Spillways

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Spillway

Spillway: Structural component of a dam that evacuates flood wave from reservoir to a river at the downstream.

* Spillway is safety valve of a dam

DESIGN RETURN PERIOD

From 100 yrs for diversion weir to 15,000 yrs or more (Probable Maximum Flood-PMF) for earth-fill dams

TYPES OF SPILLWAYS

The more common types are:

1) Overflow (Ogee crested)
2) Chute
3) Side Channel
4) Shaft
5) Siphon

Dams should have **spillways** that are designed to pass water to the downstream side of the river safely.

Spillways

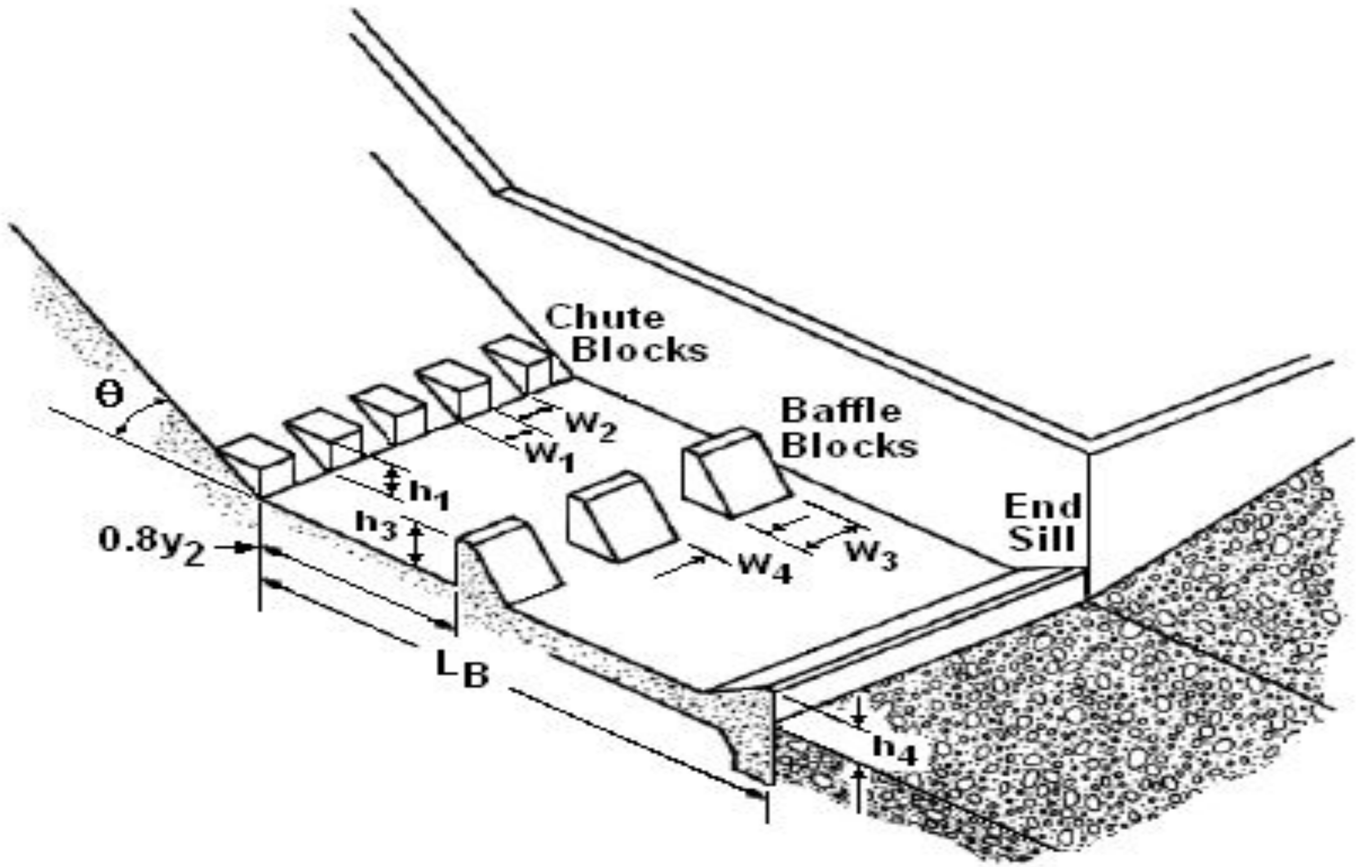
1) dissipate huge floods
2) maintain a certain quantity of water to reach the downstream side of the river for aquatic life
3) protect the dam from being overtopped

OVERFLOW SPILLWAYS

Most of the spillways are overflow types. Overflow spillways

* Have large capacities
* Have higher hydraulic conformities
* Can be used successfully for all types of dams
* Allow the passage of flood wave over its crest
* Are often used on concrete gravity, arch and buttress dams
* Are constructed as a separate reinforced concrete structure at one side of the fill-typed dams
* Are classified as uncontrolled (ungated) and controlled (gated)

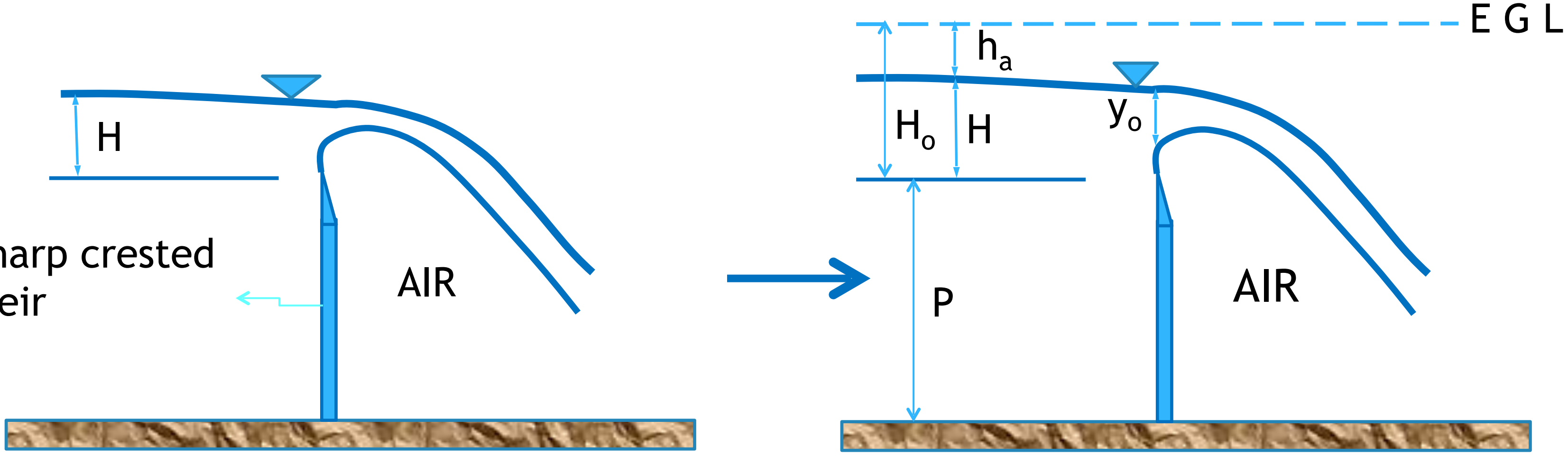
Stilling Basin



OVERFLOW SPILLWAYS

- Ideal Spillway Shape

The underside of the nappe of a sharp-crested weir when $Q=Q_{max}$



The Overflow spillway

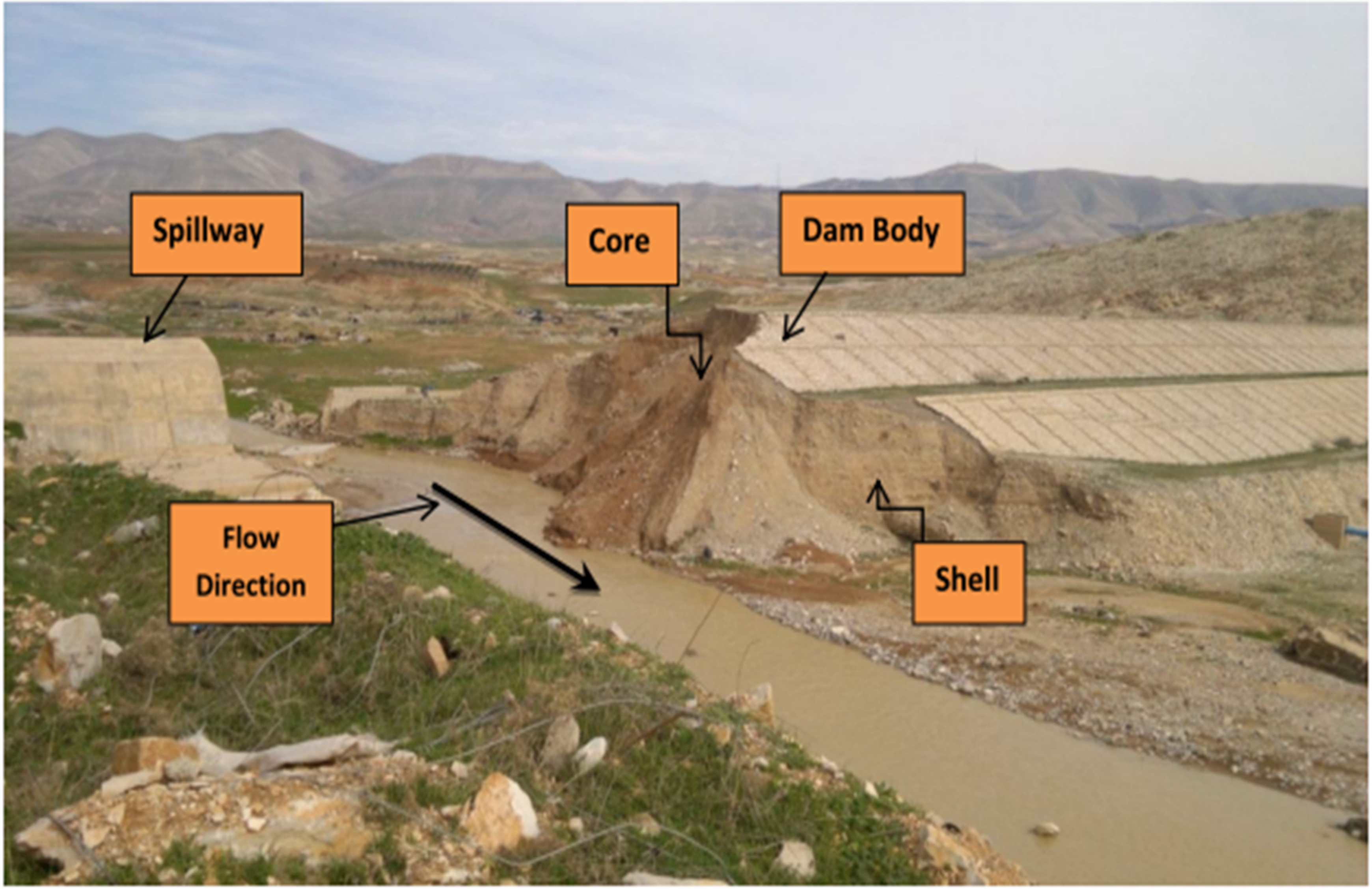
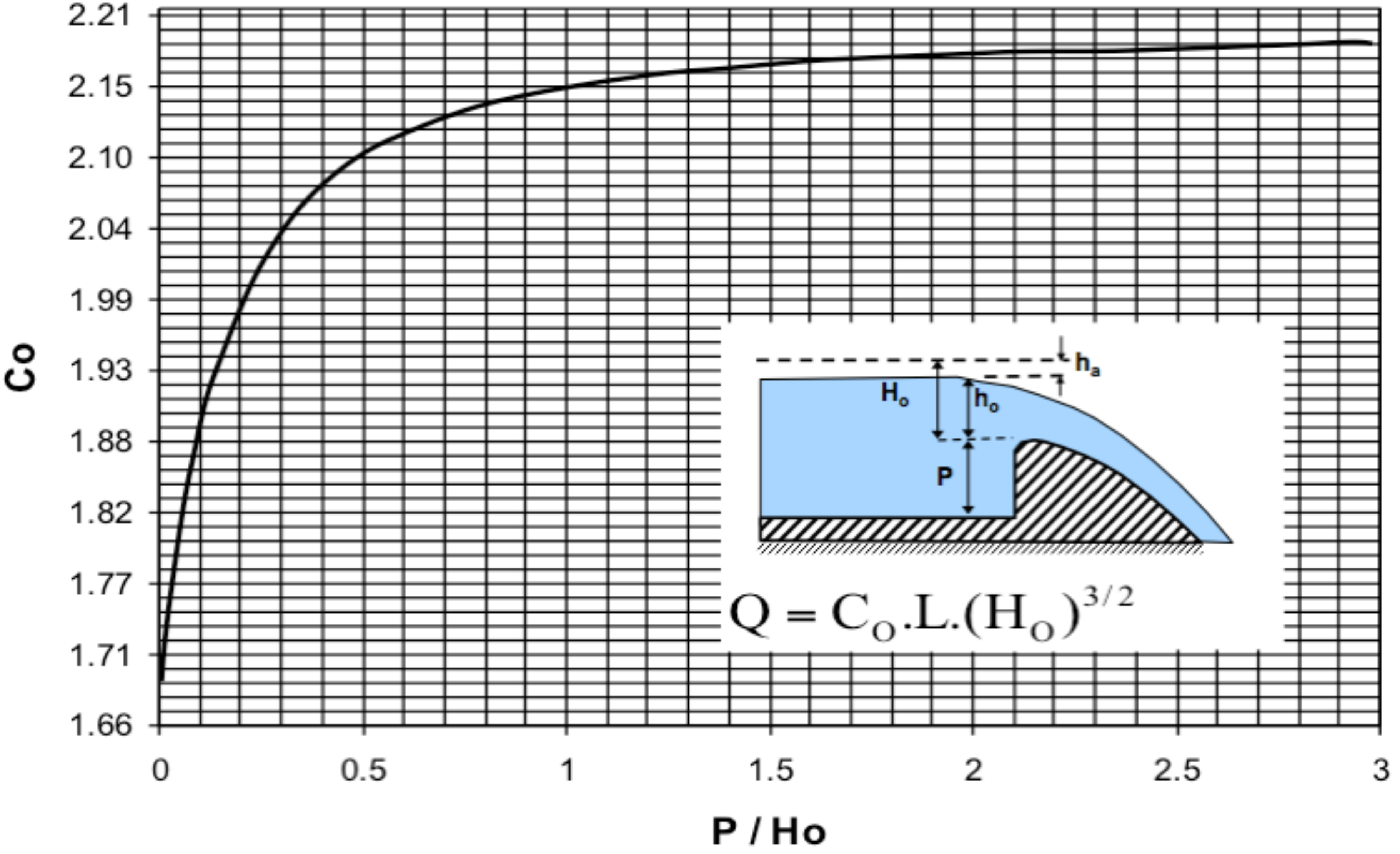


Figure 2: Photo of Chaq- Chaq dam after failure.

Determine the discharge rating curve from : $Q = C\,L\,H^{3/2}$



OVERFLOW SPILLWAYS

A. Design Discharge of Spillway

Design discharge of an overflow spillway can be determined by integrating velocity distribution over the cross-sectional flow area on the spillway from the crest to the free surface.

- The equation can be obtained as below

$$Q_o = C_o \, L \, H_o^{3/2}$$

where

* Q_o is the design discharge of a spillway
* C_o is discharge coefficient
* L is the effective crest length
* H_o is total head over the spillway crest

OVERFLOW SPILLWAYS

The effective crest length can be computed as following equation

$$L = L' - 2(N\,K_p + K_a)H_o$$

where

* L' is the net crest length which is equal to the total crest length.
* N is the number of bridge piers.
* K_p is presence of piers coefficient
* K_a is abutments coefficient
* H_o is total head over the spillway crest

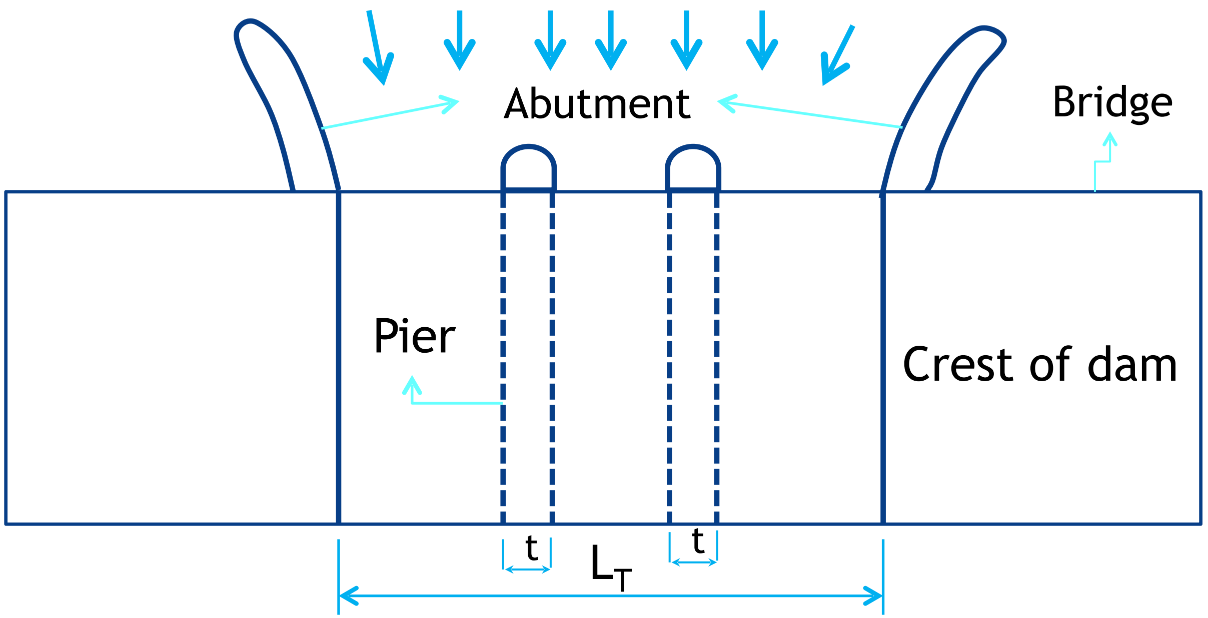
OVERFLOW SPILLWAYS

Usually, a bridge is constructed over the spillway crest to provide the transportation on the crest between two sides of a dam. Piers are constructed on the crest of an overflow spillway to mount gates, to divide the spillway in various chutes such that gentle flow conditions prevail in narrow chutes.

Contraction coefficients due to pier and abutment (USBR, 1987)

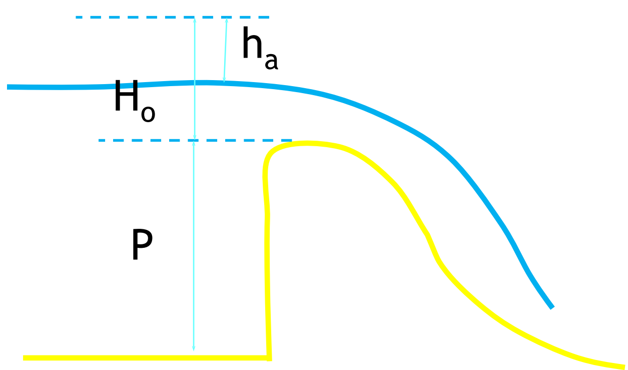
Coefficient	Value	Description
K_p	0.02 0.01 0	Square nosed piers with corners rounded by r=0.1 t Rounded nosed piers Pointed nosed piers
K_a	0.20 0.10 0	Square abutments with head wall 90^o to the direction of flow Rounded abutments with head wall 90^o to the direction of flow when $0.1\ H_o < r < 0.15\ H_o$ Rounded abutments where $r > 0.5\ H_o$ and head wall is placed not more than 45^o to the direction of flow

OVERFLOW SPILLWAYS

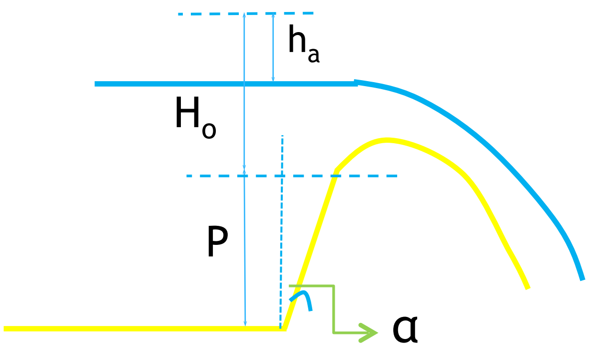


Plan view of an overflow spillway

OVERFLOW SPILLWAYS

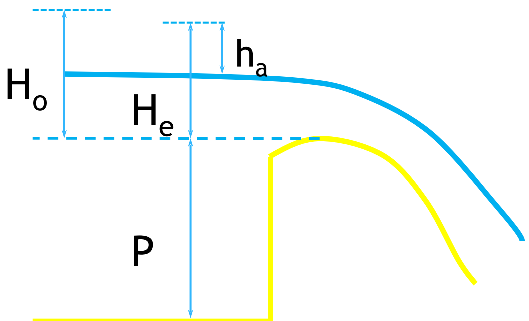


Vertical upstream face under design case

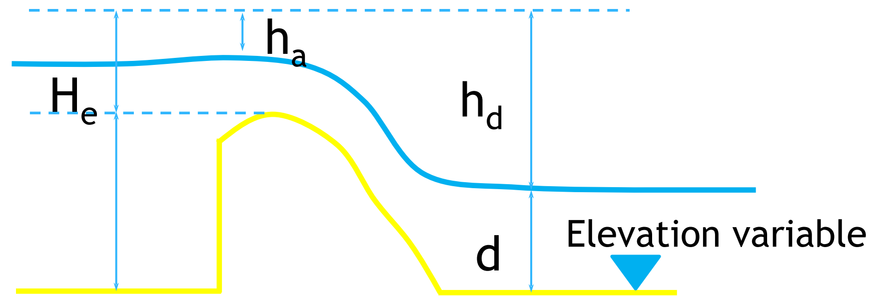


Sloping upstream face under design case

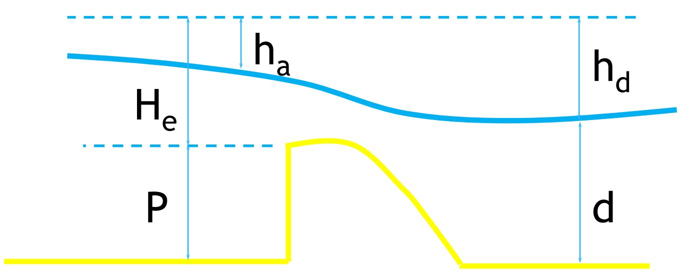
OVERFLOW SPILLWAYS



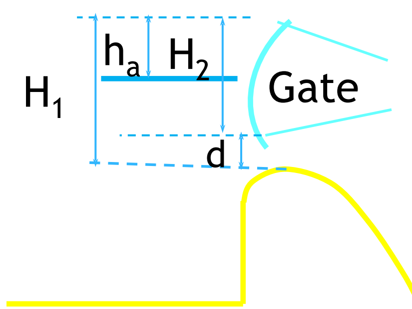
Existing heads other than design head



Position of apron level



Submergence effect



Flow through gate

OVERFLOW SPILLWAYS

Determined from Figures for the vertical overflow spillways as a function of P (spillway height) / Ho (total head)

- USE Fig. to modify C_o for inclined upstream face.
- USE Fig. to obtain C_o for heads other than design head.
- USE Fig 4.8 to reflect “apron effect” on C_o.
- USE Fig. to reflect “tailwater effect” on C_o.

OVERFLOW SPILLWAYS

B. Design Discharge of a Spillway

If the gates are partially opened, the discharge can be computed as follows

$$Q = 2/3\ (2g)^{0.5}\ C\ L\ (H_1^{3/2} - H_2^{3/2})$$

where

* g is the gravitational acceleration
* C is the discharge coefficient for a partially open gate
* L is the effective crest length
* H_1 and H_2 are the heads as defined in Figure
* **C:** Discharge Coefficient determined from Figure

OVERFLOW SPILLWAYS

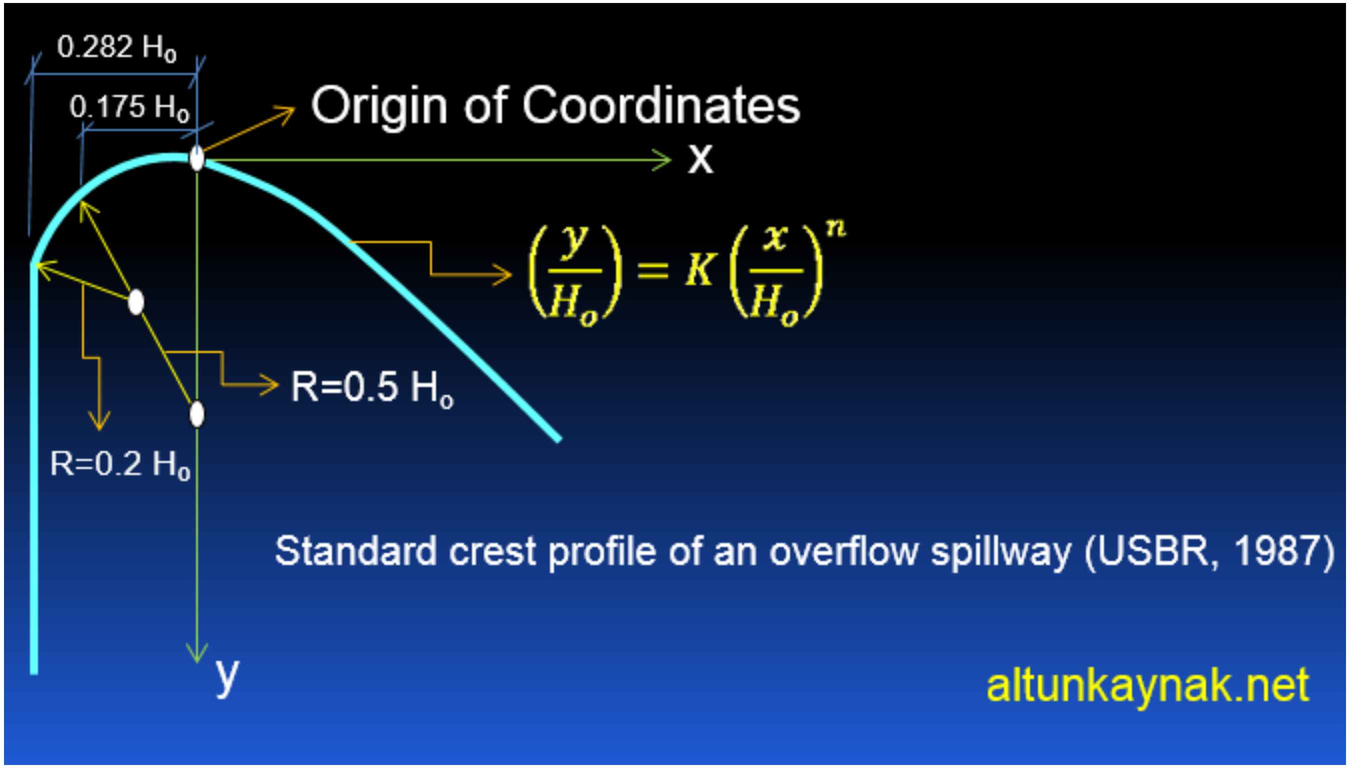
CREST GATES

* Provide additional storage above the crest
* See Fig. 4.11 for Primitive types of gates.
* See Fig. 4.11 for Underflow gates.
* Common types: radial and rolling

CREST PROFILES

The ideal shape of overflow spillway crest under design conditions for a vertical upstream face is recommended by USBR (1987)

OVERFLOW SPILLWAYS



OVERFLOW SPILLWAYS

A continuous crest profile is proposed by Hager (1987) for the upstream part of the crest which is defined by two curves as stated before. This equation is given by

$$Y^* = -X^* \ln X^* \quad for \quad \frac{x}{H_o} > -0.2818$$

$$X^* = 1.3055\left(\frac{x}{H_o} + 0.2818\right)$$

$$Y^* = 2.7050\left(\frac{y}{H_o} + 0.136\right)$$

OVERFLOW SPILLWAYS

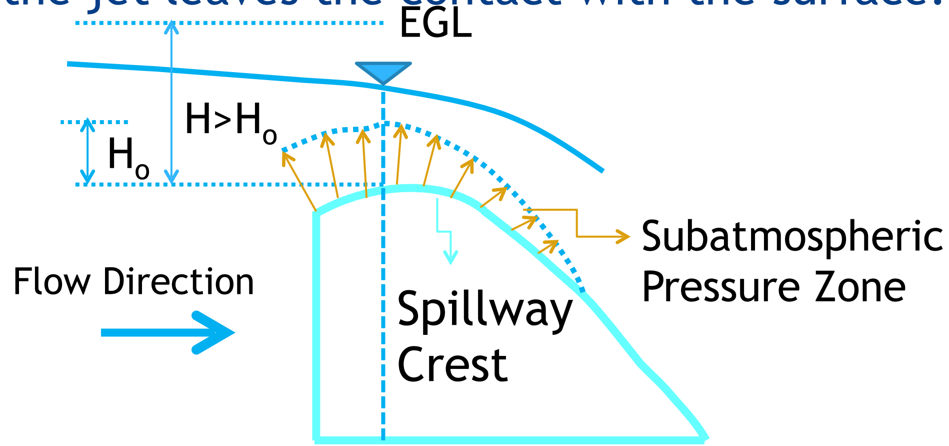
- The values of “K” and “n” in the parabolic relation given in Figure can be determined from Figure .
- The pressure distribution on the bottom of the spillway face depends on the smoothness of the crest profile.

Important Note:

  - The upstream face of the crest is formed by smooth curves in order to minimize the separation
  - For a smooth spillway face, the velocity head loss over the spillway can be ignored.

OVERFLOW SPILLWAYS

- If H (head) > H_o → $p < p_{atm.}$ ↔ "overflowing water" may lose contact with the spillway face, which results in the formation of a vacuum at the point of separation, and CAVITATION may occur.
- In order to prevent cavitation, sets of ramps are placed on the face of overflow spillways so that the jet leaves the contact with the surface.

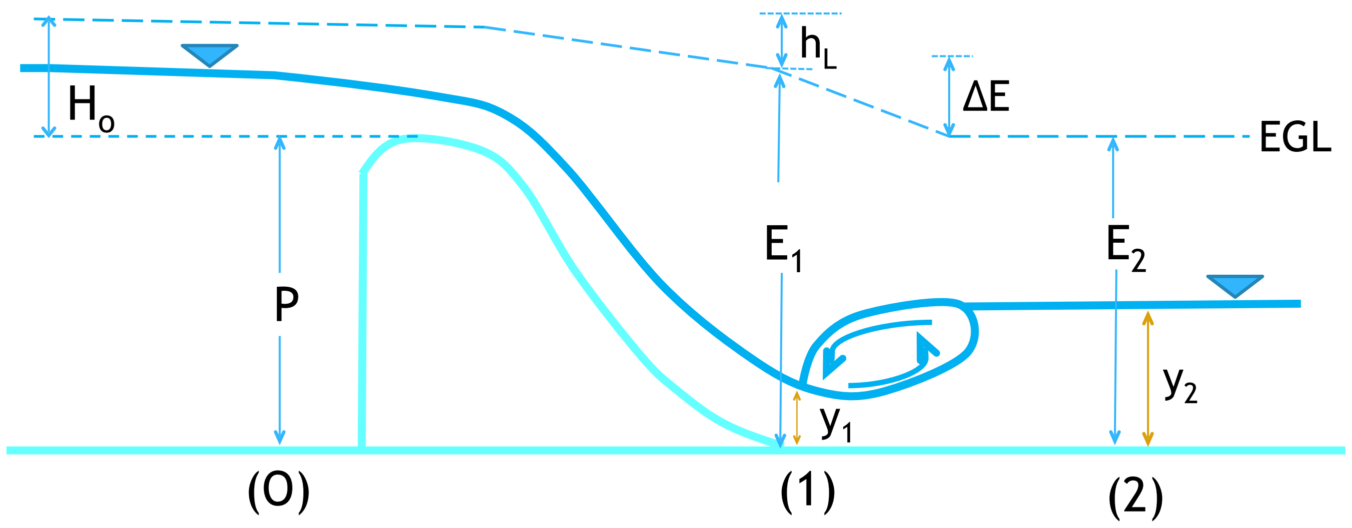


Development of negative pressures at the spillway crest for H>H

OVERFLOW SPILLWAYS

Energy Dissipation at the Toe of Overflow Spillway

- Excessive turbulent energy at the toe of an overflow spillway can be dissipated by a hydraulic jump, which is a phenomenon caused by the change in the stream regime from supercritical to subcritical with considerable energy dissipation.
- Should be done to prevent scouring at the river bed.



OVERFLOW SPILLWAYS

- Sequent depth of the hydraulic jump, y2, can be determined from the momentum equation between sections (1) and (2).
- Ignoring the friction between these sections, the momentum equation for a rectangular basin can be written as

$$\sum F = \frac{1}{2}\gamma\, y_1^2 - \frac{1}{2}\gamma\, y_2^2 = \rho\, Q(u_2 - u_1)$$

with

$$\rho = \frac{\gamma}{g}, \qquad u_1 = \frac{q}{y_1}, \qquad u_2 = \frac{q}{y_2}$$

OVERFLOW SPILLWAYS

and after simplification

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8F_{r1}^2} - 1\right)$$

and

$$F_{r1} = \frac{u_1}{\sqrt{g\, y_1}}$$

Where

- F_{r1} is the flow Froude number at section (1).

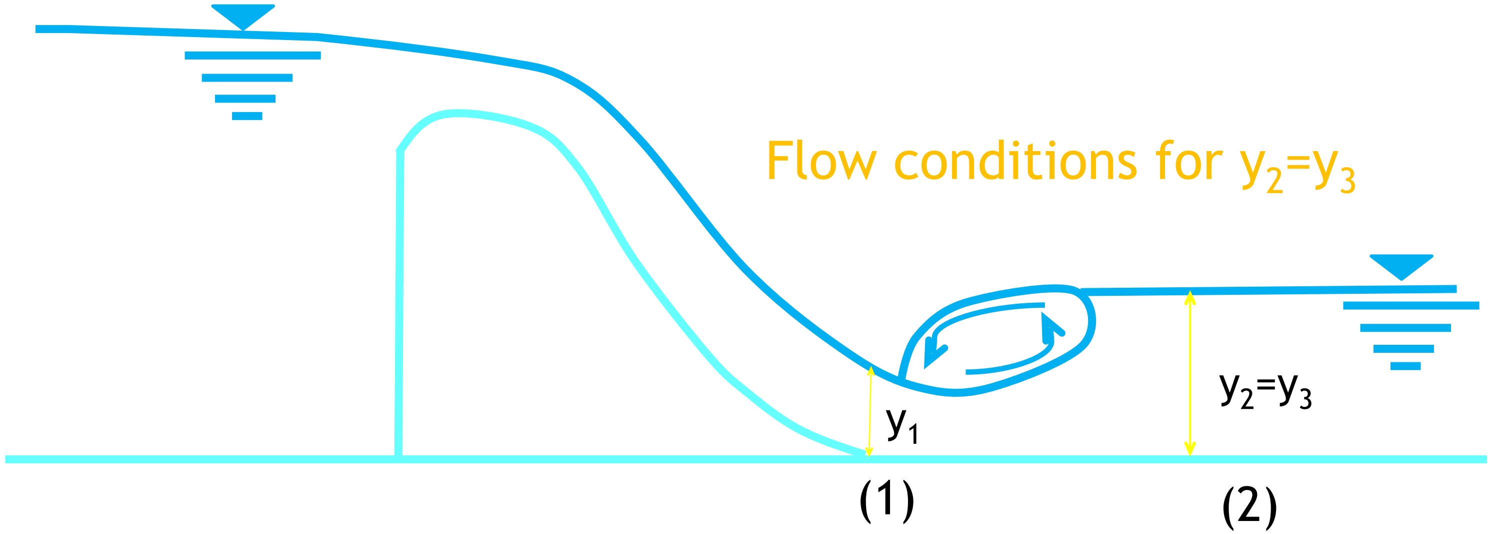
The energy loss through the hydraulic jump in a rectangular basin is computed from:

$$\Delta E = E_1 - E_2 = \frac{(y_2 - y_1)^3}{4\, y_1 y_2}$$

OVERFLOW SPILLWAYS

Case 1

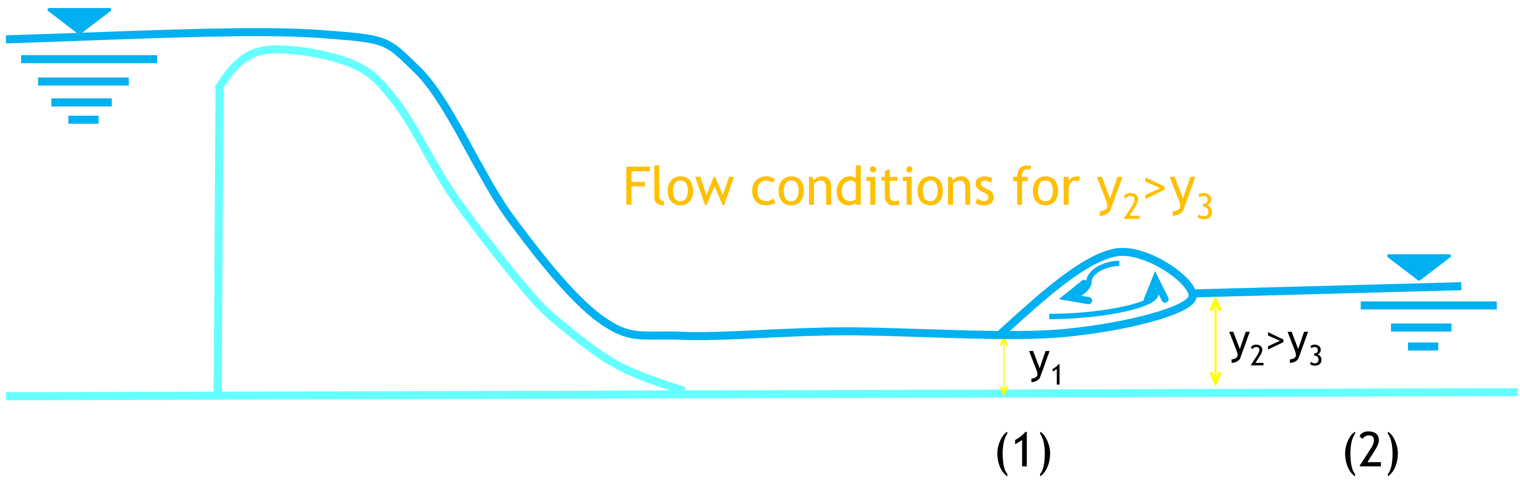
➢ If the tailwater depth, y_3, coincide with the sequent depth, y_2, the hydraulic jump forms just at toe of the spillway as shown in Figure below



OVERFLOW SPILLWAYS

Case 2

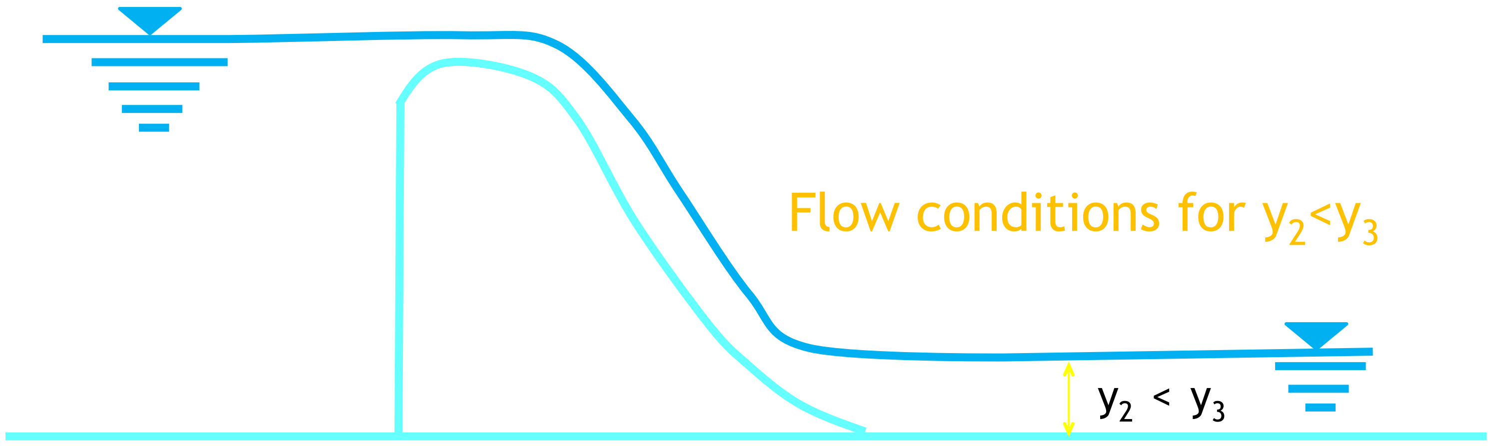
- If the tailwater depth is less than required sequent depth, the jump moves toward the downstream as can be seen from Figure below.
- This condition should be eliminated, because water flows at a very high velocity has a destructive effect on the apron.



OVERFLOW SPILLWAYS

Case 3

➢ If the tailwater depth is greater than required sequent depth, then this condition can be shown as Figure below



OVERFLOW SPILLWAYS

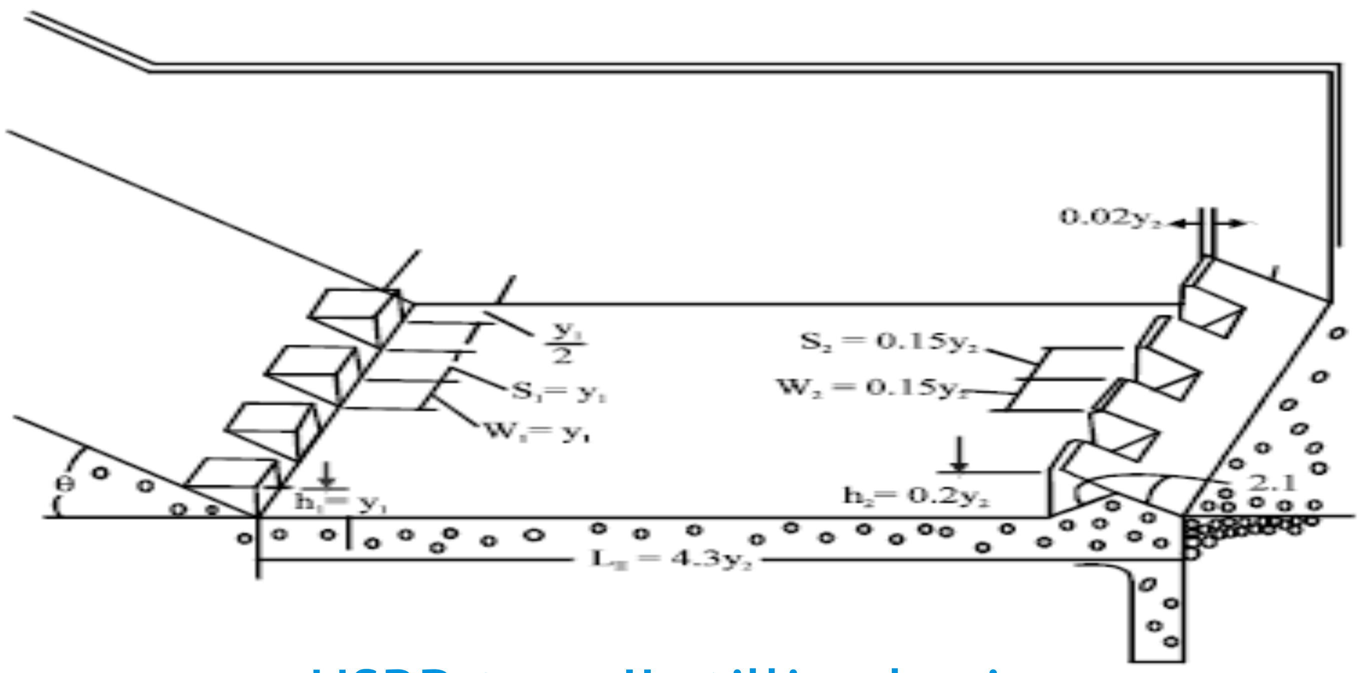
Case 4

- Sequent depth of hydraulic jump, y2, is greater than the tailwater depth, y3, at low flows and is smaller at high flows. USBR type 5 basin with an end sill can be used for this case.

Stilling Basin

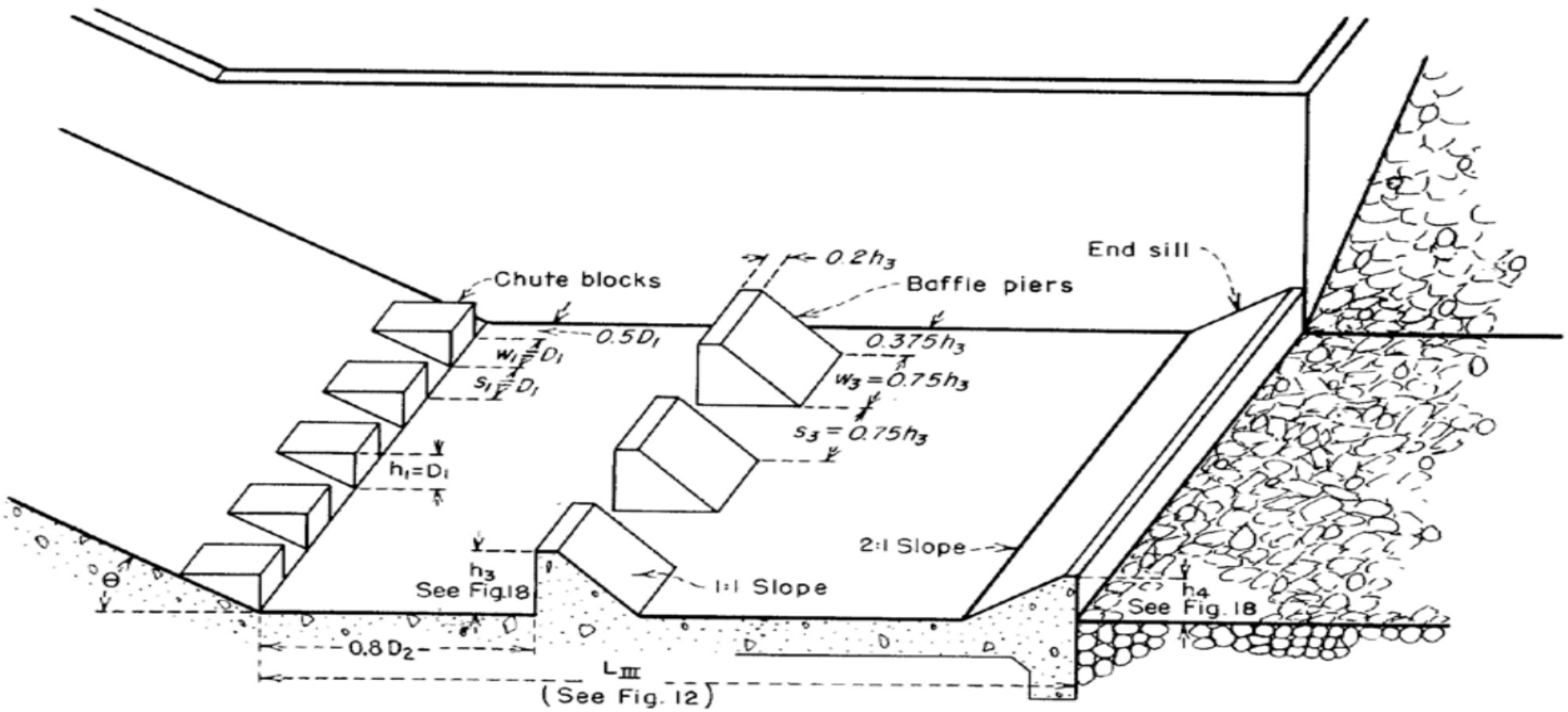
Case 5

➢ Tailwater depth, y_3, is greater than sequent depth, y_2, at low flows and is smaller at high flows. USBR types 2, 3 and 4 basins can be selected for this case.



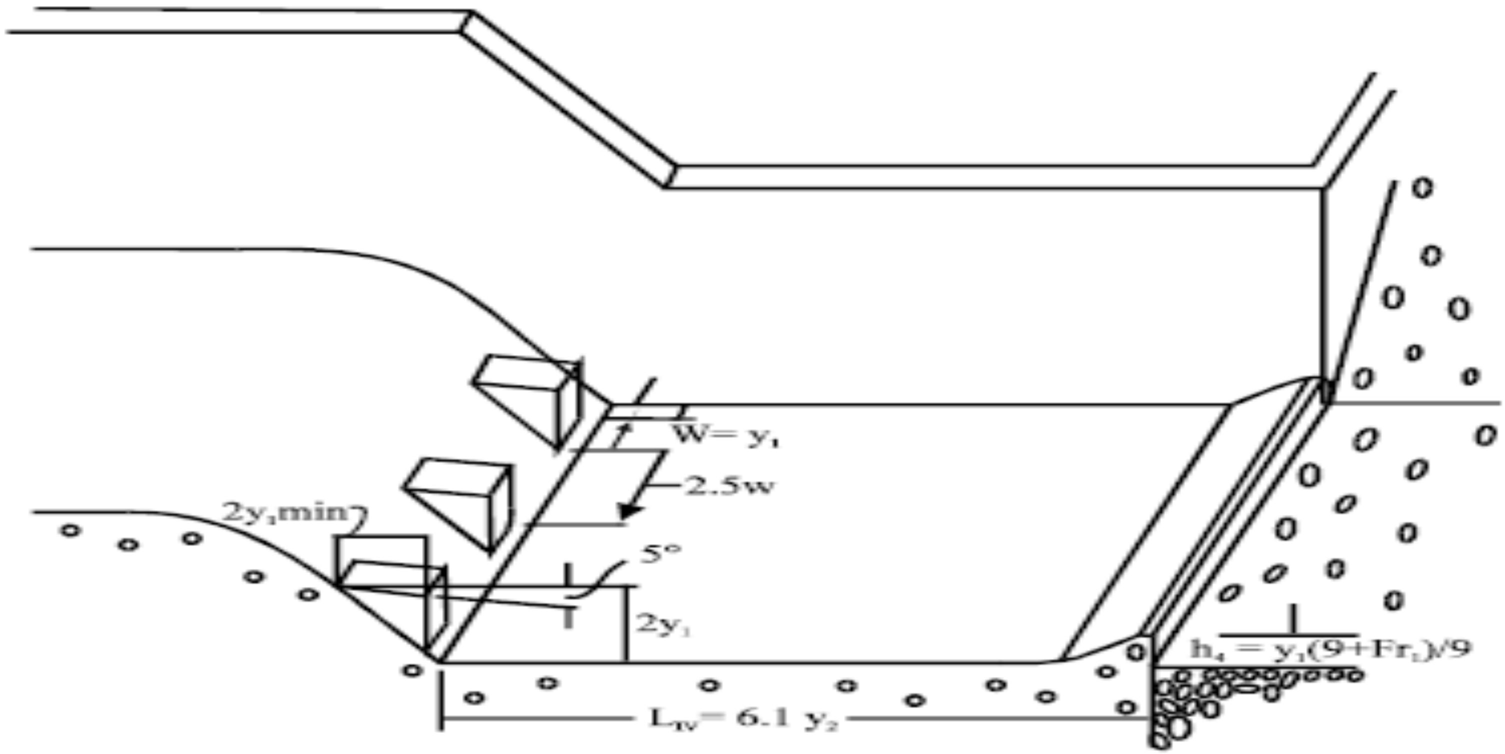
USBR type II stilling basin

Stilling Basin



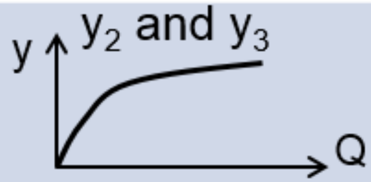
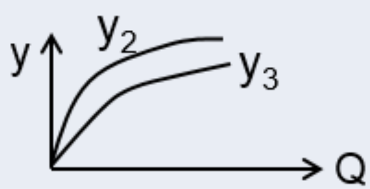
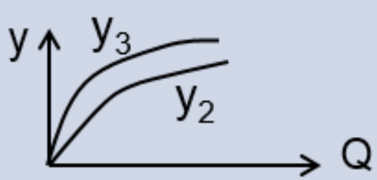
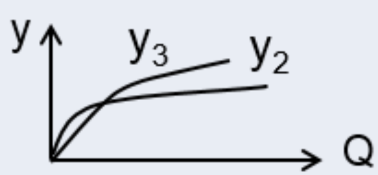
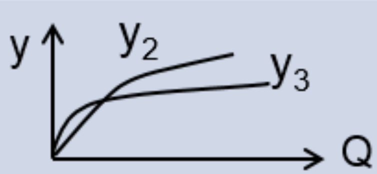
USBR types 3

Stilling Basin



USBR type IV stilling basin

Summary of sequent depth and tailwater interference at spillway toe

Number	Case	Designation	Remedial measure
1		y_2 and y_3 coincide at all flows	USBR Type 1 basin
2		y_2 is always greater than y_3	USBR Type 2, 3, 4 basins
3		y_3 is always greater than y_2	USBR Type 5 or Type 7 basins
4		y_2 is always greater than y_3 at flows and Smaller at high flows	USBR Type 5 basin with an end sill
5		y_3 is always greater than y_2 at flows and Smaller at high flows	USBR Type 2, 3, 4 basins

OVERFLOW SPILLWAYS

REMINDERS:

1. "y_1" (depth at the toe) → a supercritical depth and determined from "Energy Eq." between upstream of spillway and the toe

$$P + H_o = y_1 + \frac{u_1^2}{2g} + h_L = y_1 + \frac{q^2}{2g\, y_1^2}$$

2. If "y_2" (tailwater depth) is subcritical → a HYDRAULIC JUMP between y_1 and y_2 (toe and tailwater, see case1).
3. "y_2" (conjugate depth) → determined from Eq. as following for rectangular basin.

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8F_{r1}^2} - 1\right)$$

OVERFLOW SPILLWAYS

2) CHUTE SPILLWAYS

- In case of having sufficiently stiff foundation conditions at the spillway location, a chute spillway may replace an overflow spillway due to economic considerations.
- A steep sloped open channel is constructed in slabs with 25 to 50 cm thickness having lengths of approximately 10 m.

3) SIDE CHANNEL SPILLWAYS

If sufficient crest length is not available for overflow or chute spillways in narrow valleys, flood water is taken in a side channel. Flow conditions in a side channel spillway are given as below.

OVERFLOW SPILLWAYS

4) SHAFT SPILLWAYS (Morning Glory)

- A shaft spillway may be constructed in locations where sufficient space is not available for an overflow spillway.
- In a shaft spillway, water drops through a vertical shaft made of reinforced concrete or steel to a horizontal conduit or to the diversion tunnel which conveys water to the downstream. In this case, the discharge through the inlet may be given as

$$Q = C_s (2\pi R) H_o^{3/2}$$

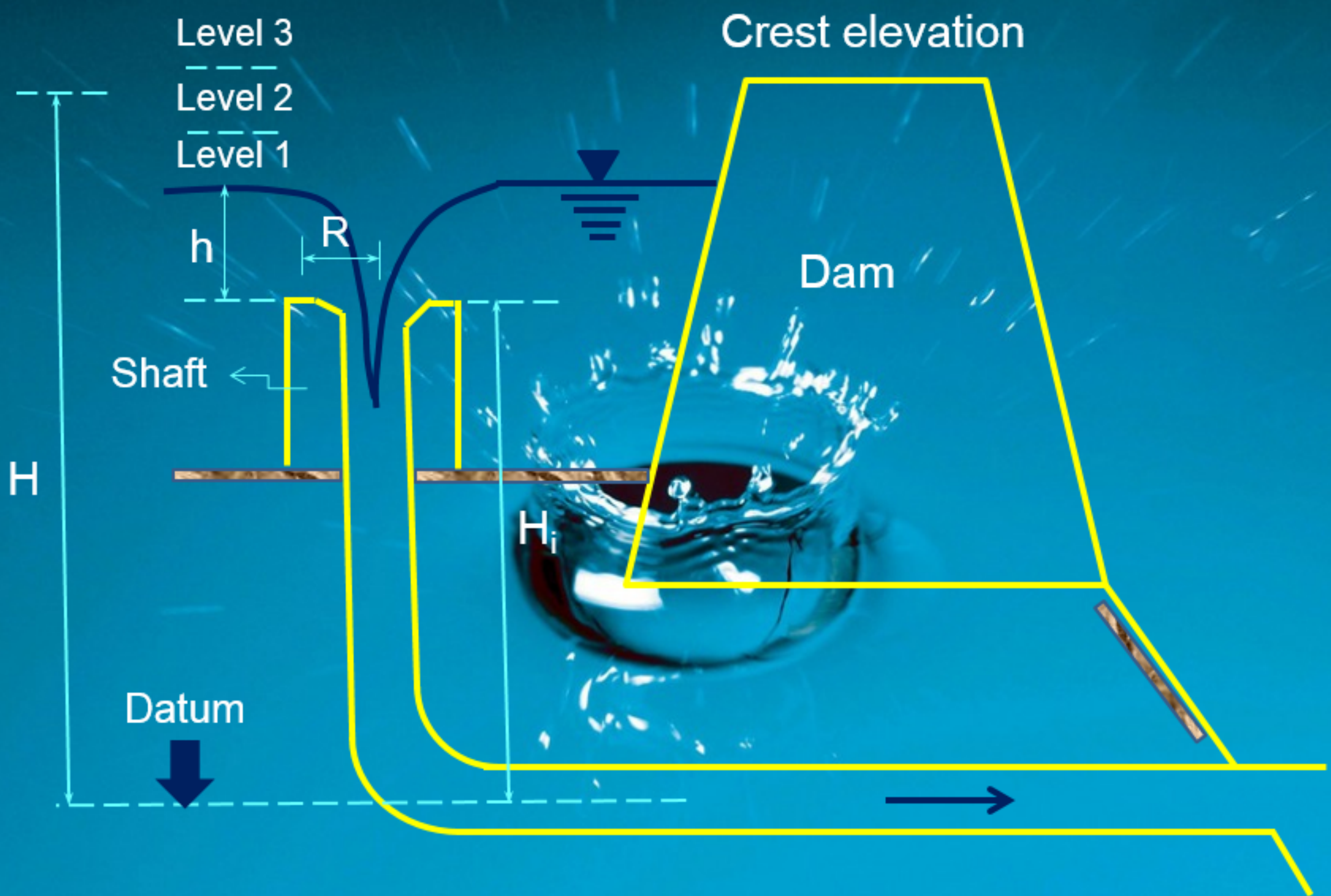
Where,

- Cs is the discharge coefficient for a shaft spillway which is different from the aforementioned spillway coefficients and can be determined from Figure 4.26.
- H_o is the total head on the inlet ($h+h_a$) and R is the radius of the shaft inlet as follows

Shaft (Morning Glory) Spillway

* This type of spillway utilizes a crest circular in plan, the flow over which is carried by a vertical tunnel on to a horizontal tunnel nearly at the stream bed level and eventually to the downstream side. The diversion tunnels constructed during the dam construction can be used as the horizontal conduit in many cases.



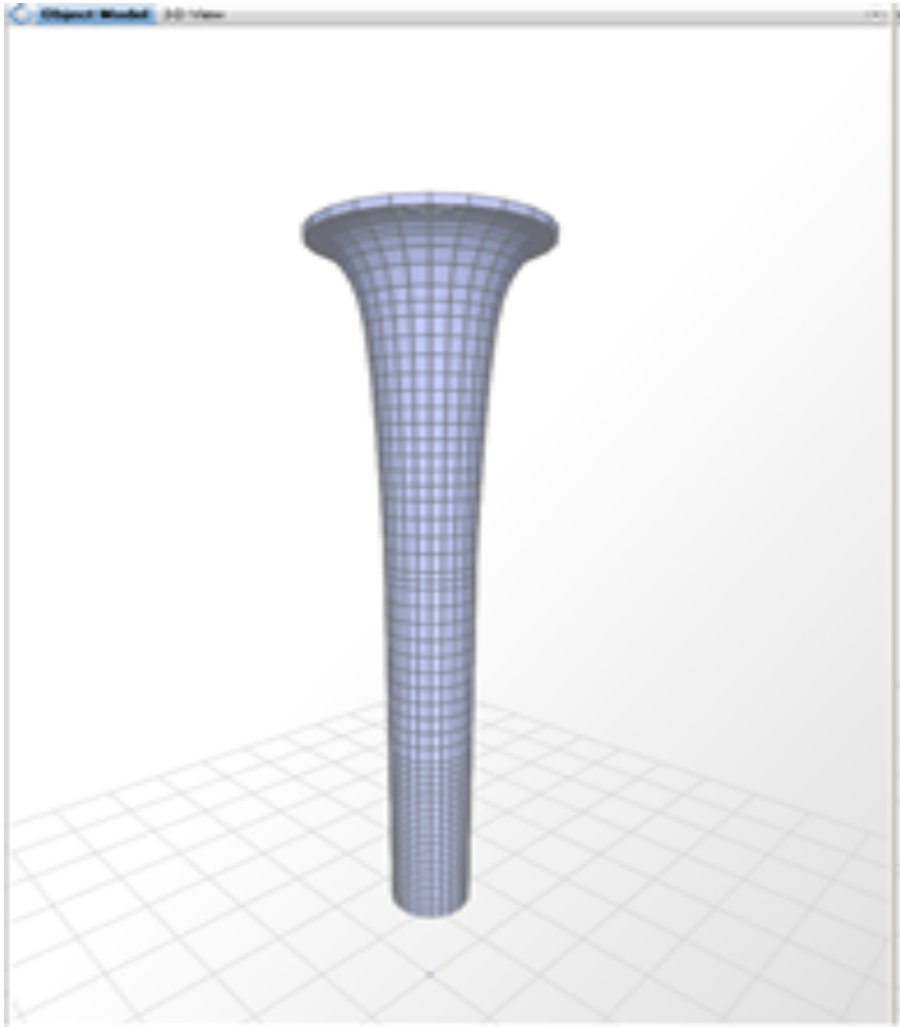



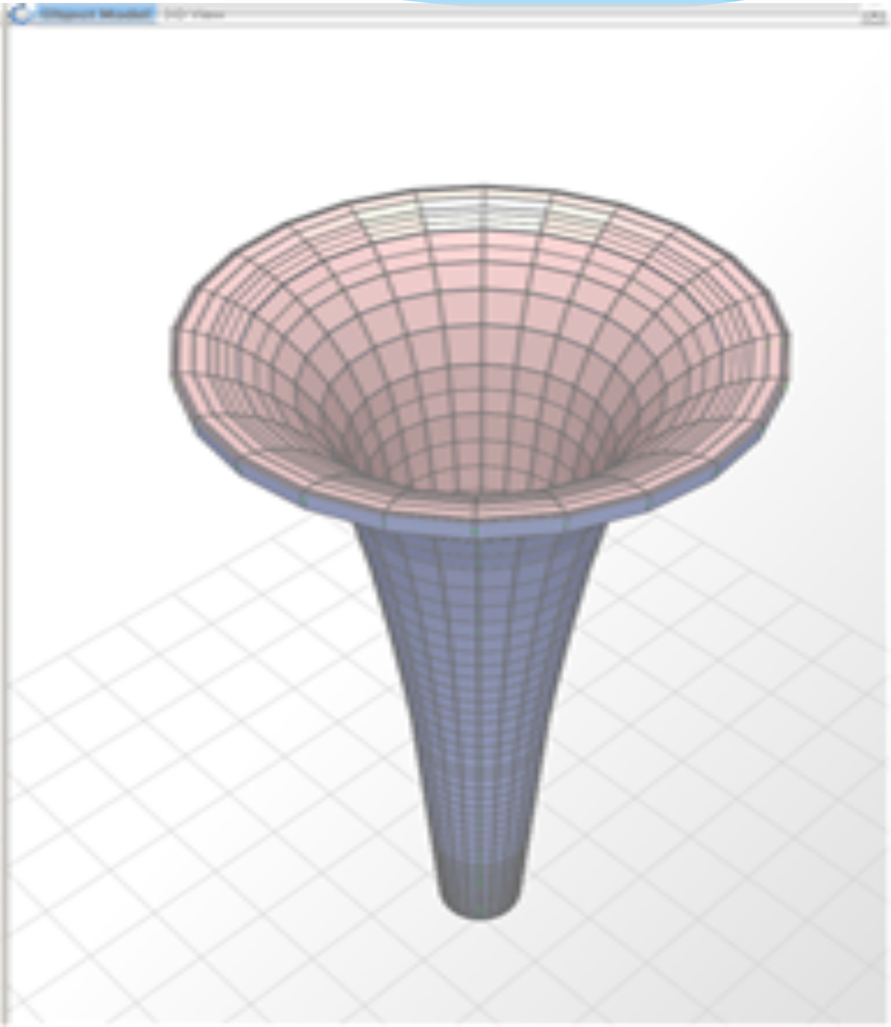
Cross-section of a typical shaft spillway

Shaft (Morning Glory) Spillway

Shaft (Morning Glory) Spillway

Shaft (Morning Glory) Spillway

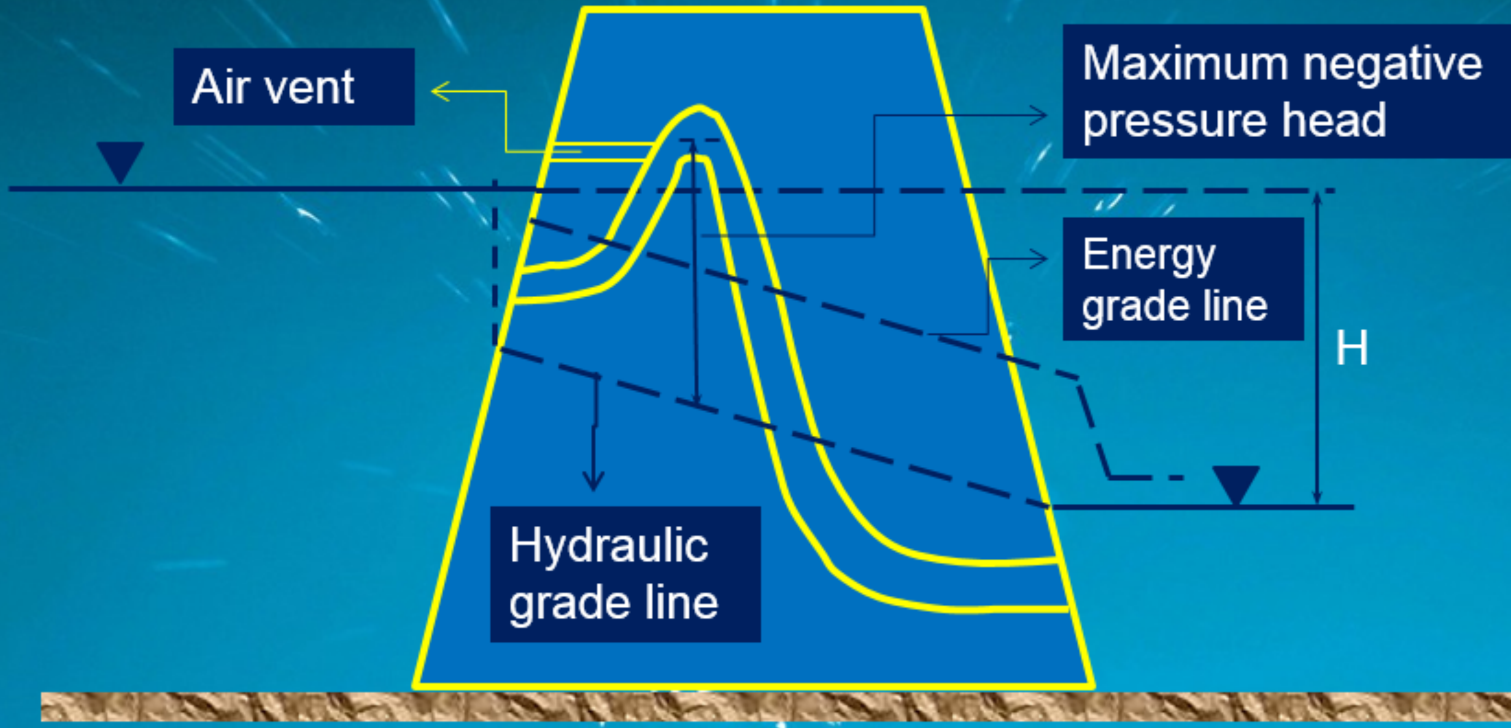




OVERFLOW SPILLWAYS

5) Siphon Spillways

- A siphon spillway, as demonstrated in next Figure, may be constructed in the body of a concrete dam at a site where there is no enough space for an overflow spillway.
- Since it is a closed conduit, which has a limited size, its capacity is not as high as that of an overflow spillway.
- Whenever there is enough head at the crown of the siphon, it operates like an overflow spillway and flow



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Thank you

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