APPLIED HYDRAULICS

CHPATER 10:

SPILLWAYS, TERMINAL STRUCTURE, CAVITATION

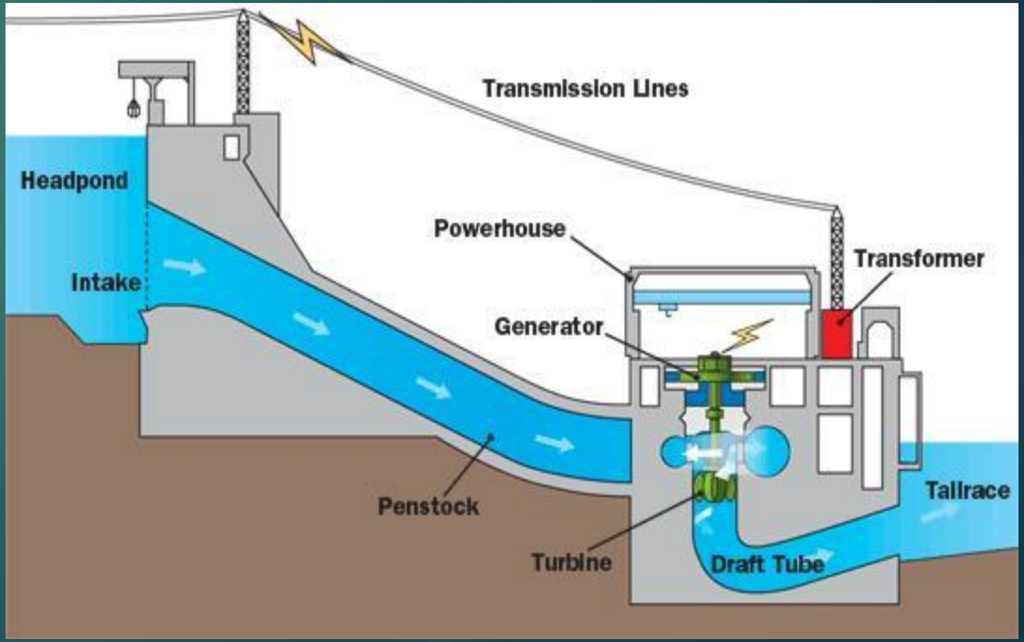
Spillways, Terminal Structure, Cavitation

- Spillways
- Terminal Structures
- Cavitation in Spillways

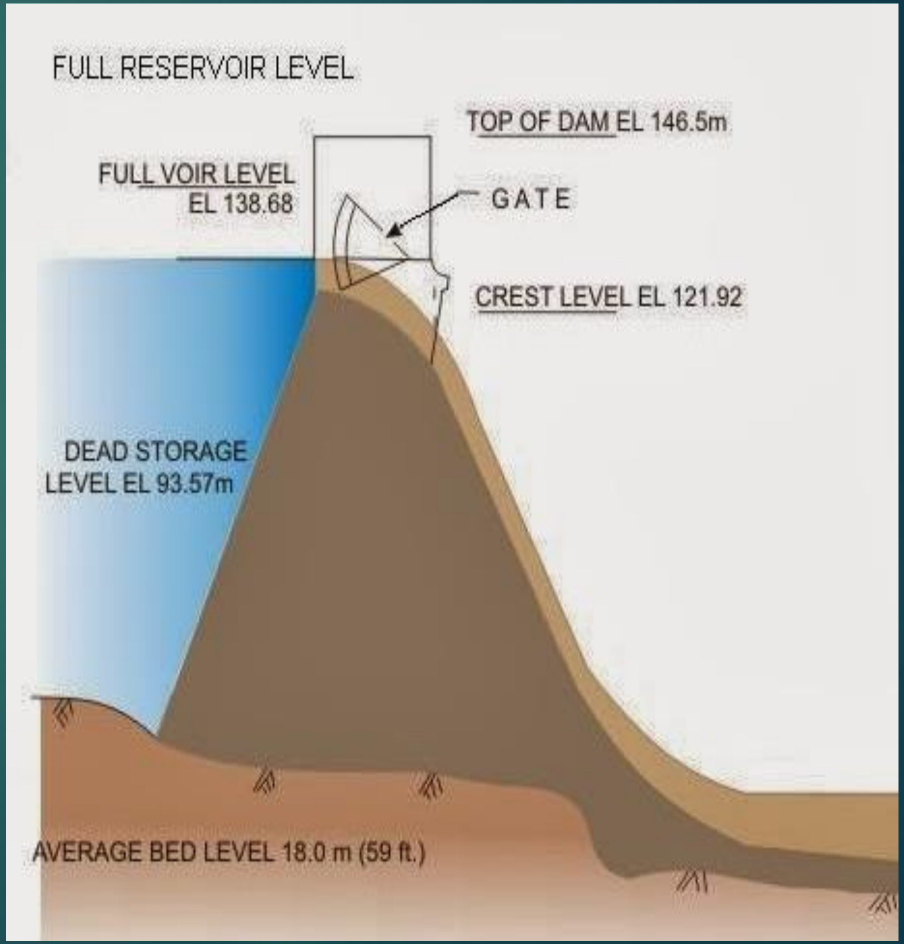
Spillways

- A Spillway is nearly always required to pass flow by a dam.
- In the case hydropower dams, where large flows pass through hydraulic turbines, spillway maybe used infrequently to pass flood.

- The safe operation of spillways is the main objective in design, because the failure to perform its design function can lead to failure of a dam.
- As dams raise water level, spillways must be designed for high velocity flow.



<u>Controlled Spillways</u>: It has mechanical structure or gates to regulate the rate of flow of water from the reservoir.



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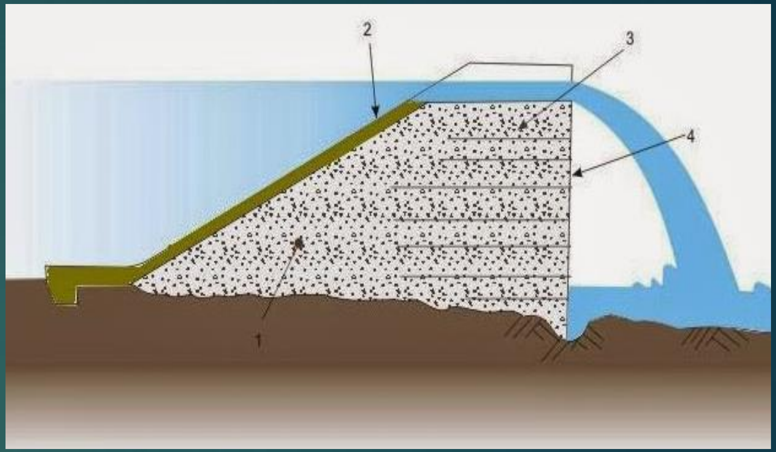
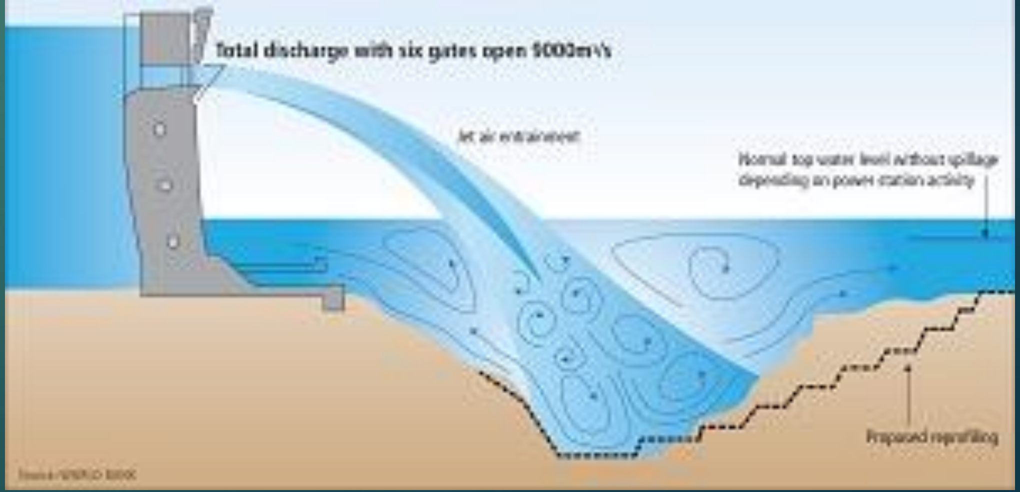
<u>Uncontrolled Spillways</u>: This doesn’t have a gate and when the water raises above the crest of the spillway, start releasing from reservoir.



Types of Spillway

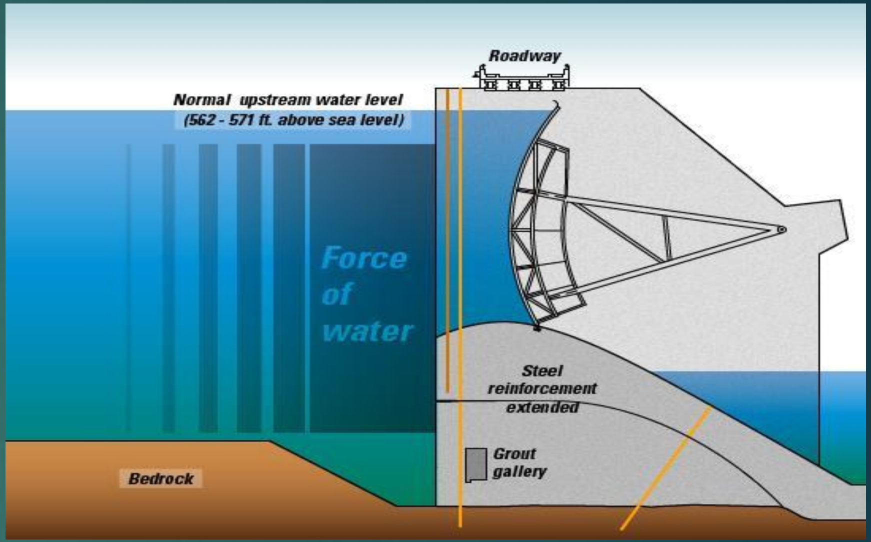
Type # 1: Free Over-Fall Spillway

- As the name of the spillway indicates, the flow drops freely from the crest of a free over-fall spillway.
- Such a spillway is better suited for a thin arch dam whose downstream face is nearly vertical.
- In order to protect the stream bed from erosion, an artificial concrete pool is usually constructed which is called Plunge pool.



Type # 2: Ogee Spillway

- The ogee or overflow spillway is the most common type of spillway.
- The structure divides naturally into three zones: the crest, the slope, and the toe.
- 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.



Type # 2: Ogee Spillway

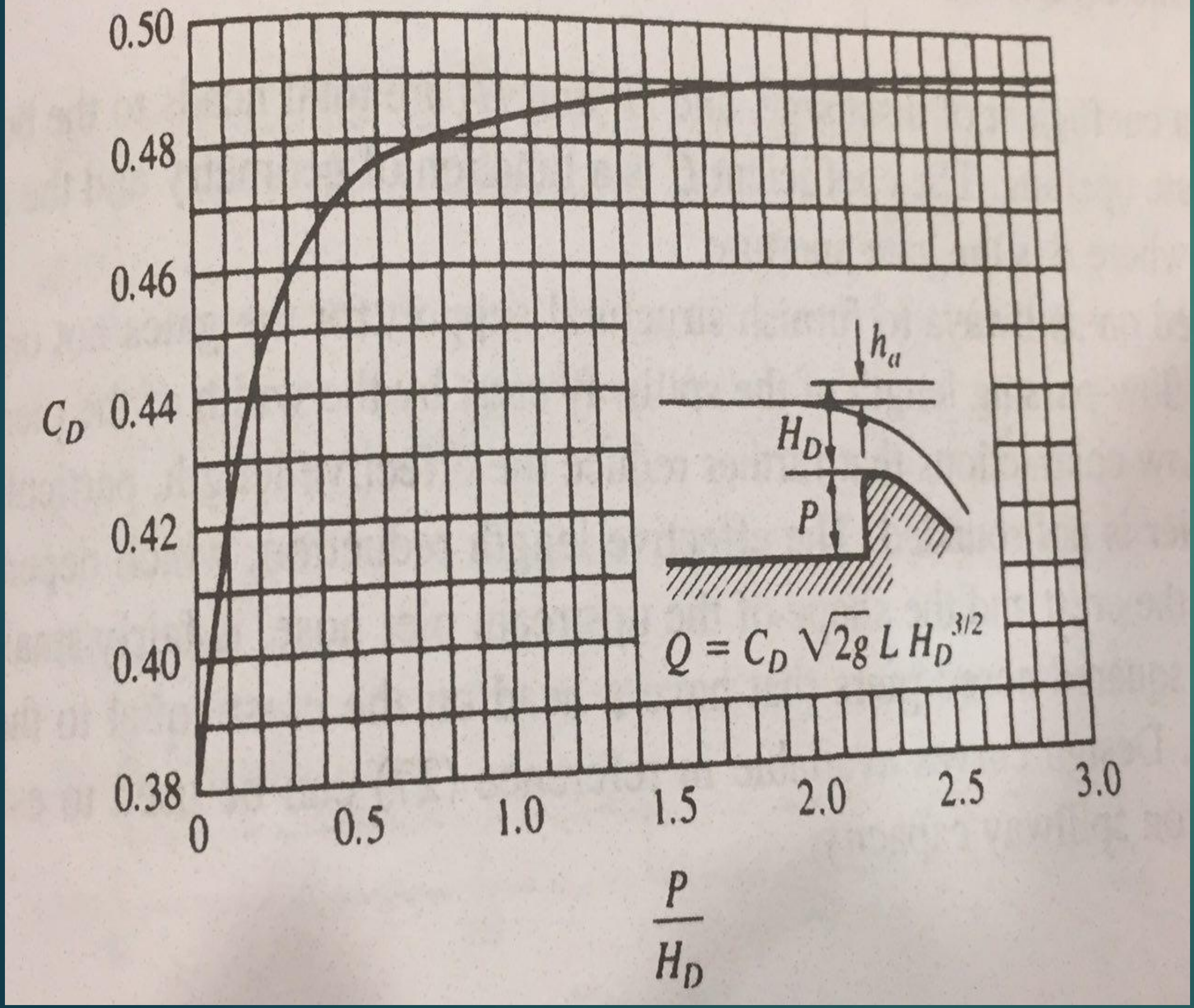
- The discharge over an ungated spillway is controlled by the head on the crest and the discharge equation is given as:

$$Q = C\sqrt{2g}LH^{3/2}$$

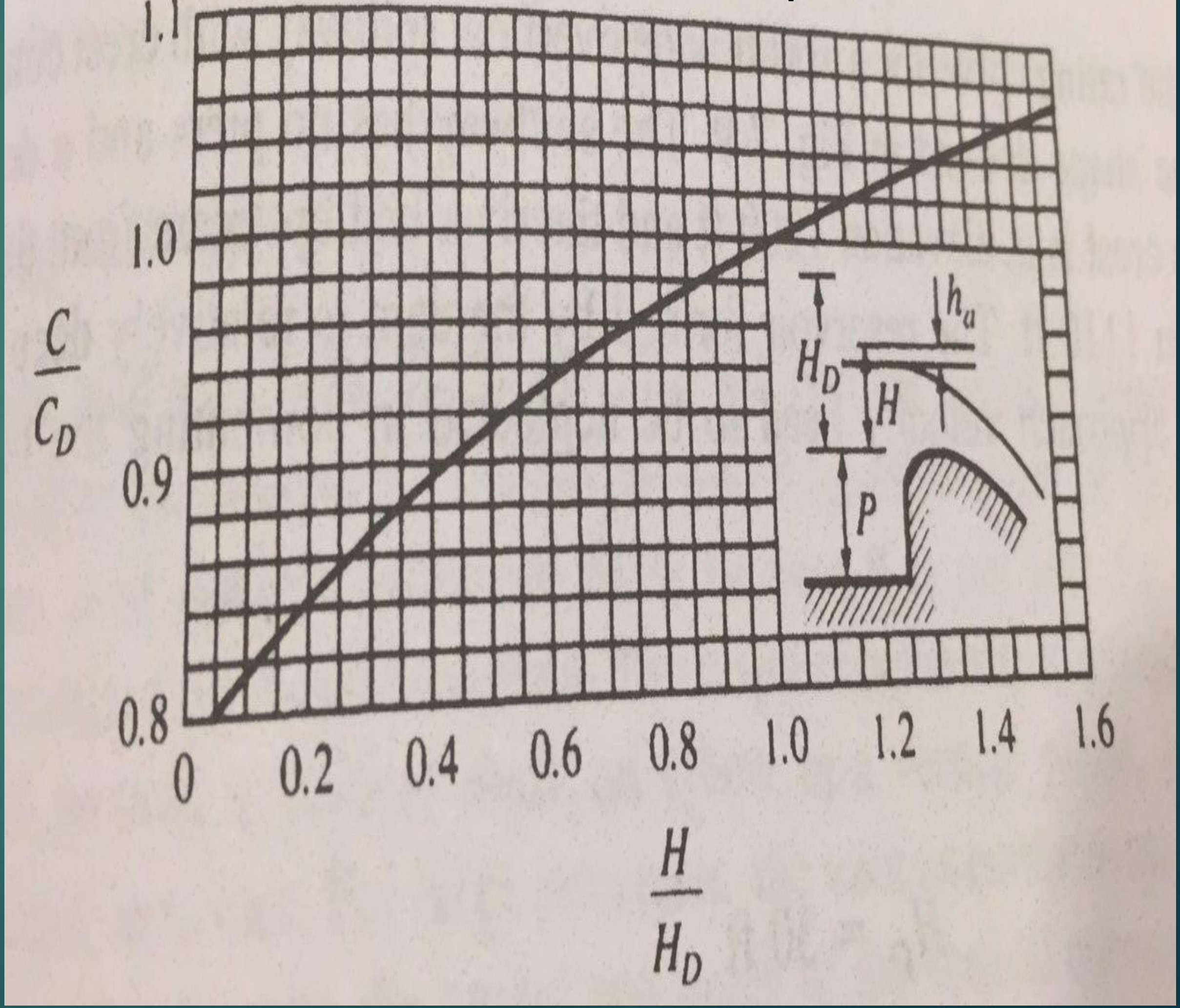
- Where, Q is flow rate, C is dimensionless coefficient of discharge, L is the crest length (or crest width), and H is the total head.
- The coefficient C depends on the approach depth, shape of the crest, and the upstream face slope.

Spillways, Terminal Structure, Cavitation

H_D is the design head, P is the height of the spillway crest



C_D is the value of C when H equals H_D

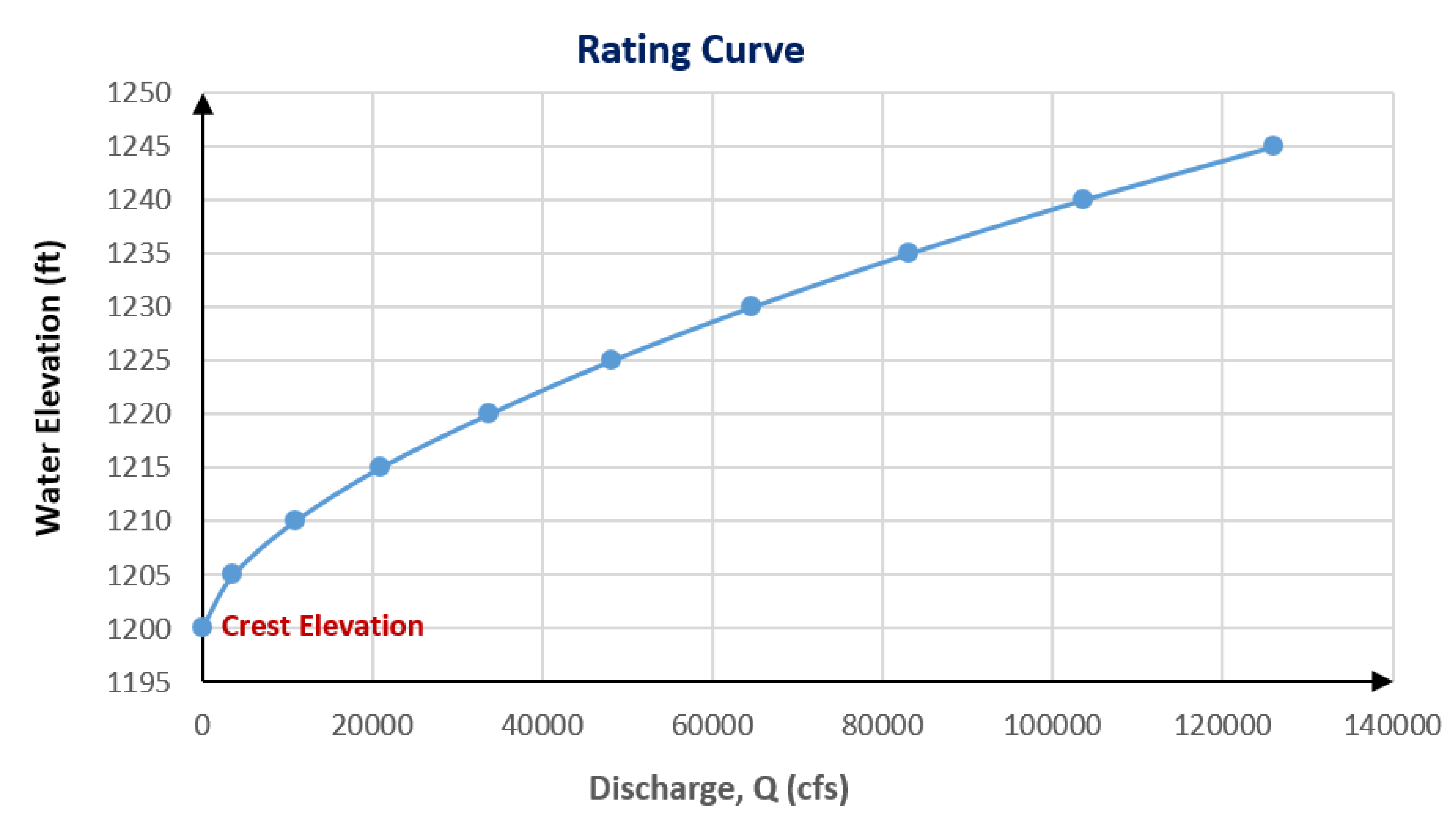


Example 1

Determine the rating curve for a 100-ft wide overflow spillway with a design head of 30 ft. The crest is at elevation 1200 ft and the river bed upstream from the spillway is at elevation 1110 ft.

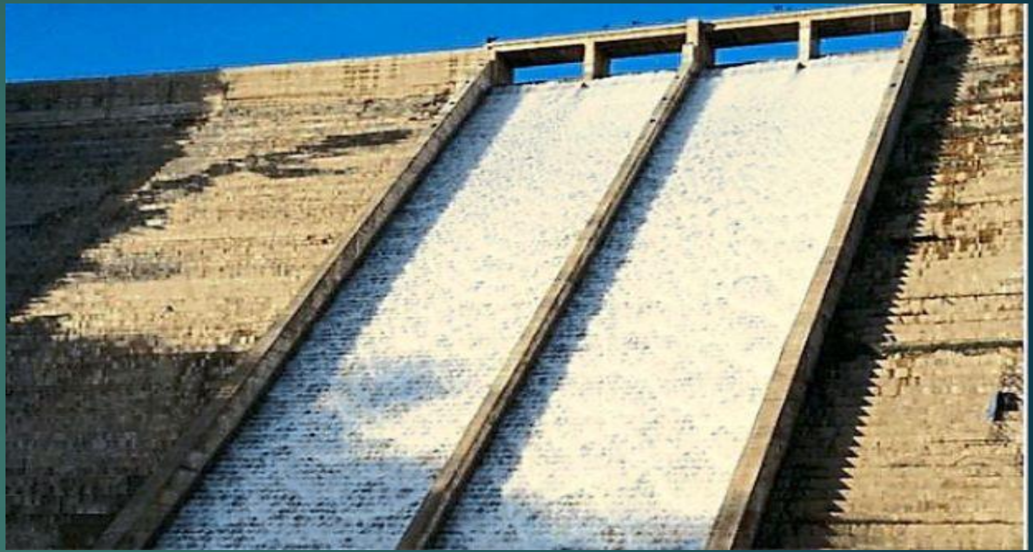
Rating Curve is a curve that shows the variation of water elevation flow rate.

Spillways, Terminal Structure, Cavitation



Type # 3: Chute Spillway

- Chute spillways are common and basic in design.
- The spillway's slope and it's sides are lined with concrete.

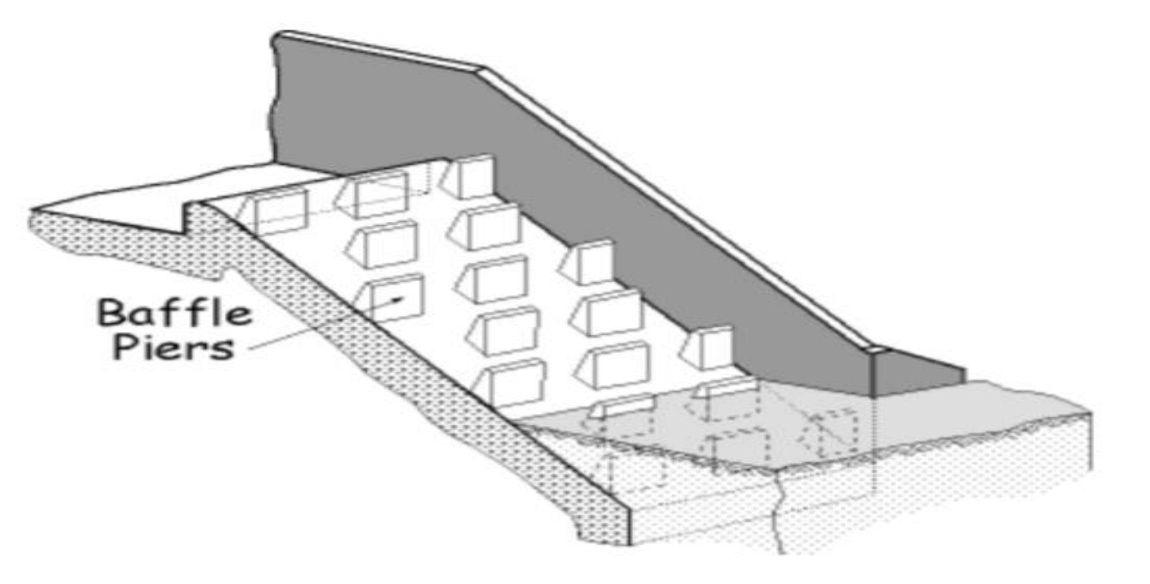


Advantages:

- The simplicity of their design and construction,
- Their adaptability to all types of foundation ranging from solid rock to soft clay.

Baffled Chute Spillway

- A baffled chute spillway is composed of a chute that the surface is covered by a number of densely spaced baffle blocks.
- The baffle blocks dissipate the kinetic energy of the flowing water effectively.
- Special design is needed to maintain sufficiently small velocities at the entrance of a chute.



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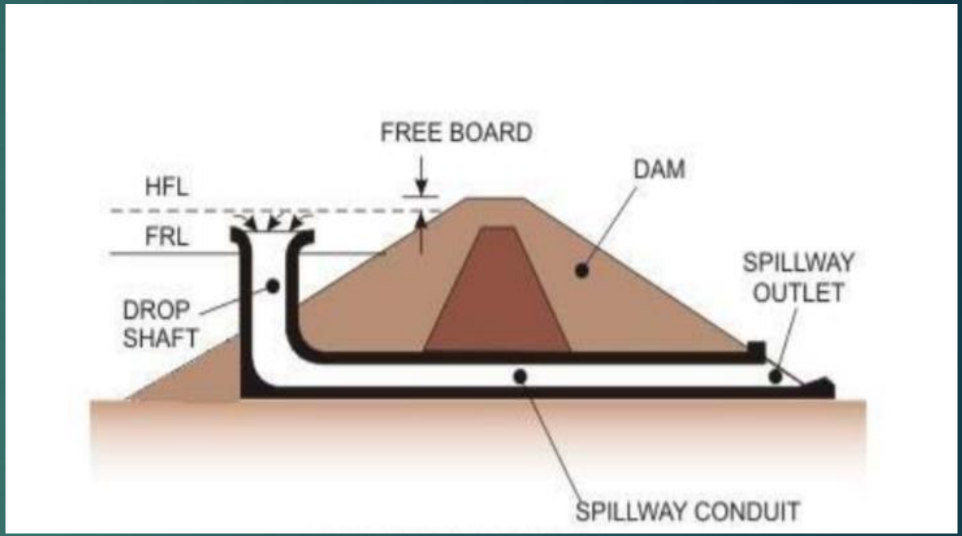
Type # 4: Shaft Spillway

- In a shaft spillway, water enters a horizontal crest, drops through a vertical or sloping shaft and then flows through a horizontal (or nearly horizontal) tunnel.
- The horizontal or the conduit may be taken either through the body of dam or through the underground.
- This spillway is not suitable for large capacity and deep reservoirs because of stability problems.
- Repair and maintenance of shaft spillways are difficult.



Shaft Spillway (uncontrolled)

Shaft Spillway (controlled)

Terminal Structures

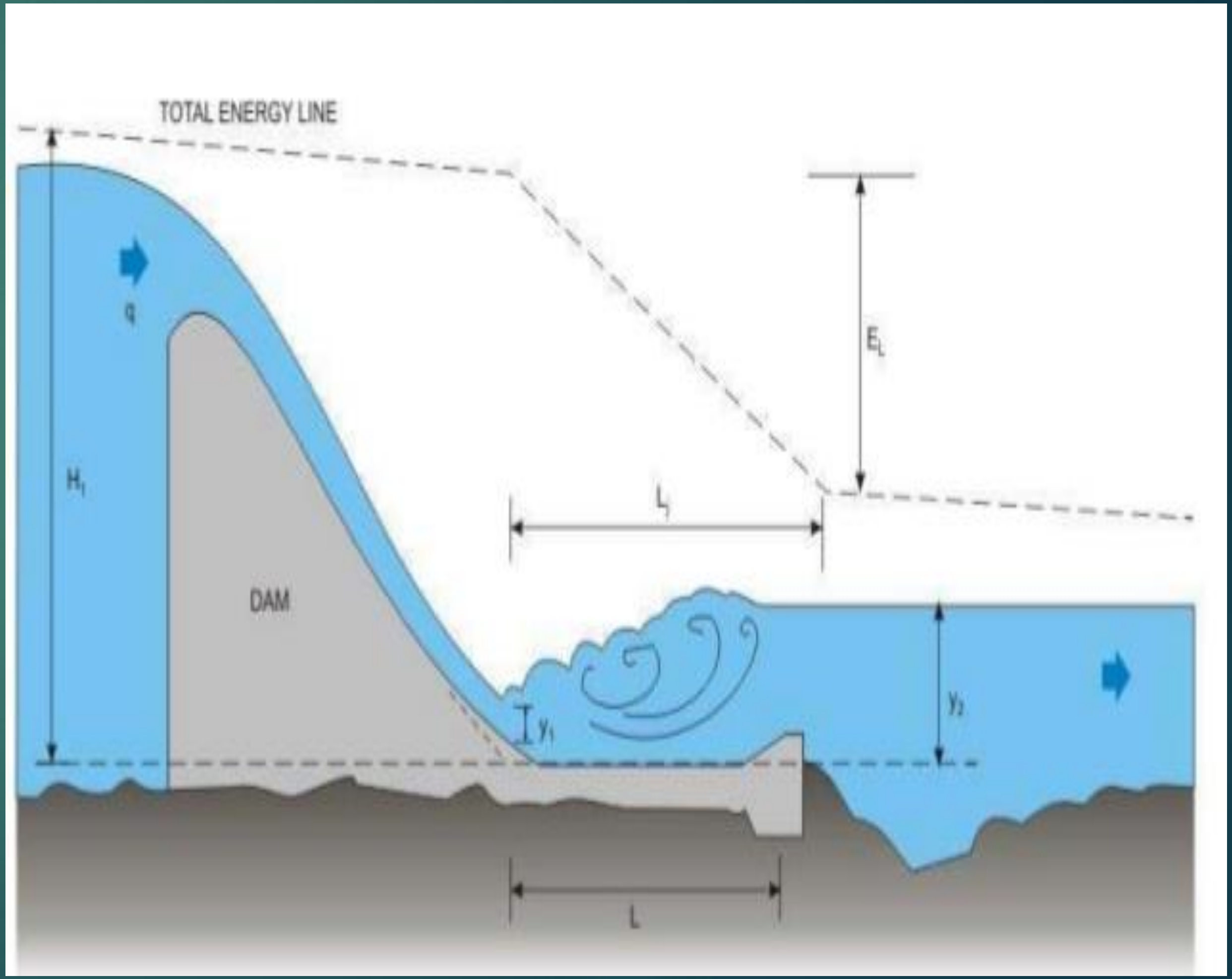
- As the water flows over the spillway crest and down the spillway body, it gains very high velocities as the potential energy is converted to kinetic energy.
- At the toe of the spillway the flow is supercritical, and it has high enough energy to cause erosion in the streambeds and banks downstream.
- Stilling basins are used for the flow to dissipate part of this energy before it is conveyed to the downstream river channel.

Position of Hydraulic Jump

- The energy dissipation occurs through a hydraulic jump in the stilling basin.

- But where and how this energy dissipated is of utmost importance in controlling erosion.

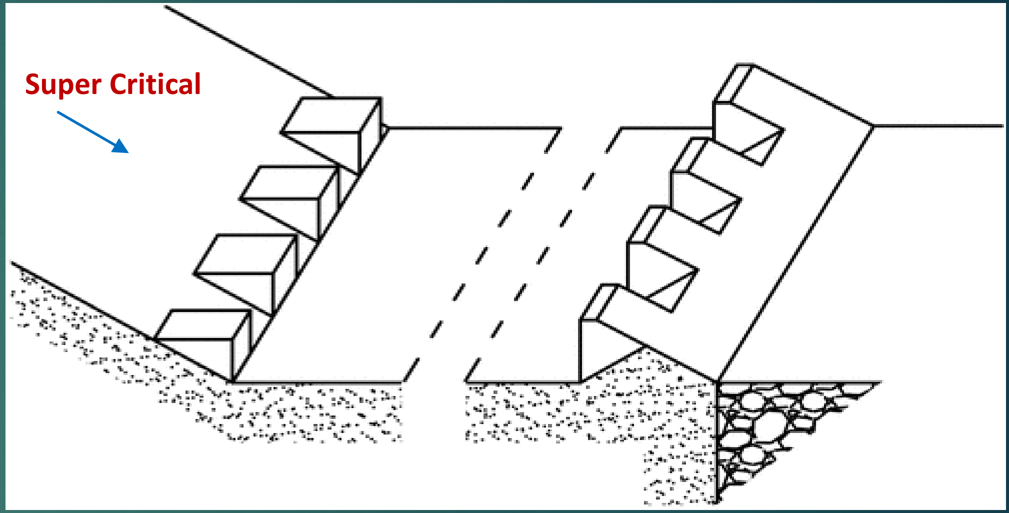
- The floor elevation, length, and width of a stilling basin should be designed to ensure a stable jump that is contained within the basin.

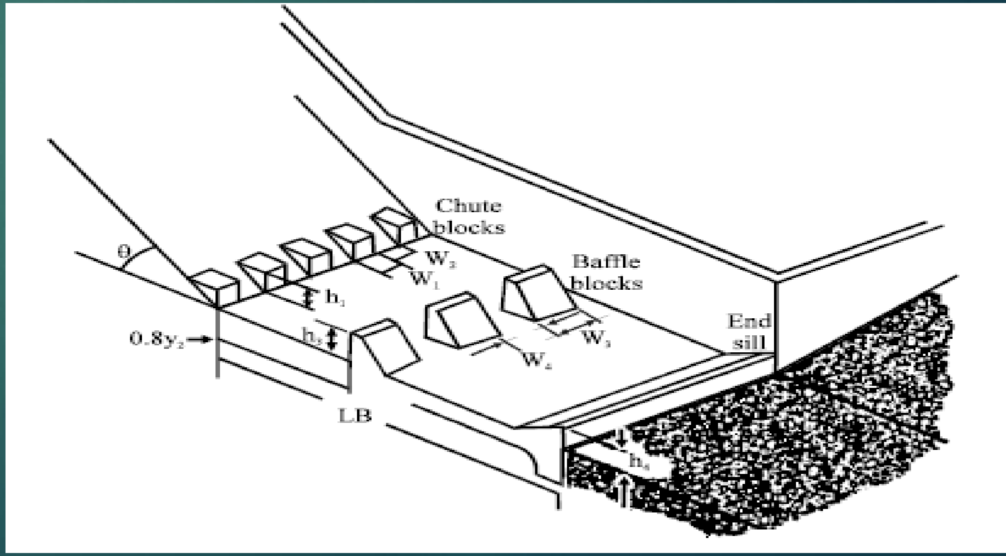


- As the flow in spillway is supercritical, we need a subcritical flow at downstream to generate a hydraulic jump.
- The stilling basin is a structure in which a hydraulic jump is generated.

$$\frac{y_2}{y_1} = \frac{1}{2}\sqrt{1 + 8Fr_1^2} - 1$$

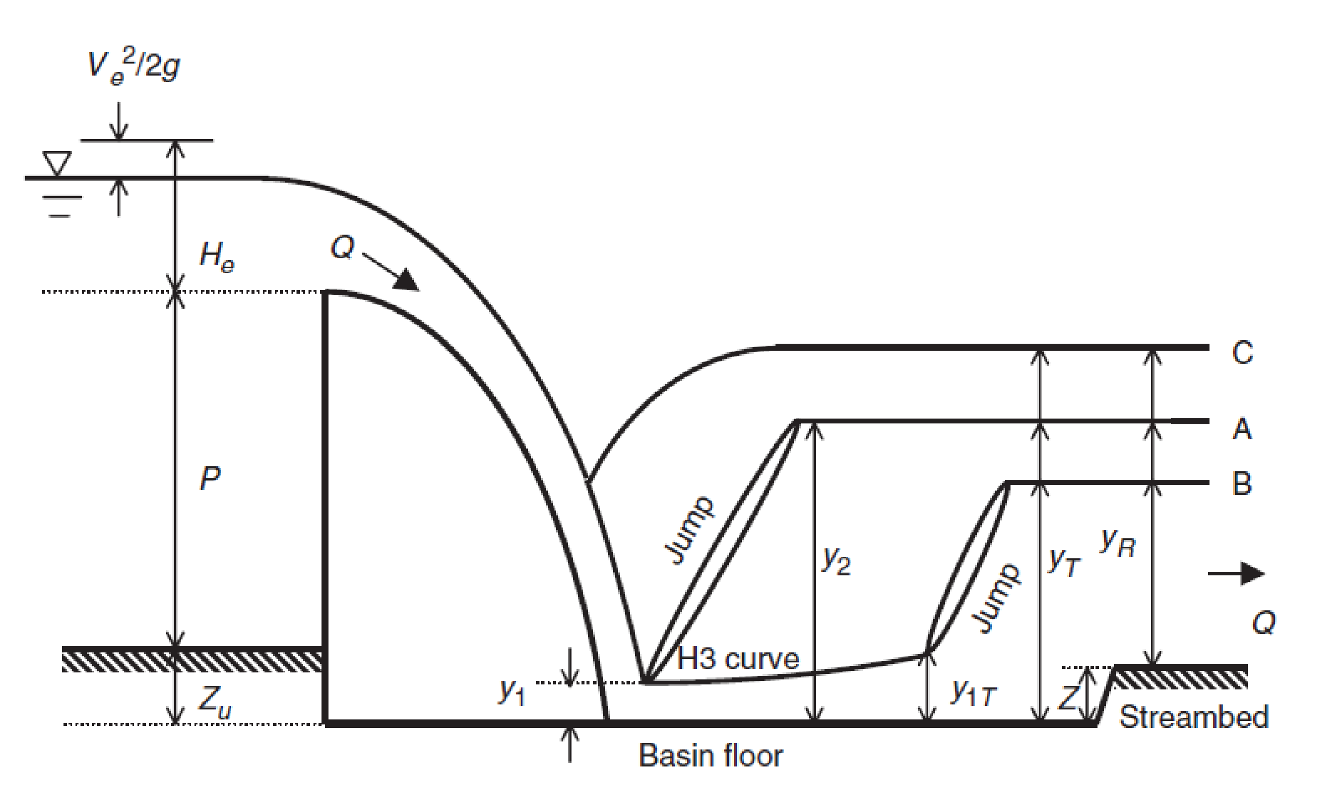
- The positioning of a hydraulic jump on the horizontal surface of the basin is very sensitive the depth y_2 from the hydraulic jump equation.





Spillways, Terminal Structure, Cavitation

- The position of a hydraulic jump below a spillway depends on the spillway head and height, the discharge, the tailwater depth, and the width of the stilling basin.

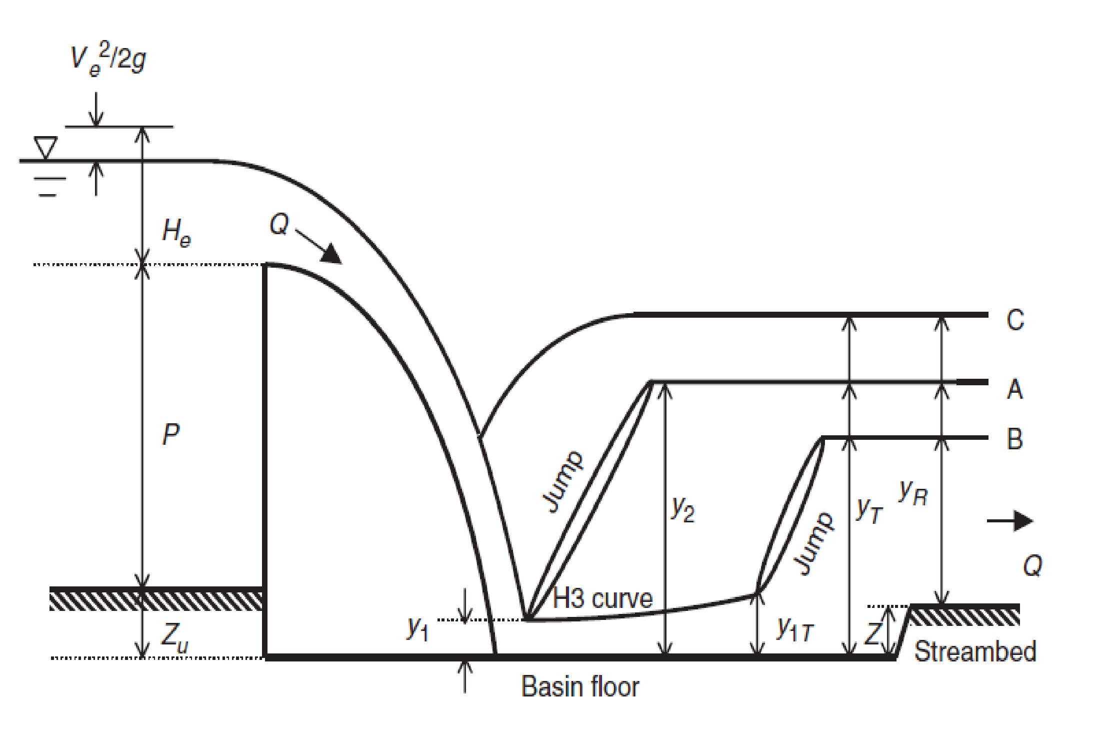


- In case A the hydraulic jump occurs at the spillway toe,
- In case B it occurs some distance downstream.
- In case C represents a drowned jump.

Spillways, Terminal Structure, Cavitation

- We can determine the flow depth, y_1, at the toe of the spillway by writing the energy equation between this section and a section just upstream of the spillway crest.
- Neglecting the energy loss between the two sections, we can write

$$Z_u + P + H_e = y_1 + \frac{V_1^2}{2g}$$



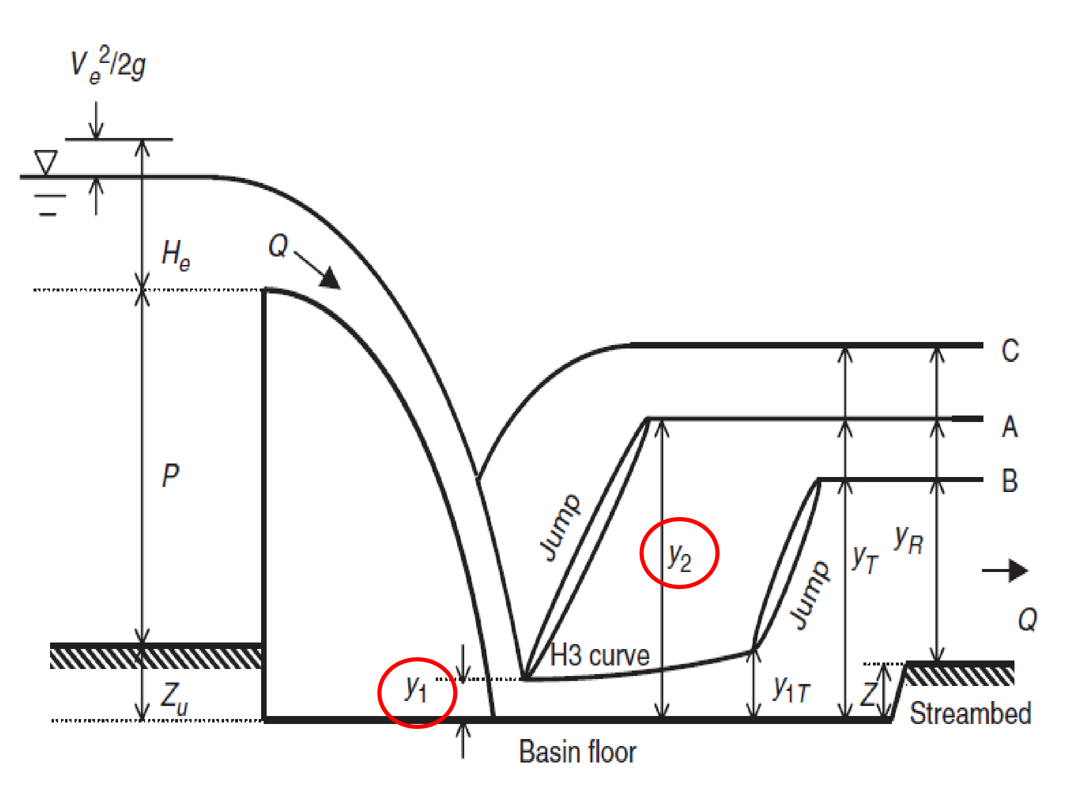
- Most stilling basins are rectangular in cross-section with a constant width, B.

$$Z_u + P + H_e = y_1 + \frac{Q^2}{2g y_1^2 B^2}$$

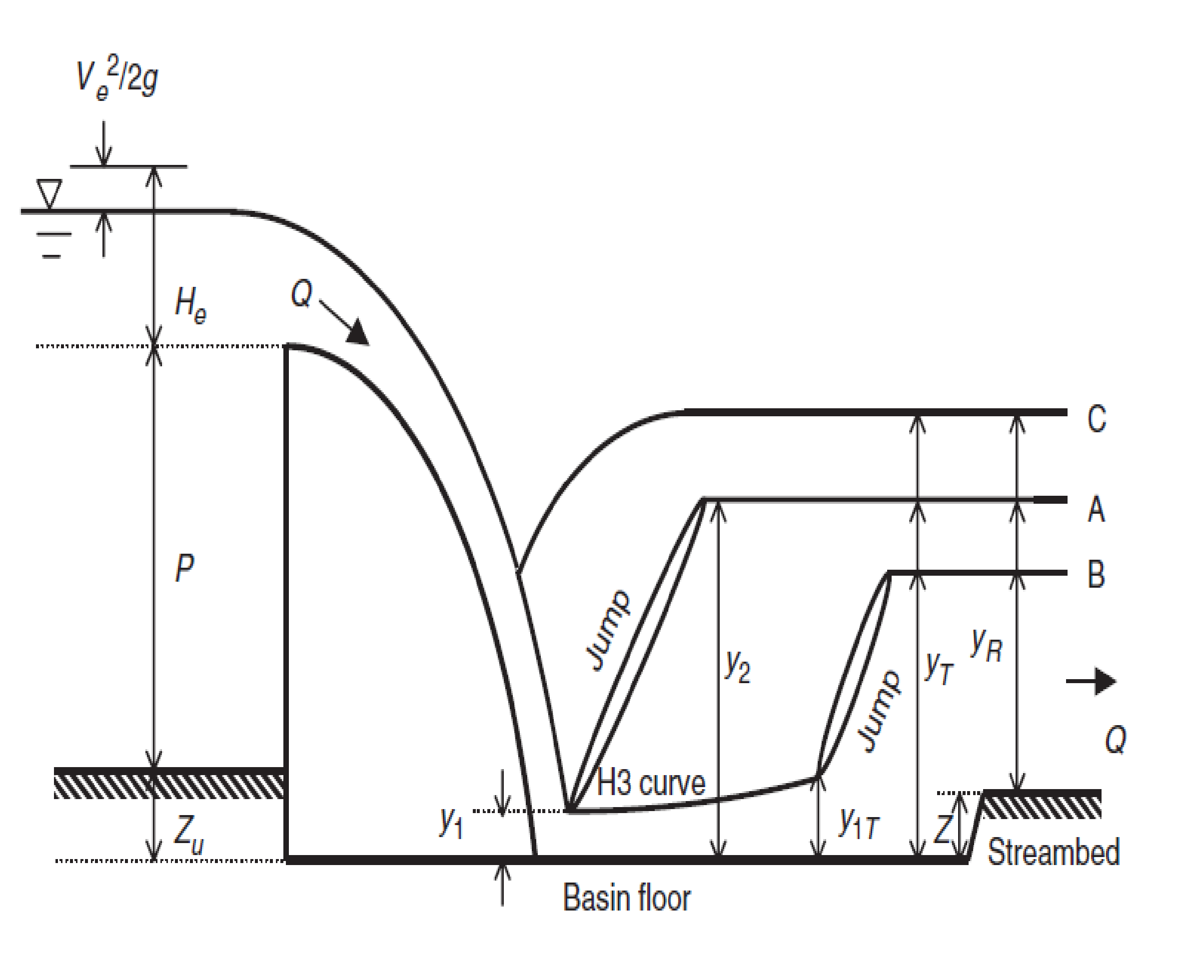
- We can solve this equation for y_1 by trial and error to find positive values of y_1 which one of them is subcritical and the other one supercritical.
- We are interested here in the supercritical depth.
- if a hydraulic jump occurred right at the toe of the spillway, the flow depth after the jump would be y_2 and can be calculated as follow:

$$\frac{y_2}{y_1} = \frac{1}{2}\sqrt{1 + 8Fr_1^2} - 1$$

$$Z_u + P + H_e = y_1 + \frac{Q^2}{2gy_1^2B^2}$$



- In Figure, y_R represents the flow depth in the downstream river channel.
- From the continuity principle, the discharge Q in the river must be the same as the discharge over the spillway.
- However, the flow depth y_R depends on the cross-sectional properties of the channel, the Manning roughness factor, and the longitudinal slope.
- If $y_2 = y_T = y_R + Z$, then a hydraulic jump will occur right at the toe of the spillway as in profile A.

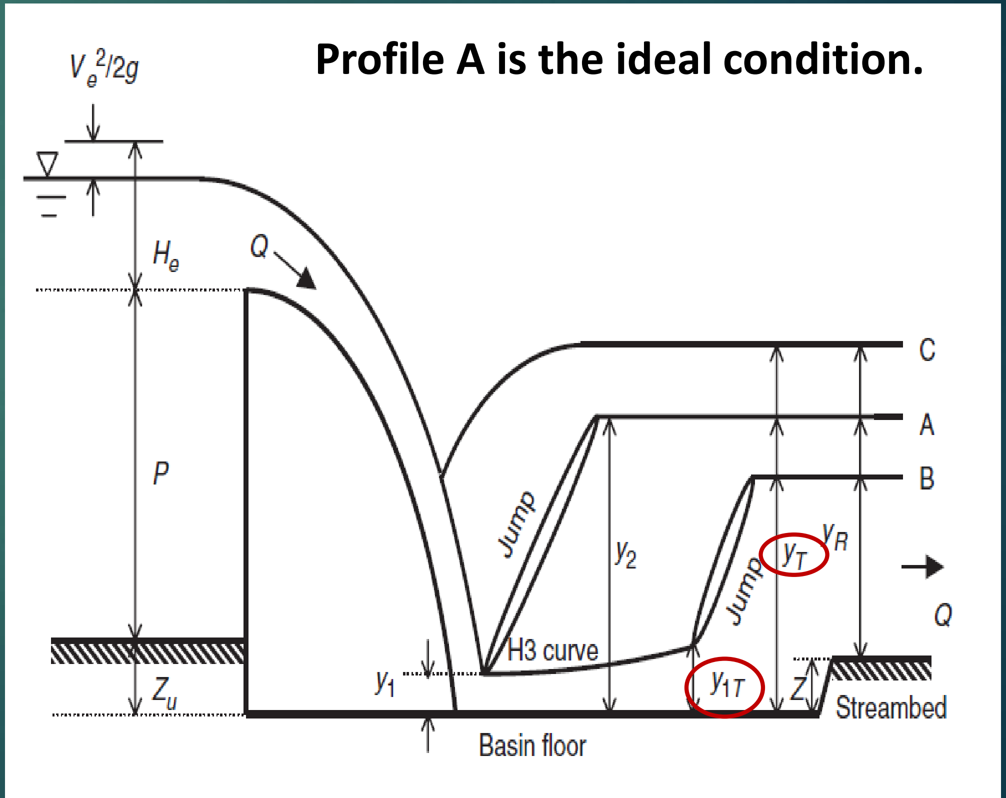


- If $y_2 > y_T$, the jump will not occur at the toe.

$$\frac{y_{1T}}{y_T} = \frac{1}{2}\sqrt{1 + 8Fr_T^2} - 1$$

- where Fr_T is the Froude number corresponding to the tailwater depth y_T.

- If $y_2 < y_T$, the jump will be forced upstream and drowned over the spillway body as shown in Figure by profile C.
- A drowned jump does not dissipate a significant amount of energy and is not desired in a stilling basin.
- However, condition B is not desirable either, since it would require a longer and more expensive stilling basin to contain the jump.

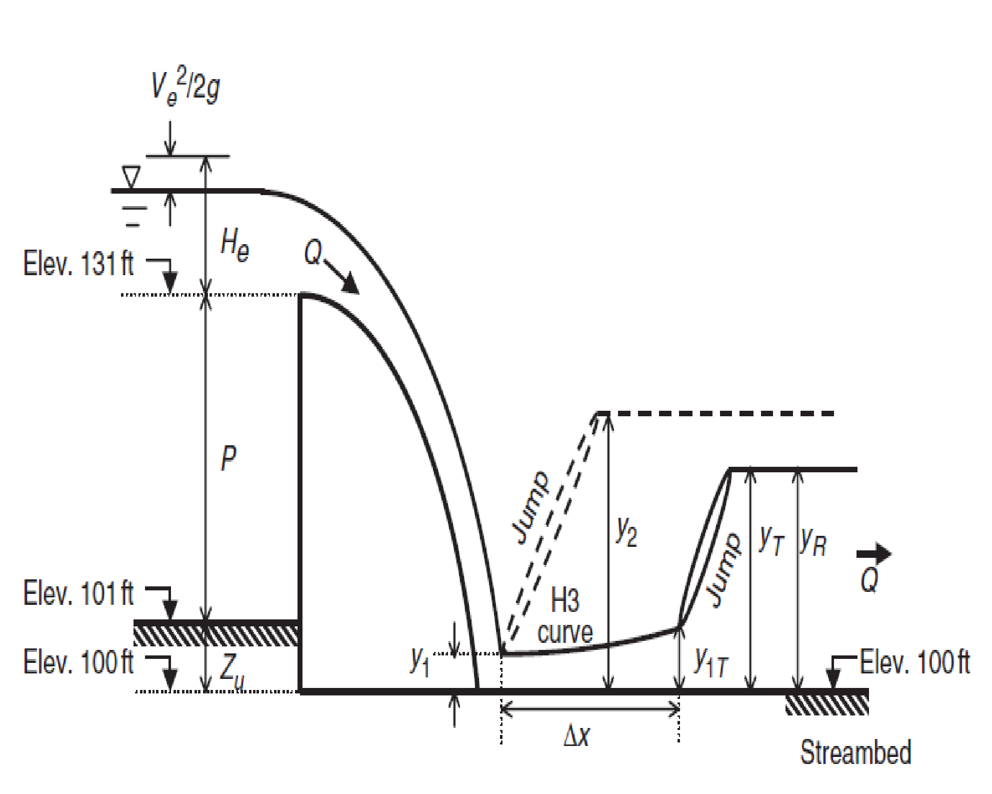


Spillways, Terminal Structure, Cavitation

Example 2

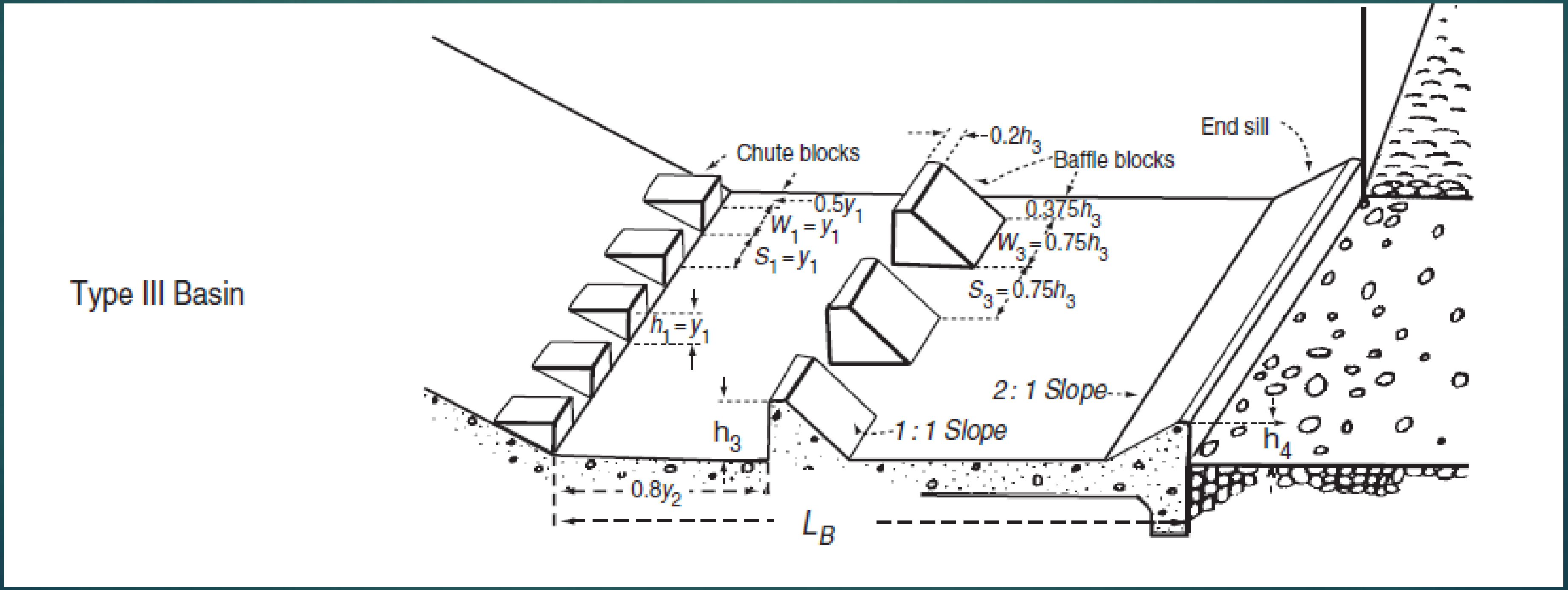
The crest of the spillway shown in Figure is shaped for a design head of 12 ft with an effective crest length of 20 ft. The crest elevation is 131 ft, and the elevation of the reservoir floor is 101 ft.

A hydraulic jump forms over a horizontal apron, which is 20 ft wide. The apron elevation is 100 ft. The natural stream can be approximated by a trapezoidal channel that has a bottom width of B=20 ft, side slopes of m=1.5, a Manning roughness factor of n=0.022, and a longitudinal bottom slope of S0=0.0001. Determine the position of the hydraulic jump with respect to the spillway toe for the design head condition.

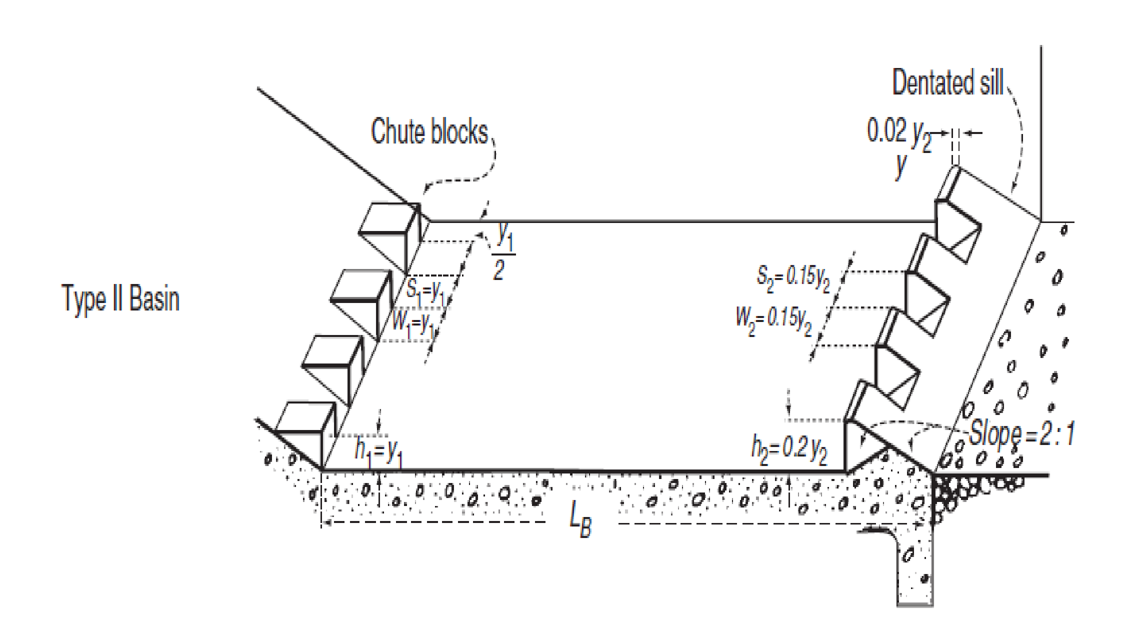


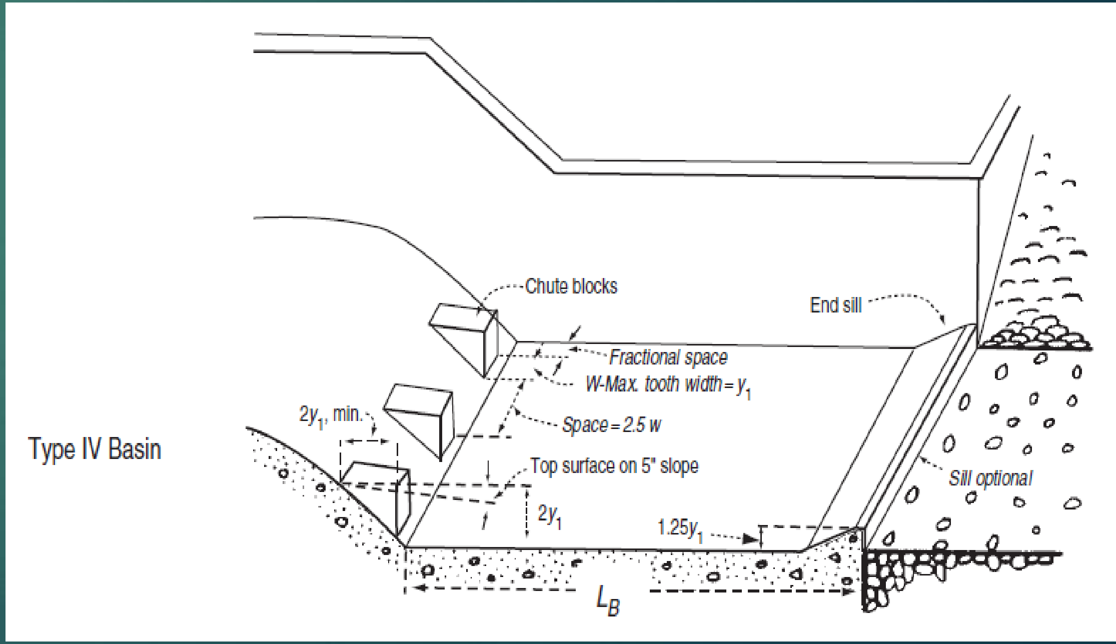
Stilling Basin Sections

- Stilling basins include chute blocks, baffle blocks, end sills.
- Chute blocks, located at the entrance to the stilling basin and help initially to spread some of the water.



- The resisting force of the baffle blocks on the flow helps to stabilize the jump.
- The sill at the end of basin lifts the flow away from the downstream bed and produces a return current that deposits bed material immediately downstream from the stilling basin.





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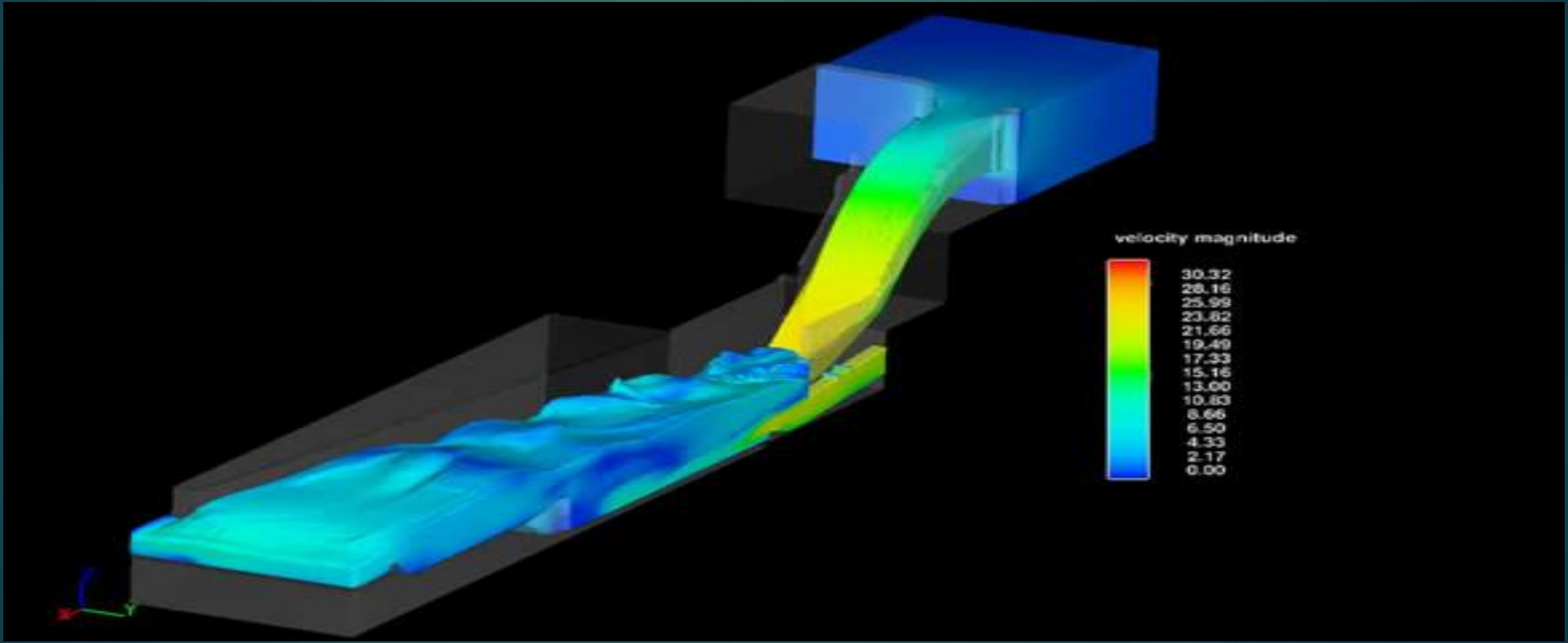
Simulation of Spillway, Stilling Basin and Bottom Outlet



Stilling Basin

Spillways, Terminal Structure, Cavitation

$S_1 = y_1$

$W_1 = y_2$

Type II

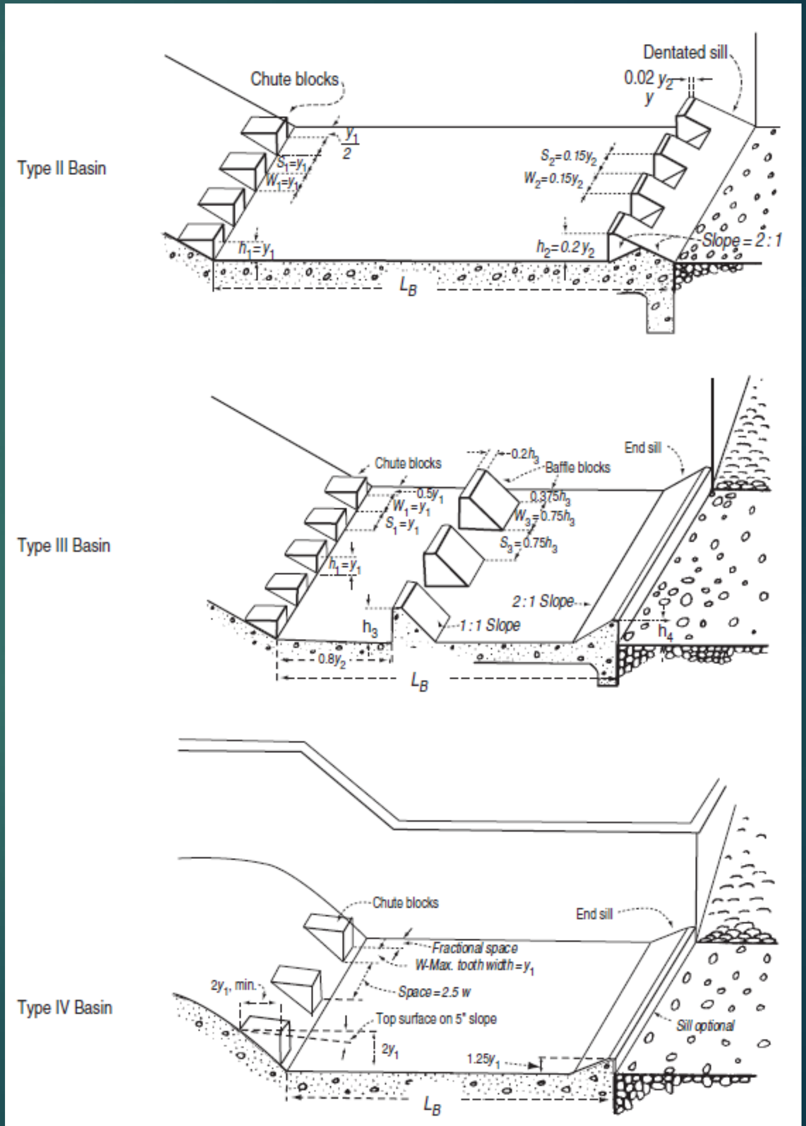
$L_B = D_2[4.0 + 0.055(Fr_1 - 4.5)]$ For $4.5 < Fr_1 < 10$

$L_B = 4.35\ D_2$ For $10 < Fr_1$

Type III

$L_B = D_2[2.4 + 0.073(Fr_1 - 4.5)]$ For $4.5 < Fr_1 < 10$

$L_B = 2.8\ D_2$ For $10 < Fr_1$



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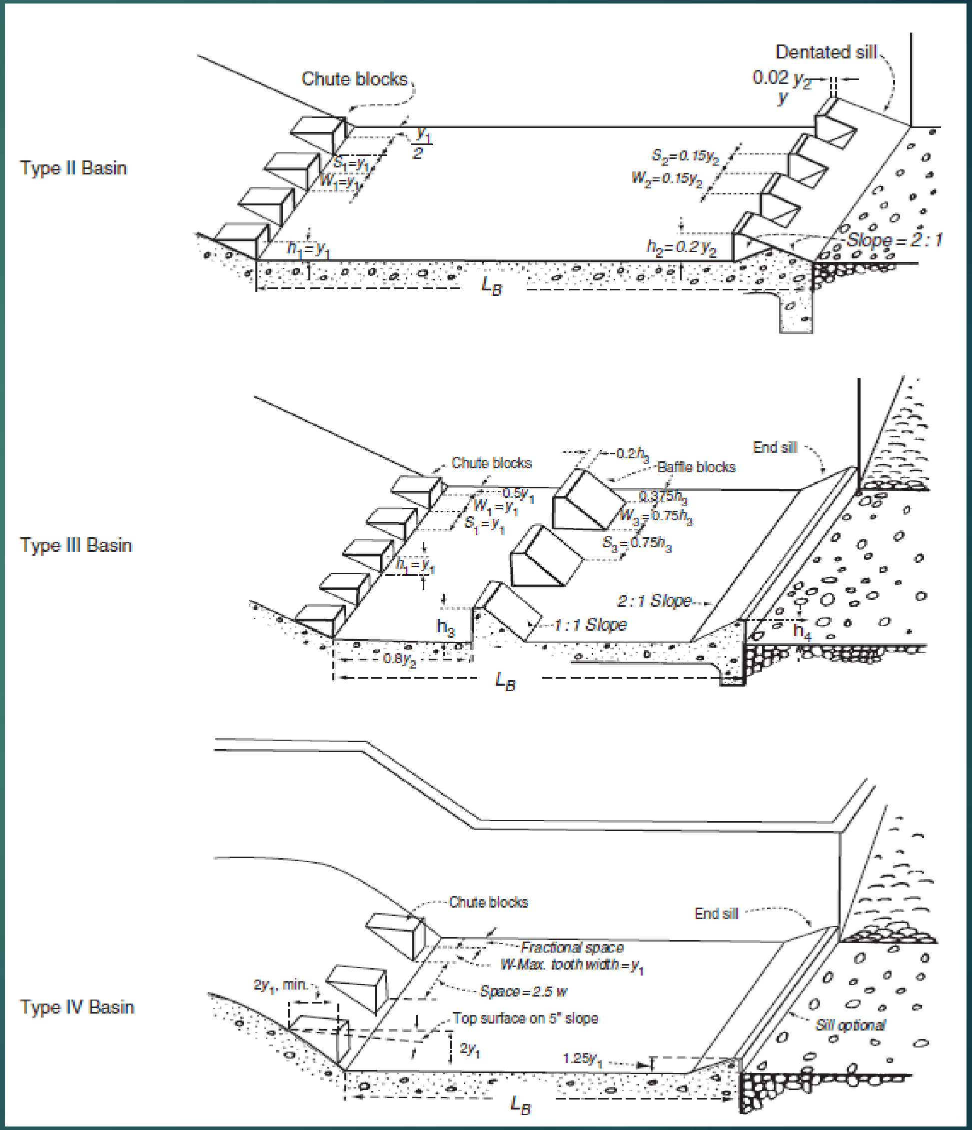
$$h_3 = D_1[1.30 + 0.164(Fr_1 - 4.0)]$$

$$h_4 = D_1[1.25 + 0.056(Fr_1 - 4.0)]$$

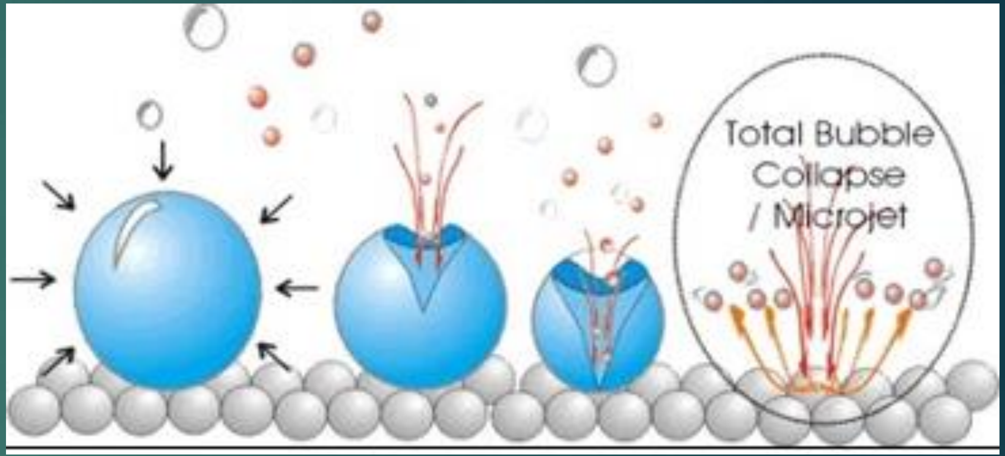
Type IV

$$L_B = D_2[5.2 + 0.4(Fr_1 - 2.5)]$$



Cavitation

- Cavitation is a rapid formation and collapse of vapour bubbles within a liquid.
- It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities where the pressure is relatively low.
- When subjected to higher pressure, the voids implode and can generate an intense shock wave and martials will be eroded.
- Cavitation causes reduced performance or potential damage to the flow surface.

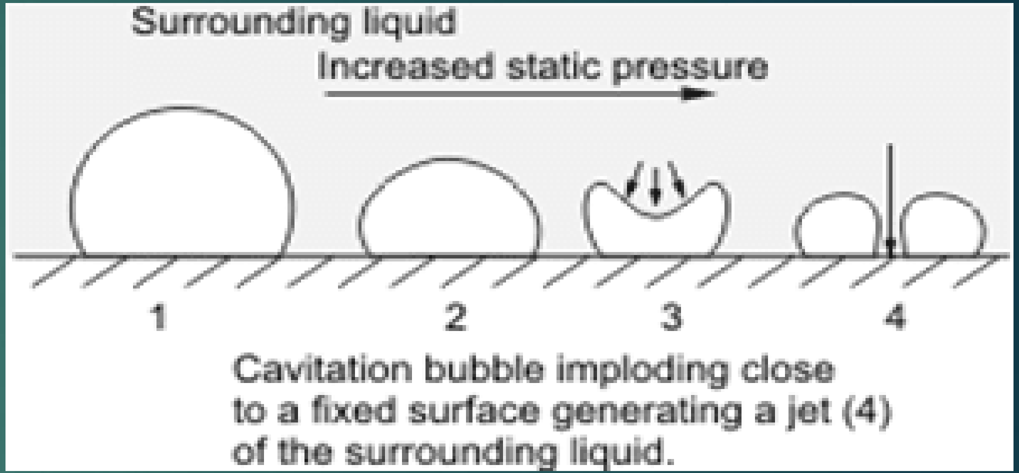


Cavitation


Phase diagram
At which pressures and temperatures is water solid, liquid or vapourised?

Cavitation in Spillways

- Spillways of high dams produce high velocities that combined with the roughness that can be resulted in cavitation.
- Cavitation damage occurs on concrete surface when discontinuity is encountered in the path of high velocity water flow.
- This discontinuity in the flow path cause the water to lift off the flow surface, creating negative pressure zones and resulting bubbles of water vapor.



- These bubbles travel downstream and collapse.

Cavitation in Spillways

- If the bubbles collapse against a concrete surface, it sends a very high pressure impact over an infinitely small area of the surface.
- Such high pressure impacts can remove particles of concrete, forming another discontinuity which then create more extensive cavitation damage.
- To date, no material, including stainless steel and cast iron, has been found capable of withstanding fully developed instances of cavitation.

Spillway Cavitation