UNIT- III

SPILLWAYS

- **Types of spillways**
- **Design principles of ogee spillways**
- **Types of spillway gates**

Introduction

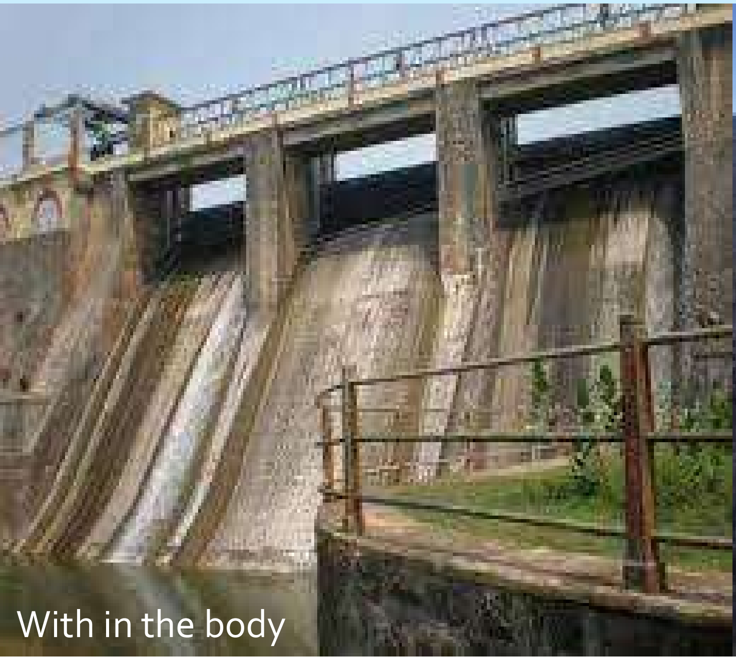
- A spillway is a structure constructed at or near the dam site to dispose of surplus water from the reservoir to the channel downstream.
- Spillways are provided for all dams as a safety measures against overtopping and the consequent damages and failure. Spillway is thus safety valve for a dam.

REQUIREMENTS OF A SPILLWAY

1. The spillway must have sufficient capacity.
2. It must be hydraulically and structurally adequate.
3. It must be so located that it provides safe disposal of water.
4. The bounding surfaces of spillway must be erosion resistant.
5. Energy dissipater should be located in downstream side of the spillway for dissipation of energy.

LOCATION OF SPILLWAY

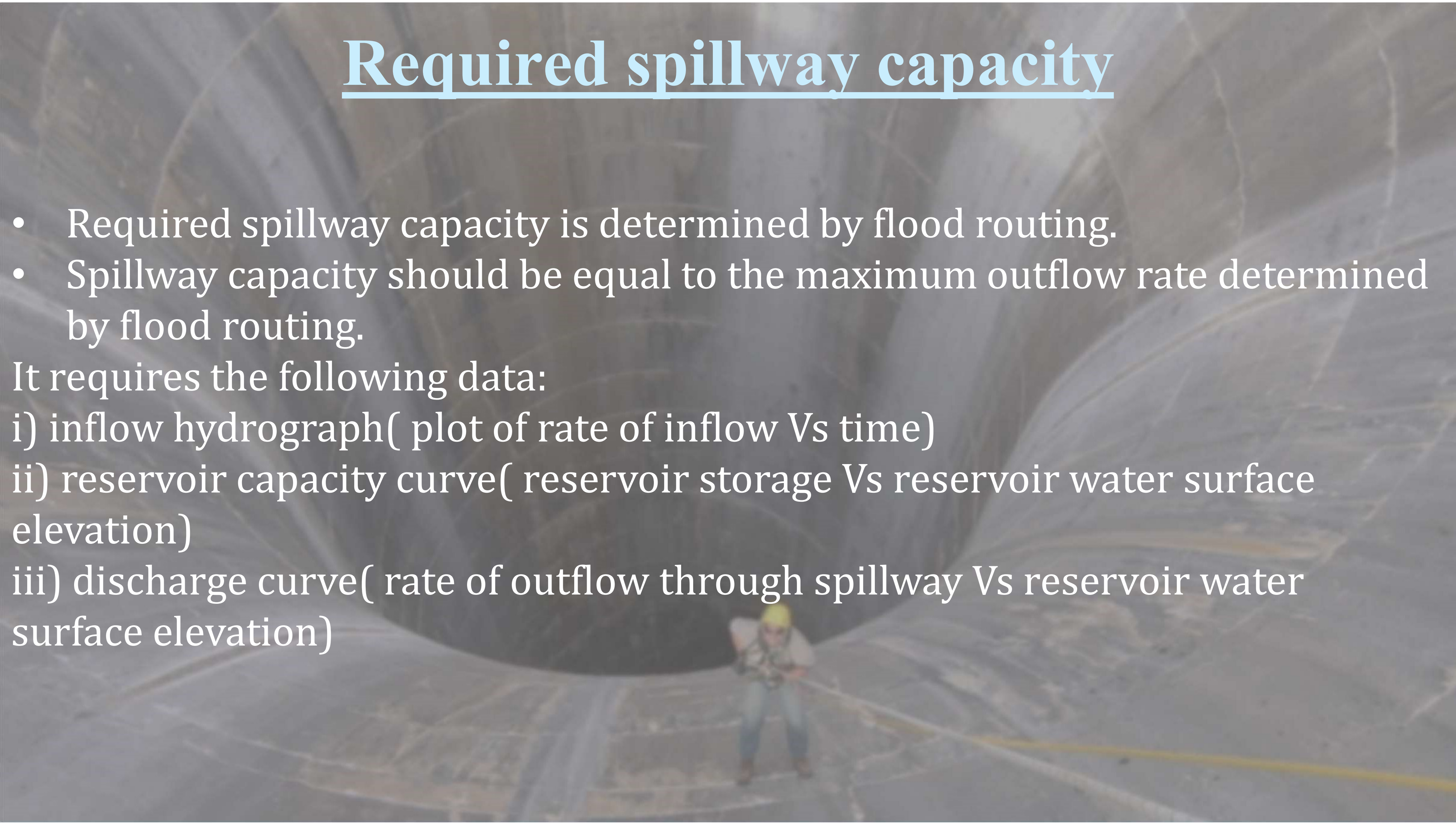
- Within the body of the dam
- At one end of dam.
- Entirely away from it, independently in a saddle.



With in the body

At one end

Entirely away



Required spillway capacity

- Required spillway capacity is determined by flood routing.
- Spillway capacity should be equal to the maximum outflow rate determined by flood routing.

It requires the following data:

i) inflow hydrograph(plot of rate of inflow Vs time)

ii) reservoir capacity curve(reservoir storage Vs reservoir water surface elevation)

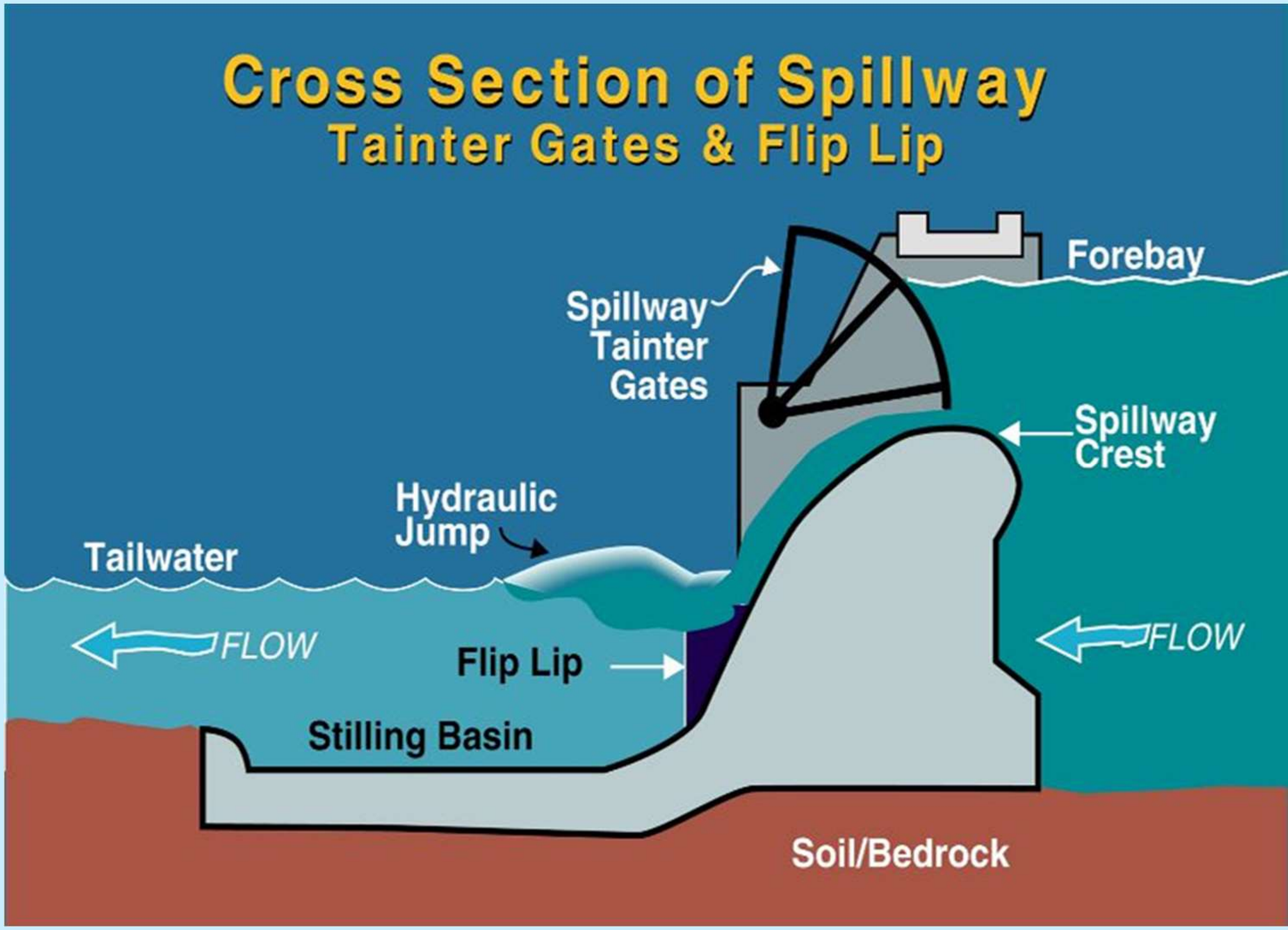
iii) discharge curve(rate of outflow through spillway Vs reservoir water surface elevation)

FACTORS AFFECTING THE REQUIRED SPILLWAY CAPACITY

1. Inflow flood hydrograph
2. Available storage capacity
3. Capacity of outlets
4. Gates of spillways
5. Possible damage, if the capacity is exceeded

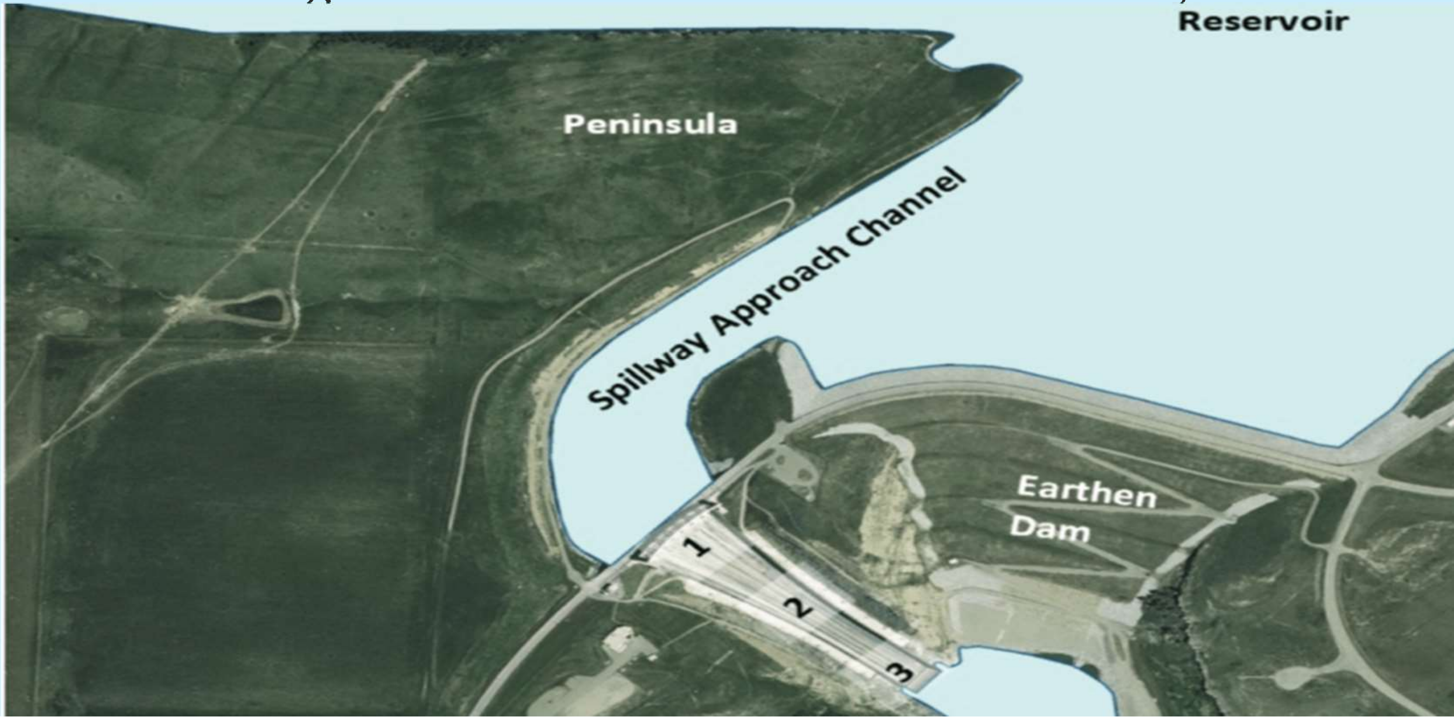
COMPONENT PARTS OF SPILLWAY

- Approach channel
- Control structure
- Discharge carrier
- Discharge channel
- Energy dissipators



Approach channel:

- Entrance structure or the path to draw water from reservoir and convey it to the control structure.
- It may be straight or curved in plan.
- Its banks may be parallel, convergent, divergent or combination of these and may be vertical or sloping.
- It may insure minimum head loss through the channel and to obtain uniformity of flow over the control structure



Control structure:

Major component of spillway provided with bridge and gates.
Regulates and controls the surplus water from the reservoir.
It does not allow discharge of water below the fixed reservoir level.

Discharge carrier:

It is the waterway provided to convey the flows released from the control structure to the downstream side of spillway.

The cross section may be rectangular, trapezoidal or of other shape.

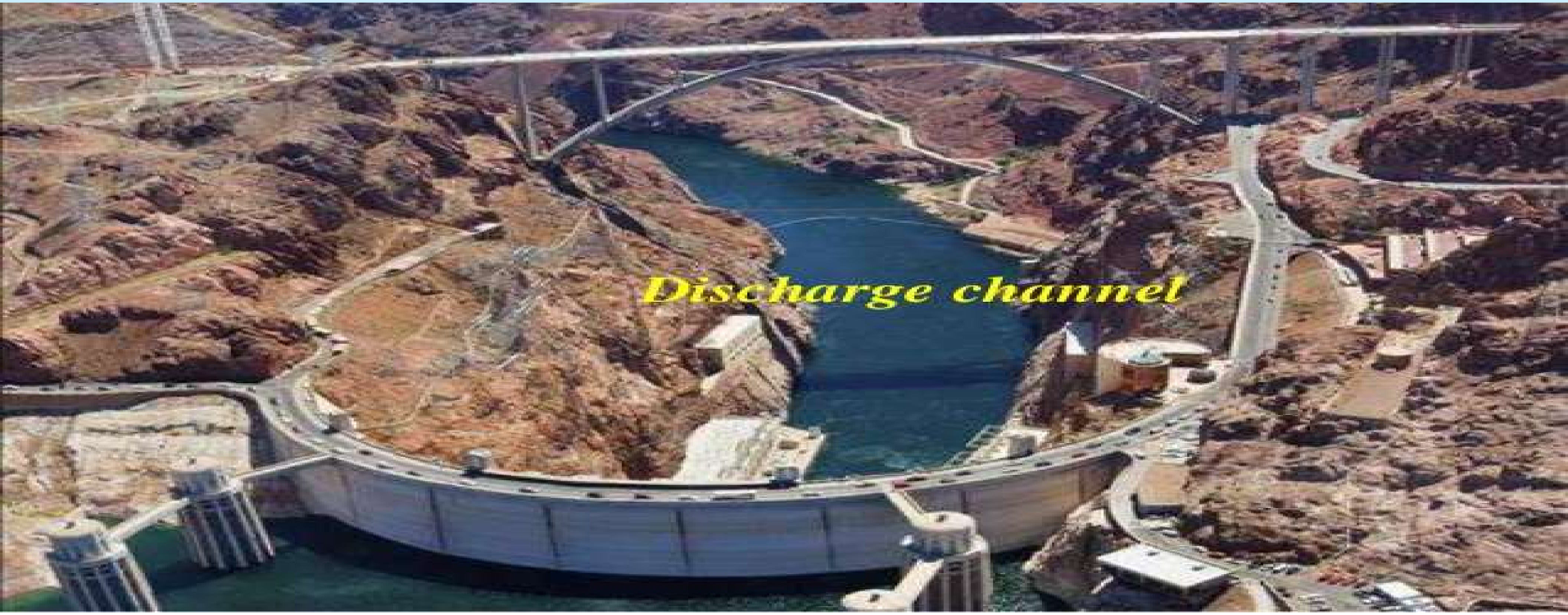
Waterway may be wide or narrow, long or short.

Discharge channel:

Provide to convey the water from bottom of the discharge carrier to the downstream flowing river.

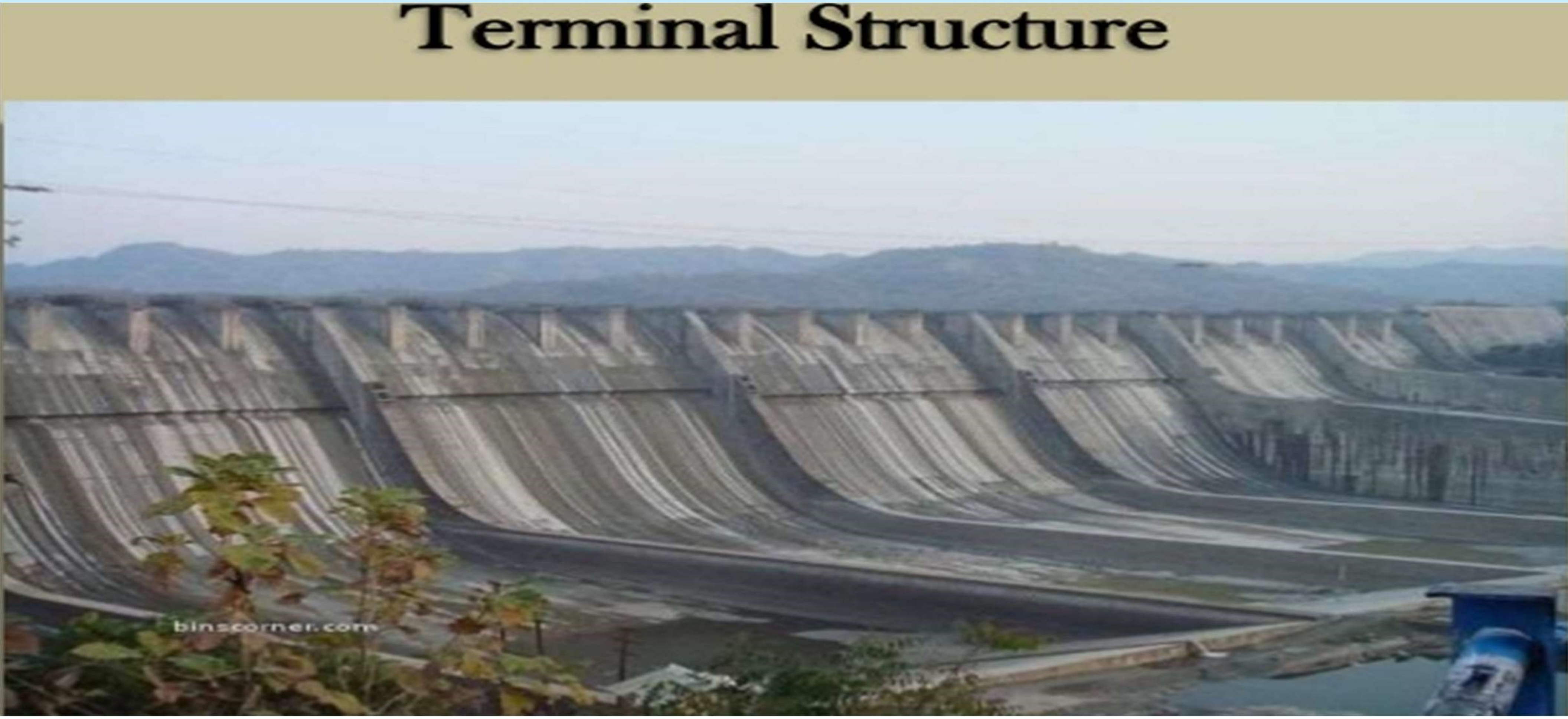
It may be the downstream face of spillway itself.

The width of discharge channel depends on amount of water to be conveyed.



Terminal structures (or energy dissipators):

Provided on downstream for dissipating the high energy of the flow, before the flow is returned to the river.



TYPES OF SPILLWAYS

Spillways can be classified into different types based on various criteria:

A. ***Classification based on purpose***

1. Main or service spillway 2. Auxillary spillway 3. Emergency spillway

B. ***Classification based on control***

1. Controlled or gated spillway 2. Uncontrolled or ungated spillway

C. ***Classification based on prominent feature***

1. free overfall (or straight drop)
2. overfall (or ogee spillway)
3. chute (or open channel or trough)
4. side channel spillway
5. shaft which (or morning glory)
6. siphon
7. conduit (or tunnel)

Classification based on purpose

- **Main spillway**

A main(or service) spillway is the spillway designed to pass a prefixed or the design flood.

This spillway is necessary for all dams and in most of the dams, it is the only spillway.

- **Auxiliary spillway**

It is provided as a supplement to the main spillway and its crest is so located that it comes into operation only after the floods for which the main spillway is designed are exceeded.

Total spillway capacity (Q) = $Q_m + Q_a$, Where Q is the designed flood,

Q_m is the capacity of main spillway,

Q_a is the capacity of the auxiliary spillway

- **Emergency spillway**

It is provided in addition to the main spillway but it comes into operation only during emergency which may arise at any time.

Classification based on control

- **Controlled spillway**

A controlled spillway is one which is provided with the gates over the crest to control the outflow from the reservoir.

In the controlled spillway, the full reservoir level (F.R.L) of the reservoir is usually kept at the top level of the gates. Thus the water can be stored up to the top level of the gates.

- **Uncontrolled spillway**

In an uncontrolled spillway the gates are not provided over the crest to control the outflow from the reservoir.

The full reservoir level(F.R.L) is at the crest level of the spillway. The water escapes automatically when the water level rises above the crest level.

Classification based on prominent feature

1. Free overfall or straight drop spillway:

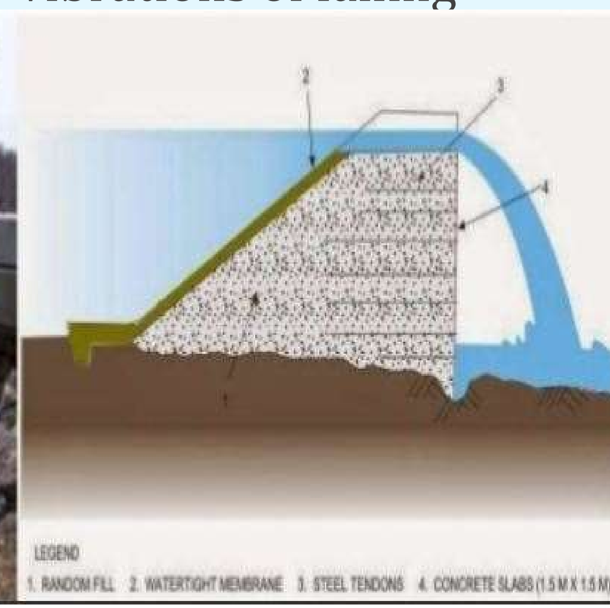
-In this type of spillway, the water freely drops down from the crest. It is a low weir and simple vertical fall type structures.

-The water falls freely from the crest under the action of gravity.

-To prevent scouring at the downstream, an auxiliary dam of artificial pool is to be constructed at the place of fall of water.

-This type of spillway is not recommended for high head since the vibrations of falling jet might damage the structure.

-To direct the small discharge away from the face of the overfall section the crest is extended to form a overhanging clip



2. Ogee or overflow spillway

-It represents the S-shape curve so, it is called ogee spillway.

-It is an improved form of straight drop spillway.

-It is mainly used in gravity dams.

-It has got the advantage over other spillways for its high discharging efficiency.

-The overflow water is guided smoothly over the crest so that water do not break the contact with the spillway surface.

3. Side channel spillway

-The flow in this spillway is turned 90˚ after passing the crest such that the flow is parallel to the weir crest.

-Best suitable for non rigid dams like earthen dams.

-It is preferred where space is not available for providing sufficient crest width for chute spillway.

-The discharge carrier may be an open channel type or a conduit type.

4. chute (or open channel or trough)

-It is often called as trough or open channel spillway.

-For earthen and rockfill dams, spillway is to be constructed separately away from the main valley.

-Chute Spillway is the simplest type of a spillway which can be easily provided independently and at low costs.

-It is lighter and adaptable to any type of foundations.

5. shaft which (or morning glory)

-The water from the reservoir enters into a vertical shaft which conveys this water into a horizontal tunnel which finally discharges the water into the river downstream.

-This type of spillway is preferred where the space is not available for providing the above type of spillways

-If the inlet leg is provided in shape of a funnel, it is called Morning Glory Spillway.

-It has maximum discharge even at low heads.

6. Siphon

-It works on the principle of syphonic action.

-It consists of a syphon pipe whose inlet leg is kept just below the normal pool level and an air vent kept at normal pool level is connected to the crown of syphon.

-When the water raises the pool level, syphonic action starts automatically and the water discharges to downstream side.

-When the water level falls below the pool level, air is

entered through air vent and the discharging of water stops.

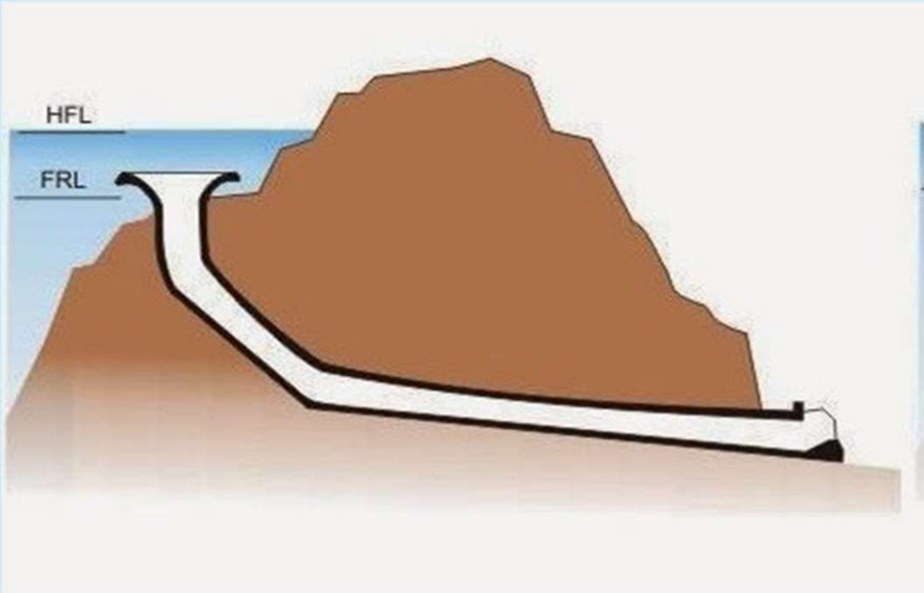
7. conduit (or tunnel)

- A conduit Spill-way consist of a closed conduit to carry the flood discharge to the downstream channel . It is constructed in the abutment or under the dam .

- The closed conduit may take the form of a vertical or inclined shaft, a horizontal tunnel, or a conduit constructed in an open cut and then covered.

- To ensure the free flow in the tunnel, the ratio of flow area to total tunnel area is often limited to 75%of air vents are provided.

- Such a spill-way is suitable for dam sites in narrow canyons with steep abutments.



Ogee profile

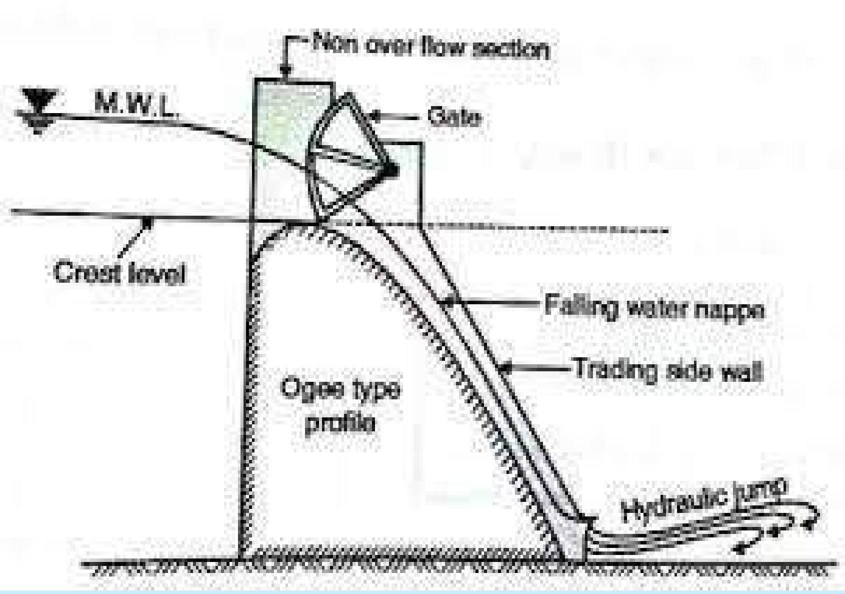
Ogee profile is acceptable as it provide

-maximum possible hydraulic efficiency

-structural stability and economy and

-avoid the formation of objectionable sub atmospheric pressures at surface

In the ogee- shaped spillway the nappe-shaped profile is an ideal profile because at the design head, the water flowing over the crest of the spillway always remains in contact with the surface of the spillway as it glides over it.

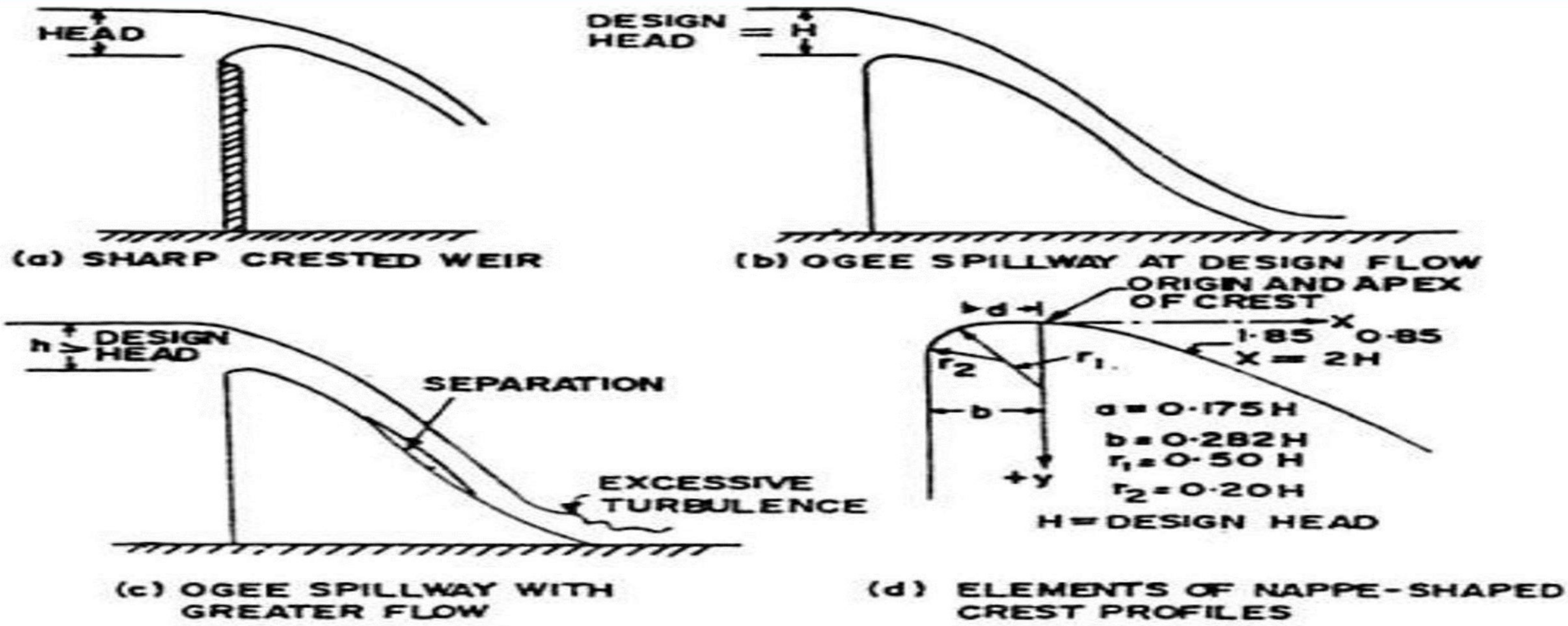


For this shape, no negative pressure will develop on the spillway surface at the design head.

Shape of the crest of the overflow spillway:

The shape of the ogee-shaped spillway depends upon a number of factors such as

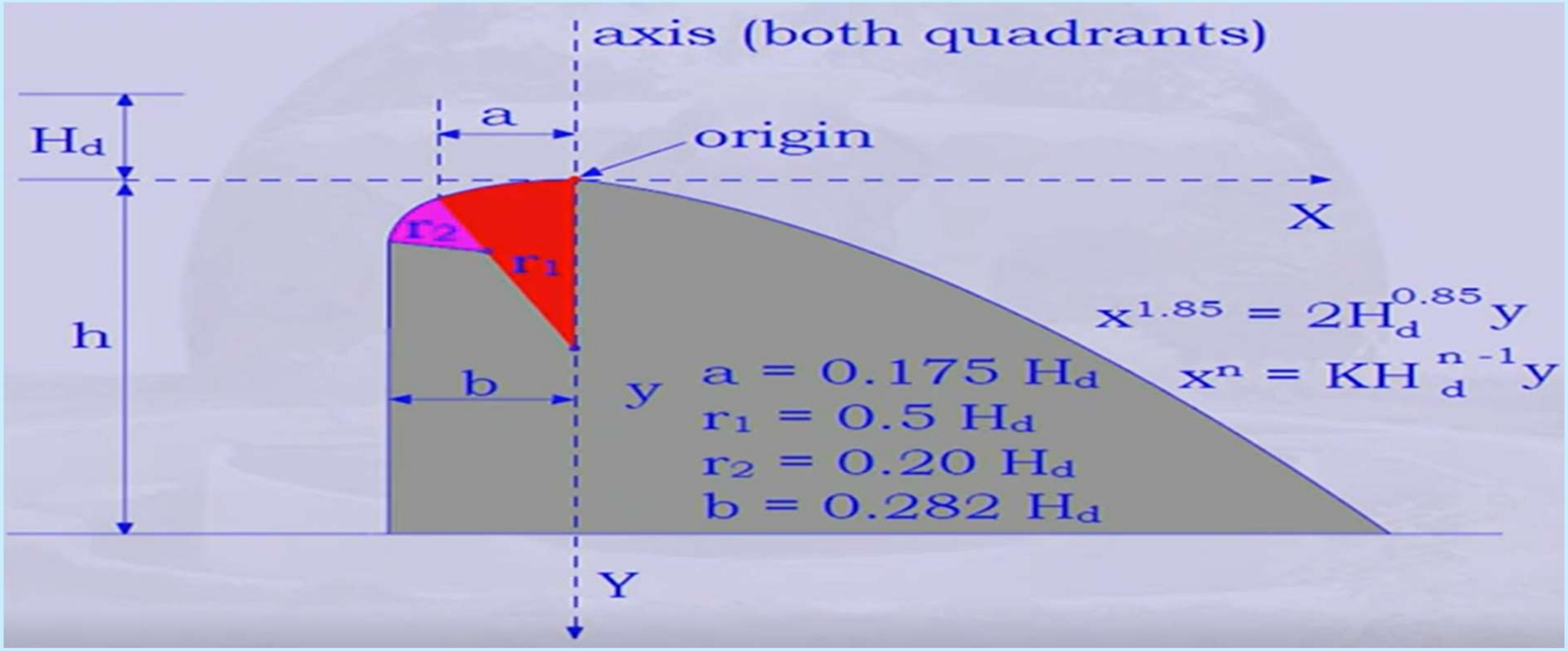
1. Head over the crest
2. Height of the spillway above the stream bed or the bed of the entrance channel
3. The inclination of the upstream face of the spillway



DESIGN PRINCIPLES OF OGEE SPILLWAY

Design criteria of downstream profile

The d/s profile of the spillway can be represented by the following equation: $x^n = KH_d^{n-1} Y$



Where x and y are the coordinates of the point on the spillway surface, with the origin at the highest point O of the crest,

H_d is the design head, excluding the head due to the velocity of approach,

K and n are constants, depends upon the inclination of the upstream face of the spillway

Design criteria of upstream profile

-To ensure that there is no discontinuity along the surface of flow the u/s profile should have zero slope at the crest axis.

-According to latest analytical studies of U.S army u/s curve of ogee shape has the equation:

$$y = \frac{0.724(x + 0.270\,H)^{1.85}}{H^{0.85}} + 0.126\,H - 0.4315\,H^{0.375}(x + 0.27\,H)^{0.625}$$

-It should be noted that u/s curve at crest should neither be made too sharp nor too broad.

-Broad crest supports the lower nappe, produces positive hydrostatic pressure & reduces discharge.

-If the curve is sharp the nappe leave the ogee profile, causing negative pressure & cavitation and increases discharge.

High overflow spillway

Overflow or ogee spillways are classified as high & low depending on ratio

$$\frac{height\ of\ the\ spillway\ crest\ from\ river\ bed}{Design\ Head\ (Hd)}$$

- **Head** (H): the distance between water surface to the crest axis.

- **Design head** (H_d): it is the value of head for which ogee profile is designed.

- **Head due to velocity approach** (H_a): it is the velocity head given by $H_a = V_a^2/2g$

- **Total energy head** (H_e): it is equal to the actual head plus the head due to velocity approach.

$$H_e = H + H_a \qquad \text{if } H = H_d,$$

$$H_{ed} = H_d + H_a$$

Discharge computation for an ogee spillway

The discharge over an ogee spillway is computed from the basic equation of flow over weirs, given below:

$$\mathbf{Q = C_d L_e H_e^{3/2}}$$

Where, Q is discharge(cumecs),

C_d is the coefficient of discharge,

L_e is the effective length

H_e is the actual effective head including the head due to the velocity of approach, i.e. $H_e = H_d + H_a$.

Effective length of crest:

The effective length of crest of an overflow spillway is given by

$$\mathbf{L_e = L' - 2(NK_p + K_a)\, H_e}$$

Where L_e is the effective length of crest,

L' is the net length of crest,

H_e is the actual total head of flow on crest,

N is the number of piers,

K_p is the pier contraction coefficient,

K_a is the abutment contraction coefficient

✓ Problems

1.

11.5. Example 11.5. *Design an ogee spillway for concrete gravity dam, for the following data :*

1. *Average river bed level* = 250.00 m
2. *R.L. of spillway crest* = 350.00 m
3. *Slope of d/s face of gravity dam* = 0.75 : 1
4. *Design discharge* = 6500 cumecs
5. *Length of spillway* = 5 spans with a clear length of 9 m each
6. *Thickness of each pier* = 2 m

Solution

Step 1 : Computation of design head

$$Q = C_d \cdot L_e H_e^{3/2} \text{ where } L_e = L - 2\,[NK_p + K_a]\,H_e$$

To start with, let us assume $C_d = 2.2$, applicable for high over flow spillway

Also, let $L_e \simeq L =$ clear water way $= 5 \times 9 = 45$ m

$\therefore$ $6500 = 2.2 \times 45\, H_e^{3/2}$ from which $H_e = 16.27$ m

The height (P) of spillway crest above river bed $= 350 - 250 = 100$ m

Since $\dfrac{P}{H_d} \simeq \dfrac{P}{H_e} = \dfrac{100}{16.27} = 6.15$ is greater than 1.33, it is a high overflow spillway, for which the effect of velocity of approach is negligible.

Also, with reference to Fig. 11.11 (*b*), we have

$$\frac{h_d + d}{H_{de}} = \frac{H_{de} + P}{H_{de}} = \frac{16.27 + 100}{16.27} = 7.15 > 1.7$$

Hence the discharge coefficient is not affected by down stream apron interference as well as on the tail water conditions.

The above value of H_e has been computed by taking $L_e \simeq L$. Actual value of L_e is given by $L_e = L - 2\,[NK_p + K_a\,]\,H_e$

Let us assume rounded nose piers and rounded abutments.

Thus we have $K_p = 0.01$ and $K_a = 0.1$. Also $N = 4$. Assuming $H_e \simeq 17.5$ m (i.e. slightly more than the one computed above), we get

$\therefore$ $L_e = 45 - 2\,[4 \times 0.01 + 0.1] \times 17.5 = 40.1$ m

Substituting this value of L_e in discharge equation, we get

$$6500 = 2.2 \times 40.1 \times H_e^{3/2} \text{ from which } H_e = 17.58 \text{ m}$$

which is quite near to the assumed value of $H_e = 17.5$ m.

Hence the crest profile will be designed for $H_d = 17.58$ m, thus neglecting the head due to velocity of approach.

However, velocity of approach, $V_a = \frac{Q}{Area} = \frac{6500}{(45 + 4 \times 2)(100 + 17.58)} = 1.043$ m/s

$\therefore$ Velocity head, $H_a = \frac{V_a^2}{2g} = \frac{(1.043)^2}{2 \times 9.81} \simeq 0.055$ m

Hence the velocity head is quite small (being only 0.3% of the total head) and it is quite justified in neglecting this.

Step 2. Determination of d/s profile

Let us keep u/s face vertical. The d/s profile suggested by WES, for vertical face is given by Eq. 11.1 :

$$x^{1.85} = 2\, H_d^{0.85} \cdot y$$

Hence
$$y = \frac{x^{1.85}}{2\, H_d^{0.85}} = \frac{x^{1.85}}{2\,(17.58)^{0.85}} = 0.04372\, x^{1.85} \quad ...(1)$$

Let us now determine the tangent point (T.P.), for a downstream slope of 0.75 $(H) : 1\ (V)$

$$\therefore \quad \frac{dy}{dx} = \frac{1}{0.75} \quad ...(2)$$

However, differentiating Eq. (1), w.r. to x, we get

$$\frac{dy}{dx} = 1.85 \times 0.04372\, x^{1.85-1} = 0.0809\, x^{0.85} \quad ...(3)$$

Equating (2) and (3), $0.0809\, x^{0.85} = \frac{1}{0.75}$

or
$$x^{0.85} = 16.484, \text{ from which } x = 27.03 \text{ m}$$

Hence from (1), $y = 19.48$ m

Hence the coordinates of the tangent points are (27.03 m , 19.48 m).

The co-ordinates of the curve for $x = 0$ to $x = 27.03$ m are given in the table below.

x (m)	$y = 0.04372\, x^{1.85}$	x (m)	y (m)	x (m)	y (m)
1	0.044	7	1.600	18	9.182
2	0.158	8	2.048	20	11.158
3	0.334	10	3.096	22	13.310
4	0.568	12	4.337	24	15.654
5	0.859	14	5.768	26	18.129
6	1.203	16	7.384	27.03	19.480

Step 3. Determination of u/s profile

For vertical u/s face, the u/s profile is given by Eq. 11.2. The u/s curve extends upto $x = -0.27\, H_d$. Thus

$$y = \frac{0.724\,(x + 0.27\, H_d)^{1.85}}{H_d^{0.85}} + 0.126\, H_d - 0.4315\, H_d^{0.375}\,(x + 0.27\, H_d)^{0.625}$$

Taking $H_d = 17.58$ m, we get

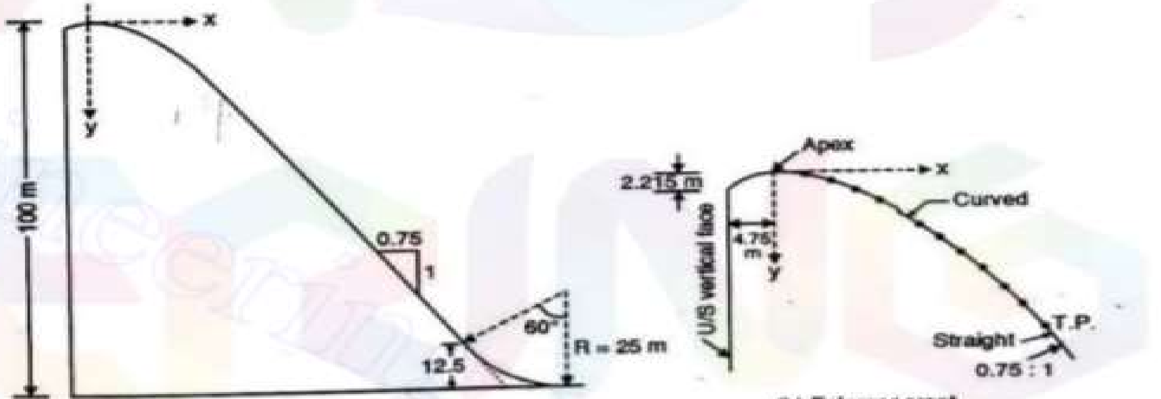
$$y = \frac{0.724\,(x + 0.27 \times 17.58)^{1.85}}{(17.58)^{0.85}} + 0.126 \times 17.58 - 0.4315\,(17.58)^{0.375}\,(x + 0.27 \times 17.58\,)^{0.625}$$

or $$y = 0.0633\,(x + 4.7466)^{1.85} + 2.2151 - 1.2643\,(x + 4.7466)^{0.625} \qquad ...(4)$$

The curve will extend upto $x = -0.27 \times 17.58 \simeq -4.75$ m

Hence the value of y coordinates are calculated for the values of $x = -0.5$ m, -1.0 m, -1.5 m, -2 m, -3 m, -4 m and -4.75 m and tabulated as under.

x (m)	y (m)
−0.5	0.012
−1.0	0.057
−1.5	0.135
−2.0	0.248
−3.0	0.601
−4.0	1.199
−4.75	2.215



(a) Spillway section (b) Enlarged crest

FIG. 11.23

4. *Step 4: Design of d/s bucket*

The profile of the spillway is shown in Fig. 11.23 (a). A reverse curve at the toe is provided to form a bucket. The radius of the bucket is generally kept at $R = P/4 = 100/4 = 25$ m. The bucket will subtend an angle of 60° at the centre, as shown.

...TION BELOW SPILLWAYS

2.

Design of spillway

- Design an ogee spillway for concrete gravity dam, for the following data :
- (1) Average river bed level = 250.0 m
- (2) R.L. of spillway crest =350.0 m

- (3) Slope of d/s face of gravity dam = 0.75 H : 1 V
- (4) Design discharge = 6500 cumecs
- (5) Length of spillway = 5 spans with a clear width of 7 m each.
- (6) Thickness of each pier = 2.0 m

- Calculation of design head

$$Q = CL_e H_e^{3/2}$$

$$L_e = L - 2[N * K_P + K_a] H_e$$

$$L_e = L = 5 * 7 = 35$$

$$6500 = 2.2(5 * 7)\ H_e^{3/2}$$

$$H_e^{3/2} = 84.41$$

$$H_e = 19.24$$

$$H_e = 19.50$$

$$h = 350 - 250 = 100$$

$$\frac{h}{H_d} = \frac{100}{19.5} = 5.12 \geq 1.33$$

VELOCITY APPROACH CAN BE NEGLECTED

$$\frac{h + H_d}{H_d} = \frac{100 + 19.5}{19.5} = 6.12 \geq 1.7$$

EFFECT ON DISCHARGE COEFFICIENT IS NEGLECTED

$$L_e = L - 2[N * K_p + K_a]H_e$$

$$L_e = 35 - 2[4 * 0.01 + 0.1]20$$

$$= 29.4$$

$$Q = CL_e H_e^{3/2}$$

$$6500 = 2.2(29.4)H_e^{3/2}$$

$$H_e = 21.6$$

$$x^{1.85} = 2 \cdot H_d^{0.85} \cdot y$$

$$Y = \frac{X^{1.85}}{27.24}$$

$$\frac{dy}{dx} = \frac{1}{0.75}$$

$$\frac{dy}{dx} = \frac{1.85x^{0.85}}{27.24}$$

$$\frac{dy}{dx} = 0.0678x^{0.85}$$

Comparing both dy/dx we get x = 33.26 and Y =24.01

$$Y = \frac{X^{1.85}}{27.24}$$

X	Y
1	0.036
2	0.132
3	0.265
4	0.477
5	0.720
6	1.01
7	1.343
8	1.719
9	2.138
10	2.598
14	4.843
18	7.709
22	11.175
26	15.22
30	19.836
33.6	24.463

u/s profile :

$$y = \frac{0.724\,(x + 0.27\,H_d)^{1.85}}{(H_d)^{0.85}} + 0.126 H_d - 0.4315\,(H_d)^{0.375}\,(x + 0.27\,H_d)^{0.625}$$

$$y = 0.05(x+5.832)^{1.85} + 2.72 - 1.365(x+5.832)^{0.625}$$

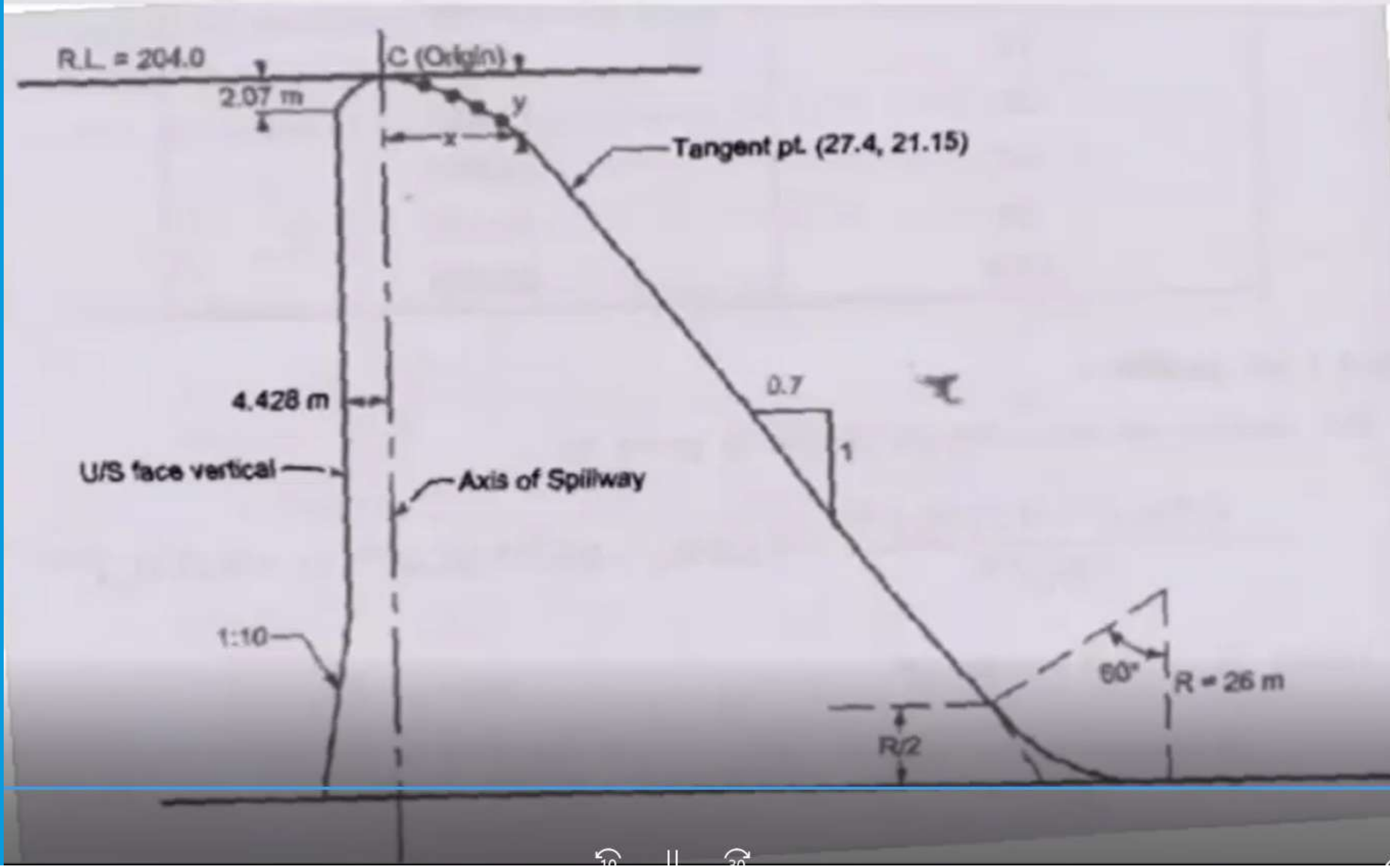
- ***This curve will extend up to,***

$$x = -0.27\,H_d$$

X=-0.27*21.6

= - 5.832

$$y = 0.05(x+5.832)^{1.85} + 2.72 - 1.365(x+5.832)^{0.625}$$


R.L. = 204.0
C (Origin)
2.07 m
y
x
Tangent pt. (27.4, 21.15)
4.428 m
0.7
1
U/S face vertical
Axis of Spillway
1:10
60°
R = 26 m
R/2

TYPES OF SPILLWAY GATES

Gates are placed to control the flow of water from the crest. This gives the spillway a controlled spillway.

A spillway without gate is called an uncontrolled spillway.

1. Flash boards, stop logs and needles
2. Radial gates
3. Drum gates
4. Vertical lift gates
5. Bear trap gates
6. Rolling gates

Flash boards:

-Flash boards are wooden boards or panels, placed side by side, on the crest of the spillways to form a continuous shutter.

-These are simplest and oldest types of gates.

-These are quite efficient and economical for small heights where they can be readily handled by the lifting arrangements.

-The flash boards can be temporary or permanent.

Stop logs:

-Stop logs are horizontal wooden timber beams which span the space between grooved piers constructed on the crest of the spillway.

-Stoplogs are pushed down into the grooves from top, one over the other.

-The logs may be raised by hands or with a hoist.

-Stoplogs are generally used for small spillways.

Needles:

-Needles are wooden logs placed in an inclined position, with their lower ends resting in a keyway on the spillway crest and their upper ends supported on a bridge.

-These are placed and removed by hands.

-Needles are somewhat easier to remove than stop logs, but are more difficult to place in flowing water.

-Needles are also used for small spillways and weirs.

Radial gates:

-A tainter gate(or radial gate) has the upstream face cylindrical. The axis of the segment of the cylinder forming the u/s face is horizontal.

-The face is formed of a steel skin plate shaped to a segment of a hollow cylinder supported on a steel framework.

-Radial gates have a number of advantages over the vertical gates and are quite popular. The friction in the radial gates is concentrated at the pins and is usually much less than that in the vertical gates.

-Because of the face of radial gates is cylinder, the water pressure acts normal to the face and the resultant water pressure passes through its centre.

-These gates have been used up to 15m height and 20m span.

-These are usually more economical than the vertical gates of the same size.

Radial gates

Drum gates:

-A drum gate consists of a segment of cylinder of such a shape that when the gate is in the lowered position, it fits in a recess made in the top portion of the spillway, and the flood water passes over it.

-The drum gates is formed by fixing skin plates to an internal bracing systems. It is hinged on its upstream edge at the centre of curvature to the spillway crest.

-This type of gate can also be designed for automatic operation. Drum gates are suitable for long spans with moderate heights.

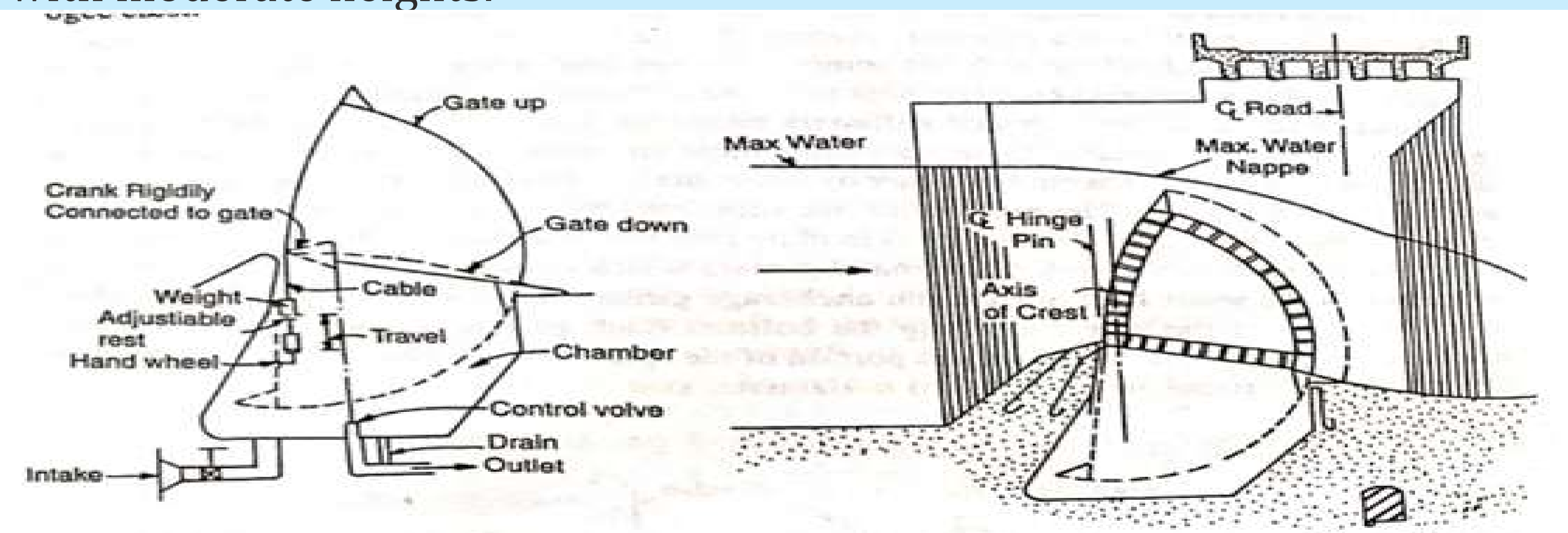


Fig. 20.33 (a) Drum gate.

Fig. 20.33 (b) Diagramatic layout of drum gate.

Drum gates

Vertical lift gates:

-Vertical rectangular gates are commonly used for spillways.

-A vertical lift gate consists of a vertical framework fabricated of steel members.

-A steel skin plate is fixed on the upstream side of the steel framework. The vertical gate can move vertically on its own plane in the grooves provided in piers.

-The vertical gates are raised or lowered by a hoisting arrangement through cables attached to them. These gates are usually provided with counterweights to reduce the lifting force.

The vertical gates are mainly of the following types:

i)Sliding gates

ii)Stoney gates

iii)fixed- wheel gates

Bear trap gates:

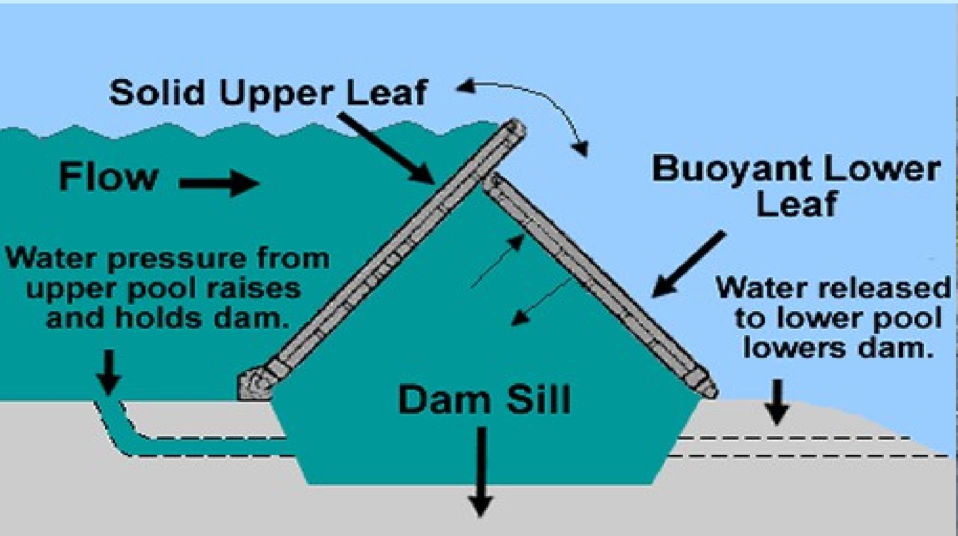
-Bear trap gates are also known as movable drum gates.

-A bear trap gate consists of two leaves of steel, with one leaf hinged on the upstream side and the other on the downstream side over the crest.

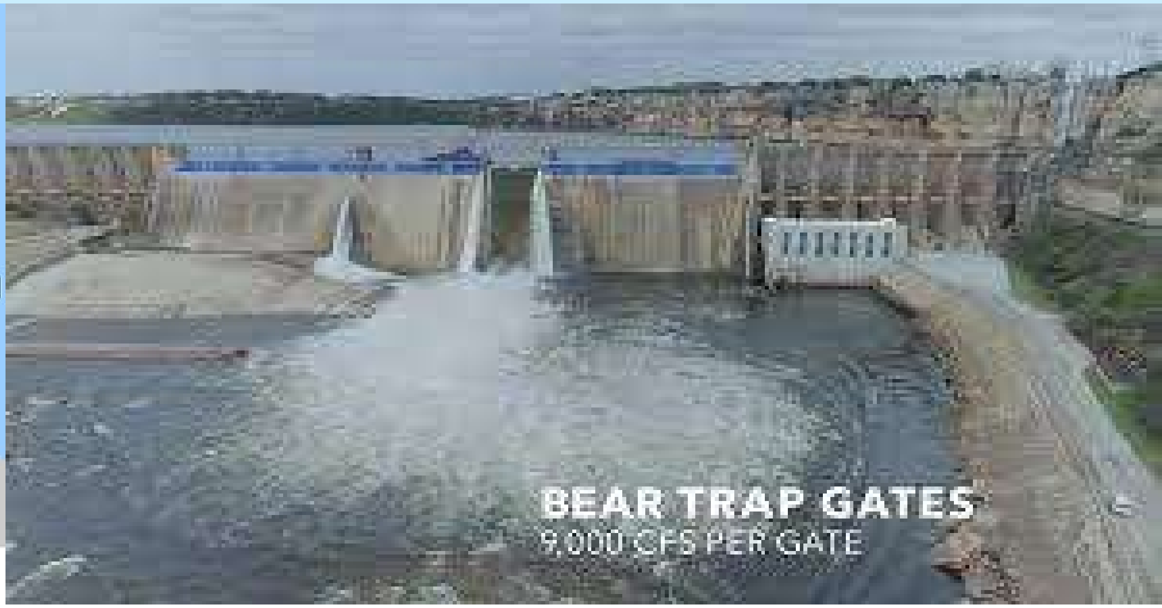
-The bear trap gates are suitable for low navigation dams.

-These gates have a wide base but a deep recess is not required.

-These gates may be designed to operate automatically.



Bear trap gate



Thank you