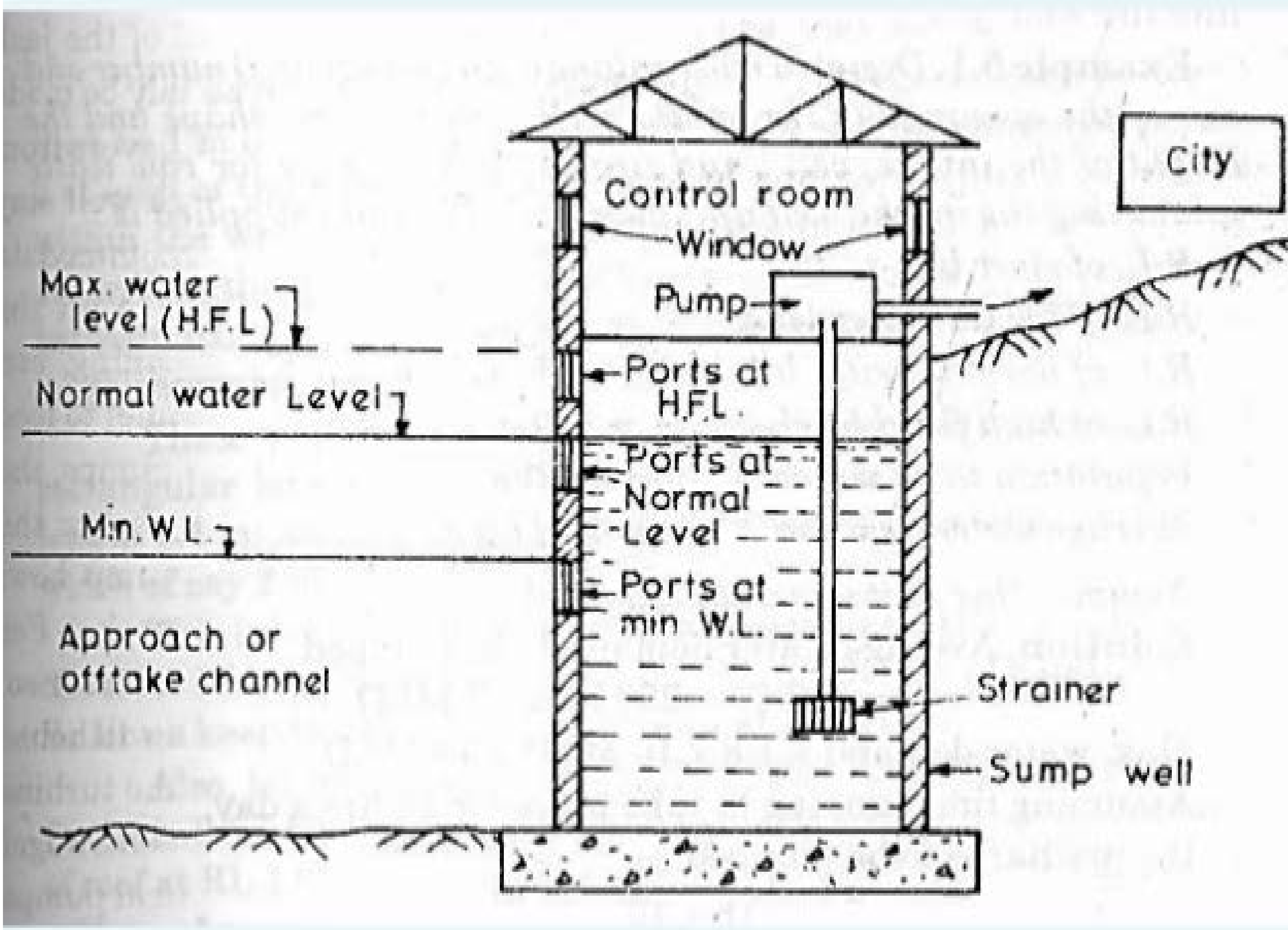
  b) An inlet pipe (intake pipe)

  c) A jack well


CITY
PUMP ROOM
TO TREATMENT PLANT
ORIGINAL GROUND LINE
CONTROL ROOM
FOOT BRIDGE ETC.
MIN. WATER LEVEL DURING SUMMER
FINE SCREEN
SUCTION PIPE
RIVER WATER LEVEL
ENTRY
BAR SCREEN
PORT
STRAINER
WITHDRAWAL CONDUIT
INTAKE CHAMBER OR INTAKE WELL
1 to 3m slit zone
SUMP WELL OR JACK WELL

Single well types of intake structure

- No inlet and inlet pipe in this types of river intake .
- Opening or ports fitted with bar screens are provided in the jack well itself .
- The silt entering the jack well will partly settle down in the bottom silt zone of jack well or may be lifted up with the pumped water since pumps can easily lift sediment water .
- The jack well can be periodically cleaned manually by stopping the water entry in to the well.


City
Control room
Window
Max. water level (H.F.L)
Pump
Ports at H.F.L.
Normal water Level
Ports at Normal Level
Min. W.L.
Ports at min W.L.
Approach or offtake channel
Strainer
Sump well

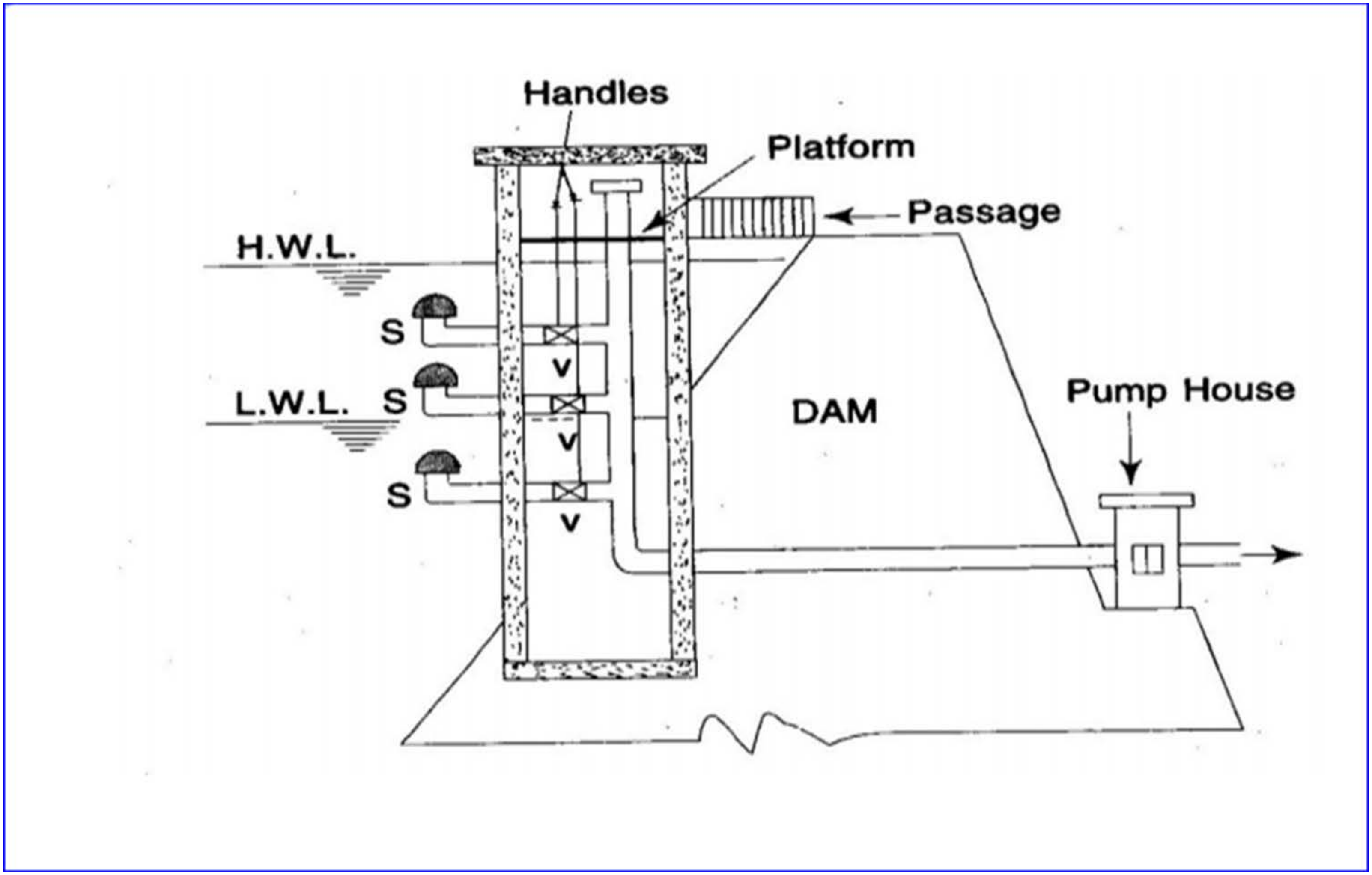
Cont.…

- A river intake consists of a port (conduit) provided with a grating and a sump or gravity well.
- The conduit is supported on pillars 1-2m above the bottom to prevent entry of silt. Also it is kept 1m below the top surface to avoid entry of floating particles.
- Velocity should be kept less than 0.15 m/s to prevent entry of small fish.
- River intake structure should be constructed above the point of sewage disposal or industrial waste water disposal.

Reservoir Intake

- When the flow in the river not guaranteed throughout the year , a dam is constructed across the river to store the water in the reservoir so formed .
- **Reservoir intakes** essentially consists of an intake tower constructed on the slope of dam at such a place where intake can draw water in sufficient quantity even in the driest period .
- **Intake pipes** are fixed at different levels , so as to draw water near the surface in all variations of water levels.

Cont..



Canal intake

- It is a very simple structure constructed on the bank of the canal.
- The well may be circular or rectangular and it is constructed with masonry work.
- It has an opening on its side provided with screen.
- An inlet pipe is inserted in to the well extending up to the L.W.L of the canal for drawing water and it carries a hemispherical screen at the end.
- A manhole is provided on the well cap for inspection work.
- The intake pipe is connected to the pumping unit for sending water to treatment unit.

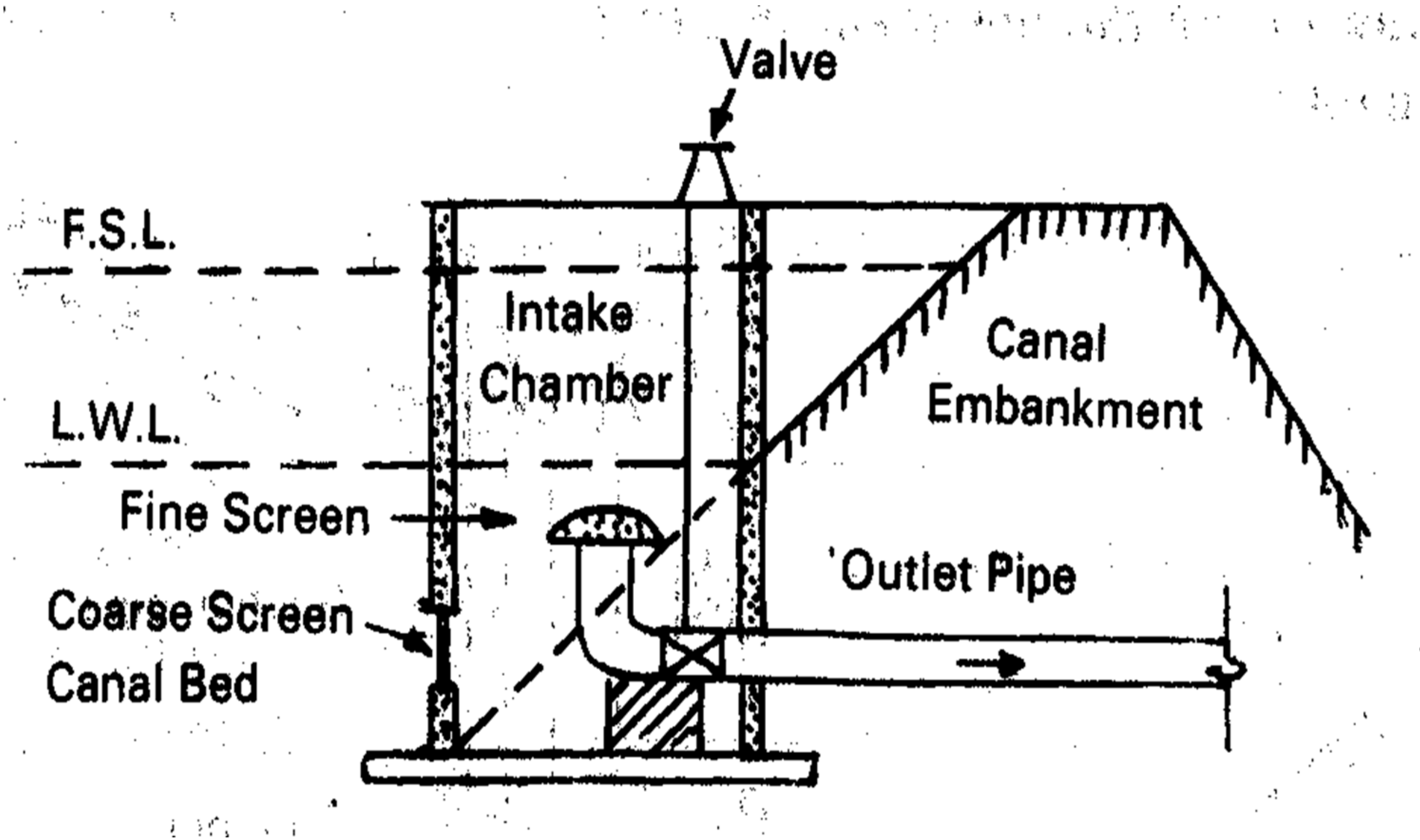
Cont….

- In some cases, **source of water supply** to a small town may be an irrigation canal passing nearer or through the town. Then it will be constructed.
- Generally it consists of masonry or concrete intake chamber of rectangular shape, admitting water through a coarse screen.
- **A fine screen** is provided over the bell mouth entry of the outlet pipe.

Cont..

- **The intake chamber** may be constructed inside the canal bank if it does not offer any appreciable resistance to normal flow in the canal.
- It's preferred to provide lining to the canal near the intake chamber.

Cont….



Valve
F.S.L.
Intake
Chamber
Canal
Embankment
L.W.L.
Fine Screen
Outlet Pipe
Coarse Screen
Canal Bed

Dam outlet

- Outlet works controls are designed to release water as specific rates, as indicated by
  - downstream needs
  - flood control regulation
  - storage canted regulation
  - storage considerations, or legal requirements.

Cont..

- A major portion of the storage volume in the reservoir on the up stream of a dam is below the spill way crest level .
- **Dam outlets** are provided in the body of the dam or its abutments below the crest level of the spillways so that the water can be with drow from the reservoir .
- **Sluice ways** are the special type of outlets provides in the body of a concrete gravity dam.

Selection Criteria

- The costs of operation, maintenances, modification, and possible replacement should be included in these **economic studies**.
- **Project requirements** will include; properly positioning intakes gating, and terminal structures; sizing components; selecting appropriate components including operation controls; providing adequate means for maintenance and replacement of components.

Cont..

- **Site conditions** involve topography, climate, geology and seismicity.
- **The type of dam** (concrete or embankment) greatly affects the design and the cost of an outlet.
- The lengths of waterways and the requirements for energy dissipation have important effects on costs.

Classification of outlets based on purpose :

- River outlet – discharge water into the river
- Canal outlet –discharge water into the canal.
- Pipe outlet – delivers water in to a closed pipe

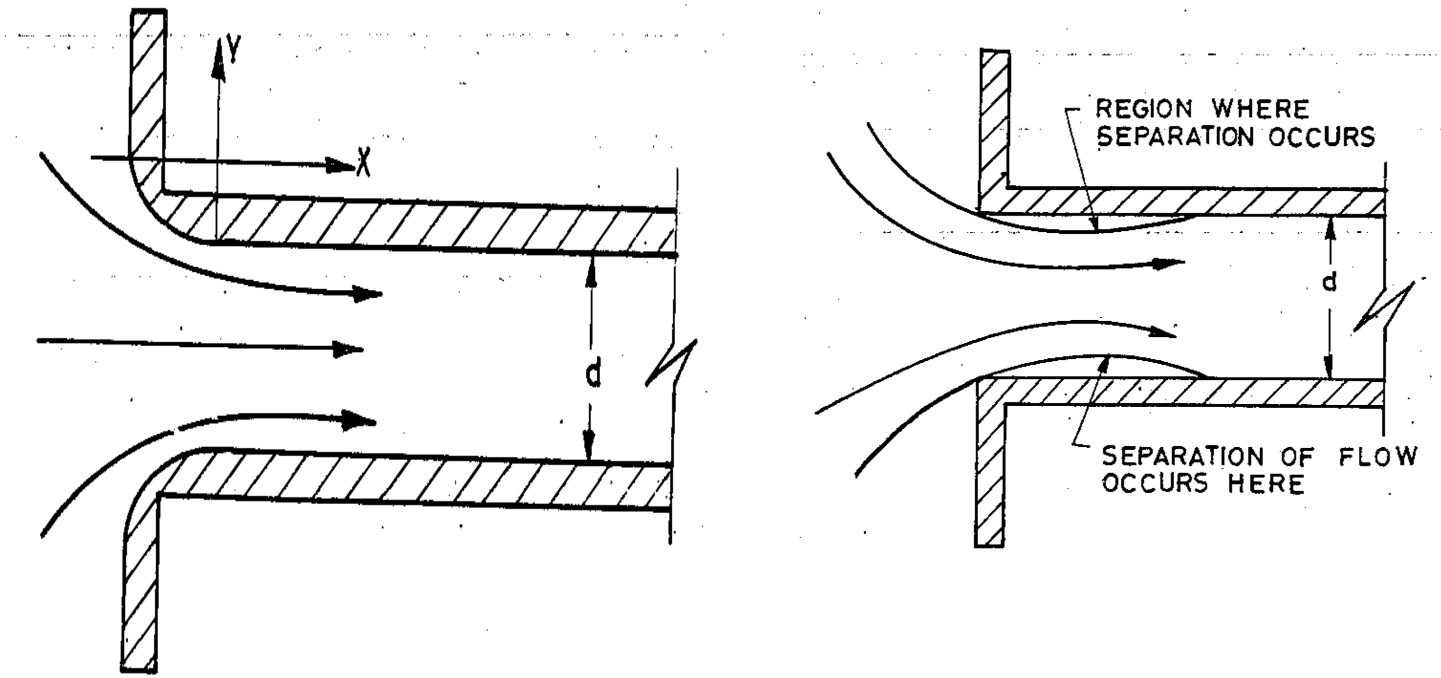
Classification of out let based on gates

- ✓ Gated outlets
- ✓ Un gated outlets

Cont….

- An outlet works regulates or releases water impounded by a dam.
- It can:
  - Release incoming flows at a retarded rate
  - Divert incoming flows into canals or pipelines
  - Release stored waters at rates dictated by downstream needs

Entrance shapes of outlets



Conduits Flowing Full

- The objective of the analysis of conduits flowing full is to establish the relation between discharge and total head and to determine pressures in critical locations.
- The total head H, which is defined as the difference in elevation of the upstream pool and the elevation of the hydraulic (pressure) grade line at the exit portal.

$$H = H_f + H_l + H_v$$

H_f, H_l, H_v are head loses due to friction, alignment/expansion or contraction/ and velocity respectively.

For sudden expansion

$$h_\ell = \left(1 - \frac{A_1}{A_2}\right)^2 \frac{V_1^2}{2g} = K \frac{V_1^2}{2g}$$

Cont….

- Where A_1 and A_2 are the respective upstream ad downstream conduit cross-sectional areas, and the reference velocity is the upstream velocity $V_{1,}$ "k" expansion coefficient

For sudden contraction:

$$h_\ell = \left(\frac{1}{C_c} - 1\right)^2 \frac{V_2^2}{2g} = K\frac{V_2^2}{2g}$$

cavitation

- Cavitation results from the sudden reduction of local pressure at any point to the vapor pressure of water.
- Such reductions in pressure are caused in water passages by abrupt changes in the boundary which causes a tendency of separation of the flow from the boundary

Hydraulics of outlet works

- The discharge passing through the dam outlet can be easily calculated by:

$$Q = C_d \cdot A \sqrt{2gH}$$

Where Q=Discharge

A=Area of sluice outlet

H=head difference, u/s and d/s

C_d= Coefficient of discharge

Trash Racks

- ❖The entrances to intakes and dam outlets are generally covered with trash racks so as to prevent entry of debris.
- ❖They are bar screens usually made from steel bars.
- ❖The floating materials that are retained by the racks are later removed manually or machine driven in large structures.

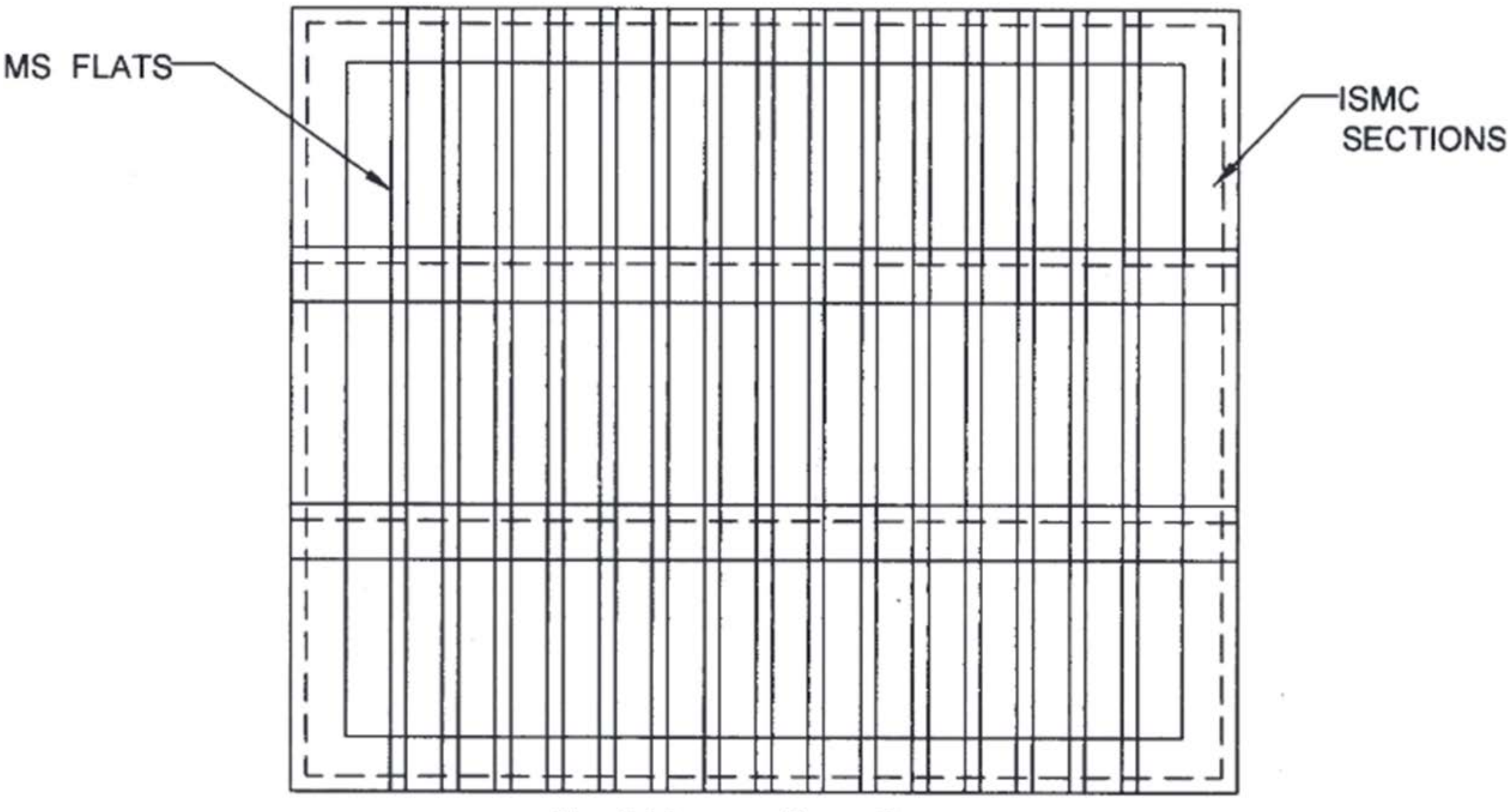
selection of type of Trash

- The selection of type of rack for an installation depends upon the following considerations:
- ❖ Accessibility for maintenance or replacement;
- ❖ Size and quantity of trash expected; and
- ❖ Mechanism available for raking
- Racks should be installed in slanting position except for guided racks where these can be kept in vertical position as well.
- For manual raking of the racks, the slope should be 1 vertical to 1/3 or 1/2 horizontal.

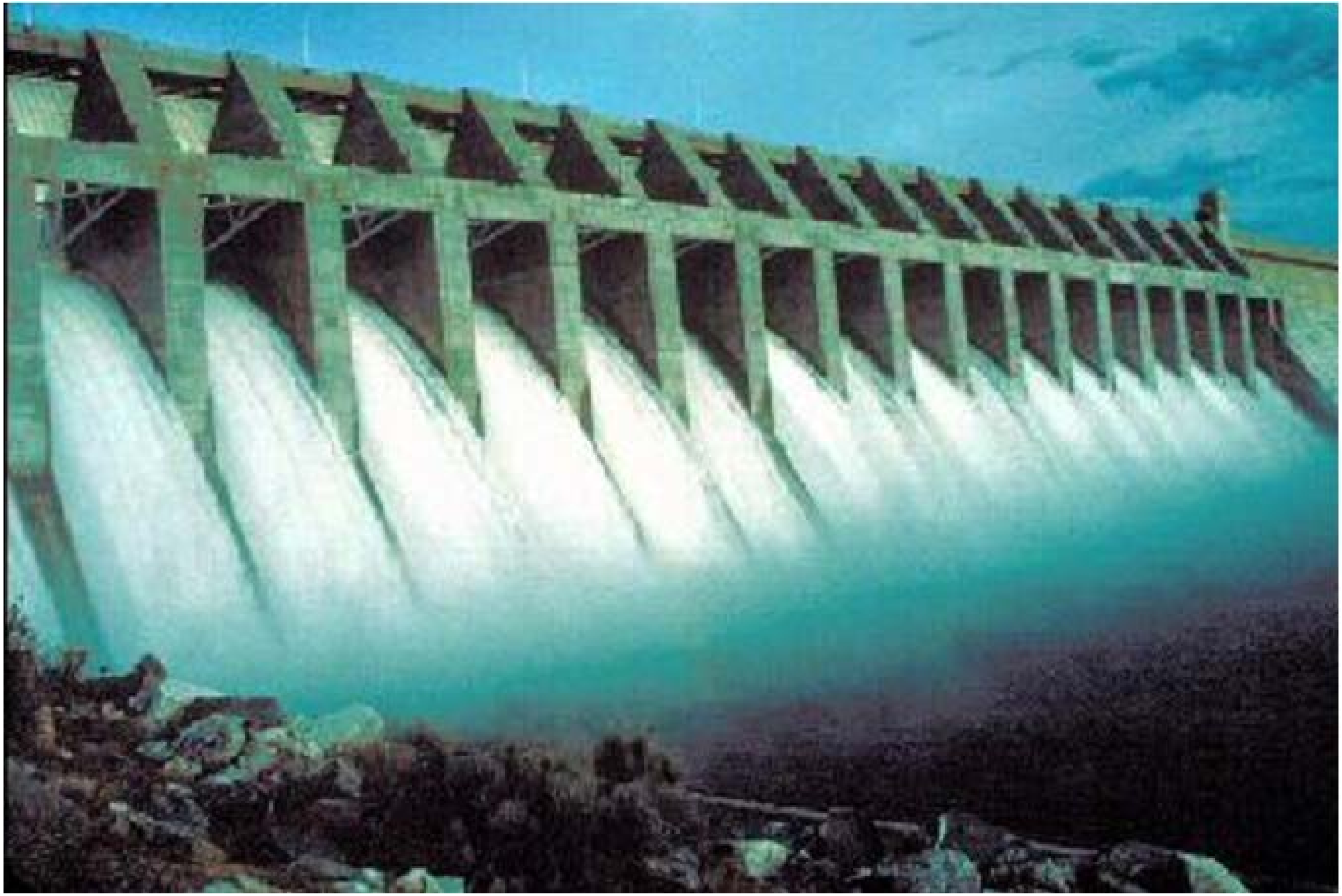
STRUCTURAL DESIGN OF TRASH RACKS

- The structural arrangement of racks generally consist of equally spaced trash rack vertical bars supported on horizontal members connected to end vertical members, which sit in the grooves of piers.
- The trash rack should be constructed from structural steel conforming to IS 800 and IS 2062.
- The clear spacing usually varies from 40 mm to 100 mm.

STRUCTURAL DESIGN OF TRASH RACKS



Spillway



By Zelalem A.

SPILLWAY

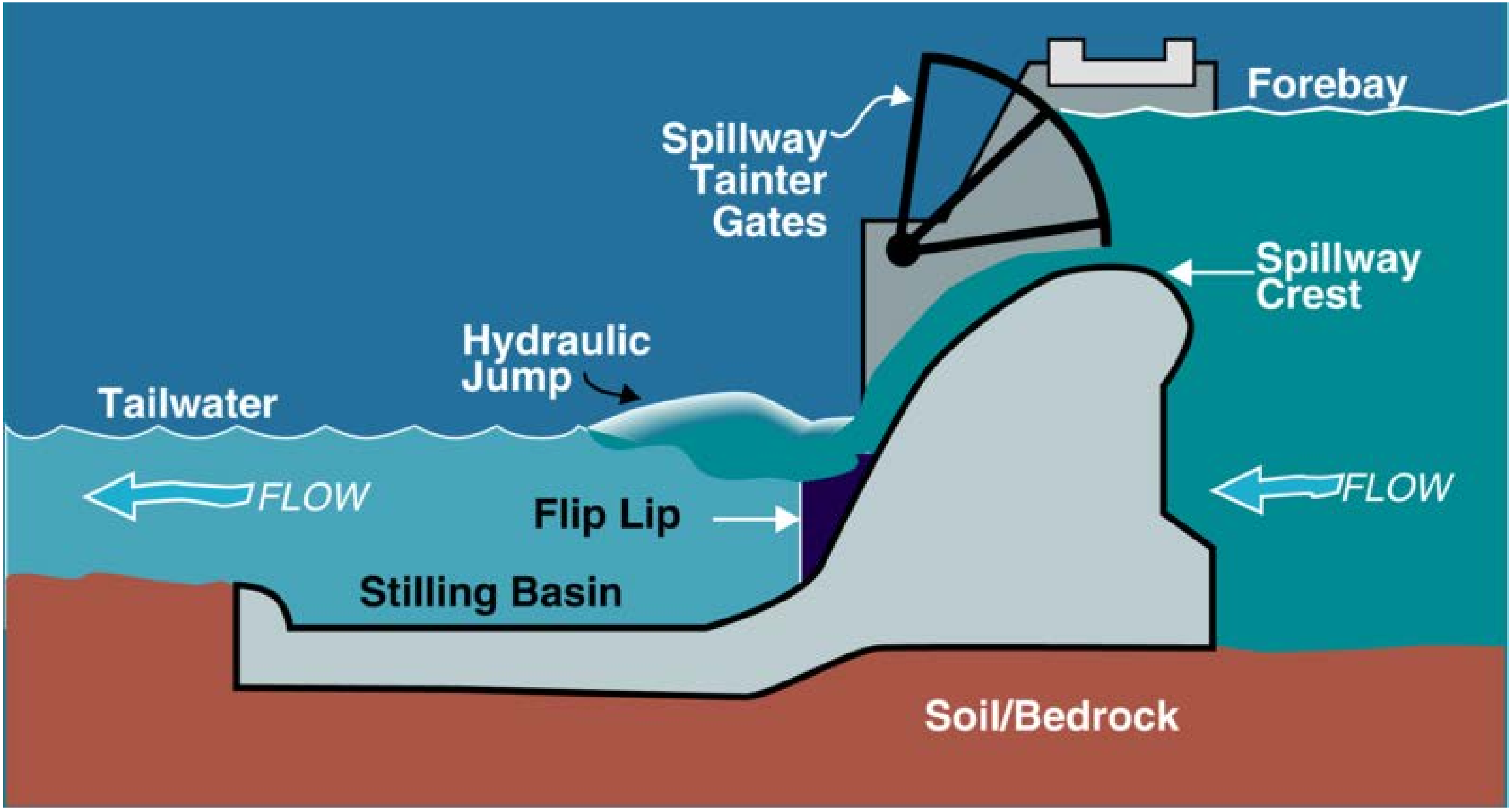
- It is a structure constructed to pass surplus flood water on the D/S of reservoir and Dam.

Essential requirements of a spillway

- The spillway must have sufficient capacity.
- It must be hydraulically and structurally adequate.
- It must be so located that it provides safe disposal of water i.e., spillway discharge will not erode or undermine the D/S toe of the dam.
- The bounding surface of spillway must be erosion resistant to withstand high scouring velocity created by the drop from reservoir surface to tail water.
- Usually some devices are needed for energy dissipation on the D/S side of spillway.

E:\Old_Laptop\Hydraulic_Structures-a\Hydraulic_structure_II_class presentation\spillway_types\Spillway operation animation.flv

Components of Spillway



Spillway Capacity

- The required capacity of spillway i.e., maximum outflow rate through spillway must be determined by flood routing knowledge:
  - Inflow rate Vs. time
  - Reservoir capacity curve (reservoir surface elevation v/s reservoir storage)
  - Discharge curve (out flow v/s reservoir water surface elevation).

- However the required capacity of a spillway depends on the following factors:
  - Inflow flood, I
  - Available storage capacity, S
  - Discharge capacity of outlet works, O
  - Whether gated or un-gated spillway
  - Possible damage if a spillway of adequate capacity is not provided.
- Large dam with inhabited area on the D/S side needs large protection.
- Whereas, Small dams with uninhabited area on its D/S side needs limited protection.

- A reservoir with larger storage capacity will normally require a smaller out flow rate through the spillway.
- If the out flows through the spillway are supplemented by release through the outlets then the required capacity of spillway may be reduced.
- For gated spillway more water is stored.
- By proper operation of gate higher heads may be developed so that greater out flow through the spillway is possible to pass the flood.

Types of Spillway

- **Classification based on the time when the spillways come into operation**
  - Main or Service Spillway
  - Auxiliary Spillway
  - Emergency Spillway

Main or service spillway

- Main spillway is the one which comes into operation and is designed to pass the entire spillway design flood.

Auxiliary spillway

- It is provided as a supplement to the main spillway
- It's crest is so located that it comes into operation only after the floods of the main spillway is exceeded.
- Conditions favorable for the provision of auxiliary spillway are the existence of a saddle or depression along the rim of the reservoir

Auxiliary Spillway

Emergency spillway

- It is also provided in addition to main spillway
- It comes into operation only during emergency
- It may not be considered in the normal design of main spillway.
- Some of the situations which may lead to emergency are:
  - An enforced shutdown of the outlet works
  - A malfunctioning of main spillway gates.
  - The necessity of bye passing the regular spillway because of damage or failure of some part of the structure.
  - Further an emergency may also arise if a recurring flood occurs before a previous flood is evacuated by the main spillway and outlet works.
- Emergency spillways are also provided in the saddles or depressions if available.

- **Classification according to flow through the spillway**
  - controlled or gated spillway
  - un controlled or un-gated spillway

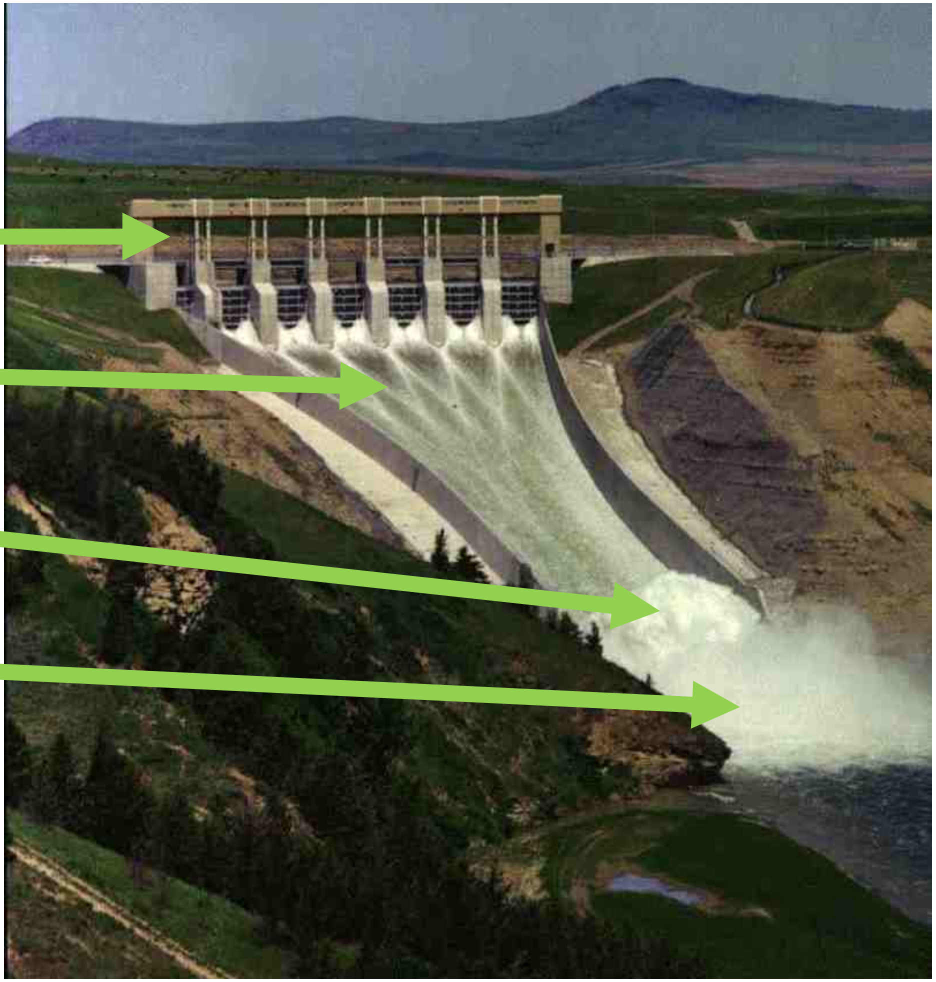
Dam spillway components

The various components of a spillway are

- Control structure
- Discharge channel
- Terminal structures – energy dissipaters
- Entrance & outlet channels.

Spillway components

- Control Structure
- Discharge Channel
- Terminal Structure
- Entrance & Outlet Channel



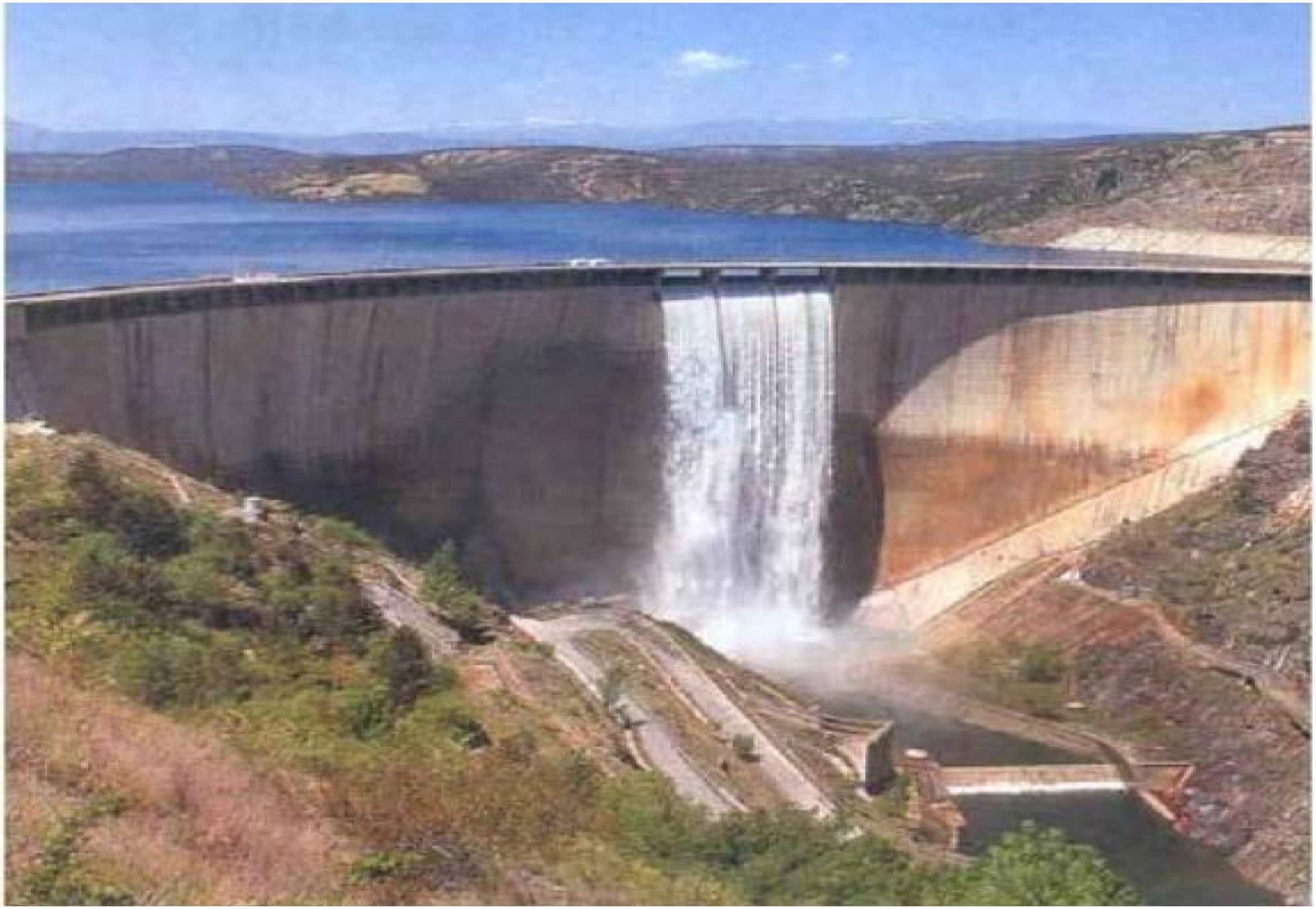
- **With respect to control structures discharge channel etc., the spillway is classified into following types.**
    i. Free over-fall or straight drop spillway
    ii. Over flow or Ogee spillway
    iii. Chute or open channel or trough spillway
    iv. Side channel spillway
    v. Shaft or morning glory spillway
    vi. Conduit or tunnel spillway
    vii. Siphon spillway
    viii. Stepped spillway

I. Free over-fall or straight drop spillway

- Is the one for which the control structure is low height, narrow crested weir having its down face vertical or nearly vertical.
- The over flowing water may be discharged as a sharp crested weir.
- Water, flowing over the crest, drops as a free jet clearly away from the down stream face of the spillway.

E:\Old Laptop\Hydraulic Structures-a\Hydraulic structure II class presentation\spillway_types\Free overfall Tsankov Kamak Dam Spillway test video1.flv

Straight Drop Spillway

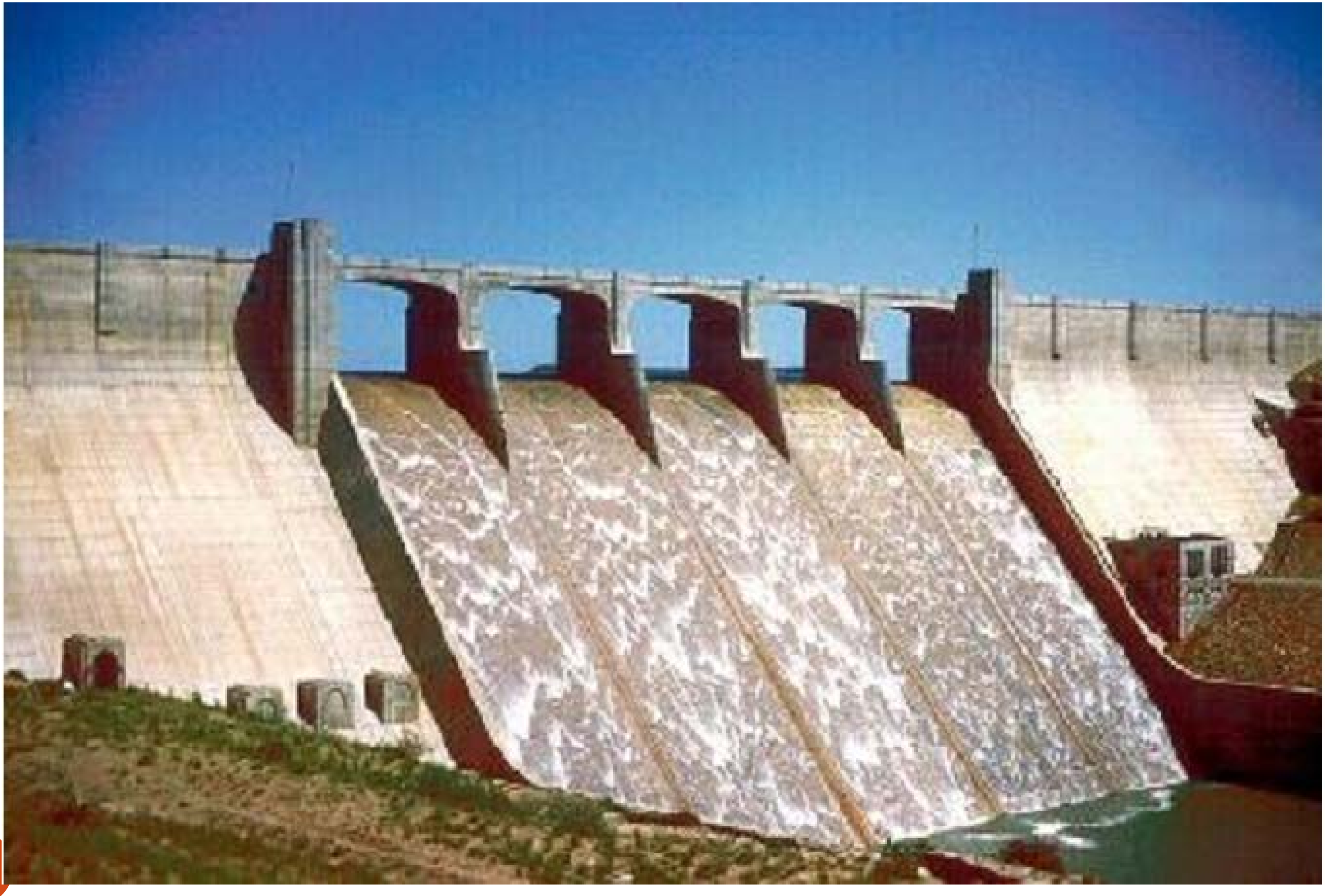


II. Overflow or Ogee spillway

- Overflowing water is guided smoothly over the crest of the spillway and is made to slide over the d/s face of the spillway.
- The profile of the ogee weir is generally confined to the lower nape
- The control structure is a weir which is ogee or S-shaped.
- The shape of such a profile depends upon the
  - Head
  - The inclination of U/S face of the overflow section and
  - The height of the overflow section above the floor of the entrance channel.

E:\Old Laptop\Hydraulic Structures-a\Hydraulic structure II class presentation\spillway_types\Ogee spillway-Hartwell Dam Spillway Test.flv

Ogee spillway



Ogee Spillway

The ogee profile may be categorized into three groups:

I. **Overflow dams with vertical U/S face**

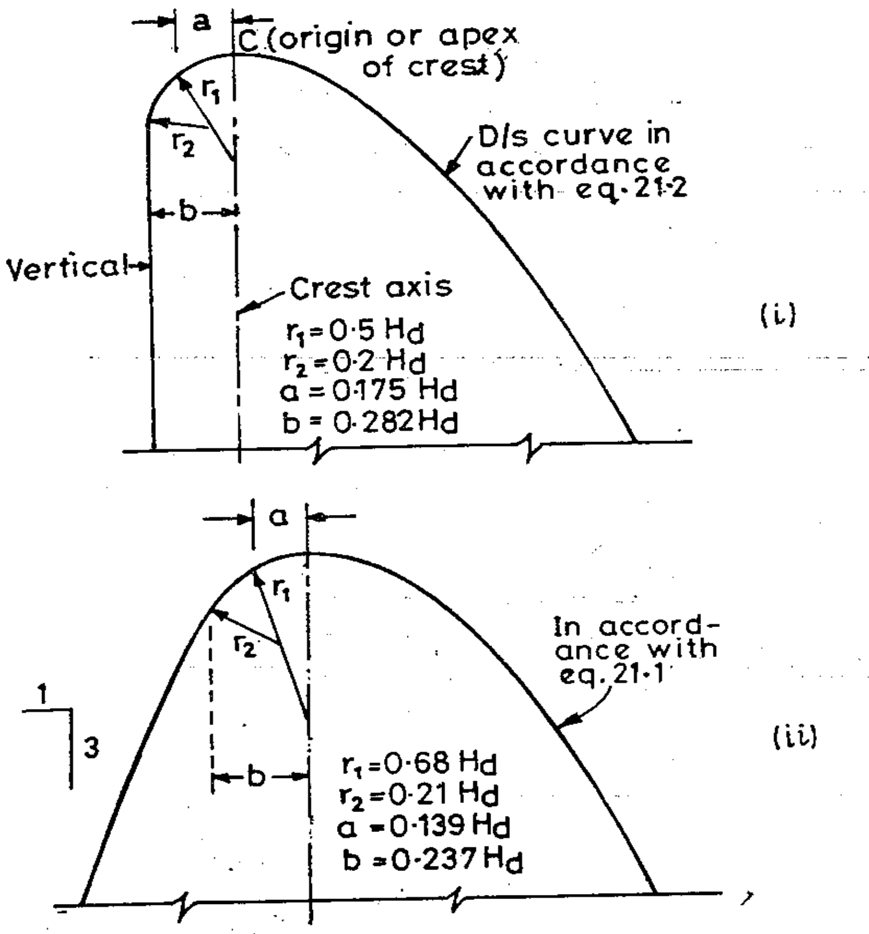
- U.S. Army Corps of Engineers may be used for finding coordinates (X ,Y) for the D/S profile

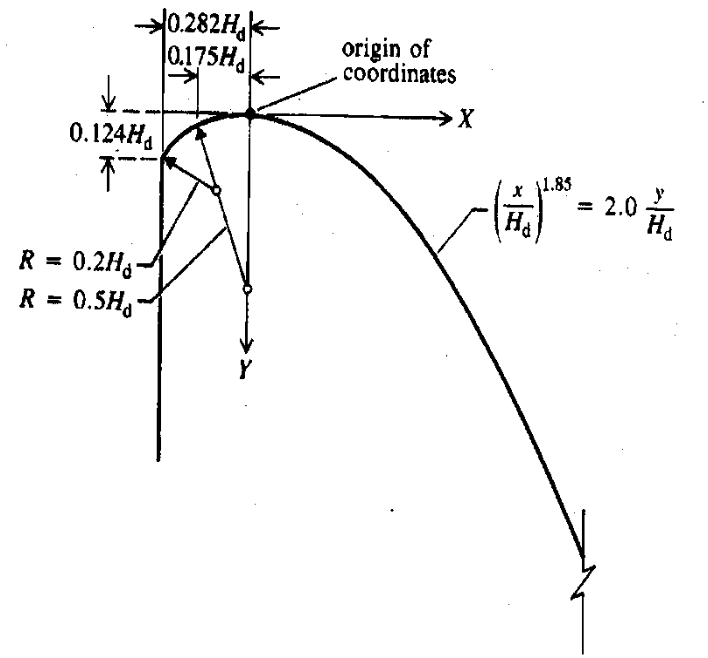
$\mathbf{x^n = K*(H_d)^{(1-n)}*y}$ or most commonly $x^{1.85} = 2\,(H_d)^{0.85}\,y$,
Where X & Y are coordinates and H_d is the design head.

- For U/S profile following coordinates with origin at crest are recommended

E:\Old Laptop\Hydraulic Structures-a\Hydraulic structure II class presentation\spillway_types\Ogee spillway-Hartwell Dam Spillway Test.flv

Profile of ogee spillway





Shape of U/S face	K	n	R_1/H_d	R_2/H_d	a/H_d	b/H_d
Vertical	2.000	1.850	0.5	0.20	0.175	0.282
3V: 1H	1.936	1.836	0.68	0.21	0.139	0.237
3V: 2 H	1.939	1.810	0.48	0.22	0.115	0.240
3V: 3H	1.873	1.776	0.45	0.00	0.119	0.000

- At the end of the sloping surface a curved circular surface called BUCKET is provided to create a smooth transition of flow from spillway surface to river.
- The BUCKET is also useful for dissipation of energy and prevention of scour.
- **Discharge over ogee crest**

$$Q = C_d * b * H^{1.5}$$

Where, Q = Discharge in cumec

Cd = coefficient of discharge

b = effective length of overflow crest in meters

H = Head of over flow in meters including velocity of approach head.

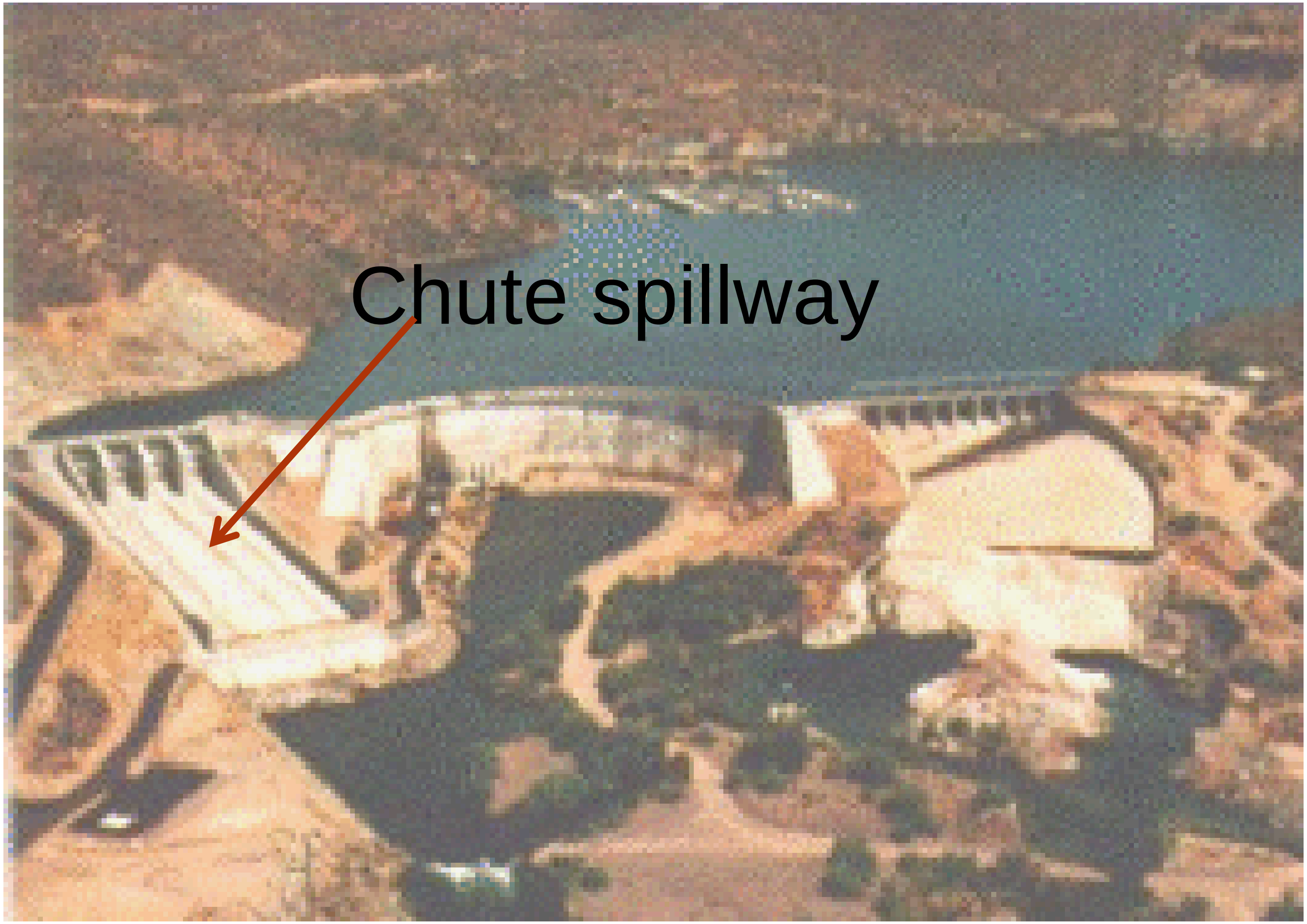
$$H = H_d + Ha$$

Chute Spillway or Trough Spillway

- An ogee and chute spillways are suitable for concrete Gravity dam,
- For Earth & Rock-fill dam, a separate spillway is constructed in a flank or saddle, away from main valley.
- Some times even for gravity dams a separate spillway is required because of the narrowness of the valley.
- The chute spillway is the simplest type of spillway which can be easily provided at low costs.

Chute Spillway

Chute spillway



- It is lighter & adoptable to any type of foundation and hence provided easily on Earth & Rock-Fill dam.
- If it is constructed in continuation of the dam at one end, it may be called a **Flank weir**.
- If it is constructed in a natural saddle in the bank of the river separated from the main dam by a high ridge it is called a **Saddle Weir**.

- A chute spillway essentially consists of a sloping open channel
- It leads the water from the reservoir to the downstream channel or river
- Slope of chute can conform to available topography leading to minimum excavation,

Side Channel Spillway

- In a side channel spillway, the crest of the control weir is placed along the side of the discharge channel.
- The crest is approximately parallel to the side channel at the entrance.
- Thus the flow after passing over the crest is carried in a discharge channel running parallel to the crest.
- The side channel spillway is usually constructed in a narrow canyon where sufficient space is not available for an overflow spillway, and where there is neither a suitable saddle, nor there is a availability of a wide flanks to accommodate a chute spillway.
- The crest of a side channel spillway is usually an ogee- shaped section made of concrete.

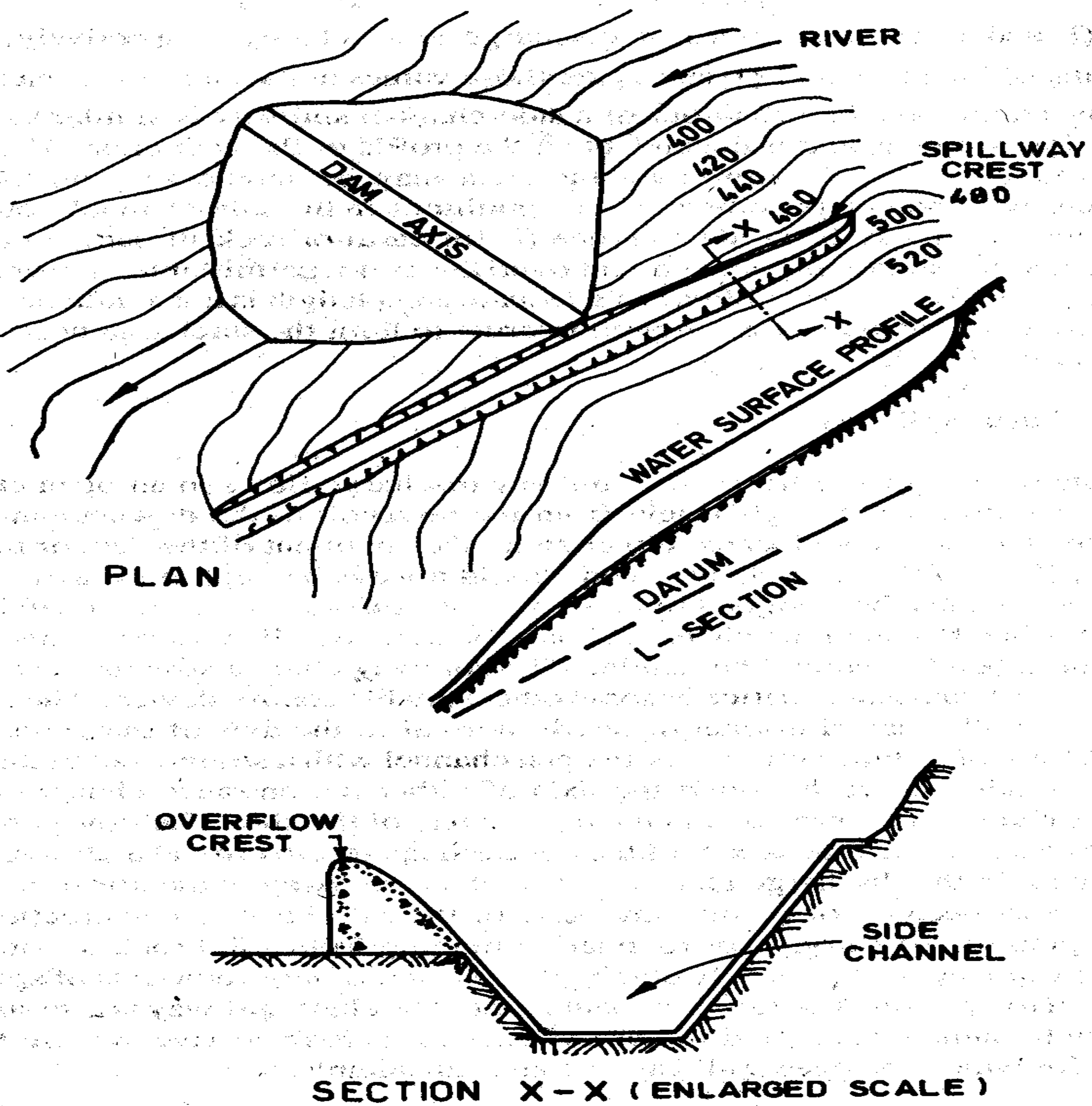


Fig. 17.8 Side-channel Spillway

$$\Delta y = \frac{Q_1(v_1 + v_2)}{g(Q_1 + Q_2)}\left[(v_2 - v_1) + \frac{v_2(Q_2 - Q_1)}{Q_1}\right] \quad (17.5)$$

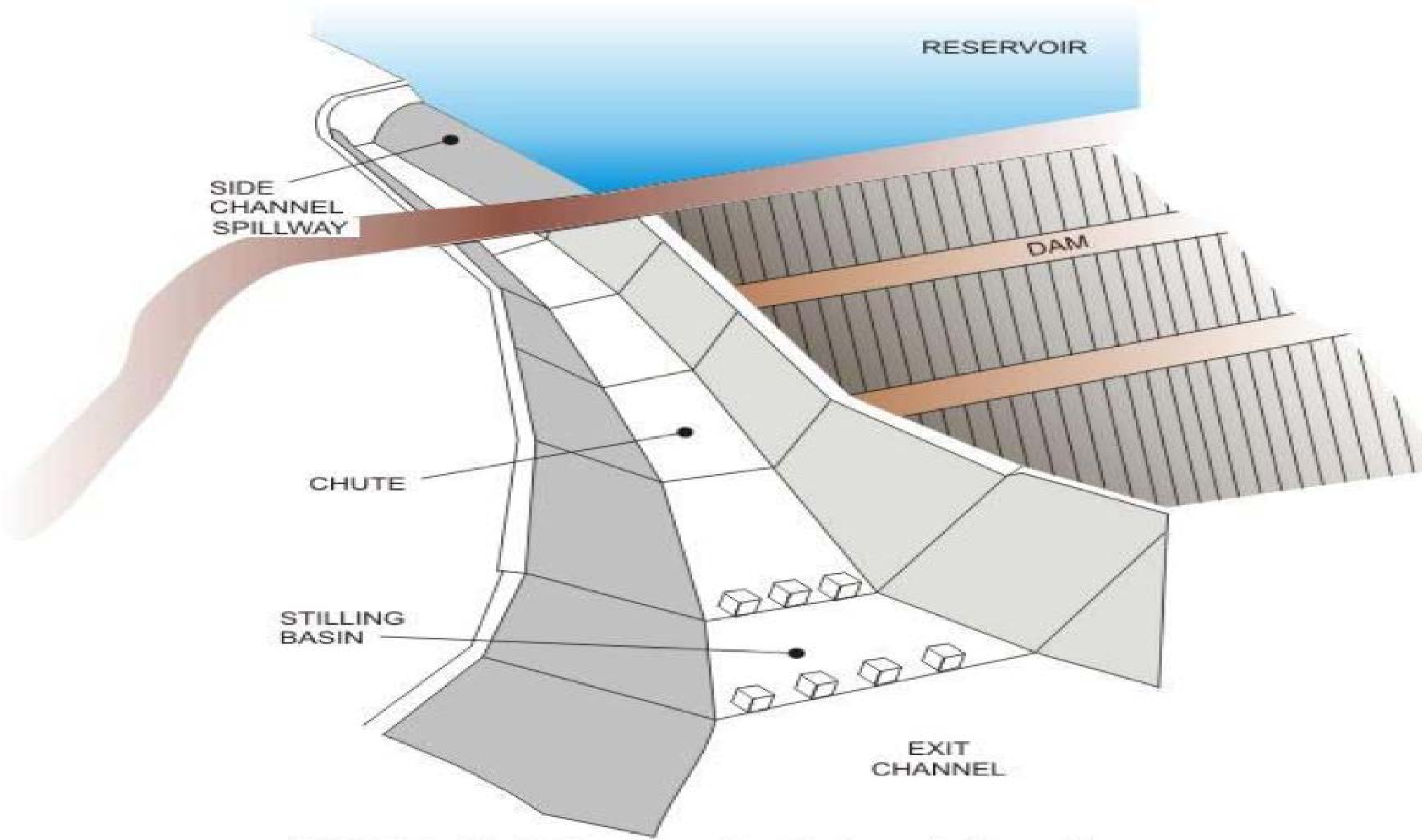
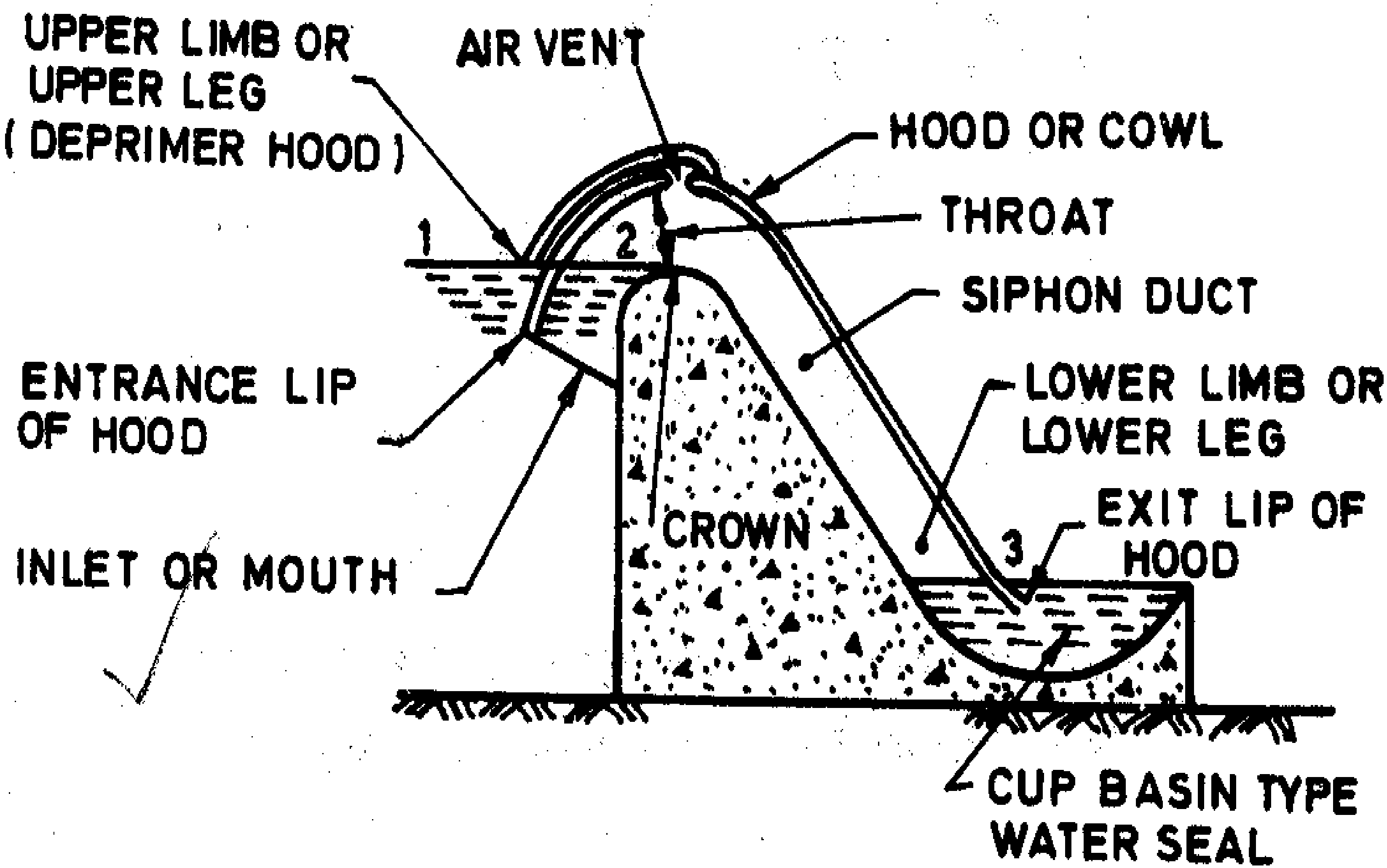


FIGURE 10. Side channel entry to a chute spillway

Saddle Siphon Spillway

- The saddle Siphon spillway consists of an air tight reinforced concrete cover called "Hood" or "cowl" provided over an ogee shaped body wall to form a siphon duct.
- Hence this spillway is also known as 'Hood siphon spillway' or 'Hood siphon'.
- The top of the body wall forms the crest of the siphon spillway and hence it is located at full Reservoir level.
- The entrance and the exit lips of the hood are so shaped that siphon duct has bell mouthed entry and exit.
- The inlet of the siphon duct is kept submerged well below the full reservoir level so that floating debris etc., does not enter the siphon duct and also the formation of vortices and draw downs which might break the siphonic action is avoided.

Saddle Siphon spillway



Discharge through Saddle Siphon

- The usual siphon discharge formula is $Q = CA(2gH)^{0.5}$
- where A= Area of cross section at crown = L*b

L is the length of the throat and b is the height of the throat

H= Operating Head

= Reservoir Level - Center of outlet, if outlet is discharging freely.

= Reservoir Level -Down stream tail-water level, if outlet is submerged C= Coefficient of discharge, the average value may be taken as 0.65

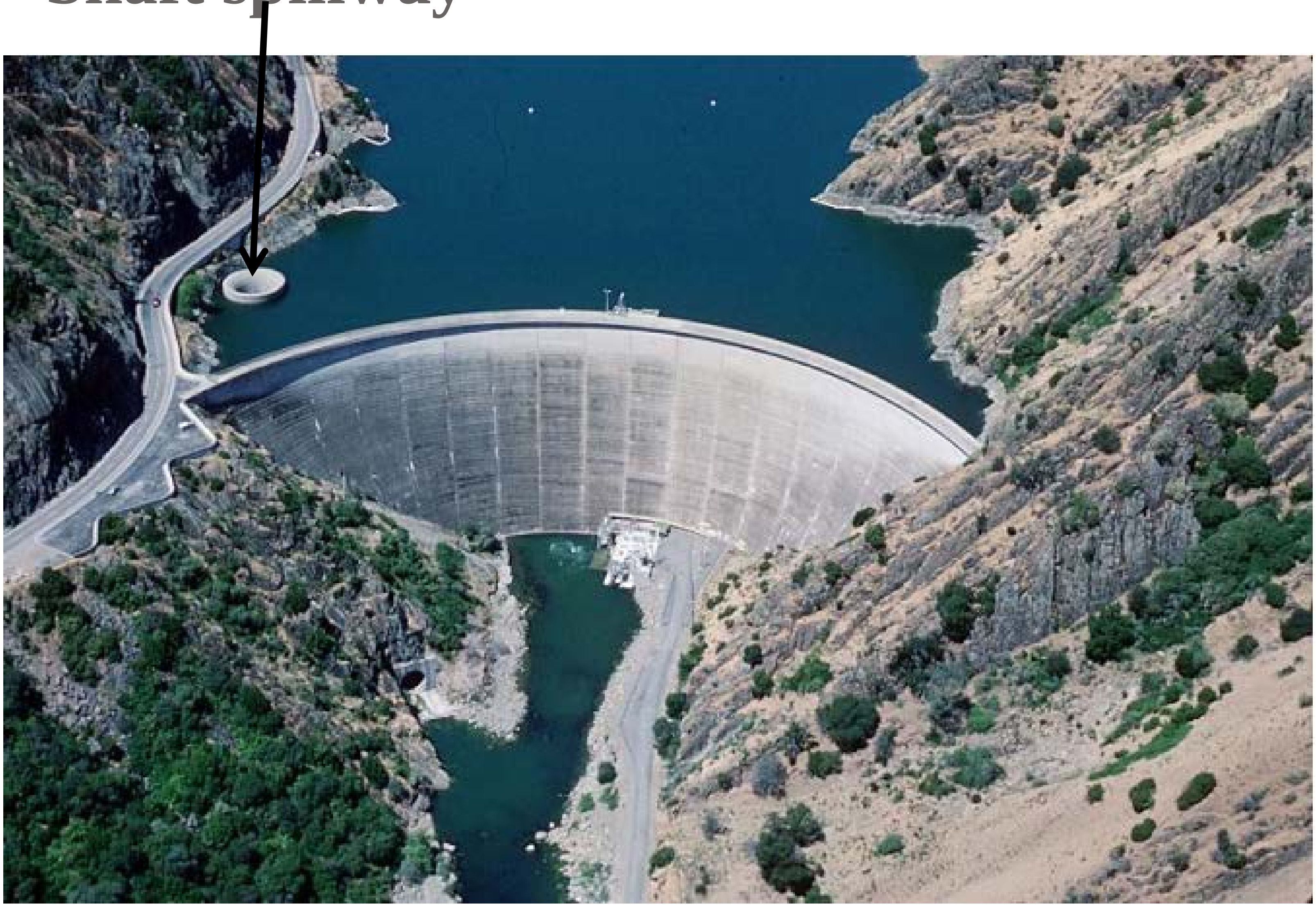
Shaft Spillway

- In shaft spillway water enters a horizontal crest, drops through a vertical or a sloping shaft and then flows to the down stream river channel through a horizontal or nearly horizontal conduit
- A rock out crop projecting into the reservoir slightly upstream of the dam would be an ideal site for a shaft spillway.
- Depending on the level of out crop and the required crest level, a spillway may have to be either constructed or excavated.

E:\Old Laptop\Hydraulic Structures-a\Hydraulic structure II class presentation\spillway types\The Morning glory or shaft spillway - Harriman Dam Spillway.flv

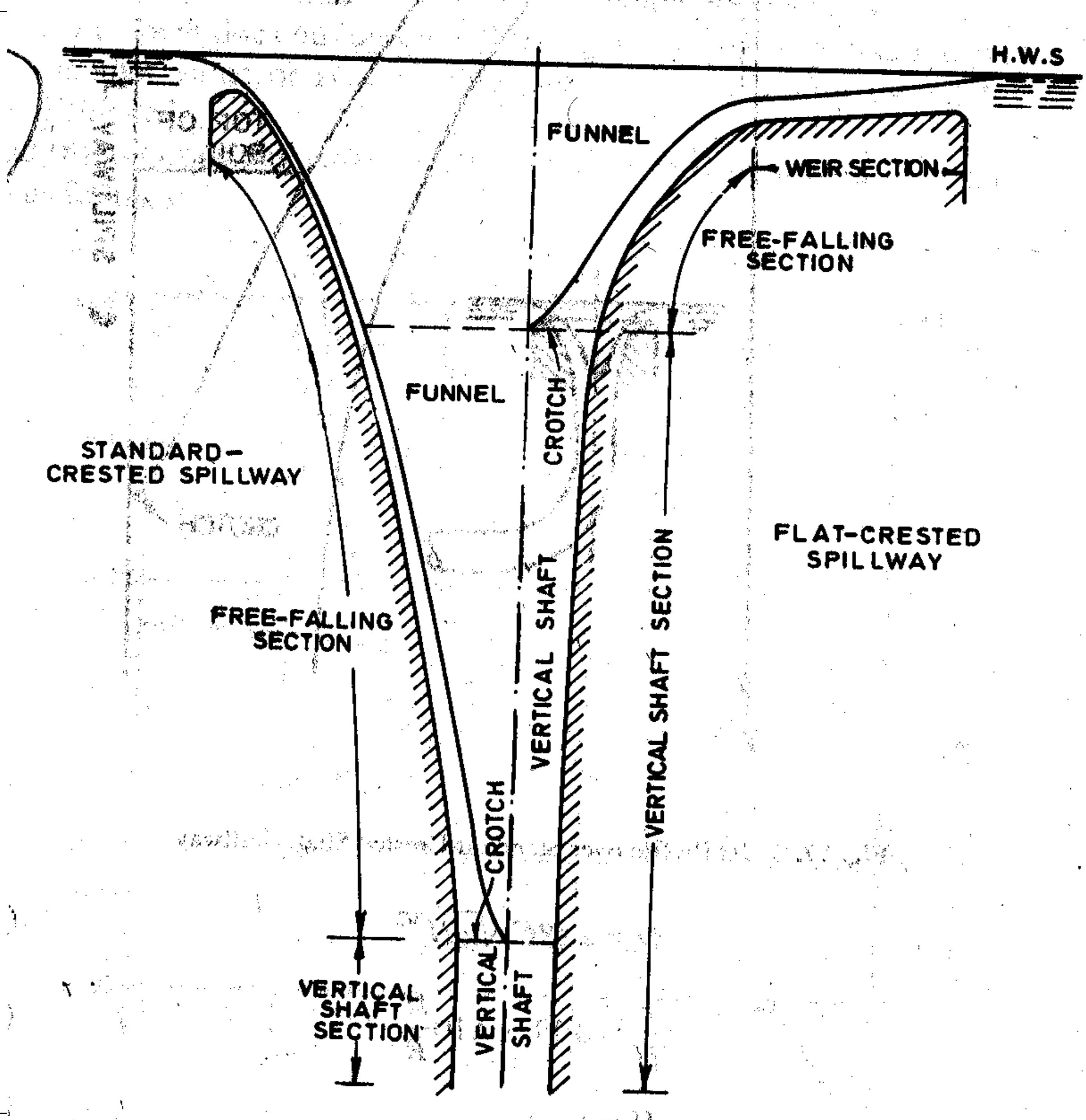
- Radial piers provided on the spillway crest ensures radial flow towards spillway and also provides support to the bridge connecting spillway and the dam or the adjoining hill.

Shaft spillway

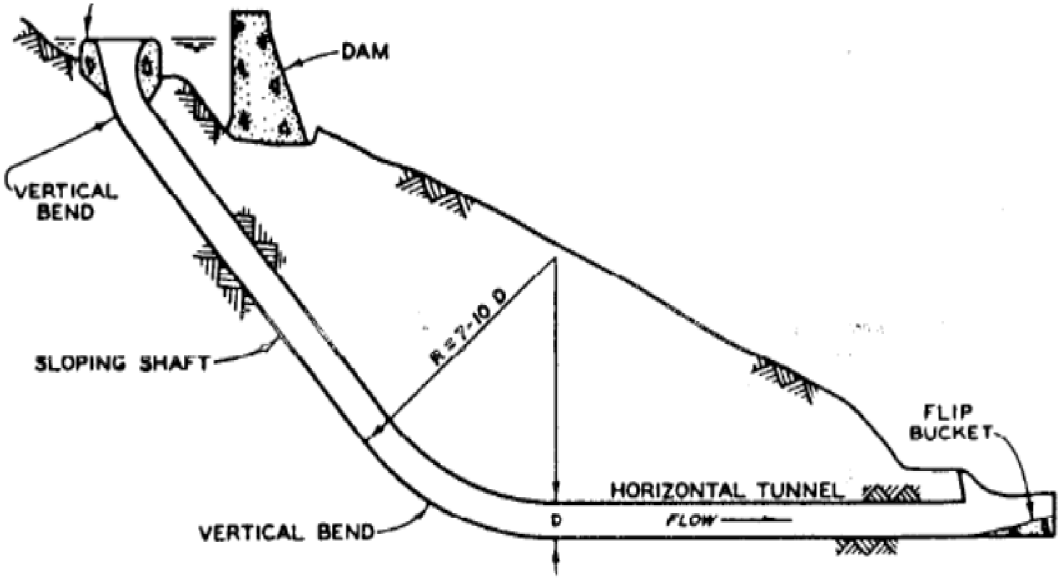


Shaft spillway

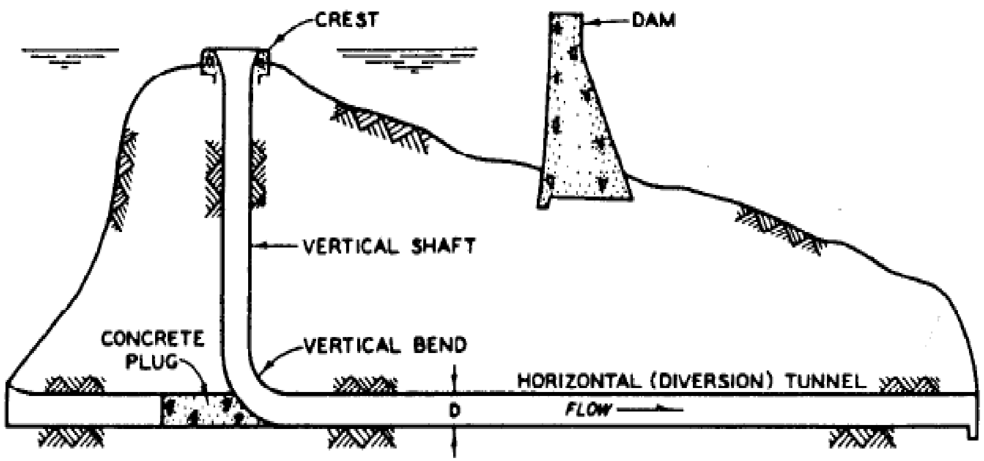
- A shaft spillway with a funnel shaped inlet is called '**Morning Glory**' or **Glory Hole** spillway.
- One of the distinguishing characteristics is that maximum capacity of the spillway is attained at relatively low heads.
- Therefore , a shaft spillway is ideal when maximum spillway discharge is not likely to be exceeded.
- Because of this feature, however, the spillway becomes unsuitable when a flow larger than the selected inflow design flood occurs.
- This disadvantage can be got rid of by providing an auxiliary or emergency spillway and using the shaft spillway as service spillway.


H.W.S
FUNNEL
WEIR SECTION
FREE-FALLING SECTION
FUNNEL
CROTCH
STANDARD-CRESTED SPILLWAY
FLAT-CRESTED SPILLWAY
VERTICAL SHAFT
VERTICAL SHAFT SECTION
FREE-FALLING SECTION
CROTCH
VERTICAL SHAFT SECTION
VERTICAL SHAFT

Shaft Spillway



SLOPING SHAFT SPILLWAY



VERTICAL SHAFT SPILLWAY

The End

Design of Ogee Spillway

General

- The ogee or overflow spillway is the most common type of spillway.
- They are mostly suitable for concrete gravity dam where the spillway is located on main dam body.
- It has a control weir that is ogee or S-shaped.
- The structure divides naturally into three zones
  - The crest,
  - The rear slope,
  - The toe
- Because of its high discharge efficiency, the nappe-shaped profile is used for most spillway control crests.

The spillway crest profile

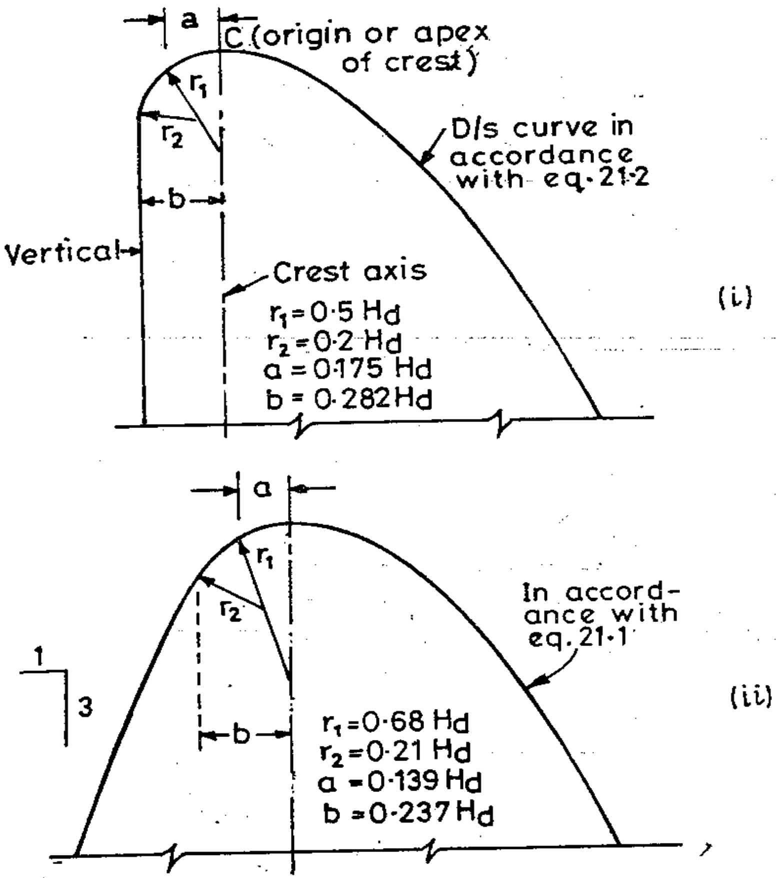
- The shape of an ogee profile depends upon;
  - The head,
  - The inclination of the upstream face of the overflow section,
  - The height of that section above the floor of the entrance channel
- The ogee profile should provide maximum possible hydraulic efficiency, structural stability and economy.
- The portion upstream of the origin is defined as a compound circular arc where as the portion downstream is defined by the equation:

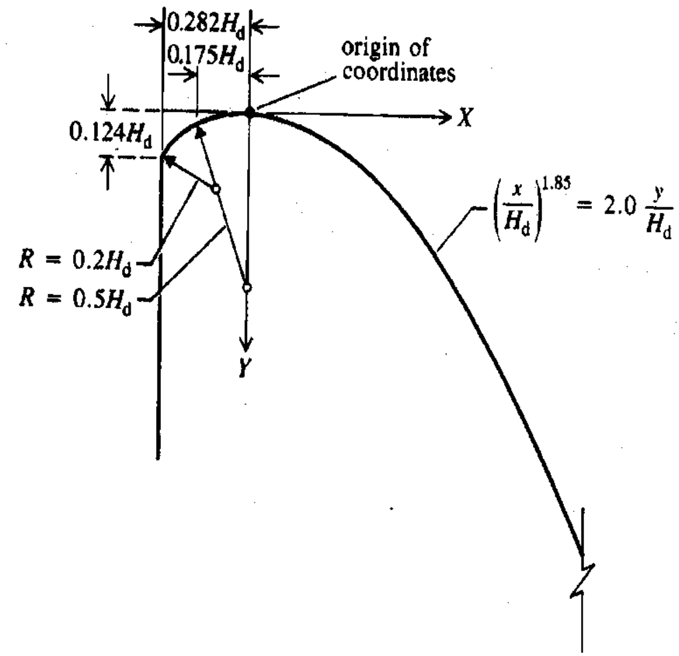
$$x^n = K*(H_d)^{(1-n)}*y$$

Where

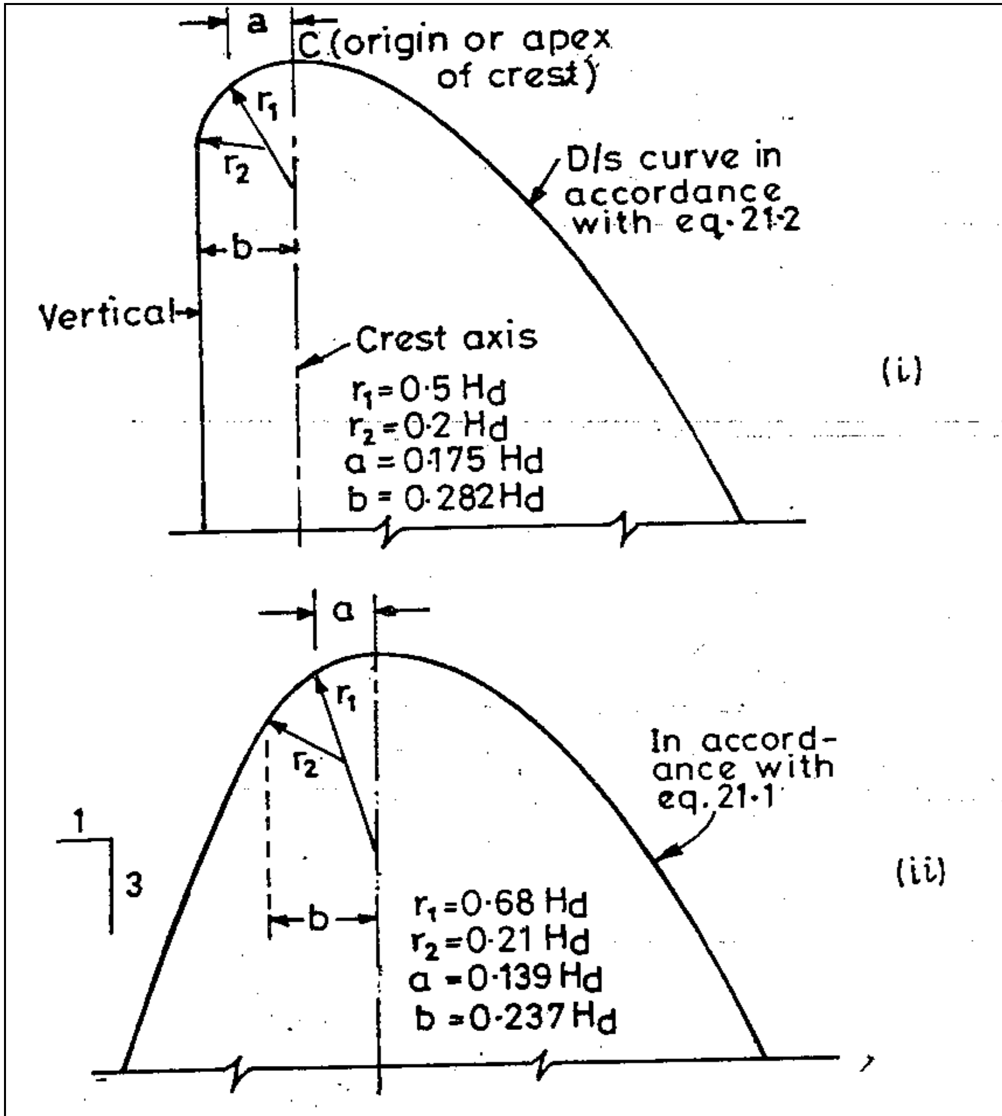
H_d=Design Head

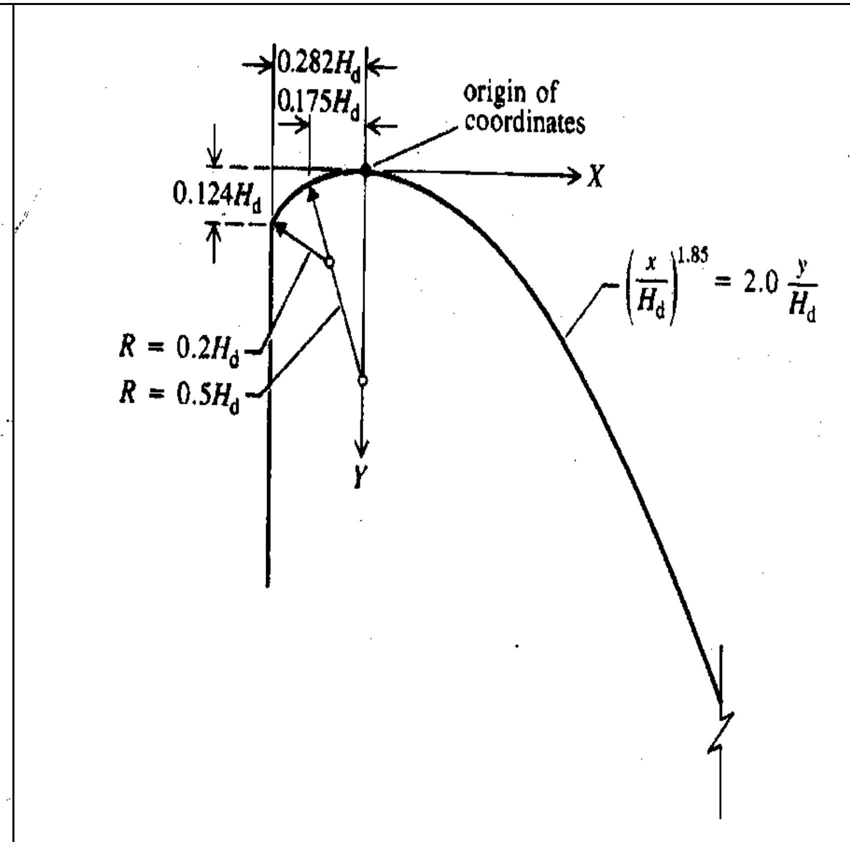
K and **n** are constants whose values depends on u/s inclination and velocity of approach.



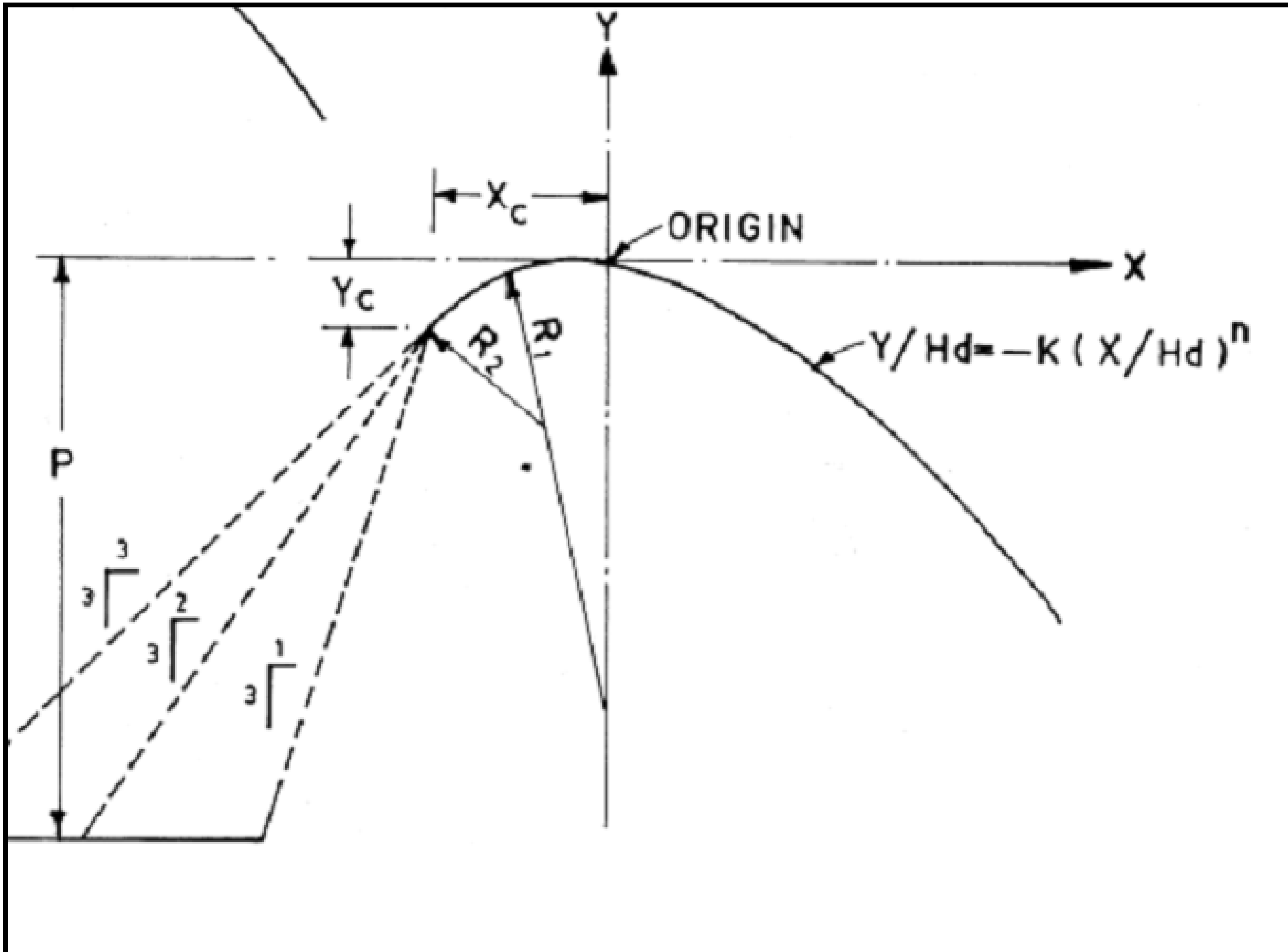


Profile of ogee spillway

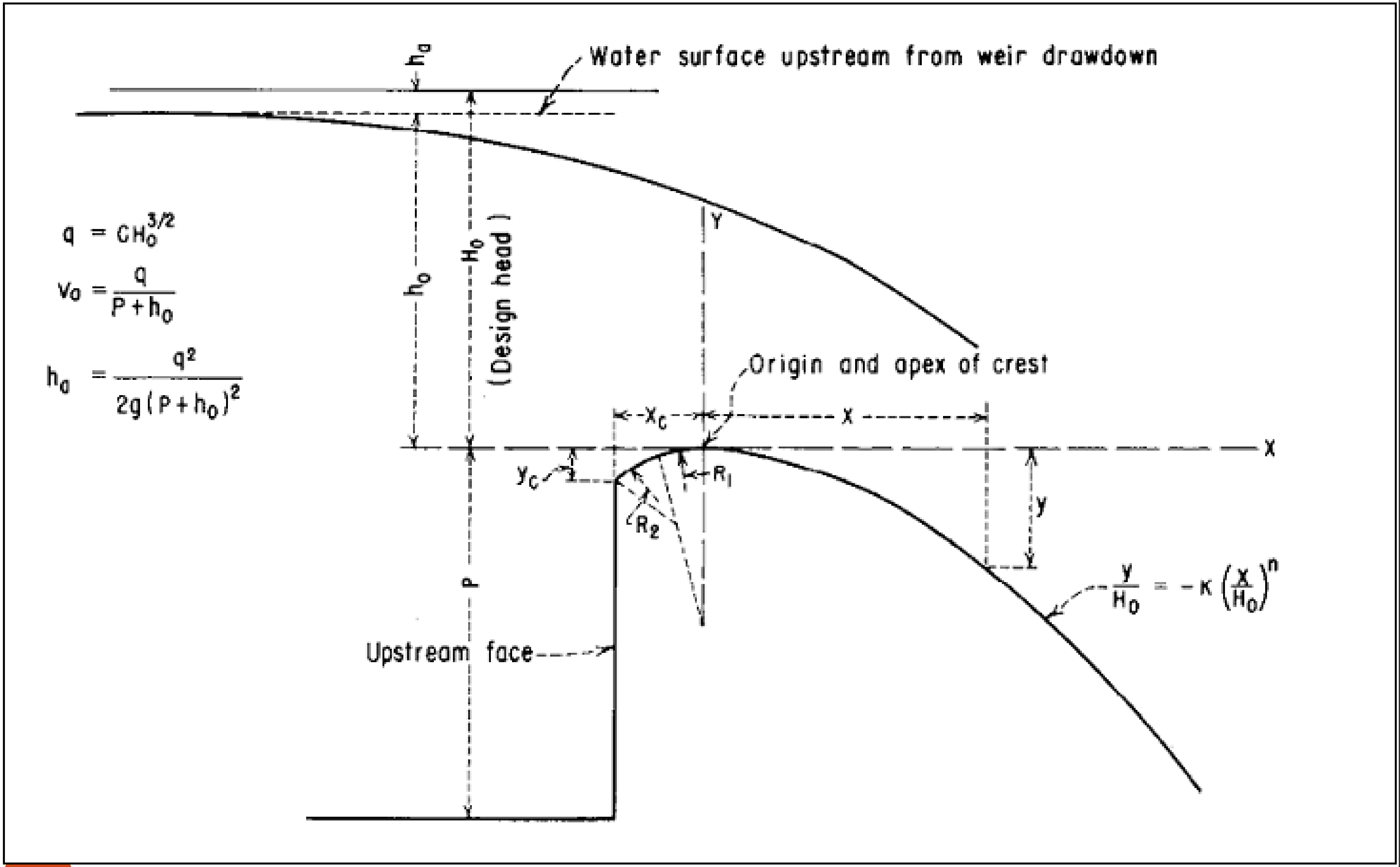




Typical profile of ogee spillway



Elements nappe shaped crest



- There is no simple universal procedure for design of overflow spillway crests (Murphy-WES). Also, there were different sets of rules depending on the inclination of the upstream face of the spillway. (WES-Waterways Experimental Station).
- Comparing the three profiles (USBR, WES-original and WES-elliptical) we can approximate the u/s profiles of an ogee spillway as shown on the table below.
- The profiles are shown for low ogee crests (p=5m and H_d=10m) and high ogee crests (p=40 and H_d=10m)

u/s profile comparison

Table 1 Comparison of Spillway Crest Profiles

Case I	Low Ogee Crests: $P=5m$, $H_d=10m$, $P/H_d=0.5$											
U/S Face	USBR				WES (Original)				WES (Elliptical)			
	X_c	Y_c	K	n	X_c	Y_c	K	n	X_c	Y_c	K	n
Vertical	2.595	0.968	0.511	1.835		not defined			2.683	1.572	0.488	1.85
1:3	2.465	0.836	0.511	1.815		not defined			2.633	1.271	0.488	1.85
2:3	2.282	0.628	0.51	1.764		not defined			2.498	1.0	0.488	1.85
3:3	2.139	0.463	0.51	1.748	2.135	0.445	0.524	1.748	2.314	0.777	0.488	1.85
Case II	High Overflow Spillways: $P=40m, Hd=10m$, $P/Hd = 4$											
Vertical	2.817	1.242	0.5	1.868	2.818	1.36	0.5	1.85	2.800	1.64	0.5	1.85
1:3	2.474	0.91	0.5	1.848	2.57	0.875	0.516	1.836	2.748	1.326	0.5	1.85
2:3	2.161	0.667	0.53	1.795	2.14	0.75	0.516	1.810	2.608	1.043	0.5	1.85
3:3	2.019	0.454	0.54	1.776	2.0	0.454	0.54	1.776	2.416	0.811	0.5	1.85

- **Although the three profile estimation have their own application, they are derivated from USBR.**

Discharge Characteristics of ogee profile

- Discharge over a spillway can be calculated by;

$$Q = C_d \cdot \frac{2}{3} \cdot b \cdot \sqrt{\left(2gH^3\right)}$$

Where

C_d=Coefficient of discharge

b= spillway opening

- Although the value of C_d depends on many factors, its standard value is 2.2.
- If normal operating head (H_o) and Design head (H_d) are considered

$$C_d = \frac{2}{3\sqrt{3}}\left[1 + \frac{4\chi}{9+5\chi}\right]$$

Where $x = H_o/H_d$

Factors Affecting Coefficient of Discharge

- The coefficient is influenced by a number of factors such as:
- The depth and alignment of approach
- The inclination of the upstream face
- The contraction caused by the crest piers and abutment
- The submergence of the crest due to downstream water level
- According to WES, crest piers and abutments cause contraction of flow and reduction in effective length of crest which subsequently reduce discharge.

$$L' = L - 2(NK_p + K_a)H_e$$

Where

L = Total length of crest for calculating discharge

L′= Net length of crest

N = Number of piers

K_p= Pier contraction coefficient

K_a= Abutment contraction coefficient

He= Total head on crest (maximum operating head)

- Average pier contraction coefficients can be taken as follows:

-For square-nosed piers with rounded corners 0.02

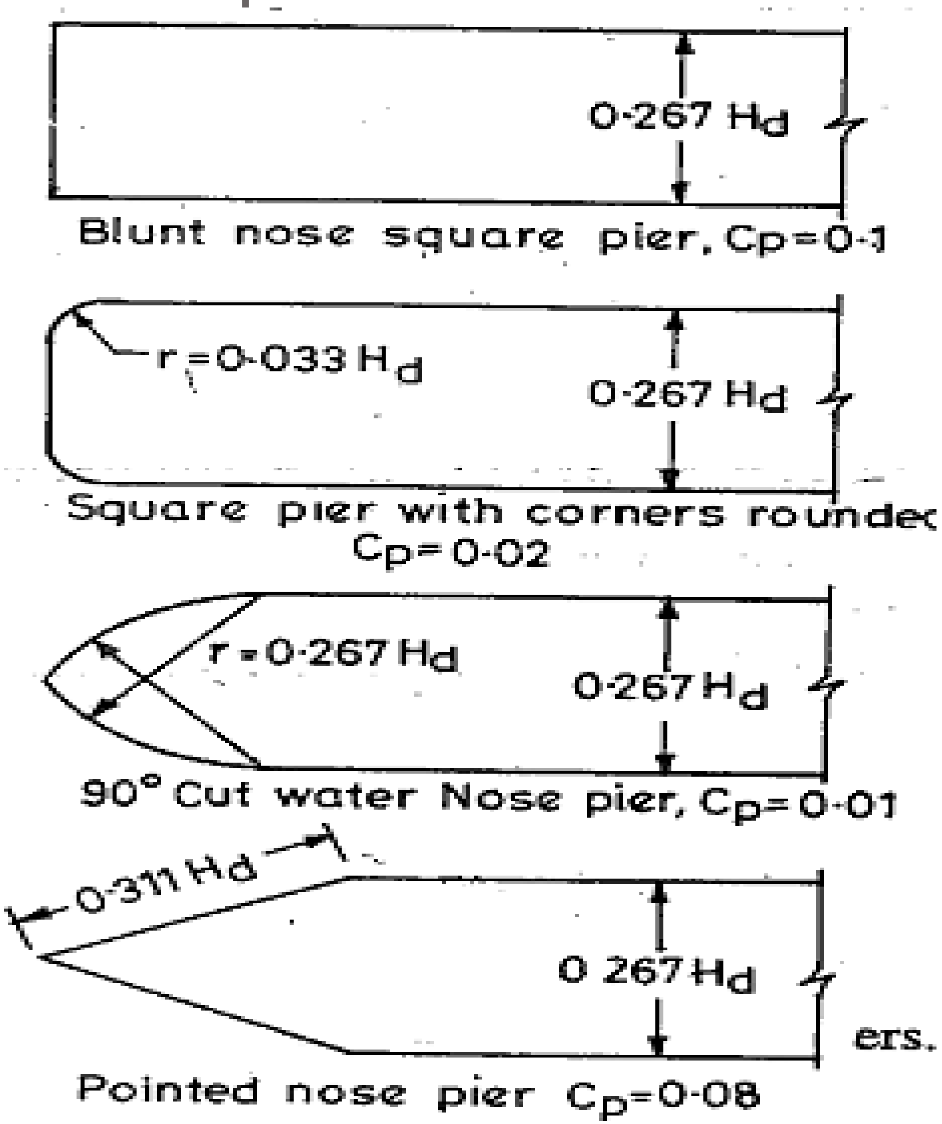
-For round-nosed piers 0.02

-For pointed-nose piers 0

Crest Piers

- Crest piers are required when gates are to be installed to control the flow passing down the spillway.
- Piers may still be required for an **un-gated** spillway for a road bridge.
- The most common shape of the pier includes a semi-circular upstream end kept flush with the upstream face of crest.
- Piers projecting upstream of the spillway face may be required from structural considerations and have smaller contraction coefficients.

Pier shapes

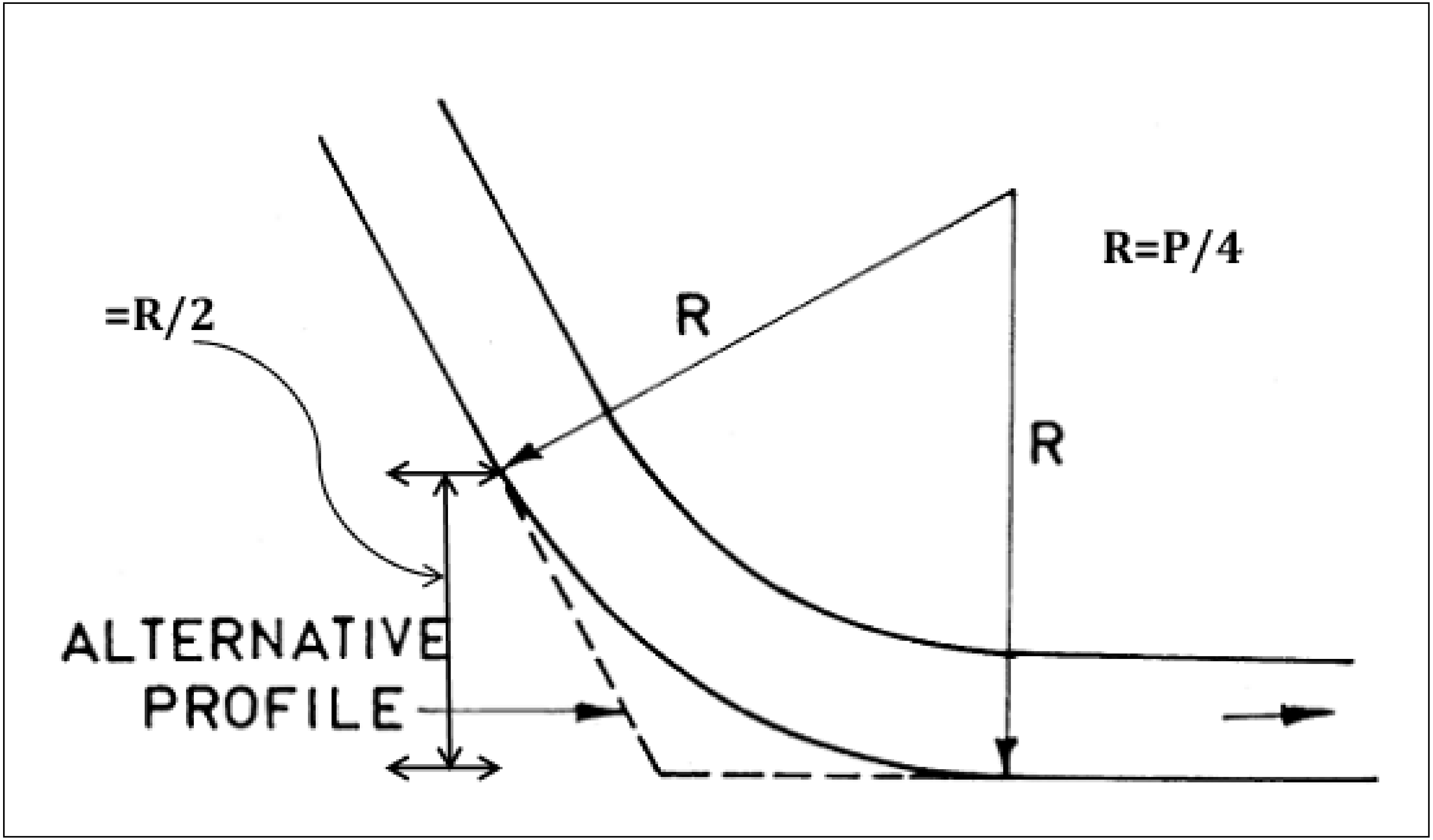


0·267 Hd
Blunt nose square pier, Cp=0·1
r =0·033 Hd
0·267 Hd
Square pier with corners roundec
Cp= 0·02
r =0·267 Hd
0·267 Hd
90° Cut water Nose pier, Cp= 0·01
0·311 Hd
0 267 Hd
ers.
Pointed nose pier Cp=0·08

Spillway Toe

- The spillway toe is the junction between the discharge channel and the energy dissipater.
- Its function is to guide the flow passing down the spillway and smoothly in the energy dissipater.
- A toe curve is made up of a circular arc, tangential to both the rear slope and the apron.
- A minimum radius of 3 times the depth of flow entering the toe is recommended. Or P/4, where P is the height up to spillway crest level.

Profile of bucket



Design of Chute and side channel spillway

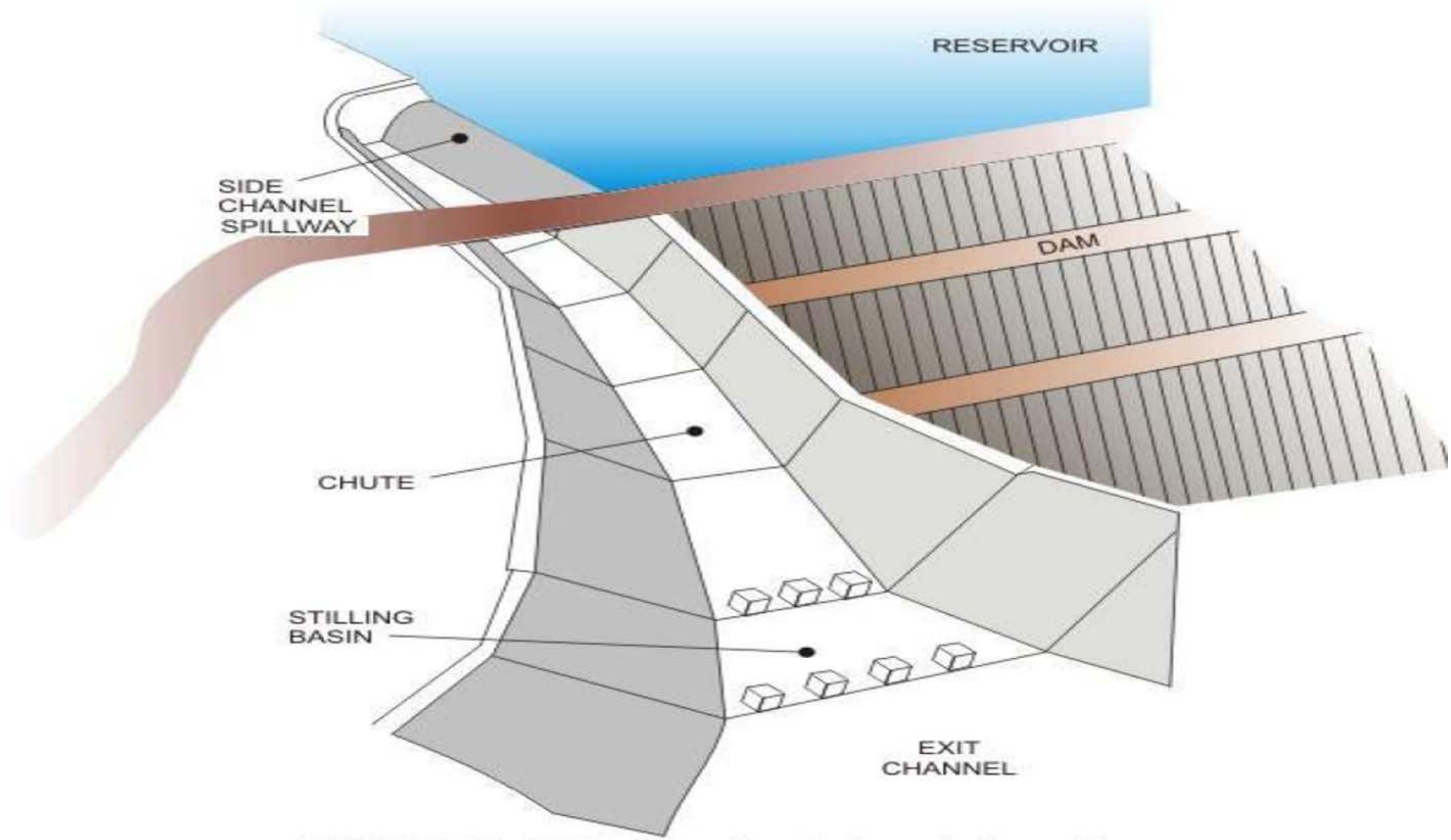


FIGURE 10. Side channel entry to a chute spillway

General

- Unlike to concrete gravity dam, spillway of an embankment dam is separated from the main dam body.
- Whenever possible, spillways are located in the main gorge of a river as this has an inherent advantage of confining flood flows within the banks of a river.
- Constructing a spillway at any place other than the main gorge involves considering the *topography* and *geology* of the site.
- Topography may favor a spillway located in a *saddle* away from the main dam with the flow from the spillway led to the main river in the downstream.
- In a chute spillway, the discharge passing down the crest is conveyed to the river downstream, with the flow taking place in a direction almost normal to the width of the spillway.

Continued

- In a side channel spillway, the crest structure is placed along the side of, and approximately parallel to, the upper portion of the spillway discharge channel.
- Flow over the crest falls into a narrow trough opposite the crest, turns approximately at a right angle, and then continues into the main discharge channel.
- Except for the control structure and the portion immediately downstream, the design of other elements such as approach channel, chute, energy dissipater, etc. is identical in both the cases (SCS & CS).

Principal Elements

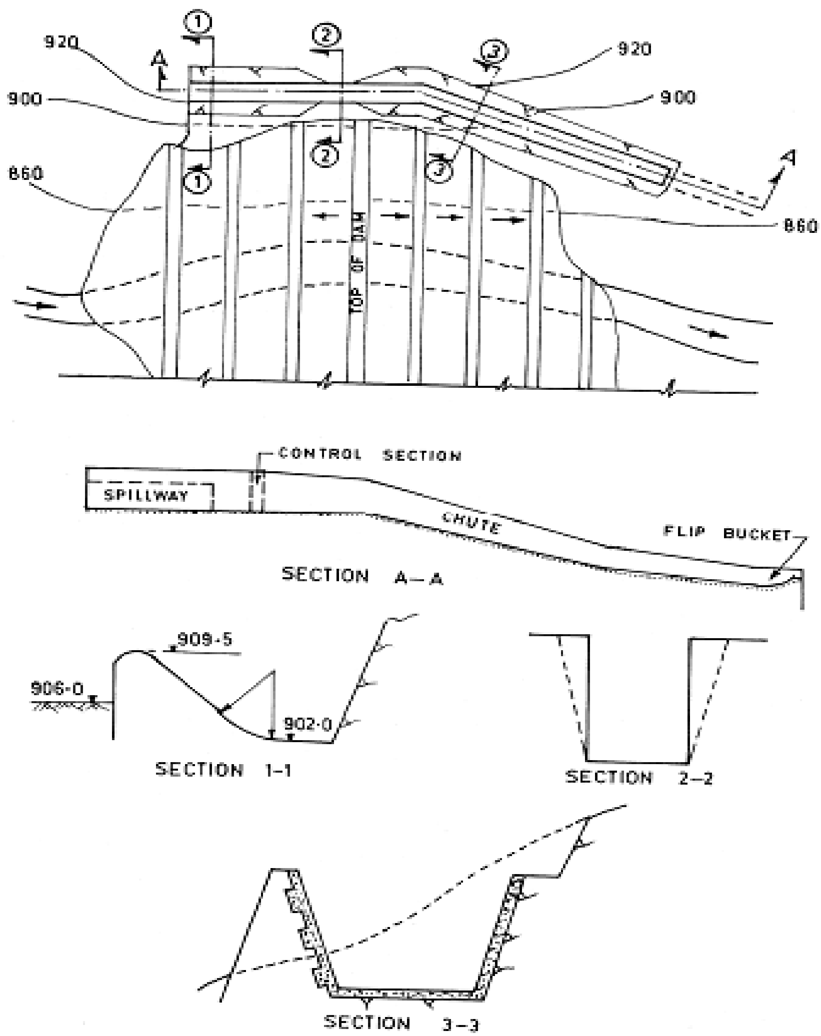
- A chute or side channel spillway generally consists of an approach channel, a flow control structure, a discharge channel or chute, energy dissipater, and a tail channel.
- Since the spillway is located on the flanks, which are at higher levels than the gorge, it becomes necessary to lead the water from the reservoir by means of an open channel called an approach channel.
- The energy dissipaters placed on the chute or side channel spillway are usually designed as a stilling basin, flip bucket or roller bucket, etc.

Approach Channel

- The approach channel is an artificial channel leading the flow from the reservoir to the spillway.
- Since chute spillways are located in the flanks it becomes necessary to create a flow passage from the reservoir to the spillway structure.
- There are two main hydraulic considerations in the design of approach channel.
- First, the length and layout of the channel should be such as to result in minimum loss of head.
- Secondly, the flow approaching the spillway should be distributed as uniformly as possible.

Continued

- A straight alignment of the approach channel would result in nearly *uniform distribution* of discharge over the spillway.



Typical cross section of side channel spillway

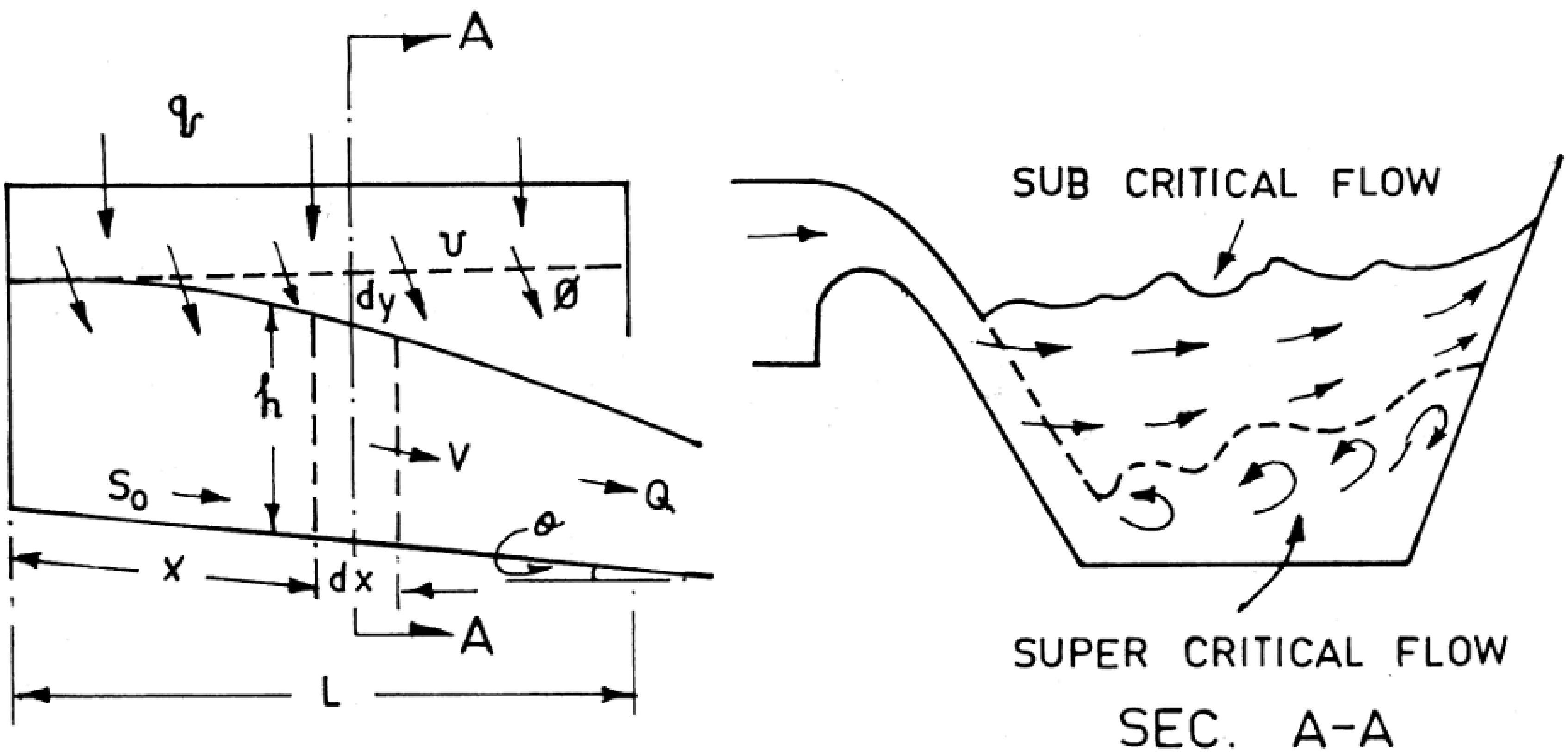
Spillway Structure in SCS and CS

- In both types of spillways, the structures consist of a standard ogee shaped crest, although unconventional shapes of crest have been used in special conditions.
- The crest structure in chute spillways is generally low in height to take advantage of the higher ground levels on the flank.
- Side channel spillways may have *straight*, *L-shaped*, or *U-shaped* layouts in plan.

Side Channel Spillway-Trough and Control Section

- A side channel spillway combines an overflow section with a channel parallel to it, which carries the spillway discharge away to a chute or a tunnel.
- The simplest form of analysis of side channel spillway is based on the law of **conservation of linear momentum**, assuming that the only force producing motion in the channel results from the fall of water surface in the direction of spillway axis.
- Analysis of side channel spillway may be estimated from the following figure.

Analysis of flow in a trough



Flow in SC

- Referring to the above figure, the differential equation of the flow profile ignoring channel friction is given by;

$$\frac{dy}{dx} = \frac{1}{g}\left(V\frac{dV}{dx} + \frac{V^2}{x} \right) \longrightarrow \text{Equation A}$$

Where

d_y =Fall in the water surface along the channel length d_x

V = Average velocity at the cross-section under consideration.

x = Distance measured along the channel from upstream end.

Flow in SC

- Since the discharge increases linearly with the distance, the velocity can also be assumed to vary with x in some arbitrary manner. An exponential type of relationship can be assumed as:
- From which;

$$V = a\,x^n$$

From equation above, by substituting we get,

$$\frac{dV}{dx} = nax^{n-1} = \frac{nV}{x}$$

The value of **n** and **a** are selected arbitrarily. But n can be assumed as ½. Because when n=1/2, the profile is linear.

$$y = \frac{a^2(n+1)}{g(2n)}x^{2n}. \quad y = \left(\frac{n+1}{n}\right)\left(\frac{V^2}{2g}\right)...$$

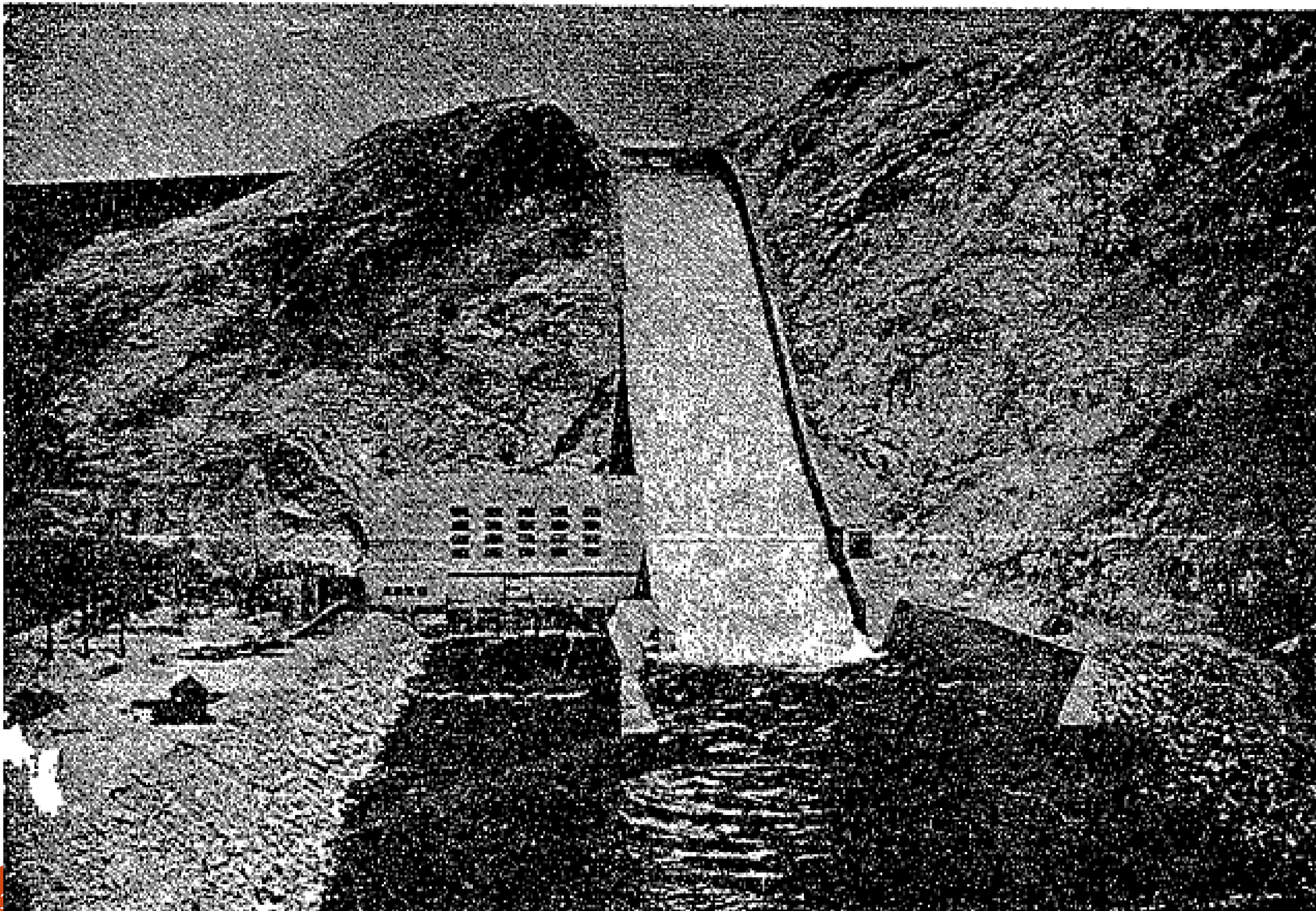
Chute

- A discharge channel downstream of the control structure, known as a chute, may be straight or curved with sides parallel, converging, or diverging.
- It may be either rectangular or trapezoidal in cross-section and may have either a constant or a variable bottom width.
- If it is constructed as a continuation of the dam at one end, it is called *flank weir*.
- Discharge channel dimensions are governed primarily by hydraulic requirements but the selection of profile, cross-sectional shapes, widths, and lengths is influenced by geological and topographical features at the site.

Chute

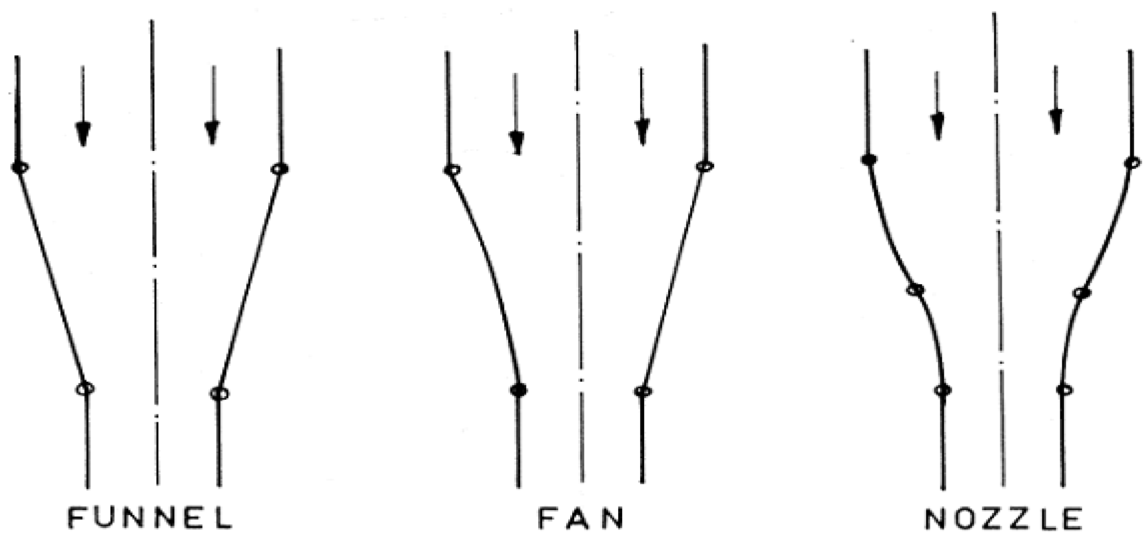
- Since the flow in the chute is always supercritical, it is advisable to have a straight alignment without transitions such as contraction, expansion, or curvature.

Chute spillway



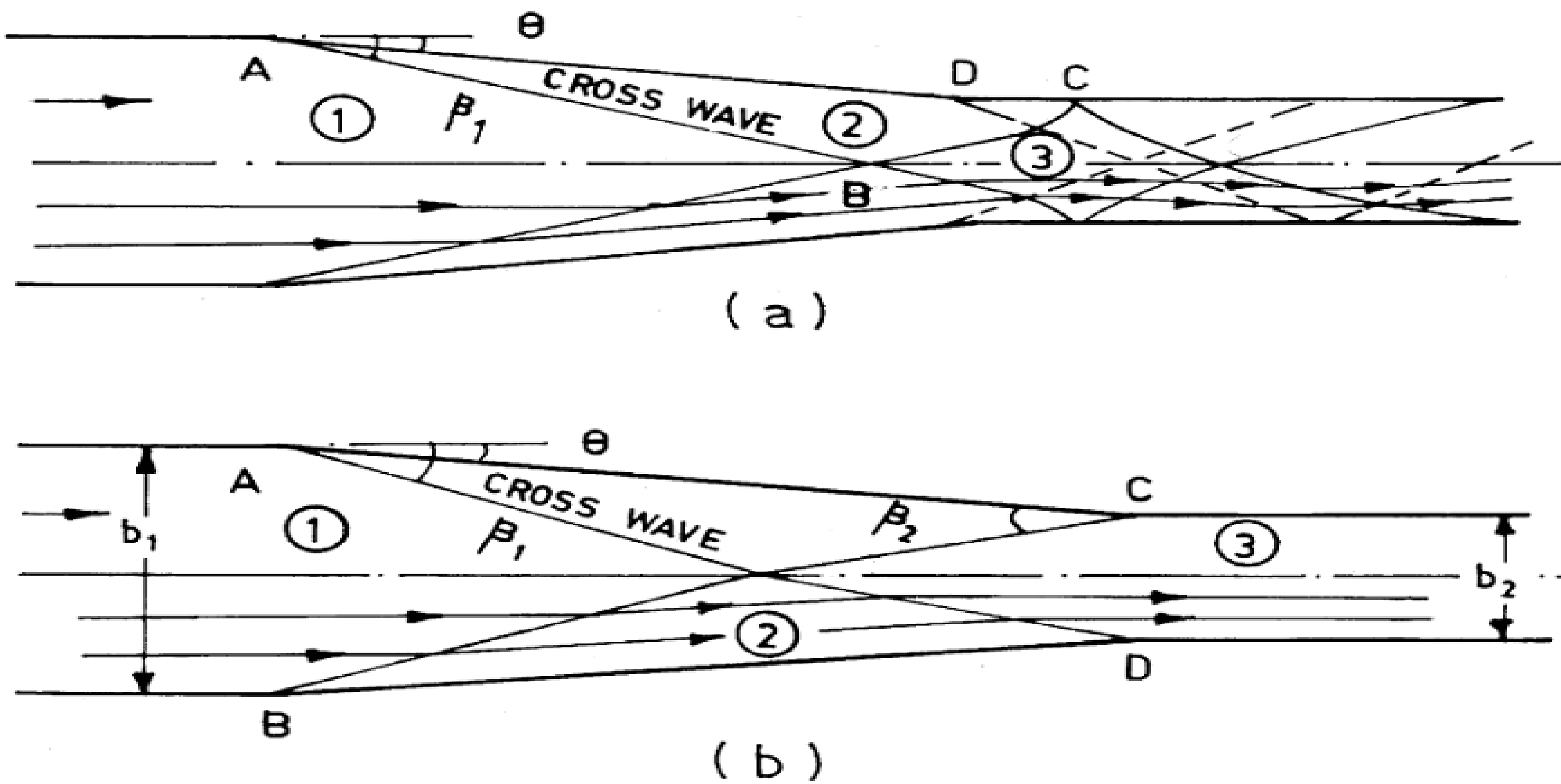
Contraction of chute

- Contracting the width of a chute immediately downstream of the chute spillway is not recommended since the flow from the end spans will be obstructed by the converging walls and will create unacceptable flow conditions.
- Three types of contractions are used: funnel, fan, and nozzle.



Funnel Type Contraction

- The simplest, most effective, widely used contraction is the funnel type, consisting of straight-lined contracting walls.



Expansion of chute

- For flows emerging from a closed conduit, spillway or steep chute, a downstream channel with a larger width may often be desired.
- If the transition from the narrow channel to the wide channel is abrupt, large cross-waves may occur.
- If the transition is too gradual, a longer and, consequently uneconomic design results.

Side walls of a chute

- The side walls of a chute spillway should be designed in such away that the height should not spill water over them.
- Sufficient free board must be provided above the top water nappe as given below;

$$\text{Freeboard} = 0.61 + 0.04 V_m \cdot d_m^{1/3}$$

V_m=mean velocity of water in the chute

d_m=mean depth of water in the chute

- The side walls may be kept vertical or inclined. But in most cases the rectangular cross section is preferred.

Selection of spillways

- Selection of a particular type of spillway depends on many factors such as;

1. ***Safety Considerations Consistent with Economy***: In selecting a type of spillway for a dam, economy in **cost** should not be the only criterion. The cost of spillway must be weighed in the light of safety required below the dam.
2. ***Hydrological and Site Conditions:***

The type of spillway to be chosen shall depend on

a) Inflow flood;

b) Availability of tail channel, its capacity and flow hydraulics;

c) Power house, tail race and other structures downstream; and

d) Topography

Spillway selection continued

3. *Type of Dam*

- For earth and rock fill dams, chute and ogee spillways are commonly provided, whereas for an arch dam a free fall or morning glory or chute or tunnel spillway is more appropriate. Gravity dams are mostly provided with **ogee spillways**.

4. ***Purpose of Dam and Operating Conditions***
5. ***Conditions Downstream of a Dam***

Selection of specific spillway

a) Ogee spillway

- It is most commonly used with gravity dams. However, it is also used with earth and rock fill dams with a separate gravity/concrete structure.
- It has got the advantage over other spillways for its high discharging efficiency.

b) Chute spillway

i) It can be provided on any type of foundation

ii) It is commonly used with the earth and rock-fill dams

Selection of specific spillway cont…

Side channel spillway

- It is useful where the abutments are steep, and it is useful
- where the control is desired by the narrow side channel.

Morning glory spillway

- This can be adopted very advantageously in dam sites in narrow canyons, and
- Minimum discharging capacity is attained at relatively low heads

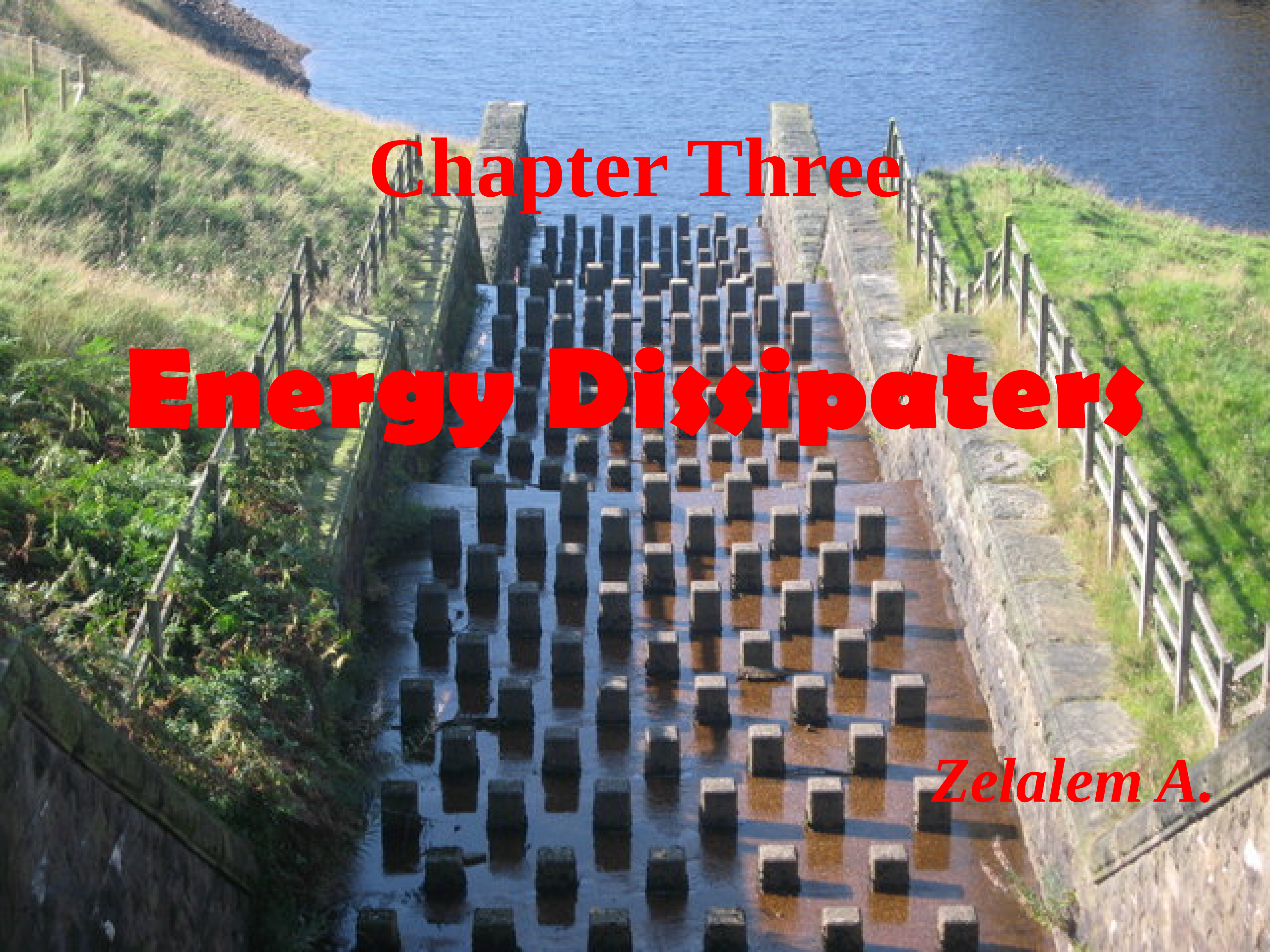
Over-fall or Free Fall Spillway

- This is suitable for arch dams or dams with downstream vertical faces; and this is suitable for small drops and for passing any occasional flood.

Continued

Tunnel or Conduit Spillway

- This type is generally suitable for dams in narrow valleys, where overflow spillways cannot be located without risk and good sites are not available for a saddle spillway.



Chapter Three

Energy Dissipaters

Zelalem A.

Energy Dissipation

✓ The water flowing over the spillway acquires a lot of kinetic energy by the time it reaches near the toe of the spillway due to the conversion of potential energy into kinetic energy.

✓ If the velocity of the water is not reduced, large-scale scour can take place on the downstream side near the toe of the dam and away from it.

✓ For the dissipation of the excessive kinetic energy possessed by the water, the two common methods adopted are:

➢ By converting the supercritical flow into subcritical flow by hydraulic jump.

➢ By using different types of buckets, i.e. by directing the flow of water into air and then making it falls away from the toe of the structure.

Jump Height and Tail water Rating Curves

✓Hydraulic jump can form in a horizontal rectangular channel when the following relation is satisfied between the pre-jump depth (y_1) and post – jump depth (y_2).

$$y_2 = \frac{y_1}{2}\left[-1+\sqrt{1+8\,F_r^{\,2}}\right]$$

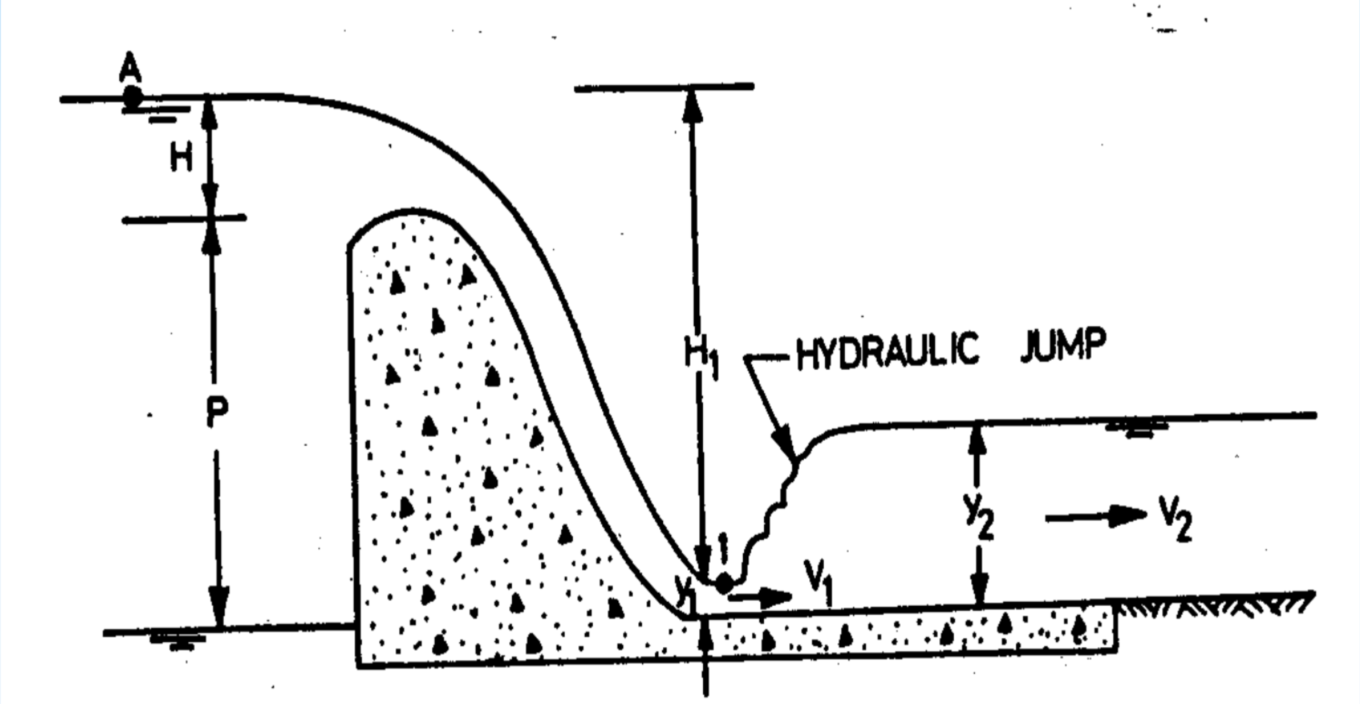
Where y_1 = pre-jump (initial) depth

y_2 = post- jump (sequent) depth

F_{r1} = Froude number of the incoming flow

✓For a given discharge intensity q over a spillway, y1, will be equal to q/v1; and v1 (mean velocity of incoming flow) is determined by the drop H_1 , if head loss is neglected.

$$\left(V_1 = \sqrt{2gH_1}\right) \qquad Fr_1 = \frac{v}{\sqrt{g * y_1}}$$



✓ Hence, for a given discharge intensity and given height of spillway, y_1 is fixed and thus y_2 is also fixed

✓ The values of y_2' corresponding to different values of q may be obtained by actual gauge discharge observations and plot of y_2' versus q prepared, known as Tail water Rating curve (T.W.R.C.).

✓ Plot of y_2 versus q may be made which is known as **jump height curve** (J.H.C.). If J.H.C. and T.W.R.C. are plotted on the same graph, five possibilities exist regarding the relative positions of these curves

I. T.W.R.C. ($y_{2'}$) coinciding with y_2 curve for all discharges

II. T.W.R.C. ($y_{2'}$) lying above the y_2 curve for all discharges

III. T.W.R.C. ($y_{2'}$) lying below the y_2 curve for all discharges

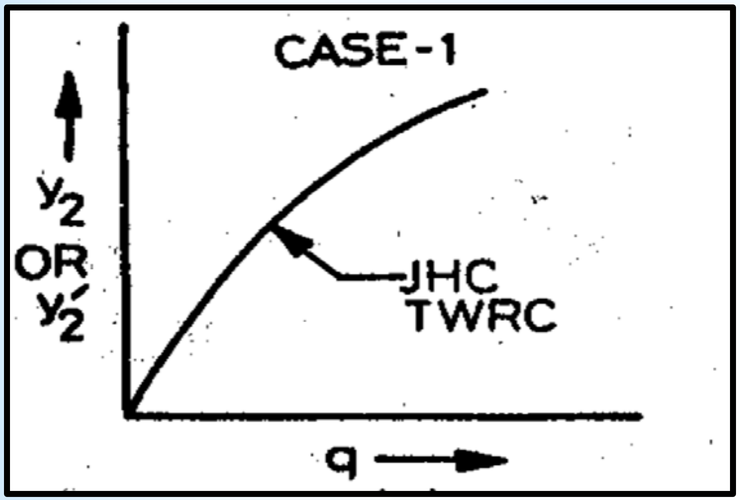
IV. T.W.R.C ($y_{2'}$) lying below the y_2 curve for smaller discharges and lying above y_2 curve for larger discharges

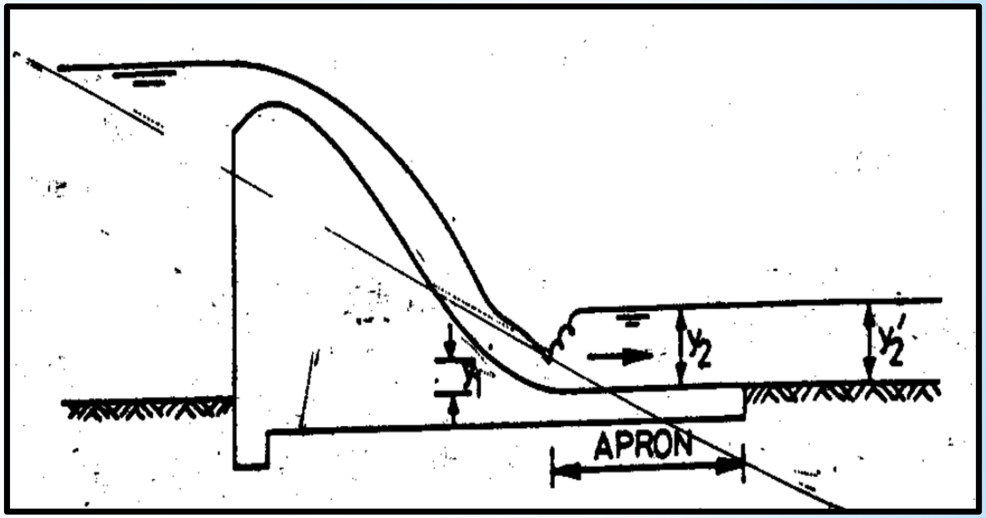
V. T.W.R.C. ($y_{2'}$) lying above the y_2 curve for smaller discharges and lying below the y_2 curve for larger discharges

➢ The energy dissipation arrangement that can be provided is dependent upon the relative positions of T.W.R.C. and y_2 curve.

Condition 1: (T.W.R.C. (y_2') coinciding with y_2 curve for all discharges)

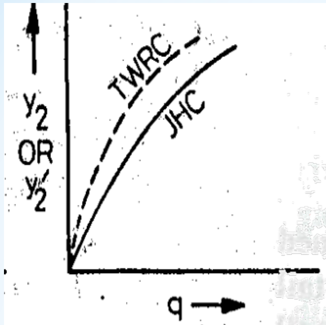
- In this case for the entire discharges jump will develop close to the toe of the spillway. Hence simple horizontal concrete apron may be provided
- Length is equal to the length of the jump corresponding to the maximum discharge over the spillway





Condition 2: (T.W.R.C. (y2') lying above the y2 curve for all discharges)

- The jump forming at toe will be drowned out by tail water, and little energy will be dissipated.
- Water may continue to flow at high velocity along the channel bottom for a considerable distance. The problem can be solved by constructing a sloping apron over the riverbed extending from the downstream surface of the spillway.



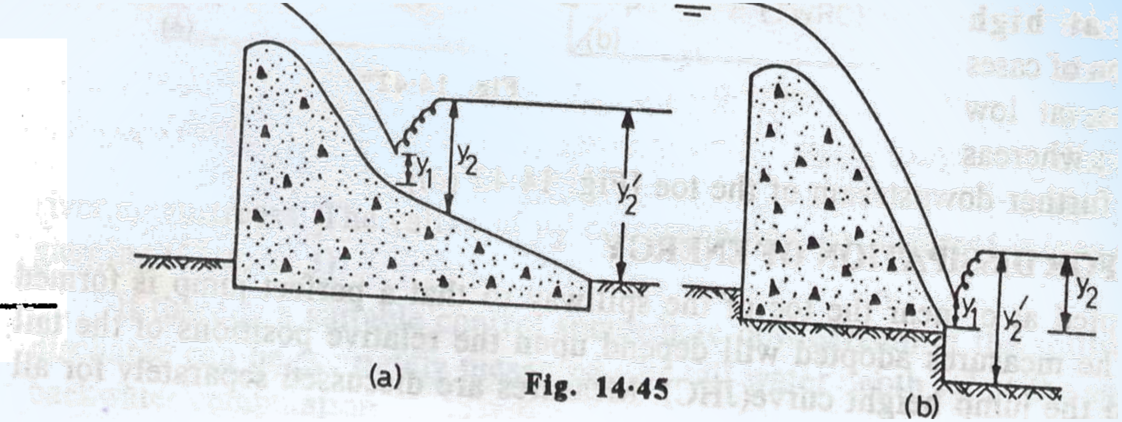
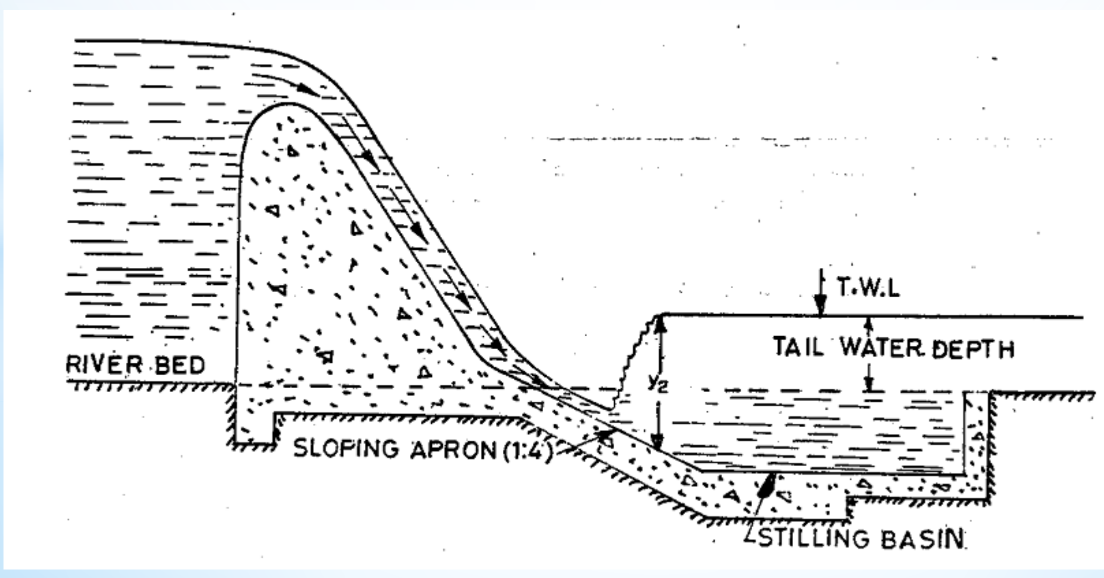


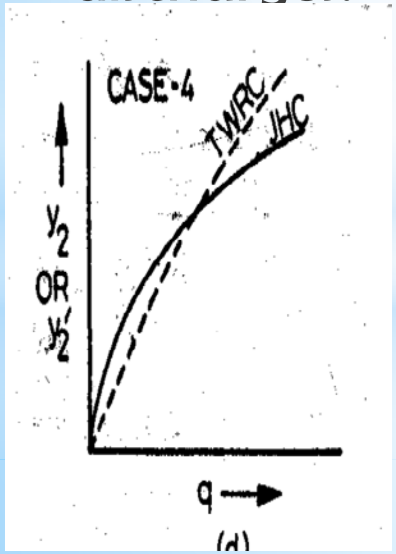
Fig. 14·45

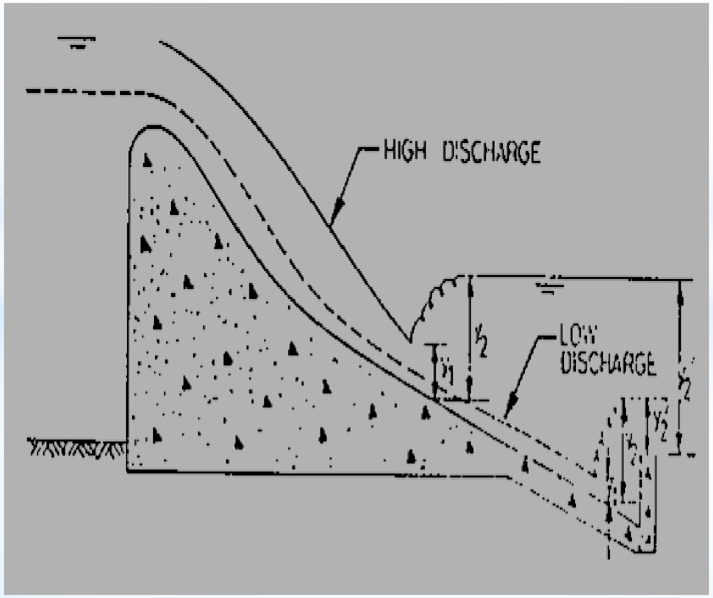
Condition 3: In this case the jump will develop at a certain section far downstream of the toe of the spillway. This is the **most frequent one**, and shows that a stilling basin (with a depressed horizontal apron) is required for all discharges in order to produce a jump close to the toe of the spillway.

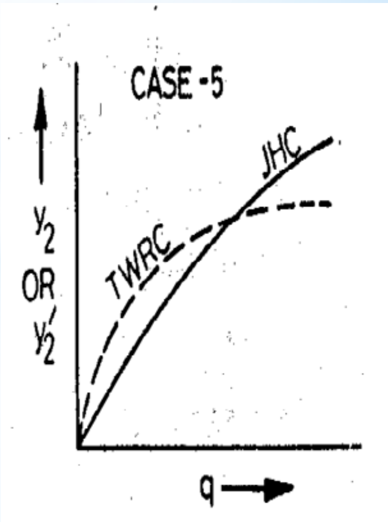


Condition 4: In this case the following measures may be taken to develop jump close to the spillway.

- Provide a stilling basin with an end sill for developing a jump at low discharges and combine the basin with a sloping apron for developing a jump at high discharges.
- Provide a sloping apron which lies partly above and partly below the riverbed so that jump will develop at lower portion of the apron at low discharges and at higher portion of the apron at high discharges.







Stilling Basin

- A stilling basin consists of a short, level apron at the foot of the spillway
- The function of the basin is to decelerate the flow sufficiently to ensure the formation of a hydraulic jump within the basin.

Hydraulic Jump Stilling Basin

- The energy dissipation process may occur in the following stages, all of which may be combined.
- ✓ On the spillway surface
- ✓ In the stilling basin
- ✓ At the outflow into the river

- The stilling basin is the **most** common form of energy dissipater
- Convert the supercritical energy to subcritical form of energy at the d/s river regime.
- It's principle of working is simple hydraulic jump
- Standard basins were developed with chute blocks, baffles, and special end sills by USBR.

U.S.B.R. Stilling Basins

1. *stilling basins for Froude's number between 1.7 and 2.5 (Type I).*

- ✓ For this case only a horizontal apron needs to be provided.
- ✓ As the flow in this case does not have much turbulence usually no accessories are required to be provided.
- ✓ However, the apron should be sufficiently long to contain the entire jump over it.
- ✓ Length of apron = Length of jump = 5 -6*Y2- where Y_2 is the sequent depth (jump height).

2. *Stilling basins for Froude's number between 2.5 and 4.5 (Type IV)*

- For this range of Froude number **Type IV** stilling basin has been found to be effective for dissipating the energy of flow.
- The basin is provided with chute blocks and an end sill (optional).
- The length L of the stilling basin may be obtained for different values of F_1 from the following table:

F_1	2	3	4	5
L/Y_2	4.3	5.3	5.8	6

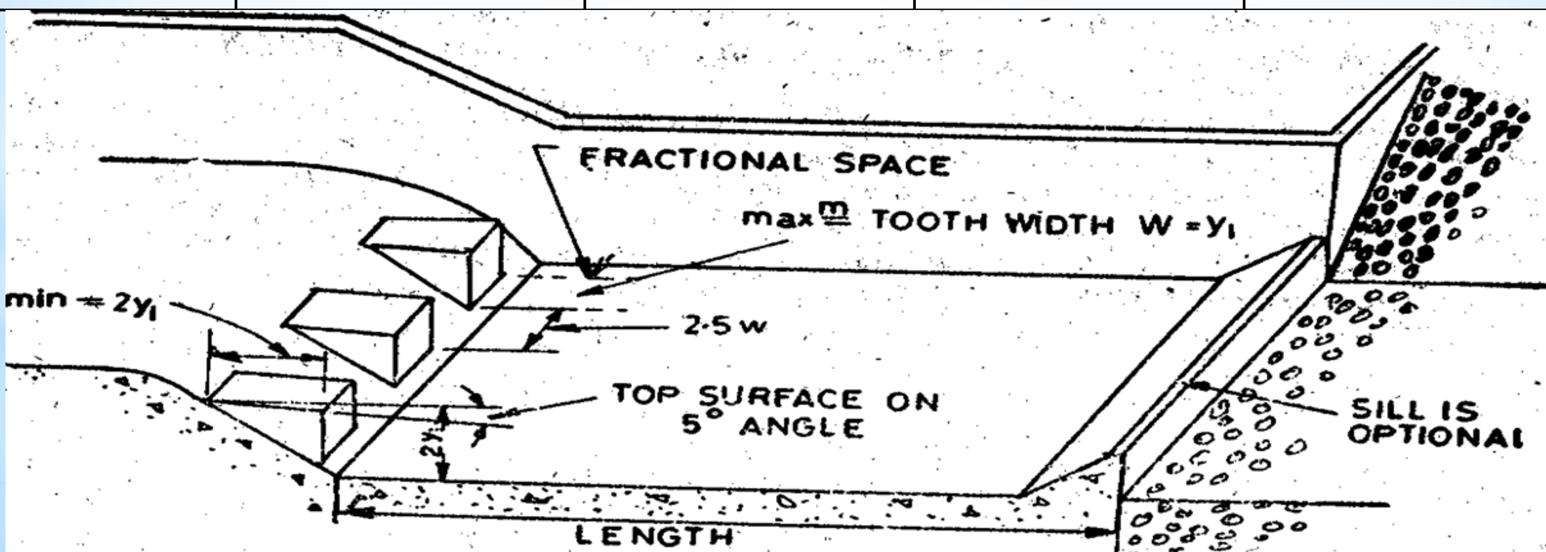
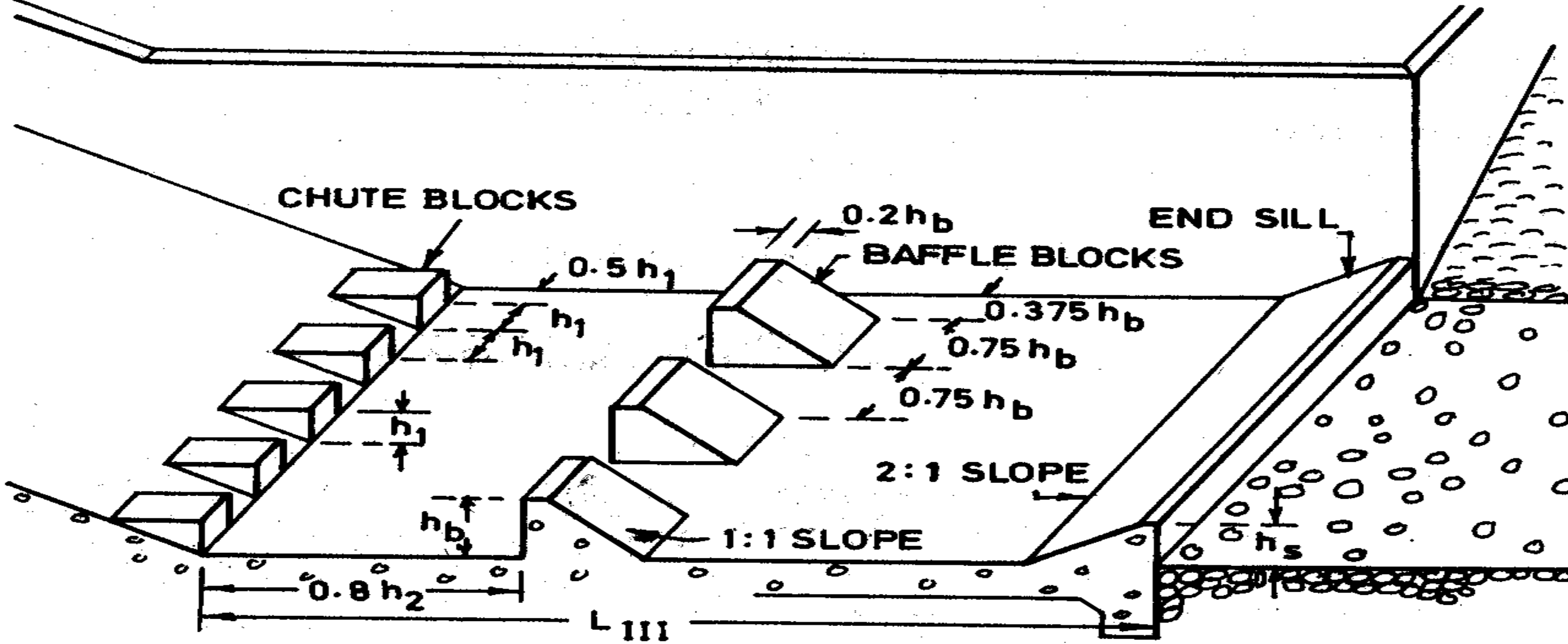


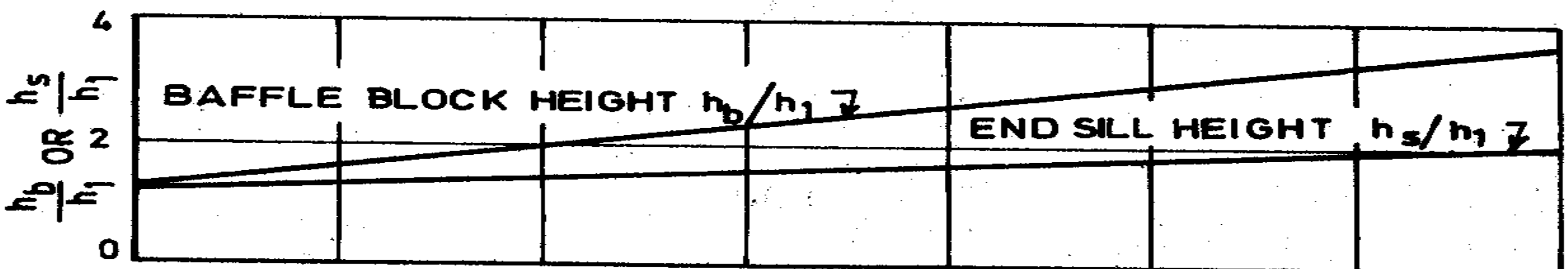
Fig. 21·33. U.S.S.R. Stilling Basin IV (F_1 lies between 2·5 and 4·5).

3. *Stilling basins for Froude number higher than 4.5*

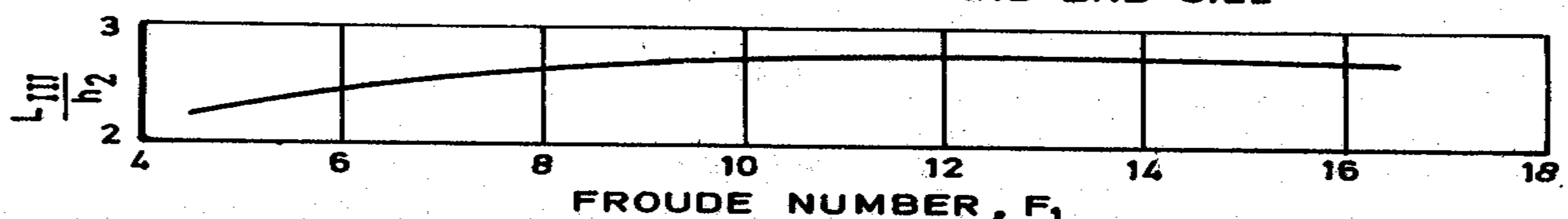
- Here true hydraulic jump will be formed.
- For this case depending upon the velocity of incoming flow, two types of stilling basin have been developed as indicated below.
- ✓ (a) When the velocity of incoming flow is less than 15m/s, **Type III** stilling basin have been adopted.
- This basin utilizes ***chute blocks, baffle block*** and an ***end-sill***.



(a) TYPE III BASIN DIMENSIONS

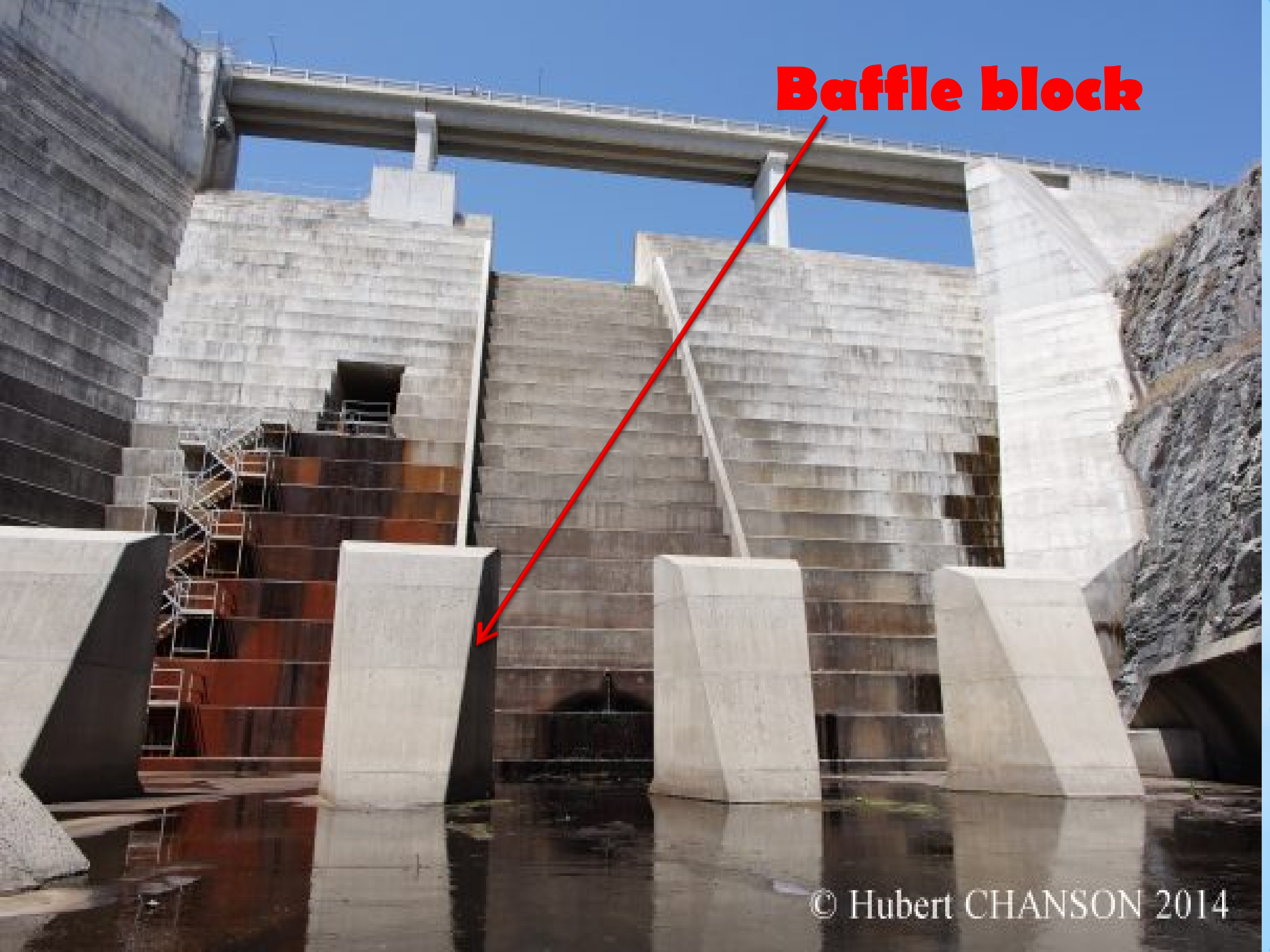


(b) HEIGHT OF BAFFLE BLOCKS AND END SILL



(c) LENGTH OF STILLING BASIN


Chute Blocks


Baffle block
© Hubert CHANSON 2014

- By providing the baffle blocks, the length of the stilling basin is considerably reduced because the dissipation of energy is accomplished by the hydraulic jump as well as by the impinging action of the incoming flow against these blocks.
- However, the baffle blocks will be subjected to large impact forces due to impingement of incoming flow.
- Moreover on the downstream face of the baffle blocks usually suction or negative pressure will be developed which will further increase the forces acting on these blocks.
- Hence, baffle blocks should be properly anchored at the base.
- Further the floor of the basin will also be subjected to additional load due to the dynamic forces created against the upstream face of the baffle blocks.

- (b) When the velocity of the incoming velocity exceeds **15 m/s**,
- **Type II** stilling basin may be adopted.
- In this basin only chute blocks are provided and instead of a solid end sill a dentate sill is provide.
- In this basin baffle blocks are not provided because
- Due to high velocity of incoming flows these blocks will be subjected to excessive large impact forces
- There is a possibility of cavitation along the downstream face of theses blocks and adjacent floor of the basin due to large negative pressure developed in the region.
- Due to baffle blocks being eliminated in this case the dissipation of the energy is primarily accomplished by hydraulic jump
- Hence, the length of the basin will be **greater than** that indicated for the Type III Basin.

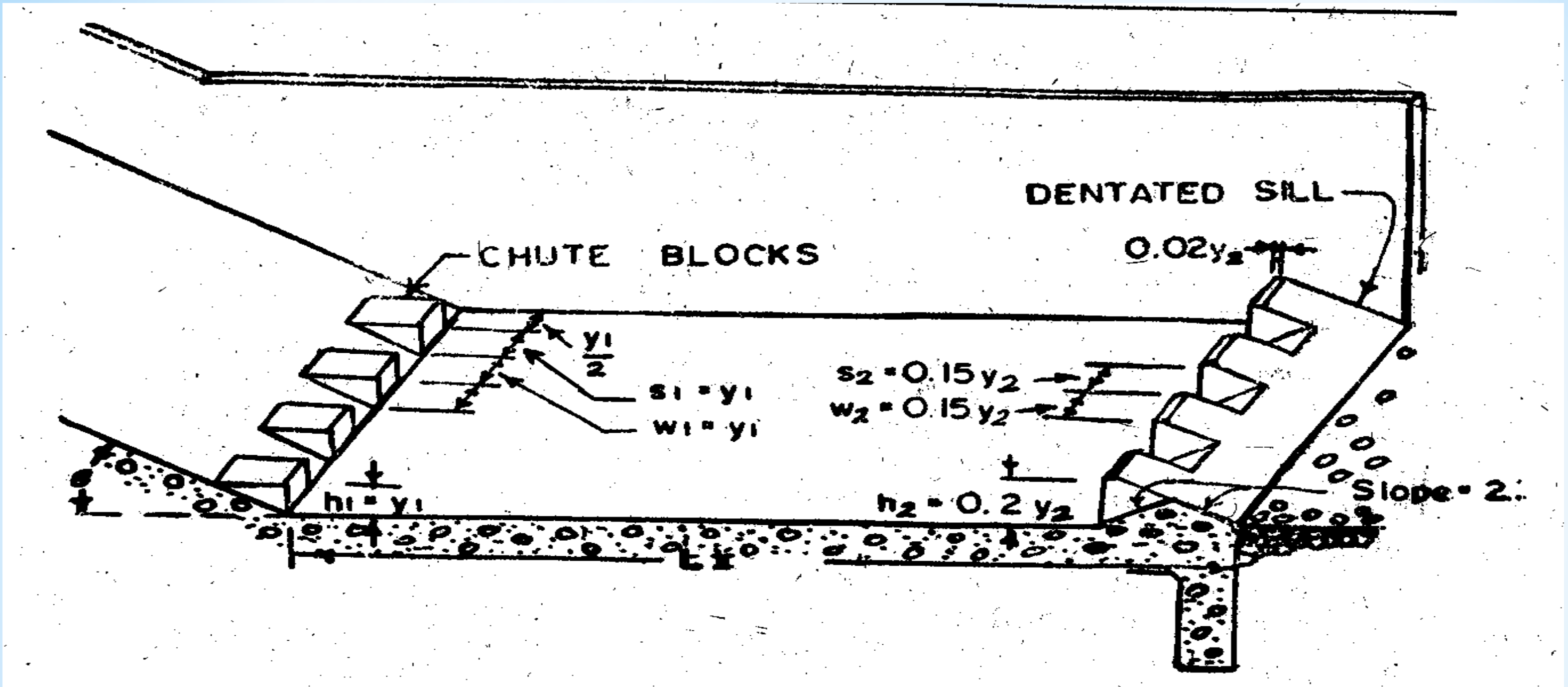


Fig. 21·32. U.S.B.R. Stilling basin II ($F_1 > 4 \cdot 5$).

F_1	5	6	8	10	12	14
L/Y_2	3.85	4.0	4.2	4.3	4.3	4.3

Bucket type energy dissipaters

- Bucket type energy dissipaters consist of an upturned bucket provided at the toe of the spillway.

C:\Users\user\Desktop\energy dissp\Srisailam dam in Andhra pradesh-bucket.flv

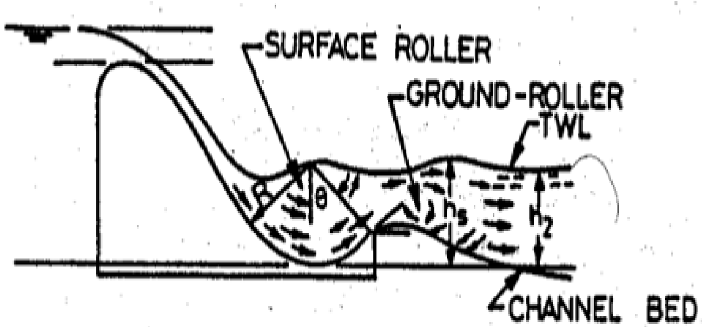
- The bucket type energy dissipaters may be used only for overflow type spillways.
- This type of energy dissipation becomes more economical than the method of stilling basins when the Froude number F_1 of the incoming flow exceeds 10,
- Because in such cases the difference between initial and sequent depths being **large and long** stilling basin would be required.
- Moreover the bucket type energy dissipaters may be used with any tail water condition.
- However, this type of energy dissipater may be used only when the river bed is composed of **stiff rock**.

- The bucket type energy dissipaters are of the following three types:
  a) Solid roller Bucket
  b) Slotted roller Bucket
  c) Ski jump (or flip or trajectory bucket)
- The solid or slotted roller bucket may be used where the tail water depths are too large as compared to the sequent depths required for the formation of the hydraulic jump.
- Both these buckets remain submerged in tail water and hence these are also termed as submerged bucket type energy dissipaters. 12:20

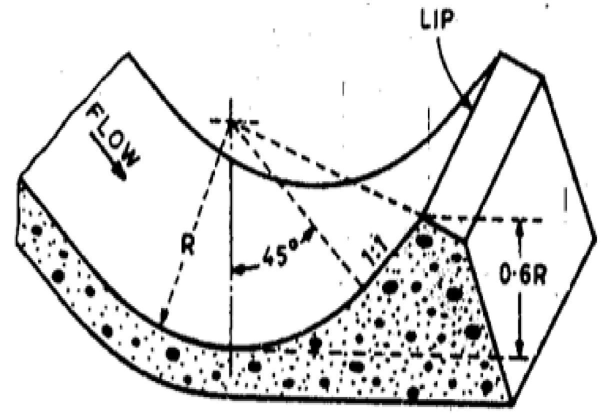
C:\Users\user\Desktop\energy dissp\Energy Dissipators_2.flv

- A **solid roller**: bucket consists of a bucket like apron with a concave circular profile of large radius and a deflector lip.
- When the water flows over the bucket the entire sheet of water leaving the bucket is deflected upward by the bucket lip and two elliptical rollers are developed as shown in the figure.
- One of the roller which moves in the counter clock wise direction is developed on the surface of the bucket and is contained within the region above the bucket. This is known as **bucket roller** (or surface roller).
- The other roller moving in the clock wise direction is developed on the ground surface immediately downstream of the bucket, which is known as **ground roller**.

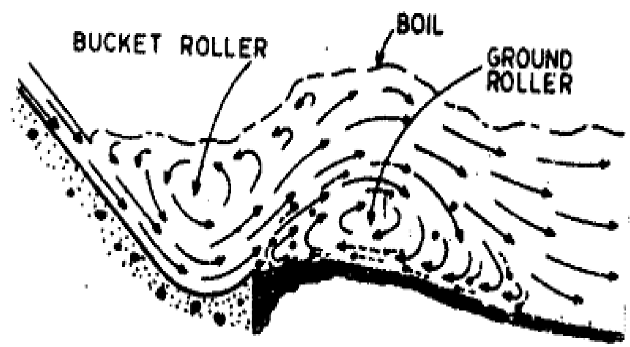
- The upward deflection of water by the bucket lip creates a high boil on the water surface and a violent ground roller.
- This ground roller continuously pulls the loose bed material backwards and deposits the same against the lip of the bucket.



(a) SOLID ROLLER BUCKET



(a) SOLID ROLLER BUCKET



(b) HYDRAULIC ACTION IN SOLID ROLLER BUCKET

* Radius of the Bucket: **$R = 0.6\sqrt{H' * H_d}$**
  * Where H' = fall from crest of spillway to bucket invert in meter.

  And H_d =Head over crest in meters
* Vente Chow's Formula **$R = 0.306 * 10^k$**

  Where $k = (v_1 + 6.4\ H_d + 4.88)/(3.6\ H_d + 19.5)$

  V_1 = velocity of flow at the toe of spillway in m/s
* ✓ The radius of bucket may also vary 3y1to 7y1

- A **slotted roller** bucket also consists of a bucket like apron with a concave circular profile of large radius but it has a slotted (or dentated) deflector lip.
- In general the hydraulic action of the slotted bucket has the same characteristics as that of a solid bucket.
- Thus in the case of the slotted bucket also the same two rollers are developed.
- However in this case the water leaves the lip of the bucket at a flatter angle and only a part of it is deflected upwards.
- Thus surface boil is considerably reduced, and less violent ground rollers occurs which results in a smoother flow on the downstream side.
- Moreover in this case the bed material is neither deposited nor carried away from the bucket lip, also any debris which might get into the bucket is immediately washed out through the slots.

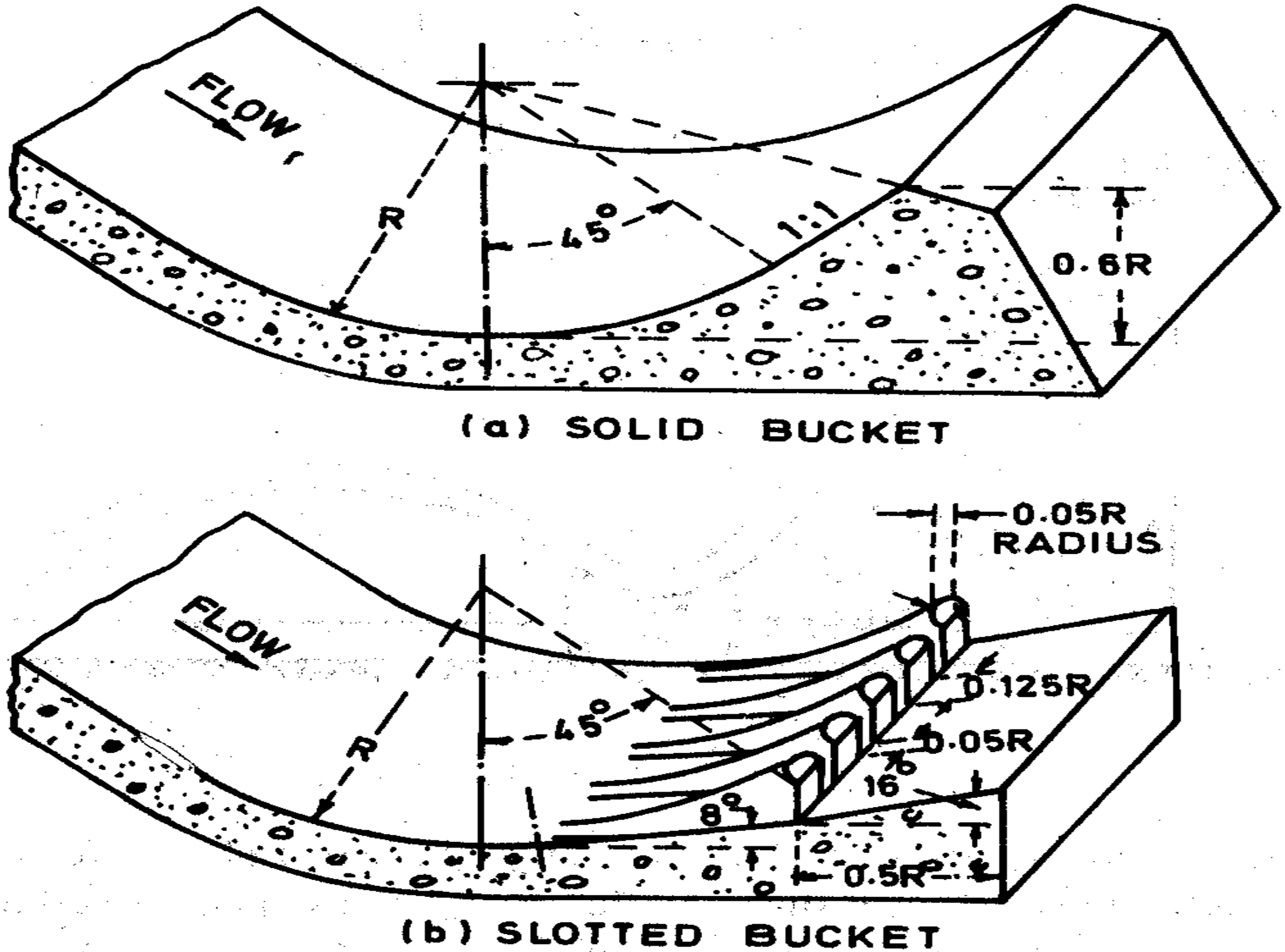


Fig. 17.21 Roller Buckets

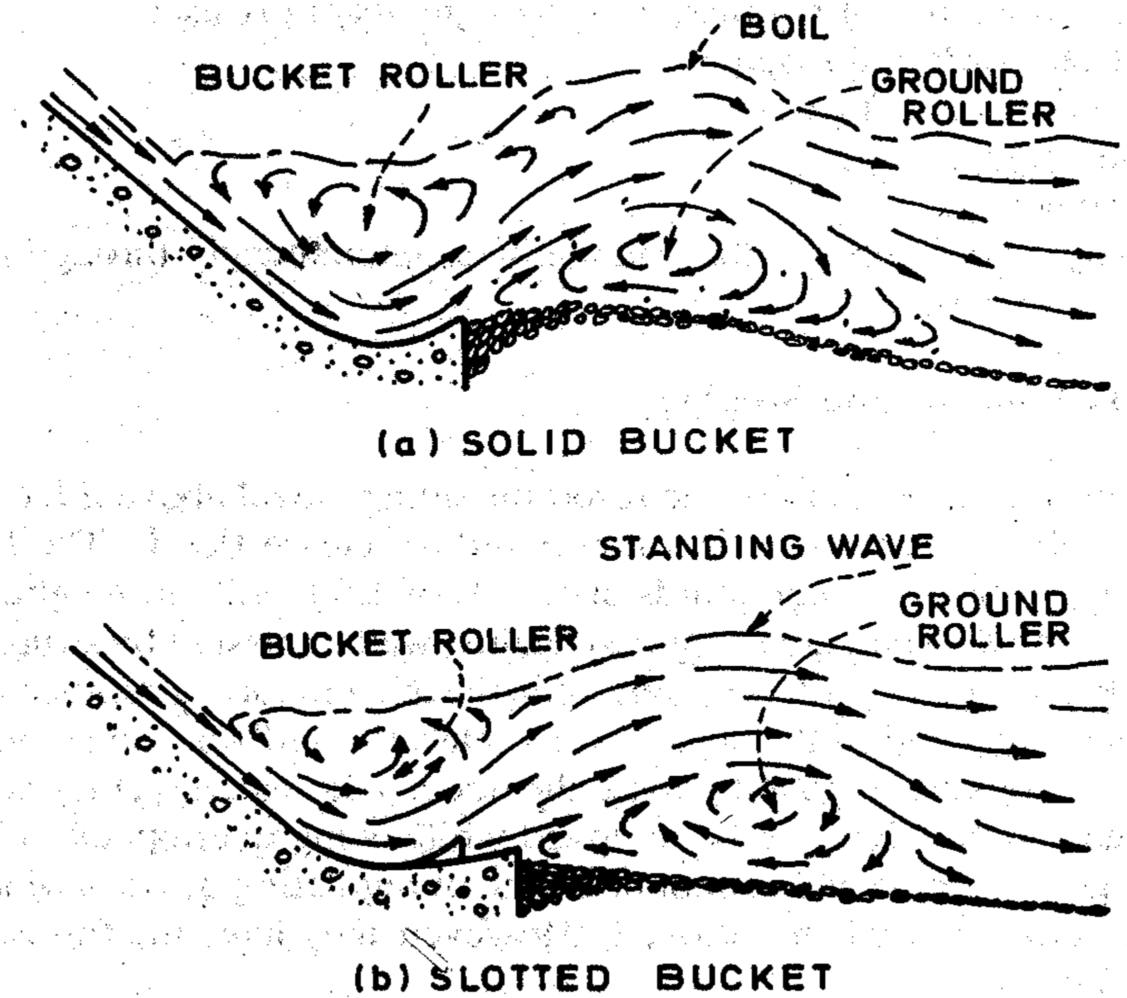


Fig. 17.22 Roller Formation in Roller Buckets

- A **ski jump bucket** may be used where the tail water depth, is less than sequent depth required for the formation of hydraulic jump and the river bed is composed of stiff rock.
- The lip of the bucket is so shaped that the entire sheet of the water flowing over the bucket is deflected as a free jet which falls back into the river channel at a safe distance away from the spillway.
- Thus in this case energy is dissipated by air resistance, breaking of the jet into bubbles and the impact of the falling jet against the river bed and tail water.
- Bucket Invert level is decided mainly from the structural point of view.
- If the power house is situated below the ski jump bucket, then the invert should be fixed higher than the roof top of power house.

River Diversion Works

Introduction

- Diversion head works are structures constructed across a river (usually head of a canal) to raise and facilitate a regulated and continuous diversion of water into the off-taking canal.

In order to harness the water potential of a river optimally, it is necessary to construct two types of hydraulic structures:

1. **Storage structure**, usually a dam, which acts like a reservoir for storing excess runoff of a river during periods of high flows and releasing it according to a regulated schedule.

2. **Diversion structure**, which may be a *weir* or a *barrage* that raises the water level of the river slightly, not for creating storage, but for allowing the water to get diverted through a canal situated at one or either of its banks.

- Since a diversion structure does not have enough storage, it is called a run-of-the river scheme. The diverted water passed through the canal may be used for irrigation, industry or domestic water needs.

Introduction

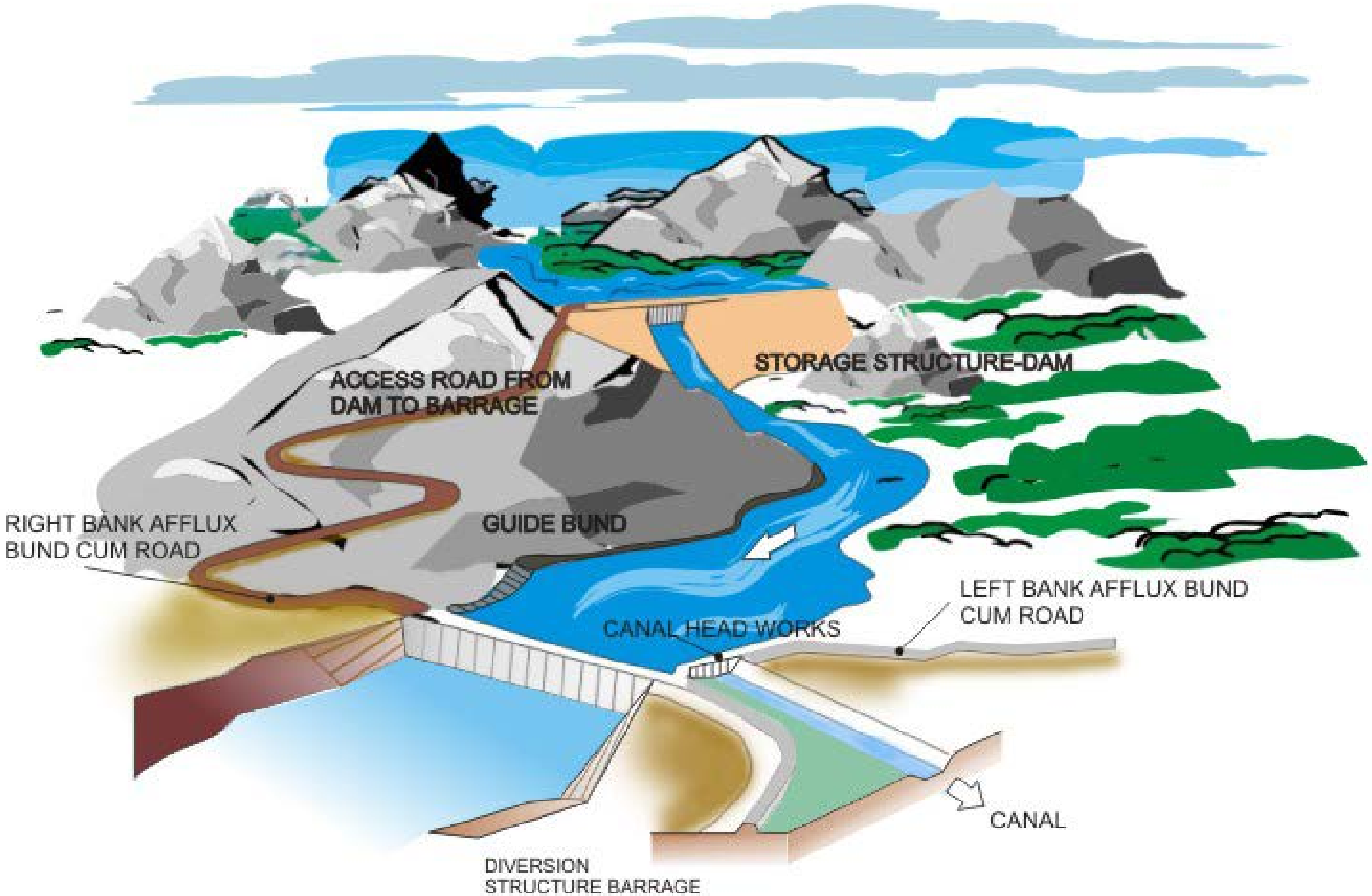


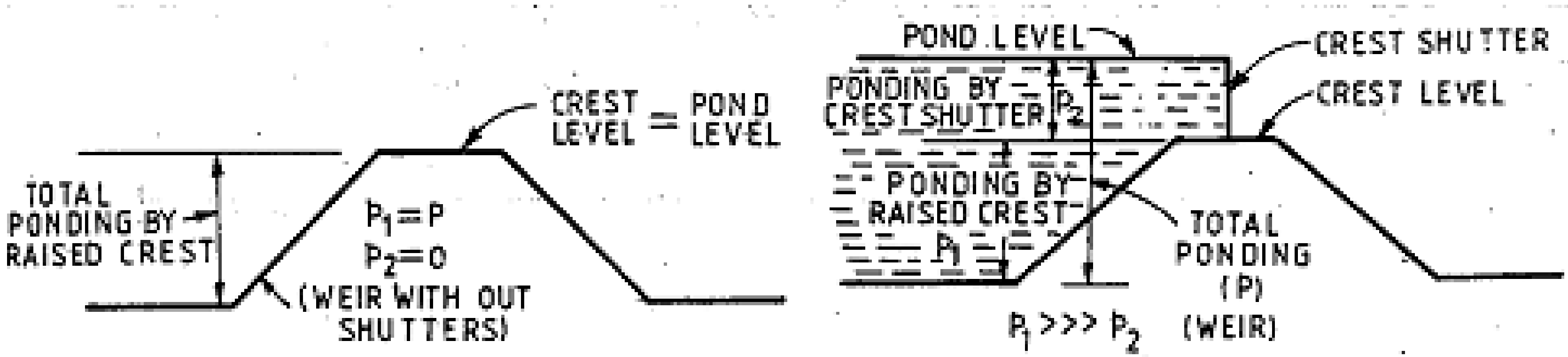
FIGURE 1. Structures for harnessing water resources potential of a river

Introduction-terms

- The works, which are constructed at the head of the canal, in order to divert the river water towards the canal, so as to ensure a regulated continuous supply of silt-free water with a certain minimum head in to canal, are known as *Diversion Head Works*.
- A *diversion headwork* serves to divert the required supply to canal from the river.
- If diversion head works are constructed on the perennial rivers which have adequate flow throughout the year, there may not be necessity of creating a storage reservoir.

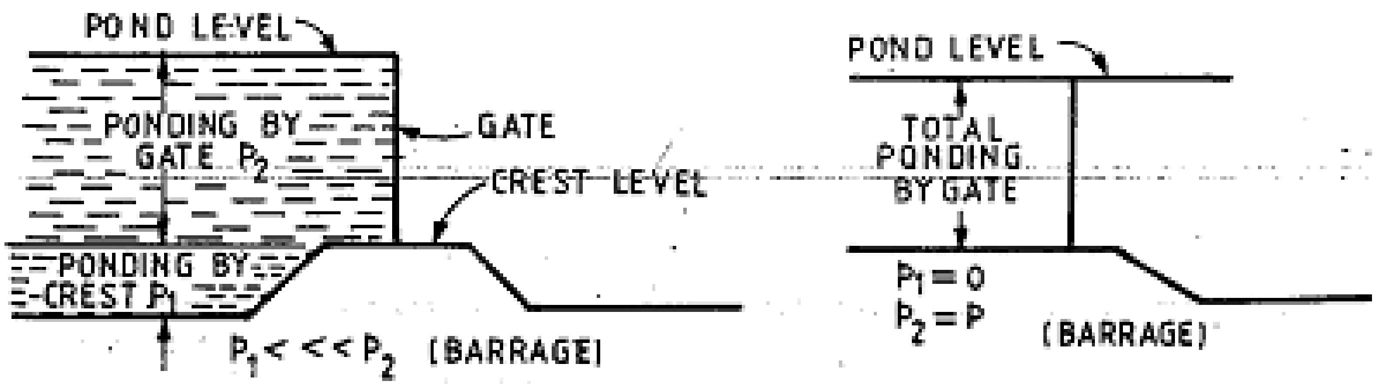
Introduction

- If the storage on the upstream of a diversion head works is significant, it is called a *storage weir*.
- If a diversion head-works is constructed on the downstream of a dam for the purpose of diverting water released from the u/s dam into the off-taking canals, it is called a *pickup weir*.



(*a*) Weir without shutters (*b*) Weir with shutters

Fig. 9.1



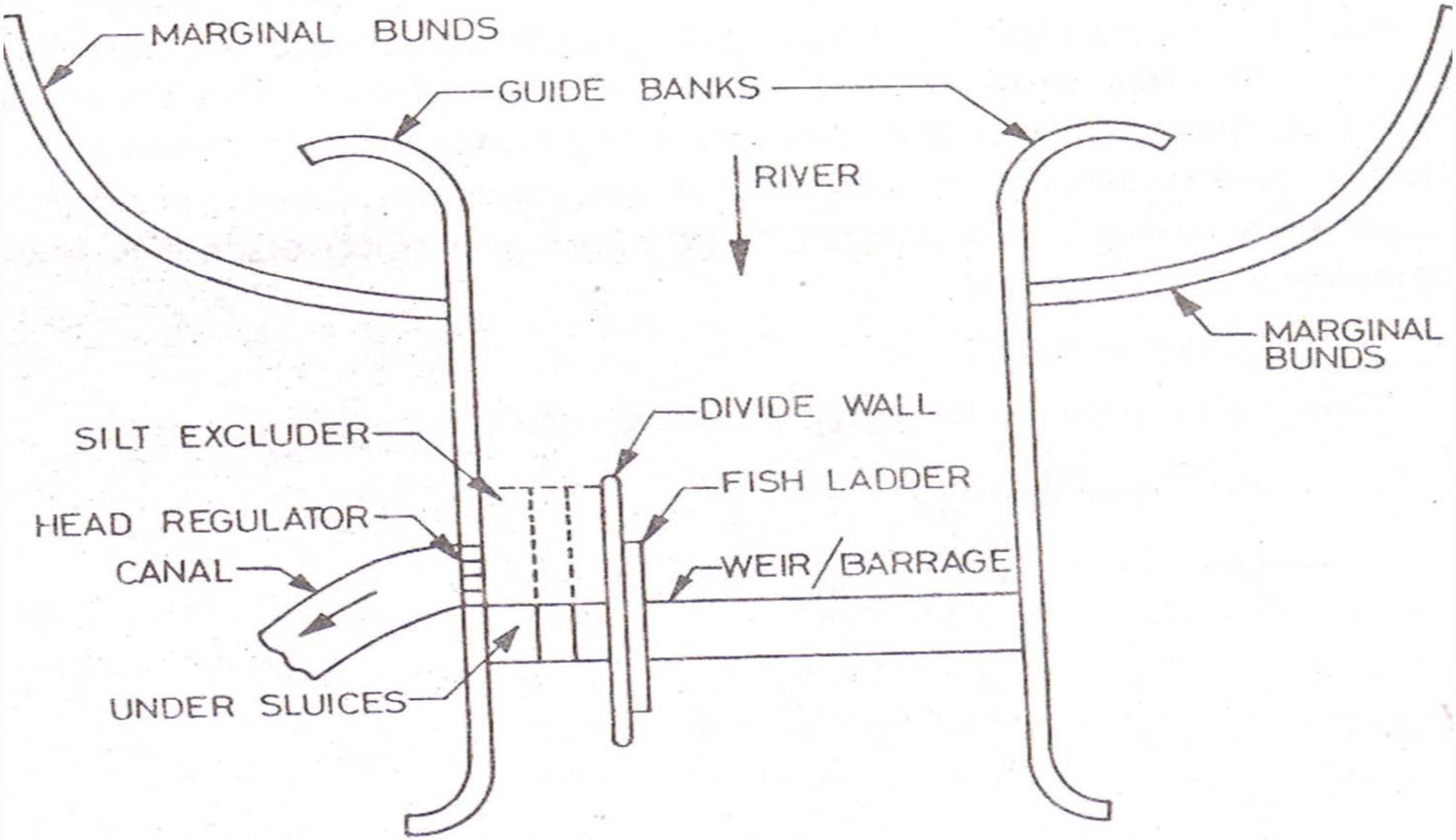
(*a*) Barrage with a small raised crest (*b*) Barrage without any raised crest

Fig. 9.2

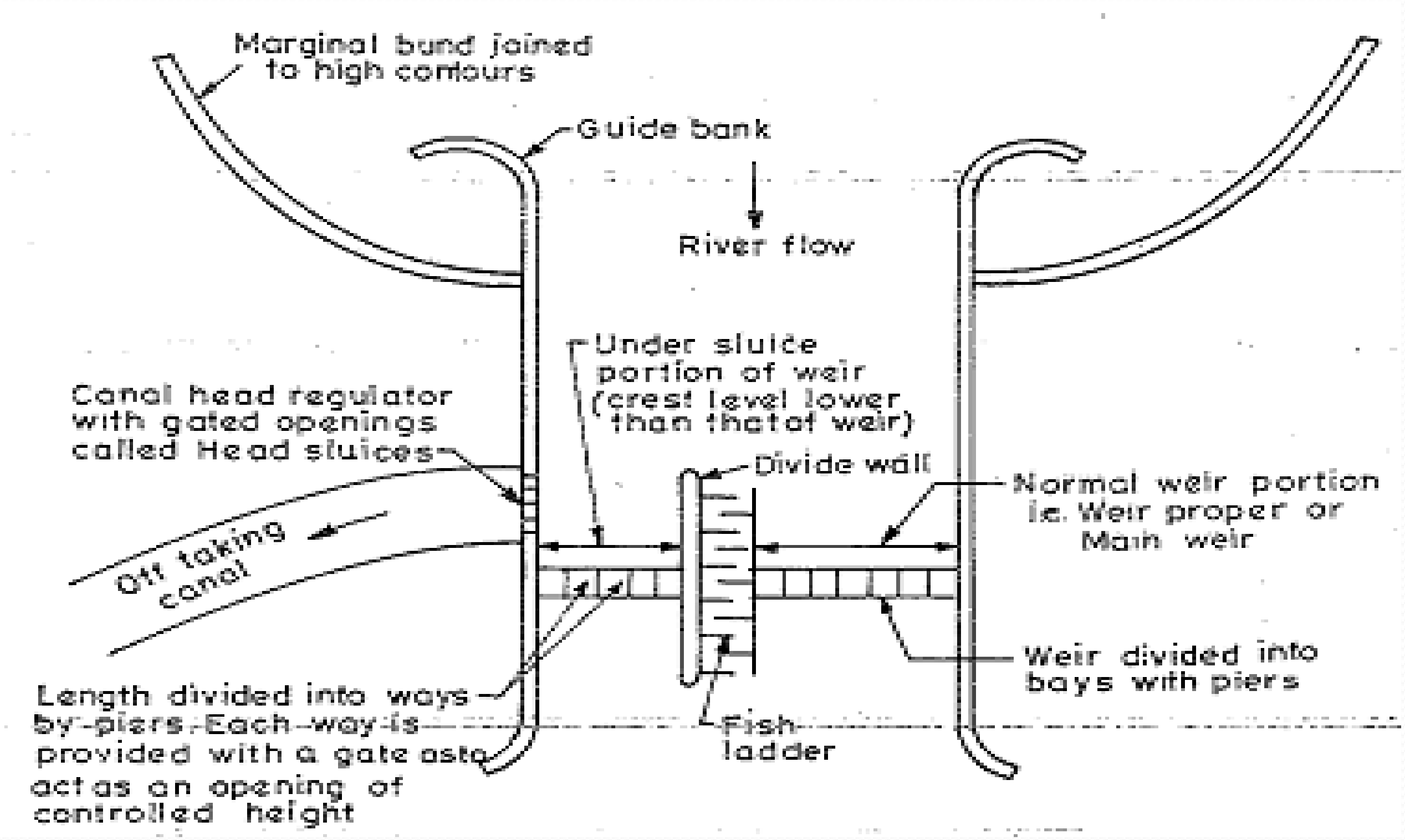
Functions of a Diversion Head-works

- It raises the water level on its upstream side.
- It regulates the supply of water into canals.
- It controls the entry of silt into canals
- It helps in controlling the vagaries of the river.

Components/Parts



Typical layout of Diversion Head Work



Undersluice

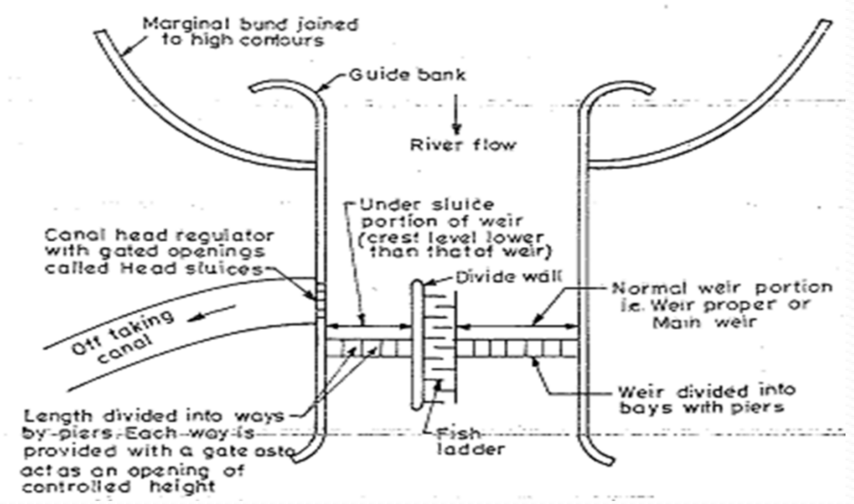
- Under sluice sections are provided adjacent to the canal head regulators.
- The under sluices are the openings provided at the base of the weir or barrage. These openings are provided with adjustable gates.
- Normally, the gates are kept closed. The crest of the under- sluice portion of the weir is kept at a lower level than the crest of the normal portion of the weir.
- The suspended silt goes on depositing in front of the canal head regulator. When the silt deposition becomes appreciable the gates are opened and the deposited silt is removed.

***The main functions of under-sluices are*:**

- To maintain a well defined deep channel approaching the canal head regulator.
- To ensure easy diversion of water into the canal through the canal head regulator even during low flow.
- To control the entry of silt into the canal
- To help prevent scouring of the silt deposited over the under-sluice floor and removing towards the downstream side.
- To help passing the low floods without dropping the shutters of the weir.

Divide Wall

- A divide wall is constructed parallel to the direction of flow of river to separate the weir section and the under-sluices section to avoid cross flows.
- If there are under-sluices at both the sides, there are two divide walls.

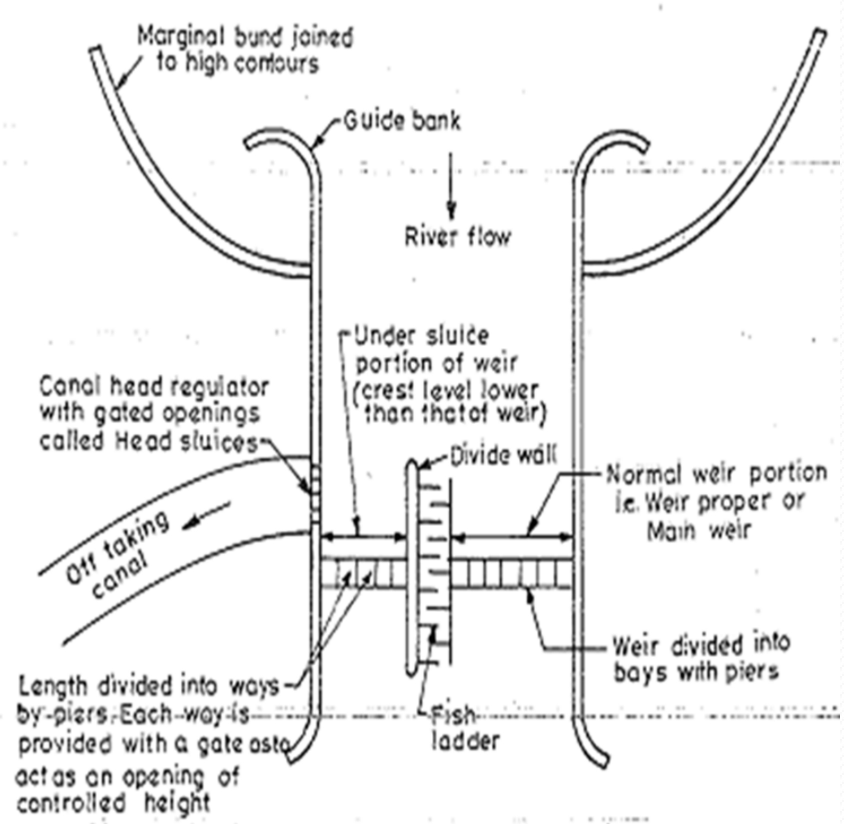


Fish Ladder

- A fish ladder is a passage provided adjacent to the divide wall on the weir side for the fish to travel from u/s to d/s and vice versa.
- Fish migrate u/s or d/s in search of food or to reach their sprawling places.
- In a fish ladder the head is gradually dissipated so as to provide smooth flow at sufficiently low velocity.
- Suitable baffles are provided in the fish passage to reduce the flow velocity.

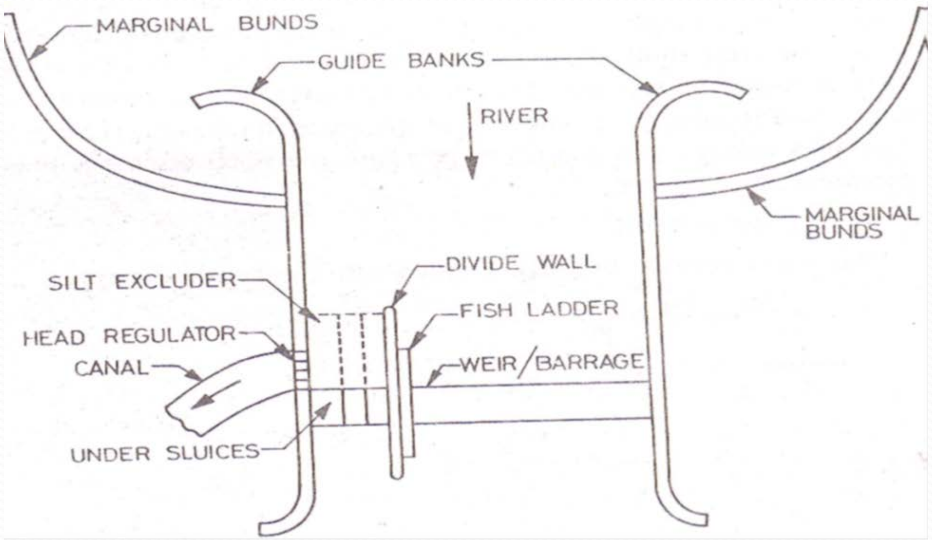
Canal Head Regulator

- A canal head regulator is provided at the head of the canal off-taking from the diversion head-works.
- It regulates the supply of water into the canal, controls the entry silt into the canal, and prevents the entry of river floods into canal.

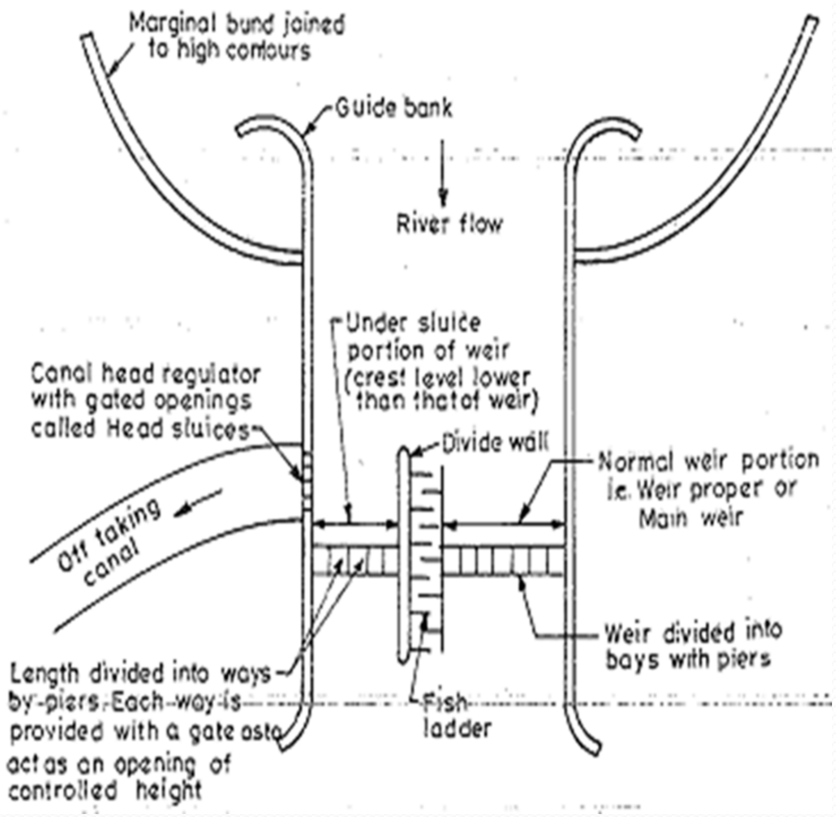


Silt Excluder

- A silt excluder is a structure in the under-sluices pocket to pass the silt laden water to the downstream so that only clear water enters into the canal through head regulator.
- The bottom layer of water which are highly charged with silt pass down the silt excluder and escape through the under-sluices.



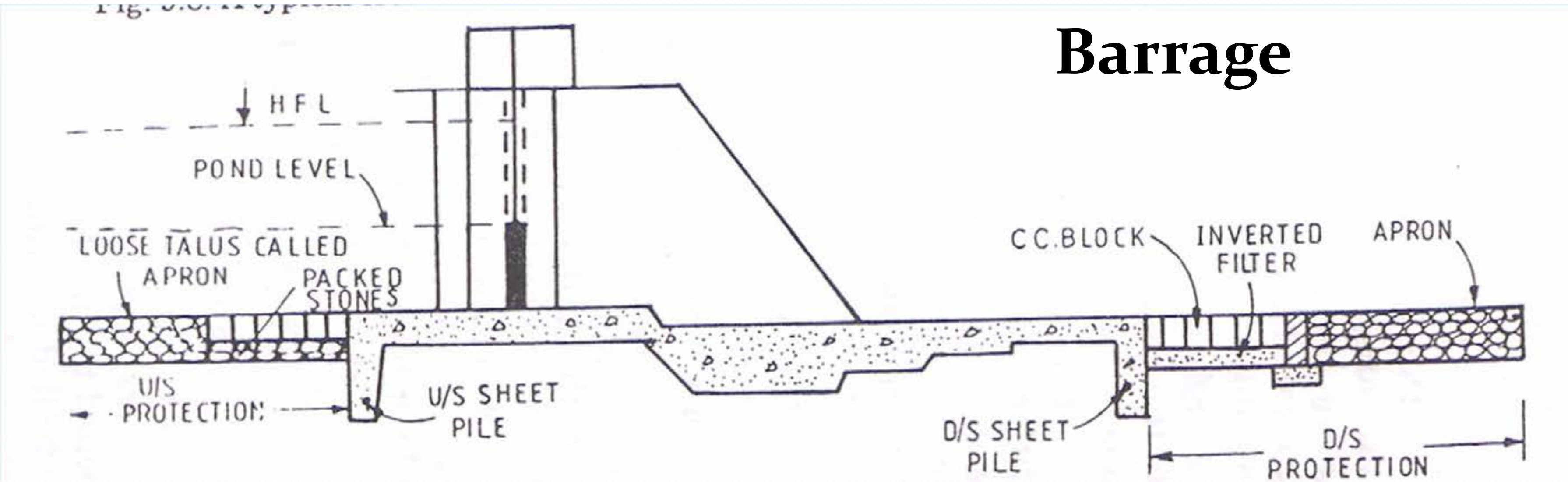
Guide Banks & Marginal Bunds



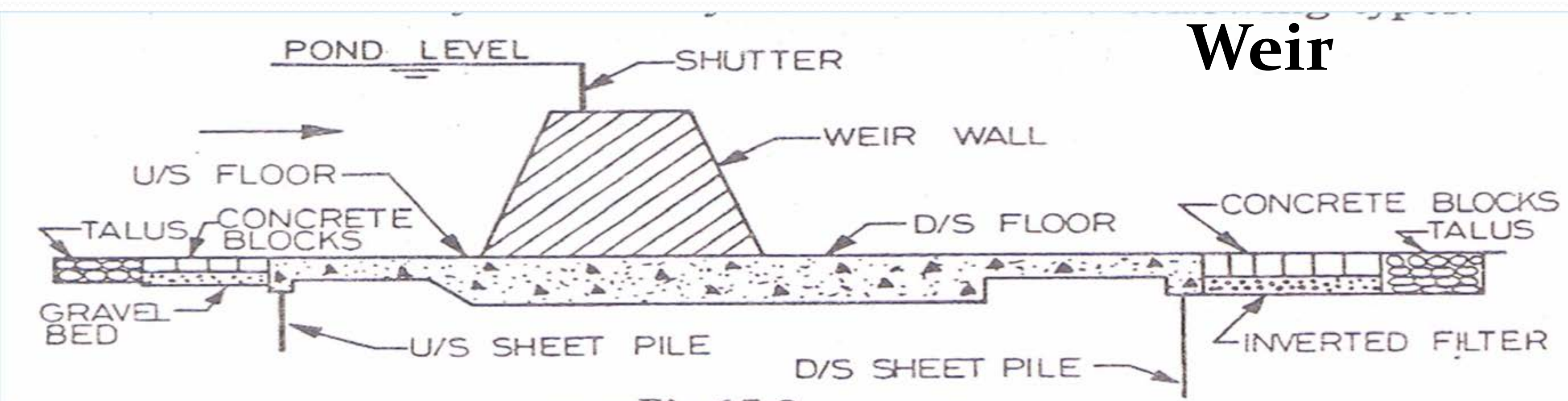
- Guide banks are provided on either side of the diversion head-works for a smooth approach and to prevent the river from outflanking.
- Marginal bunds are provided on either side of the river u/s of diversion head-works to protect the land and property which is likely to be submerged during ponding of water in floods.

Weir or Barrage

Barrage



Weir



Weir/Barrage

- A weir is a raised concrete crest wall constructed across the river.
- It may be provided with small shutters (gates) on its top.
- In the case of weir, most of the raising of water level or ponding is done by the solid weir wall and little with by the shutters/gate.
- A barrage has a low crest wall with high gates.
- As the height of the crest above the river bed is low most of the ponding is done by gates.
- During the floods the gates are opened so afflux is very small.

Weir/Barrage

- A weir maintains a constant pond level on its upstream side so that the water can flow into the canals with the full supply level.
- If the difference between the pond level and the crest level is less than 1·5 m or so, a weir is usually constructed.
- On the other hand, if this difference is greater than 1·50 m, a gate-controlled barrage is generally more suitable than a weir.
- In the case of a weir, the crest shutters are dropped during floods so that the water can pass over the crest.
- During the dry period, these shutters are raised to store water up-to the pond level.

Weir or Barrage

- Generally, the shutters in weir are usually operated manually, and there may not be a need for mechanical arrangement for raising or dropping the shutters.
- On the other hand, in the case of a barrage, the control of poundage and flood discharge is achieved with the help of gates which are mechanically operated.

Advantages and Disadvantages

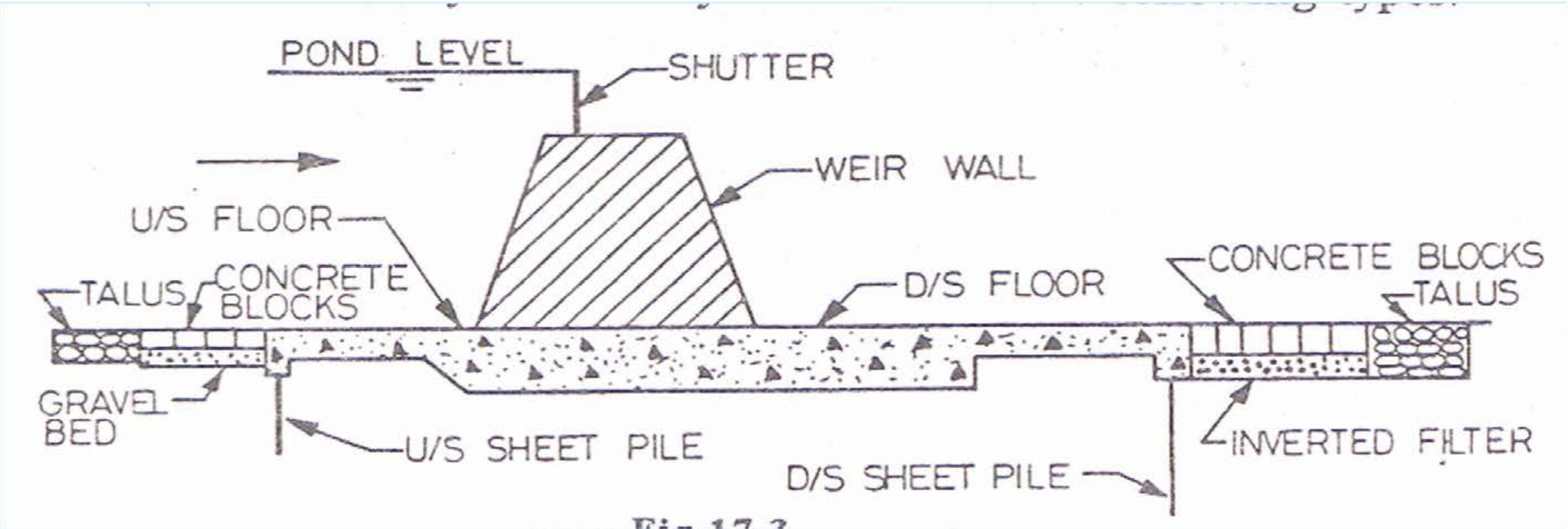
Weir	Barrage
Low cost	High cost
Low control on flow	Relatively high control on flow and water levels by operation of gates
No provision for transport communication across the river	Usually, a road or a rail bridge can be conveniently and economically combined with a barrage wherever necessary
Chances of silting on the upstream is more	Silting may be controlled by judicial operation of gates
Afflux created is high due to relatively high weir crests	Due to low crest of the weirs (the ponding being done mostly by gate operation), the afflux during high floods is low. Since the gates may be lifted up fully, even above the high flood level.

Types of Weirs

- Vertical drop weirs.
- Rock-fill weirs.
- Concrete glacis or sloping weirs.

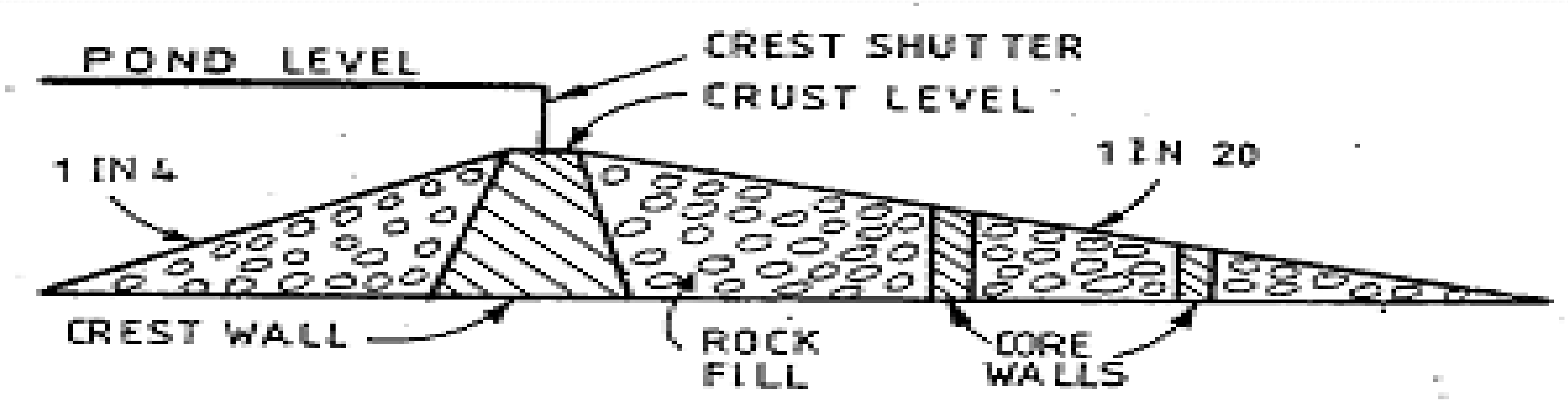
Vertical Drop Weirs

- Wall type structure on a horizontal concrete floor.
- Shutters are provided at the crest, which are dropped during floods so as to reduce **afflux**. (Afflux is the rise in water level on the u/s side of a weir/barrage due to obstruction caused by less area of impounding water.)
- Vertical drop weirs were quite common in early diversion head-works, but these are now becoming more or less obsolete.



Rock Fill Weir

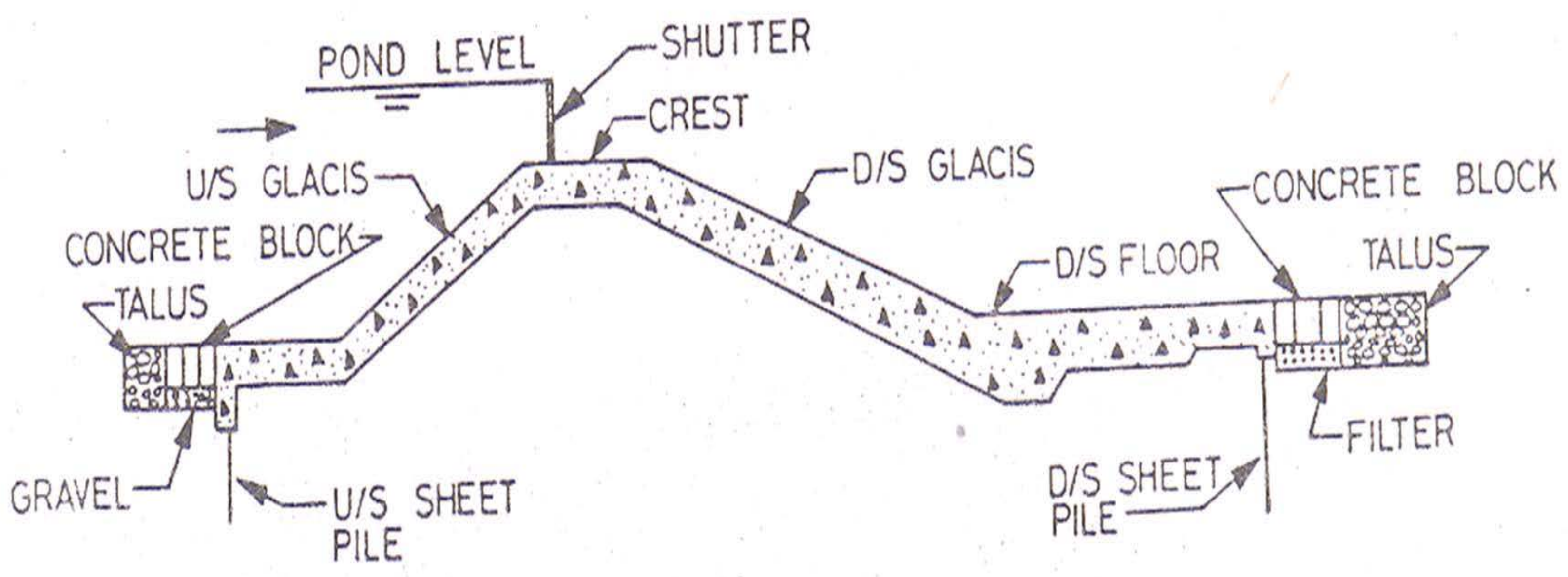
- In a rock-fill type weir, there are a number of core walls.
- The space between the core walls is filled with the fragments of rock.
- A rock-fill weir requires a lot of rock fragments and is economical only when a huge quantity of rock-fill is easily available near the weir site.
- Such weirs are also more or less obsolete these days.



Sloping/Glacis Weirs

- Concrete sloping weirs (or glacis weirs) are of relatively recent origin.
- The crest has glacis (sloping floors) on u/s as well as d/s. There are sheet piles driven upto the maximum scour depth at the u/s and d/s ends of the concrete floor.
- Sometimes an intermediate pile is also driven at the beginning of the u/s glacis or at the end of d/s glacis.
- The main advantage of a sloping weir over the vertical drop weir is that a hydraulic jump is formed on the d/s glacis for the dissipation of energy.
- Therefore, the sloping weir is quite suitable for large drops

Sloping/Glacis Weirs



Location or Site Selection

- The river section at the site should be narrow and well defined.
- The river should have high, well-defined, in-erodible and non submersible banks so that the cost of river training works is minimum.
- The canals taking off from the diversion head works should be quite economical and should have a large commanded area.
- There should be suitable arrangement for the diversion of river during construction.
- The site should be such that the weir (or barrage) can be aligned at right angles to the direction of flow in the river.

Location or Site Selection

- There should be suitable locations for the under sluices, head regulator and other components of the diversion head-works.
- The diversion head-works should not submerge costly land and property on its upstream.
- Good foundation should be available at the site.
- The required materials of construction should be available near the site.
- The site should be easily accessible by road or rail.
- The overall cost of the project should be a minimum.

Seepage Analysis in DHW

- The design of any hydraulic and irrigation structures have to consider the hydraulics of surface and subsurface flow.
- Surface flow is meant for the flow which occurs over the weir crest & under-sluices and subsurface flow for the seepage flow occurring under the foundation.

Bligh's Theory

- This theory assumes that the seeping water creeps from the upstream to the downstream of the structure along the contact base of the soil with the structure.
- The length if seepage path traversed by the seeping water is called creep length (L).
- This means that the residual uplift pressure at any point along the base is inversely proportional to the distance of the point from the upstream end of the structure.
- One of the shortcomings of the Bligh's theory is that it does not make differences between vertical and horizontal creep.

Bligh’s Theory

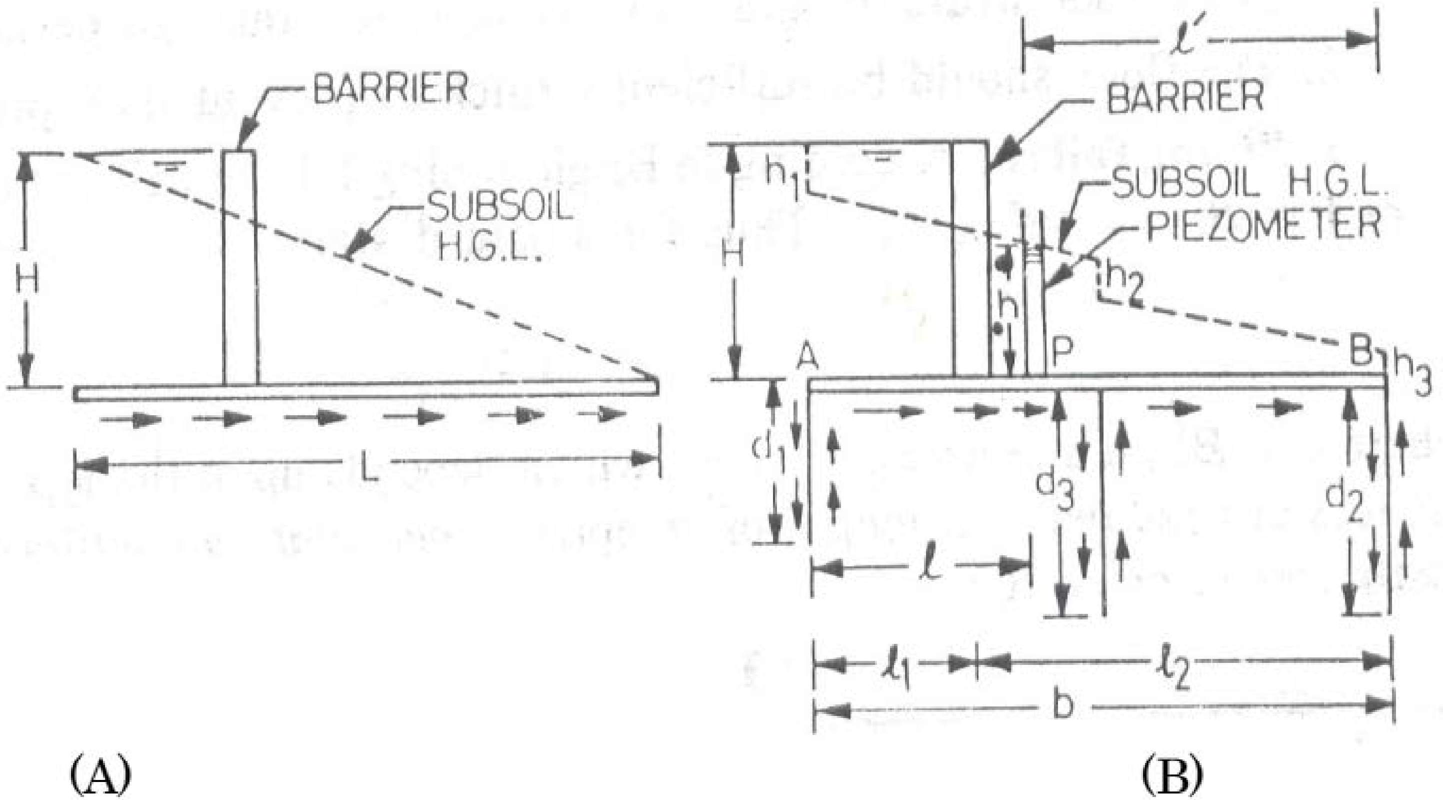


Fig: Creep under the base of the foundation

Bligh's Theory

- The creep length from the figure above is

$$L = 2d_1 + l_1 + 2d_3 + l_2 + 2d_2$$

For safe design of DHWs based on Bligh's theory,

i. The hydraulic gradient should be less than permissible value i.e.

$$i = \frac{H}{L} \le i_{safe} \rightarrow i \le \frac{1}{C}$$

ii. The floor thickness and weight should be sufficient to withstand the uplift pressure. Where floor thickness can be found by

$$t = \frac{4}{3} * \left[\frac{h}{G - 1} \right]$$

Lane's theory

- This theory gives different weights for horizontal and vertical creeps.
- According to this theory, vertical creep is 3 fold more effective than horizontal creep.

According to Lane

$$Leq = \frac{N}{3} + V$$

Where:

- Leq is the equivalent creep length

- N is the sum of horizontal contacts and all sloping contacts less than 450

- V is the sum of vertical contacts and all sloping contacts greater than 450

Lane’s Theory

- The criteria for the design are:

i. To be safe against piping, the exit gradient should be less than the safe exit gradient for that particular soil type.

$$\frac{H}{Leq} < \frac{1}{C1} \rightarrow Leq > C1 * H$$

Where: H is the total seepage head
C1 is Lane’s creep coefficient

ii. The thickness of the floor at any point should be sufficient to withstand the uplift pressure.

$$t = \frac{4}{3} * \left(\frac{h}{G - 1} \right)$$ Where h is the residual pressure above the floor.

Lane's Theory

- The residual head at any point at distance of ℓ from the upstream end and with a vertical cutoff d_1 at the upstream end is calculated as

$$h_{res} = H - \frac{H}{Leq} * \left(\frac{l}{3} + 2 d_1 \right)$$

Khosla's Theory

- Actual pressure on the base of structures and they found out that the actual up lift pressures were different from those determined on the basis of Bligh's theory.
- Khosla's expression for exit gradient is given by;

$$G_E = \frac{H_s}{d}\frac{1}{\pi\sqrt{\lambda}}$$

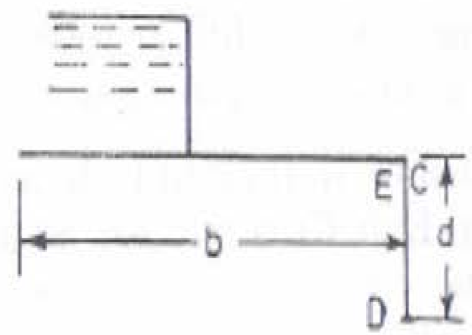
where $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$; $\alpha = \frac{b}{d}$; and d = depth of d/s pile.

Uplift pressure at key points

1- Pile at d/s end

The uplift pressure head at key points E, D and C as shown in Fig is given by

$$P_{uHE} = \frac{H_s}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right)$$



$$P_{uHD} = \frac{H_s}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right)$$

$$P_{uHC} = 0$$

where $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$; and $\alpha = \frac{b}{d}$.

Khosla's Theory

- **U/s pile**

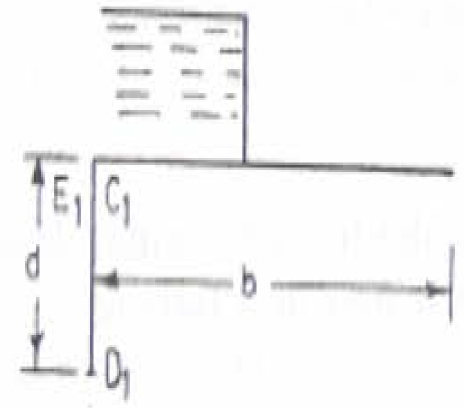
The uplift pressure head at key points E_1, D_1 and C_1 as shown in Fig is given by

$$P_{uHC1} = \frac{H_s}{\pi}\cos^{-1}\left(\frac{2-\lambda}{\lambda}\right)$$

$$P_{uHD1} = \frac{H_s}{\pi}\cos^{-1}\left(\frac{1-\lambda}{\lambda}\right)$$

$$P_{uHE1} = H_s$$

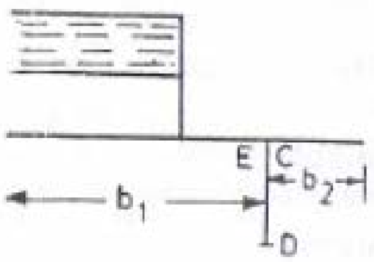
where $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$; and $\alpha = \frac{b}{d}$.



Khosla's Theory

Intermediate pile

For this case the uplift pressure head at key points E, D and C as shown in Fig is given by



$$P_{uHE} = \frac{H_s}{\pi}\cos^{-1}\left(\frac{\lambda_2 - 1}{\lambda_1}\right)$$

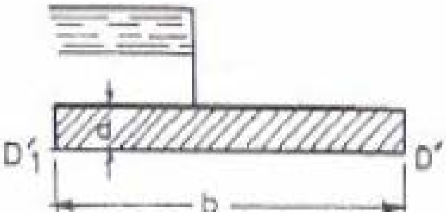
$$P_{uHD} = \frac{H_s}{\pi}\cos^{-1}\left(\frac{\lambda_2}{\lambda_1}\right)$$

$$P_{uHC} = \frac{H_s}{\pi}\cos^{-1}\left(\frac{\lambda_2 + 1}{\lambda_1}\right)$$

where $\alpha_1 = \frac{b_1}{d}$; $\alpha_2 = \frac{b_2}{d}$

$$\lambda_1 = \frac{\sqrt{1+\alpha_1^2} + \sqrt{1+\alpha_2^2}}{2}$$

$$\lambda_2 = \frac{\sqrt{1+\alpha_1^2} - \sqrt{1+\alpha_2^2}}{2}$$

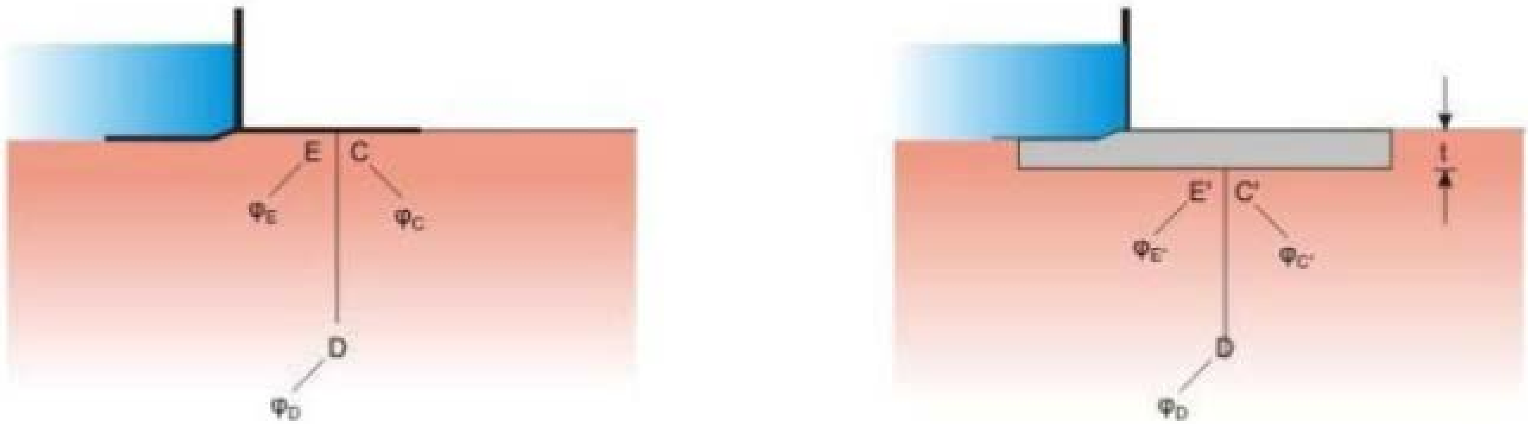


Khosla's Theory

<u>Corrections to pressures</u>

a. ***Correction for floor thickness***

The following figure illustrates the correction to the evaluated values at key points E and C that is applied considering a floor thickness t.



(a) (b)

$$\varphi_{E'} = \varphi_E - \frac{\varphi_E - \varphi_D}{d + t}\, t$$

$$\varphi_{C'} = \varphi_C - \frac{\varphi_D - \varphi_C}{d + t}\, t$$

Khosla's Theory

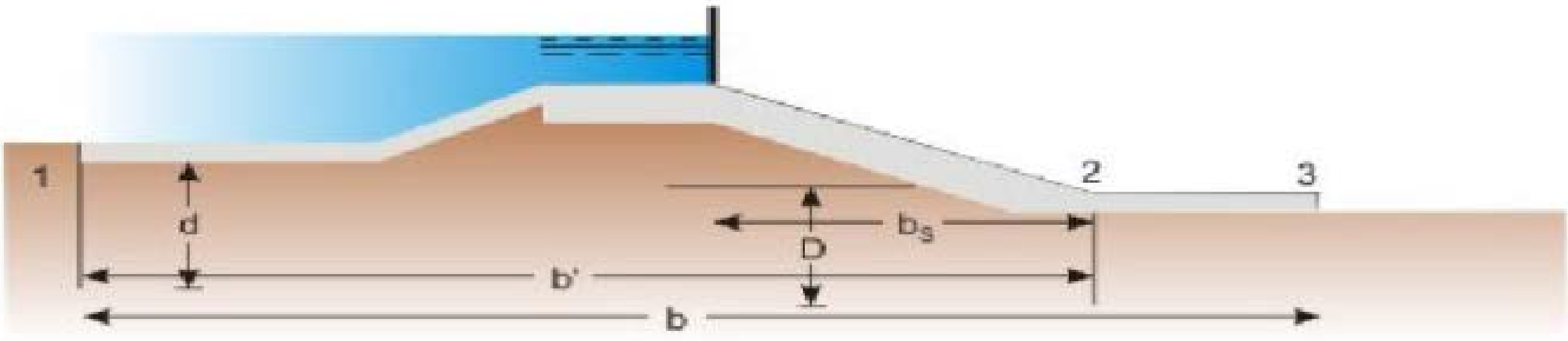
Considering the above figure, the computed pressures are at E and C instead of E_1 and C_1. The pressures at E_1 and C_1 can be obtained assuming linear variation of pressure from top to bottom of pile.

- E' is on d/s of E along the flow path indicated $\Rightarrow \phi E_1 < E$
- C' is on u/s of C along the flow path, $\Rightarrow \phi C_1 > C$
- Thickness correction at E = $-\left(\frac{\phi E - \phi D}{d\,2}\right) * t\,2$ (Negative)
- Thickness correction at C = $+\left(\frac{\phi D - \phi C}{d\,2}\right) * t\,2$. (*Positive*)

Generally:- correction positive – for C & Negative for E.

Khosla's Theory

b. Correction for Mutual interference of pile



CORRECTION FOR MUTUAL INTERFERENCE OF SHEET PILES.

$$C = 19\sqrt{\frac{D}{b'}}\left(\frac{d+D}{b}\right)$$

WHERE

C IS THE CORRECTION TO BE APPLIED AS PERCENTAGE OF HEAD.

b' IS THE DISTANCE BETWEEN THE TWO PILE LINES (SEE SKETCH).

b_s = SLOPING LENGTH OF FLOOR.

D = DEPTH OF THE PILE LINE , THE INFLUENCE OF WHICH HAS TO BE DETERMINED ON THE NEIGHBOURING PILE OF DEPTH d , D IS TO BE MEASURED BELOW THE LEVEL AT WHICH INTERFERENCE IS DESIRED.

d = DEPTH OF PILE ON WHICH THE EFFECT OF PILE OF DEPTH D IS SOUGHT TO BE DETERMINED.

b = TOTAL FLOOR LENGTH.