Hydraulics Structures

Civil Engineering Department

Tikrit University

Wesam Sameer Mohammed-Ali

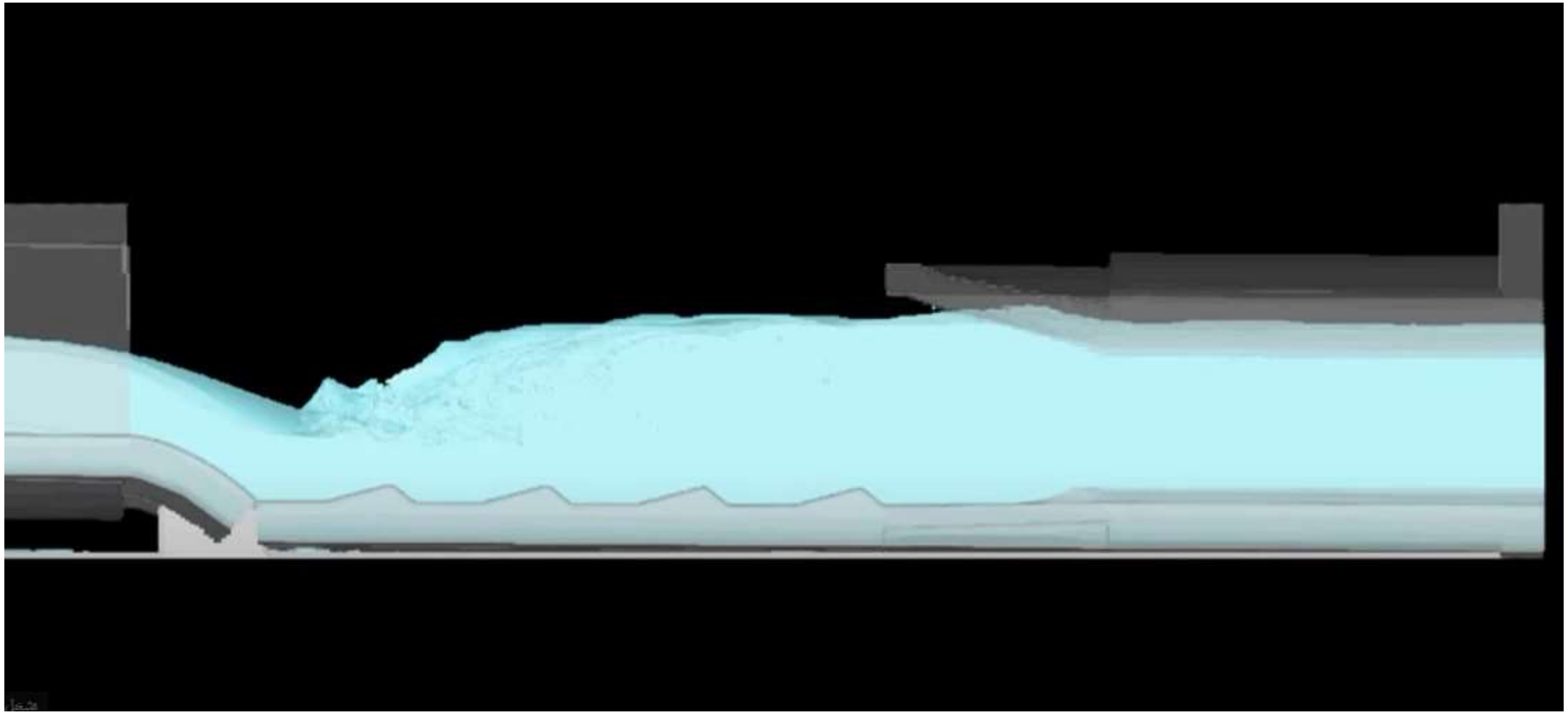
Ph.D., P.E., M.ASCE, M.AWRA

ENERGY DISSIPATERS

- **Energy dissipators** are devices designed to protect downstream areas from erosion by reducing the velocity of flow to acceptable limits.

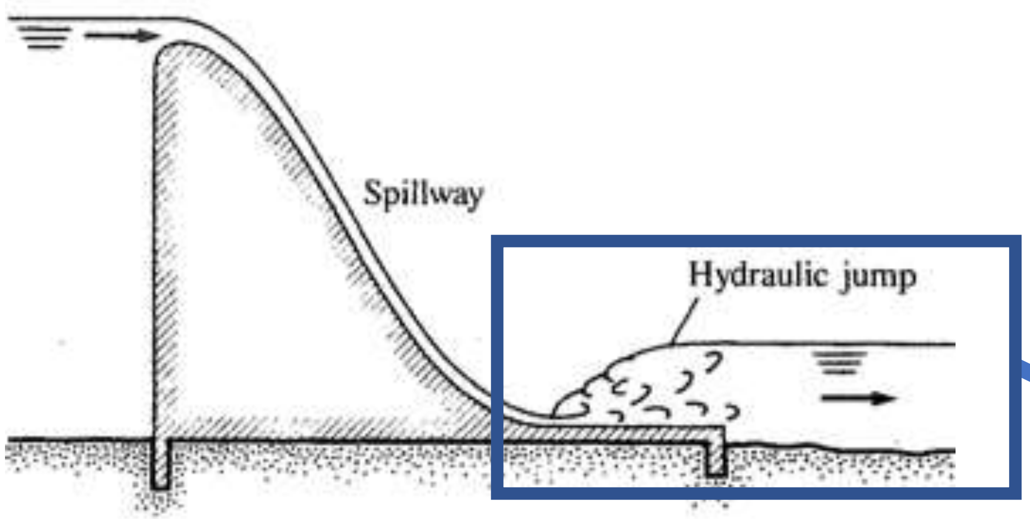
ENERGY DISSIPATERS

➢ **Hydraulic Jump** It is one of the best energy dissipaters.



❖ The Froude Number (Fr) is used as an index to the properties of this jump.

ENERGY DISSIPATERS



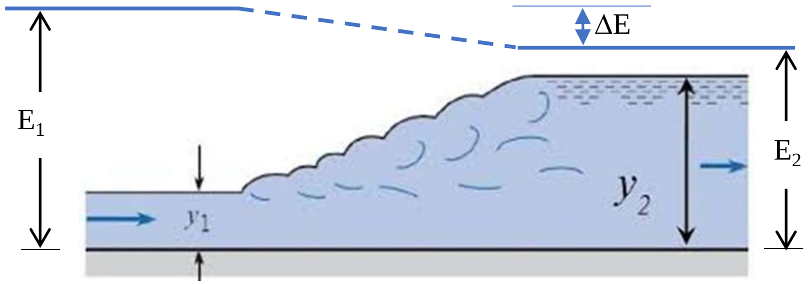
$$Fr = \frac{V}{\sqrt{gy}}$$

$$Fr > 1 \; \ldots Supercritical\ Flow$$

$$Fr < 1 \; \ldots Subcritical\ Flow$$

ENERGY DISSIPATERS

- **Hydraulic Jump** It is one of the best energy dissipaters. The Froude Number (Fr) is used as an index to the properties of this jump.



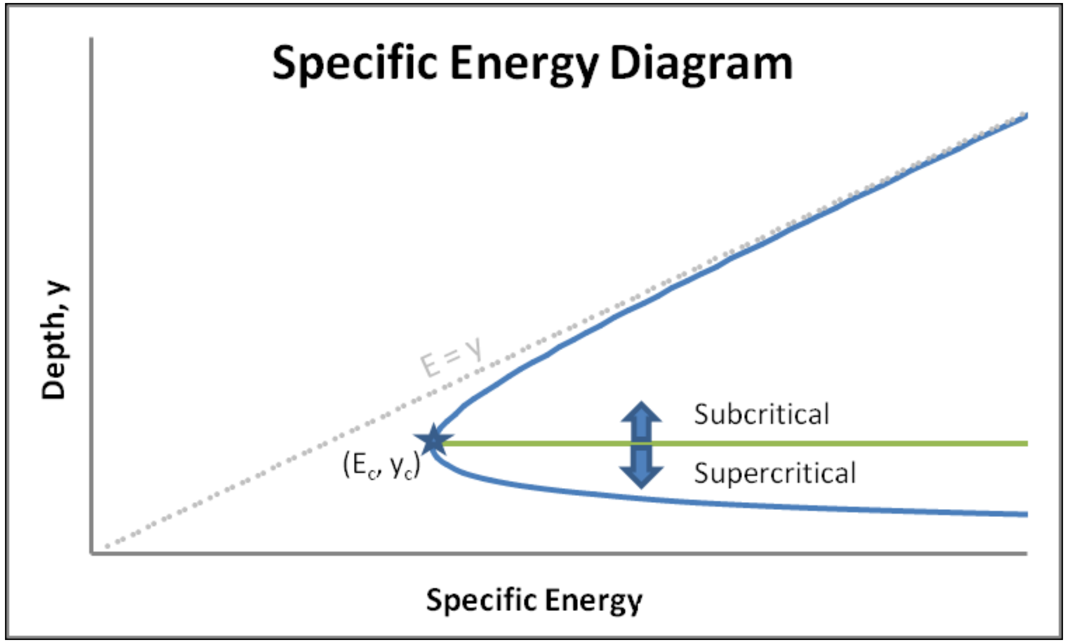
$$E = y + \frac{V^2}{2g}$$

- **Critical depth** is defined as the **depth** of flow where energy is at a minimum for a particular discharge.

$$y_c = \left(\frac{q^2}{g}\right)^{1/3}$$

$$y < y_c \quad \rightarrow Supercritical\ flow$$

$$y > y_c \quad \rightarrow Subcritical\ flow$$



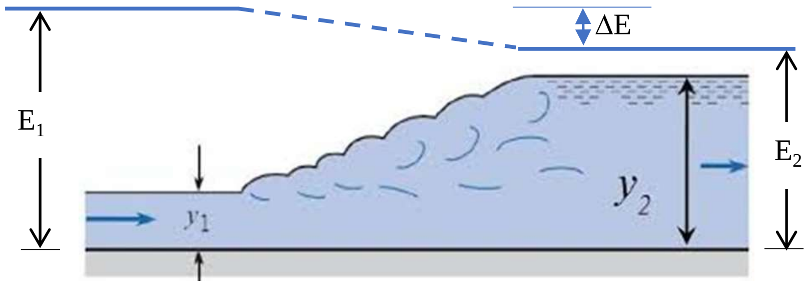
Note : A hydraulic jump will occur when the flow transfers from supercritical flow to subcritical flow

ENERGY DISSIPATERS

- **Hydraulic Jump** It is one of the best energy dissipaters. The Froude Number (Fr) is used as an index to the properties of this jump.

- **Critical depth** is defined as the **depth** of flow where energy is at a minimum for a particular discharge.

$$y_c = \left(\frac{q^2}{g}\right)^{1/3}$$



$$E = y + \frac{V^2}{2g}$$

The equation of the hydraulic jump is:

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

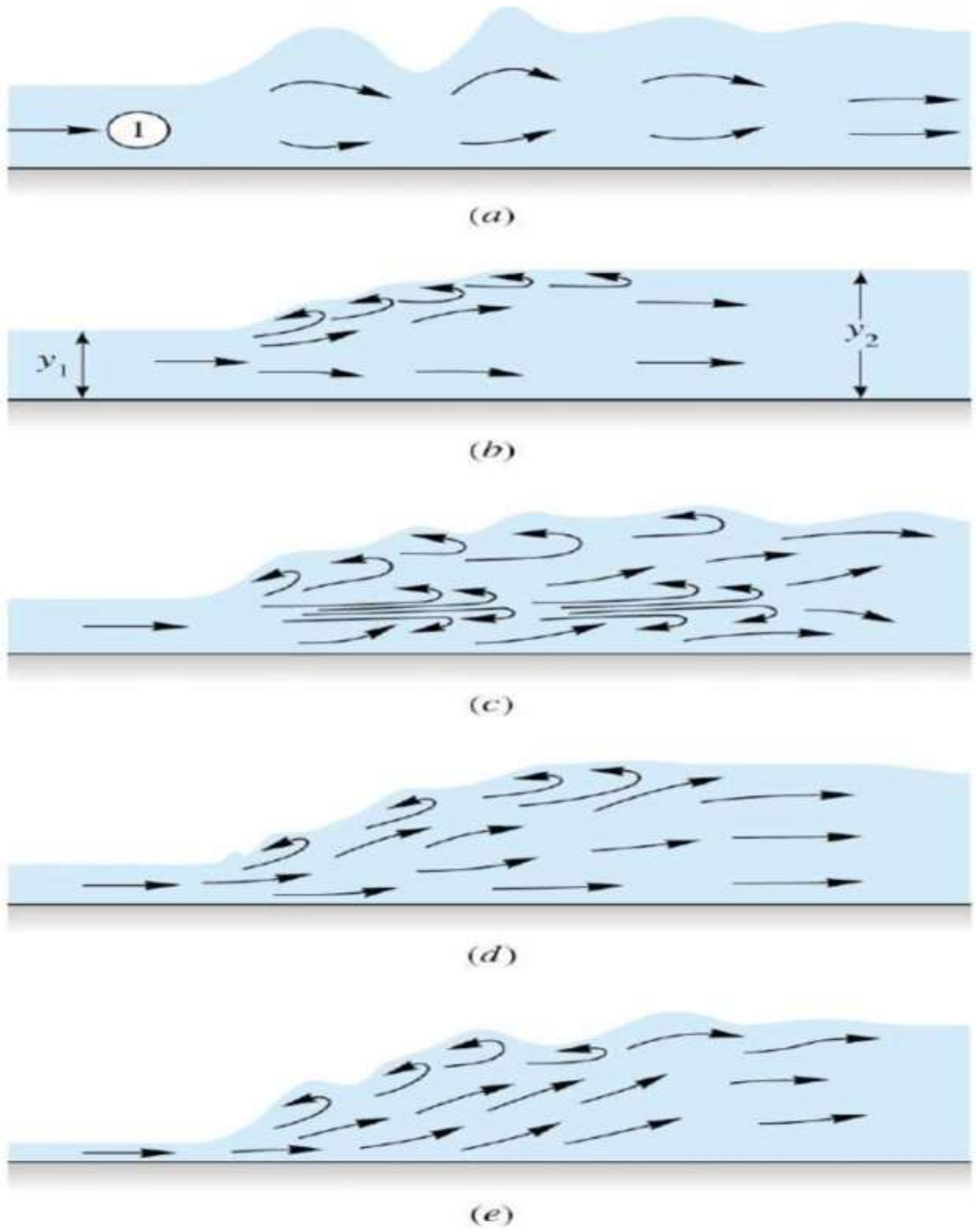
$$Fr_1 = \frac{V_1}{\sqrt{gy_1}}$$

- ***Type of Hydraulic jump:***

The jump can be classified according to Froude number as:

$$Fr_1 = \frac{V_1}{\sqrt{g y_1}}$$

No.	Fr	Type
1	1.0 to 1.7	Undular jump
2	1.7 to 2.5	Weak jump
3	2.5 to 4.5	Oscillating jump
4	4.5 to 9.0	Steady jump
5	Fr > 9.0	Strong jump



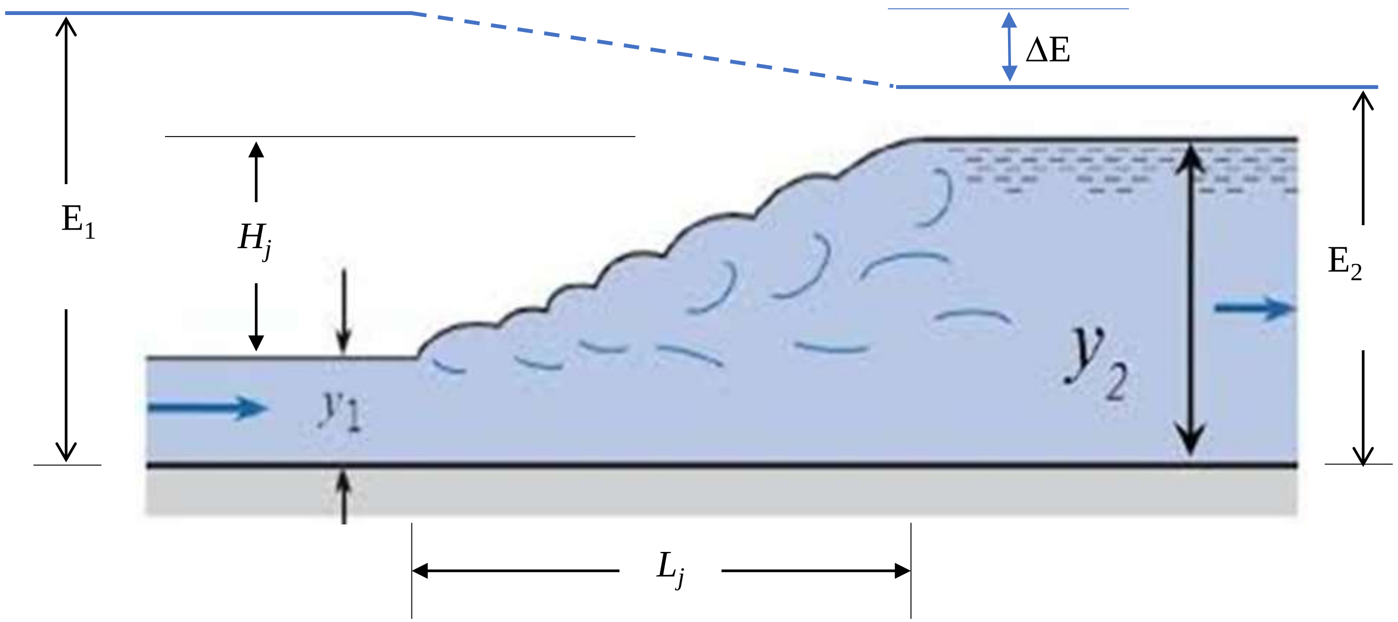
Basic characteristics of jumps

- **Energy loss (ΔE)**

$\Delta E = E_1 - E_2$ $\quad$ $\Delta E = \left(y_1 + \frac{v_1^2}{2g}\right) - \left(y_2 + \frac{v_2^2}{2g}\right)$ $\quad$ $\rightarrow \Delta E = \frac{(y_2 - y_1)^3}{4\, y_1 y_2}$

- **Efficiency of the jump**

$$\frac{E_2}{E_1} = \frac{\left(8Fr_1^{\,2} + 1\right)^{3/2} - 4Fr_1^{\,2} + 1}{8\, Fr_1^{\,2}\,(2 + Fr_1)^2}$$



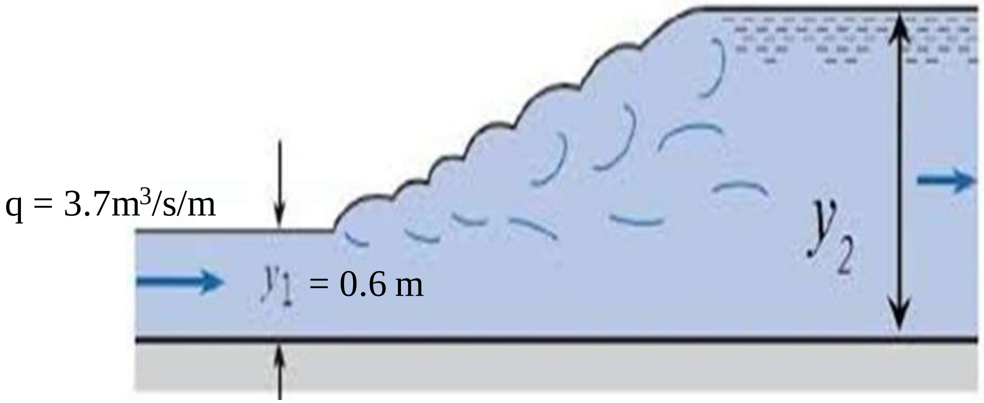
- **Height of the jump (H_j)**

$H_j \equiv y_2 - y_1$

- **Length of the jump (L_j)**

$L_j \equiv 6.9(y_2 - y_1)$

Example: Water flow through of flume with a depth of (0.6 m), and unit discharge (q) of (3.7 m3/sec/m). Does a hydraulic jump occur or not? Determine the depth of flow at the D/S of the jump and find the energy dissipation for this jump (ΔE)



Solution:

$$Fr_1 = \frac{V_1}{\sqrt{g y_1}}$$

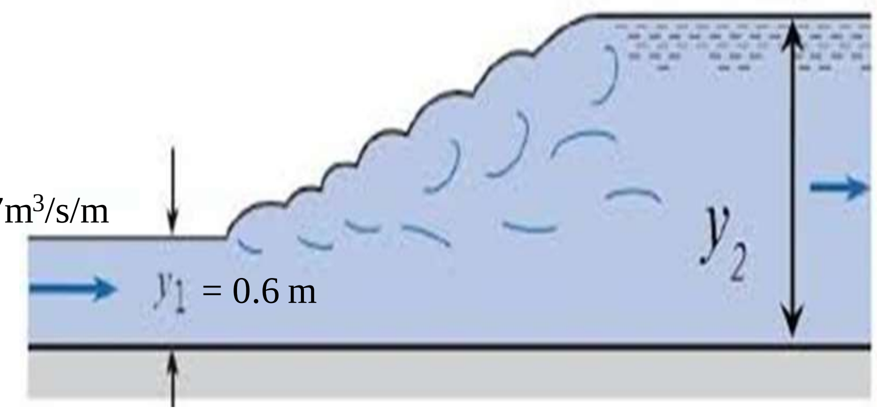
$$V_1 = \frac{Q}{A_1} = \frac{q\ B}{y_1 B} = \frac{3.7}{0.6} = 6.17\ m/sec$$

$$Fr_1 = \frac{6.17}{\sqrt{9.81 * 0.6}} = 2.54 > 1$$

The jump will occur (Oscillating Jump)

No.	Fr	Type
1	1.0 to 1.7	Undular jump
2	1.7 to 2.5	Weak jump
3	2.5 to 4.5	Oscillating jump
4	4.5 to 9.0	Steady jump
5	Fr > 9.0	Strong jump

Example: Water flow through of flume with a depth of (0.6 m), and unit discharge (q) of (3.7 m3/sec/m). Does a hydraulic jump occur or not? Determine the depth of flow at the D/S of the jump and find the energy dissipation for this jump (ΔE)



Solution:

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

$$\frac{y_2}{0.6} = \frac{1}{2}\left[\sqrt{1 + 8(2.54)^2} - 1\right]$$

$$y_2 = 1.88\ m$$

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

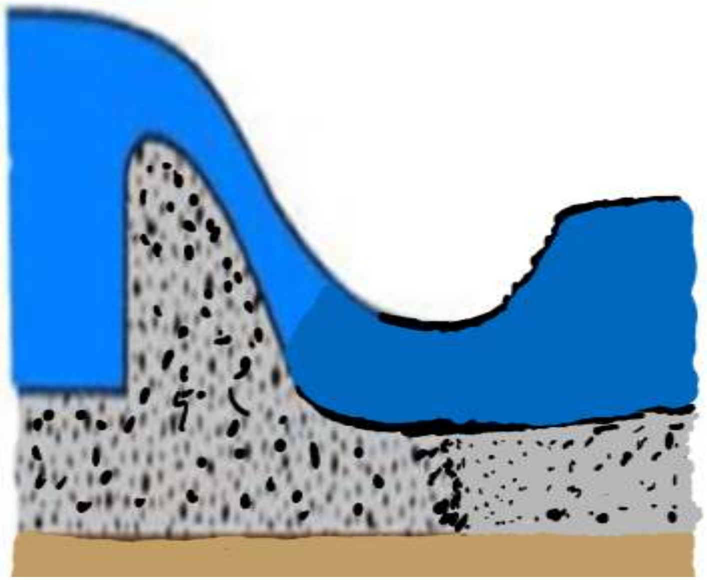
$$\Delta E = \frac{(1.88 - 0.6)^3}{4 *\ 0.6 * 1.88} \qquad \rightarrow\ \Delta E = 0.46m$$

Example: The formula of discharge over the crest of spillway show in the figure is:

$$Q = CH^{3/2}L$$

where: L= the water way of the spillway (50m), H= the water depth over the crest (2m), and C= coefficient of discharge =2.2. At the end of the spillway, a hydraulic jump occurred. The height of this jump (H_j) is 5m.

1. Find the depth of water before and after the jump (y_1 and y_2).
2. What is the name of this jump and how much is the energy loss in this jump?



Solution:

$$Q = CH^{3/2}L$$

$$Q = (2.2) * (2)^{3/2} * (50)$$

$$Q = 311.12\ m^3/sec$$

$$h_i = y_2 - y_1 \rightarrow \quad y_2 = 5 + y_1 \text{ .....(*)}$$

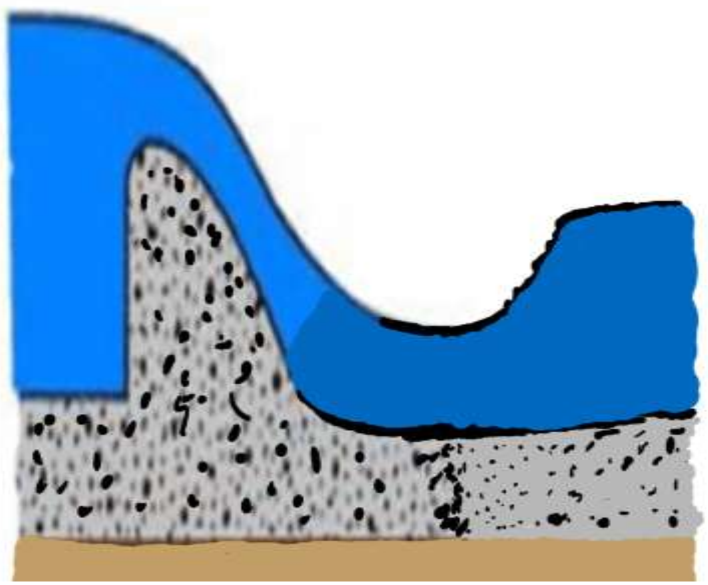
$$\frac{y_2}{y_1} = \frac{1}{2}\left[\sqrt{1 + 8Fr^2} - 1\right]$$

$$H_i = y_2 - y_1 \rightarrow \quad y_2 = 5 + y_1 \;.....(*)$$

$$Fr_1 = \frac{V_1}{\sqrt{g y_1}}$$

$$V_1 = \frac{Q}{A_1} = \frac{311.12}{50\, y_1} = \frac{6.22}{y_1}$$

$$Fr_1 = \frac{\frac{6.22}{y_1}}{\sqrt{9.81\, y_1}} = \frac{1.98}{{y_1}^{3/2}} \qquad \ldots\ldots (**)$$



$$\frac{5 + y_1}{y_1} = \frac{1}{2}\left[\sqrt{1 + 8\left(\frac{1.98}{{y_1}^{3/2}}\right)^2} - 1\right]$$

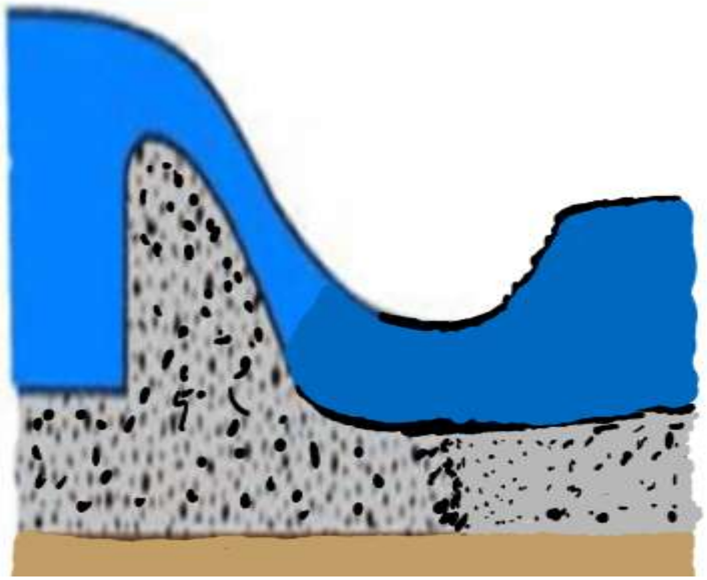
$$y_1 = \frac{y_1}{2}\left[\sqrt{1 + 8(\frac{1.98}{{y_1}^{3/2}})^2} - 1\right] - 5$$

Using try & error method to find y_1 by assume the value to get

the two equal sides: -

$y_1 \approx 0.268\, m$

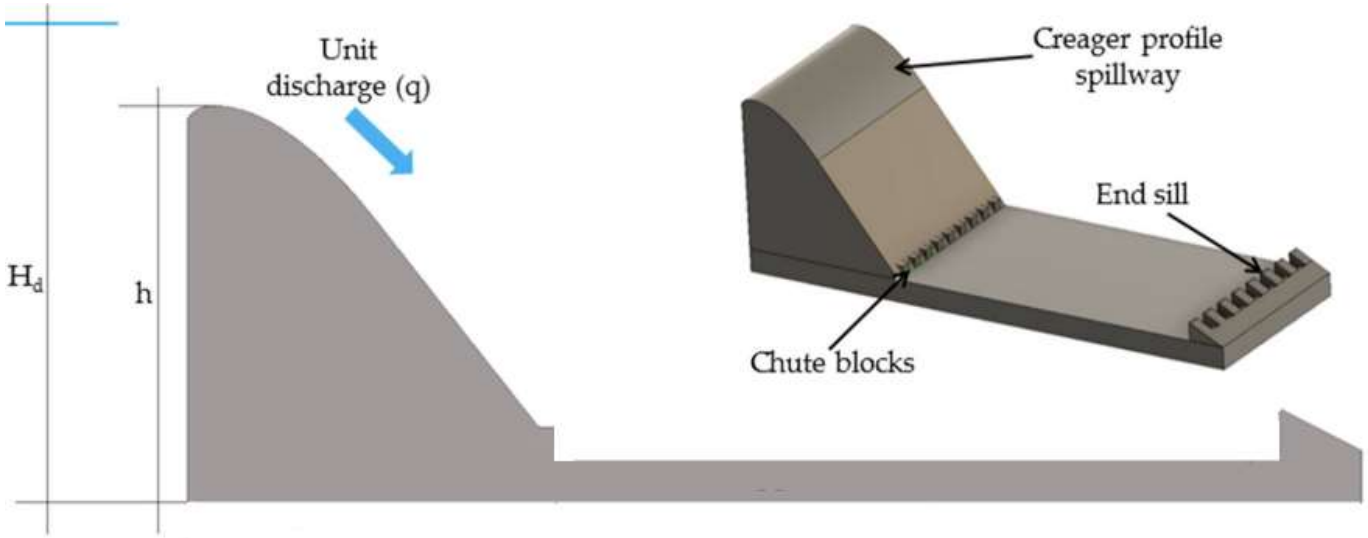
$y_2 = 5 + y_1 \rightarrow\ y_2 = 5.268\, m$



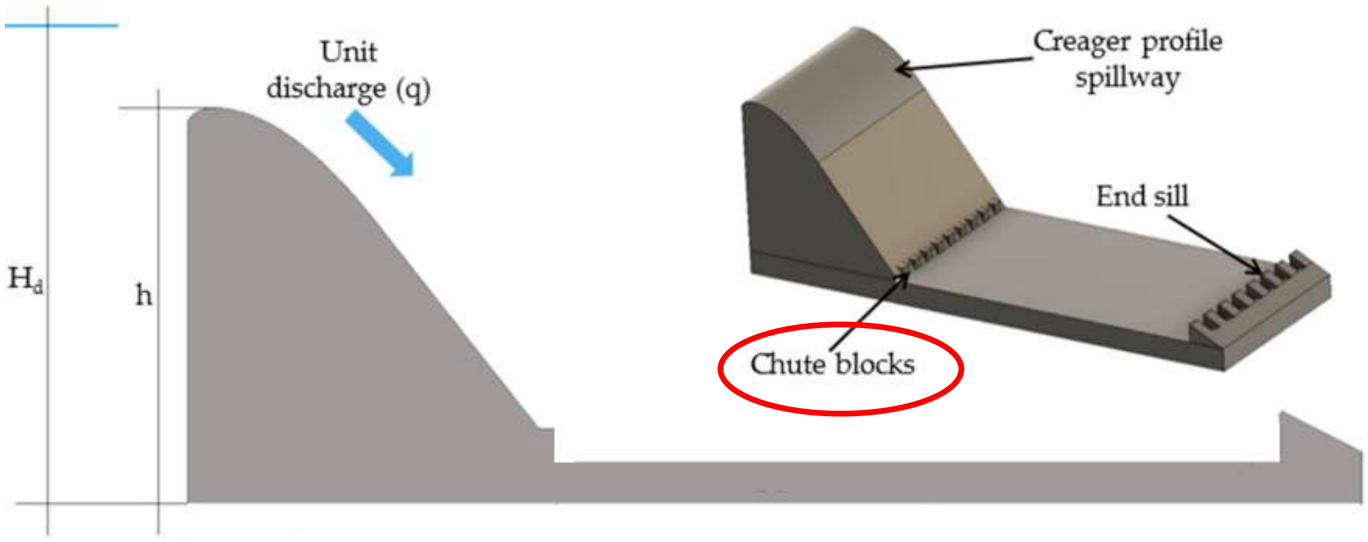
$$\Delta E = \frac{(y_2 - y_1)^3}{4 y_1 y_2} = \frac{(5)^3}{4(0.268) * (5.268)} = 22.134\, m$$

$$Fr_1 = \frac{1.98}{(0.268)^{3/2}} = 14.3\ > 9 \quad \therefore Strong\ jump$$

A still basin is a short length of a paved channel placed at the end of any supercritical flow. The aim of the designs is to make a hydraulic jump form within the basin, so that the flow is converted to subcritical before it reaches the exposed and unpaved riverbed at D/S.

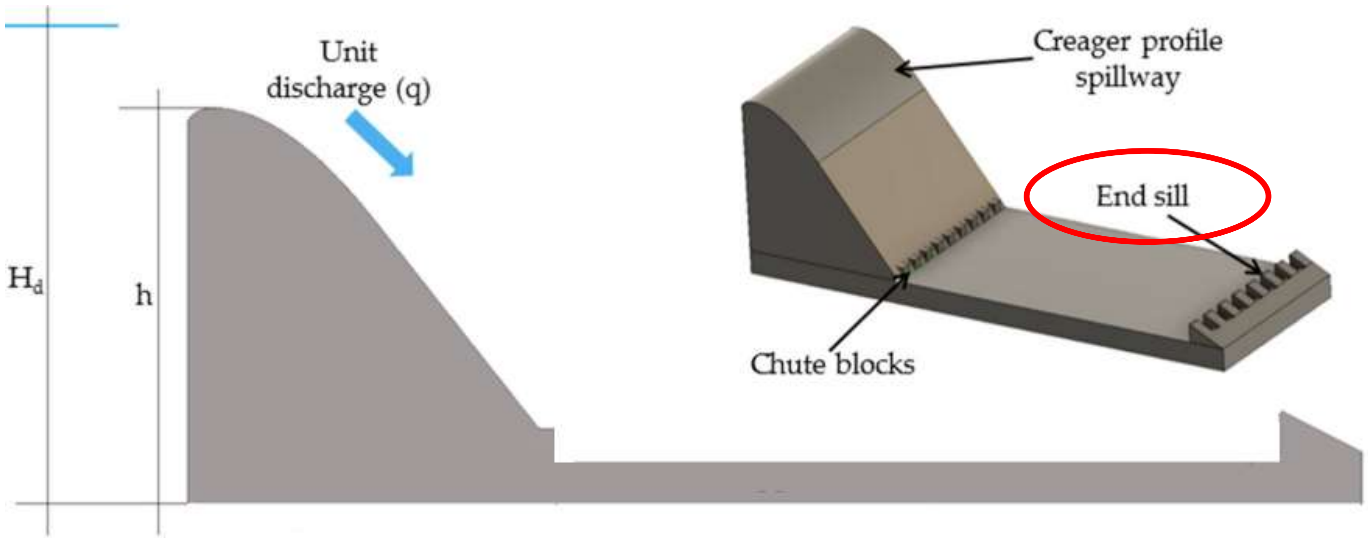


The chute blocks, located at the entrance to the stilling basin, serve to increase the effective depth of the entering stream, break the stream up into a number of small jets, and help create the turbulence required for effective energy dissipation.



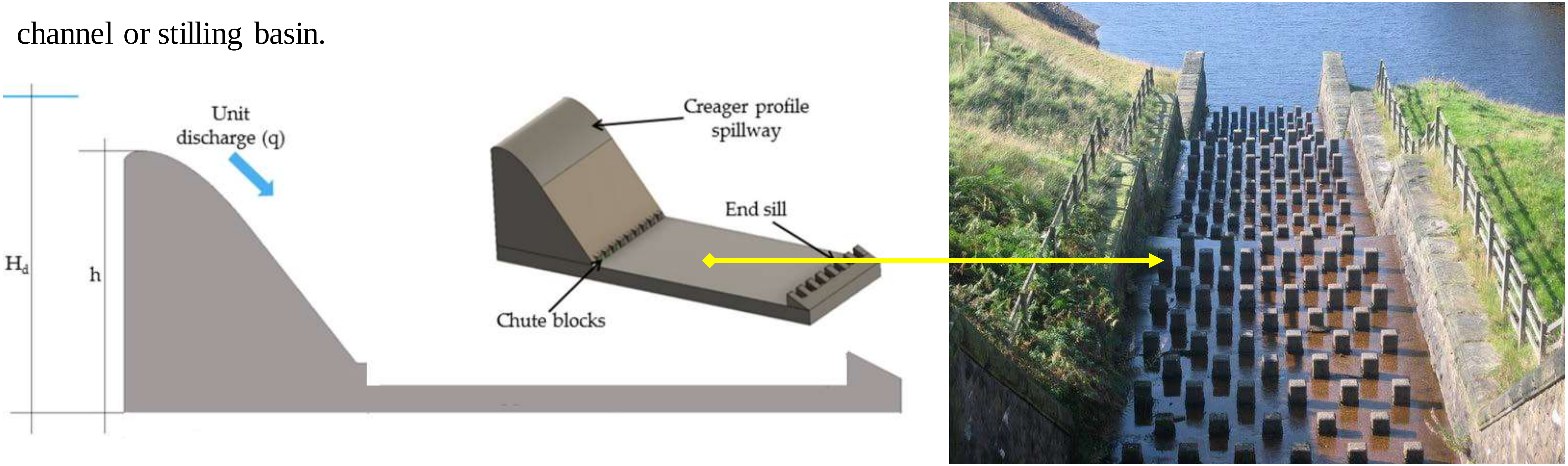
End Sill

The end sill, located at the downstream end of the stilling basin, deflects the bottom currents upward and away from the stream bed. In addition, a ground roller is created under the deflected stream which brings bed material from downstream and deposits it at the end of the stilling basin.



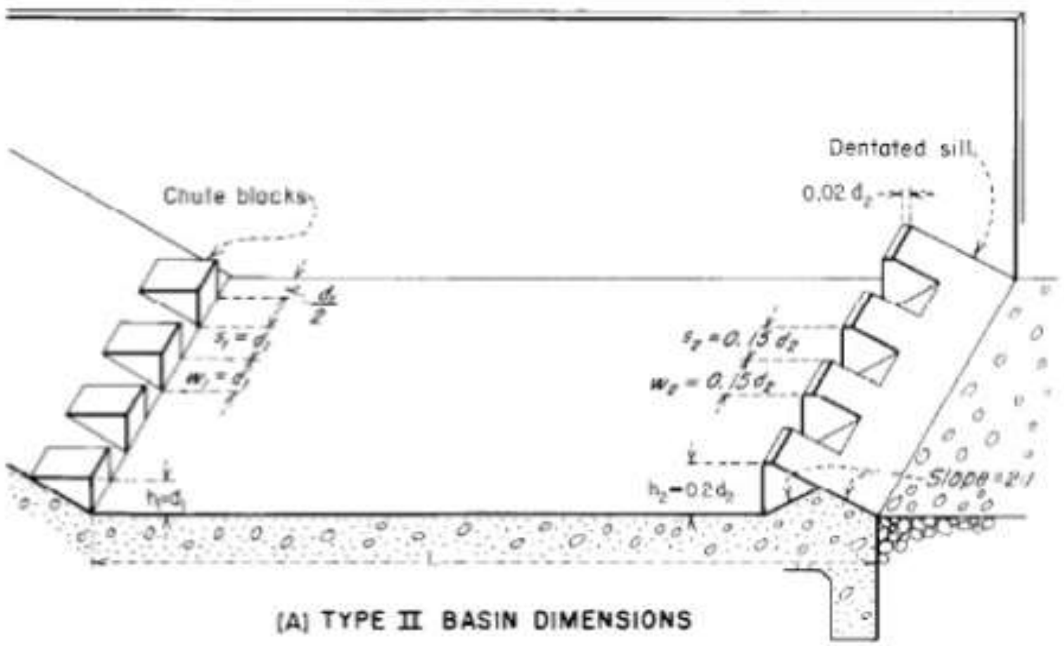
Baffle Piers

Baffle piers (Baffle block) is one of the efficient appurtenances that have a capacity in reducing the flow momentum that will decrease the flow velocity. Using baffle block is the main technique for accelerating the hydraulic jump formation and dissipating a great amount of the residual harmful kinetic energy occurring at the downstream of the spillway, channel or stilling basin.



- ***U.S.B.R Stilling Basin No. II***

It is used when the incoming velocities exceed 15 m/sec and Fr > 4.5. This basin contains chute block at the D/S end. No baffle piers are used because the relatively high velocities entering the jump might cause cavitation on piers.

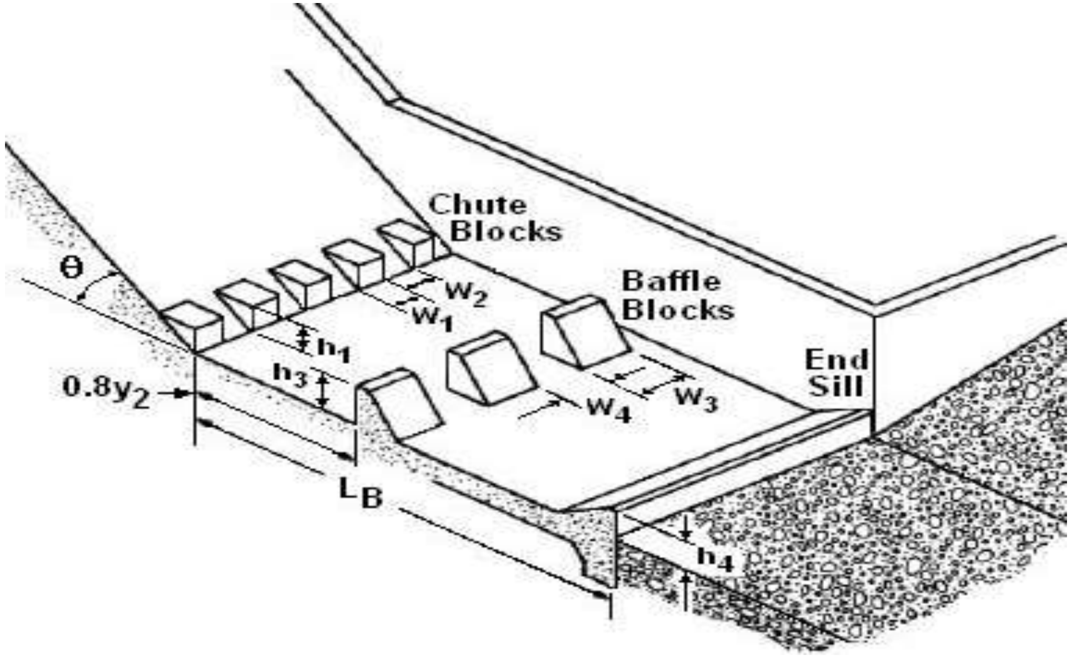


(A) TYPE II BASIN DIMENSIONS

Fr	4.5	6	8	≥10
L	3.6 y_2	4 y_2	4.2 y_2	4.3 y_2

- ***U.S.B.R Stilling Basin No. III***

This basin may be used when the incoming velocity do not exceed 15 m/sec and Fr > 4.5, but small structures. It is the same as No. II, but with additional blocks (baffle piers) and continuous sill.

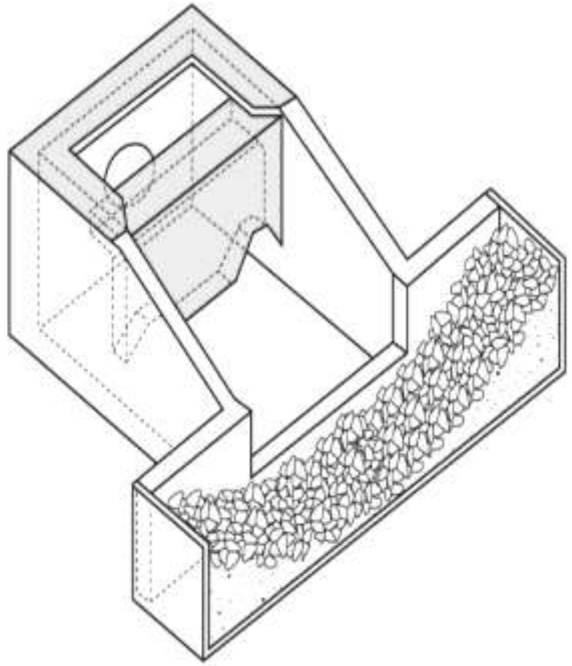


$$L = [2.4 + 0.073(Fr_1 - 4.5)]y_2 \qquad 4.5 < Fr < 10$$

$$L = 2.8\, y_2 \qquad Fr > 10$$

- ***U.S.B.R Stilling Basin No. IV***

This is recommended for use with sumps of *Fr* = 2.5 to 4.5. This usually occur on canal structures and diversion dams. This basin is applicable to rectangular cross section only.



$$L = [5.2 + 0.4(Fr_1 - 2.5)]y_2$$

➢ ***S.A.F Stilling Basin***

It is used for small structures and for Fr= 1.7-17. The stilling basin side walls be parallel (as a rectangular stilling basin) or they may diverge as an extension of the transition side walls (as a trapezoidal basin)

Fr_1	1.7-5.5	5.5-11	11-17
L_B/y_1	$4.5/Fr_1^{0.76}$	$4.5/Fr_1^{0.76}$	$4.5/Fr_1^{0.75}$
T_w/y_2	$1.1-(Fr_1^2/120)$	0.85	$1-(Fr_1^2/800)$

Example:

Design a stilling basin for an overflow spillway with the following given data:

- Design discharge (Q) =2204 m^3/sec
- Length of the spillway (L)= 200 m
- Crest level of spillway = 342.5 m
- Bed level of spillway= 320 m
- Equation of discharge over the spillway is $Q = 2.2\ L\ H^{3/2}$

Solution:

$$Q = 2.2\ L\ H^{3/2}$$

$$2204 = 2.2\ *200 *\ H^{3/2}$$

H = 2.91 m

$E_0 = E_1$

$$\frac{V_0^{\,2}}{2g} + y_0 = \frac{V_1^{\,2}}{2g} + y_1$$

$$y_0 = \frac{V_1^{\,2}}{2g} + y_1$$

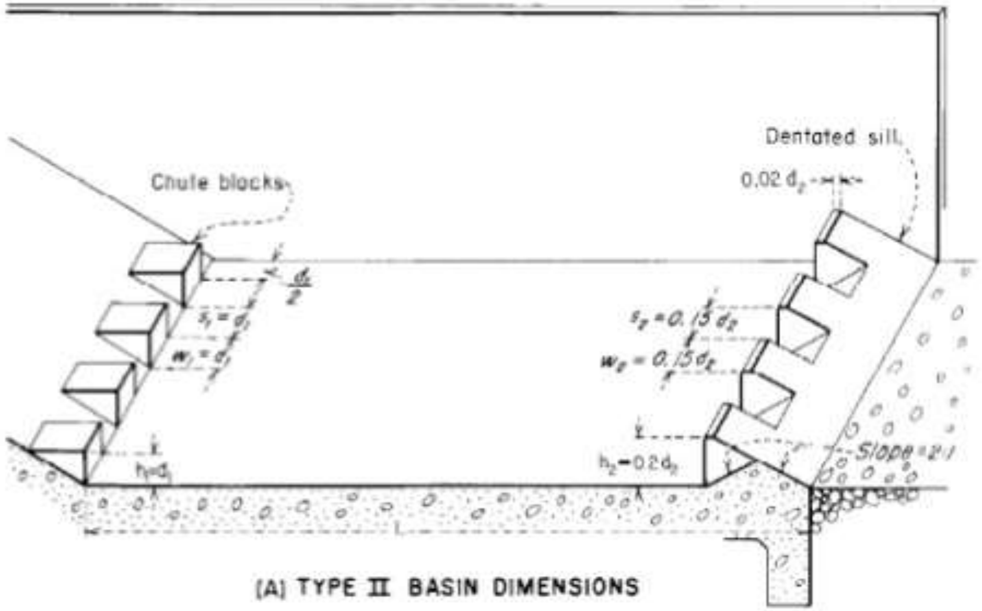
$$(342.5\text{-}320) = \frac{V_1^{\,2}}{2g} + y_1$$

$$25.41 = \frac{V_1^{\,2}}{2g} + y_1$$

$$V = \frac{Q}{A_1} = \frac{2204}{L\ y_1} = \frac{2204}{200\ y_1}$$

$$25.41 = \frac{\left(\frac{2204}{200\ y_1}\right)^2}{19.62} + y_1$$

Using try & error $y_1 = 0.5\ m$ & Then $V = \frac{2204}{200\ (0.5)} = 22.04\ m/sec$



(A) TYPE II BASIN DIMENSIONS

$$Fr_1 = \frac{V_1}{\sqrt{g y_1}} = \frac{22.04}{\sqrt{9.81 * 0.5}} = 9.96 > 4.5$$

∴ U.S.B.R Stilling basin No. II

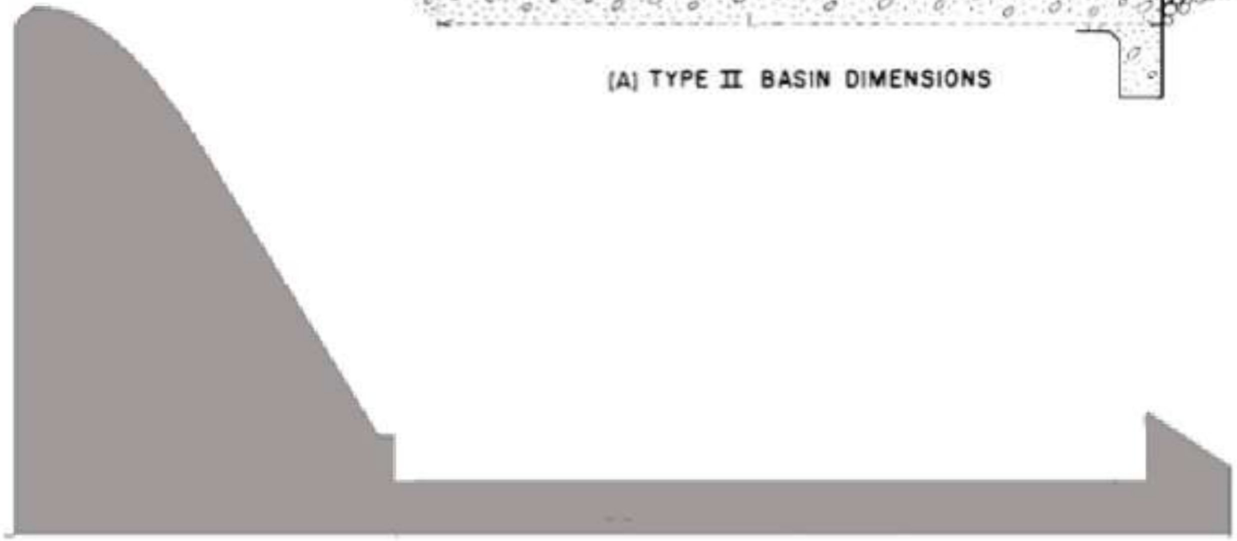
$$\frac{y_2}{y_1} = \frac{1}{2}\left[\sqrt{1 + 8Fr^2} - 1\right]$$

$$\frac{y_2}{0.5} = \frac{1}{2}\left[\sqrt{1 + 8(9.96)^2} - 1\right]$$

$$y_2 = 6.79\ m$$

L = 4.3 y_2 = 4.3*6.79

L = 29.2m



Hydraulics Structures

Civil Engineering Department

Tikrit University

Wesam Sameer Mohammed-Ali

Ph.D., P.E., M.ASCE, M.AWRA