Hydraulics Engineering Lec #4: Hydraulic jump and its practical applications.

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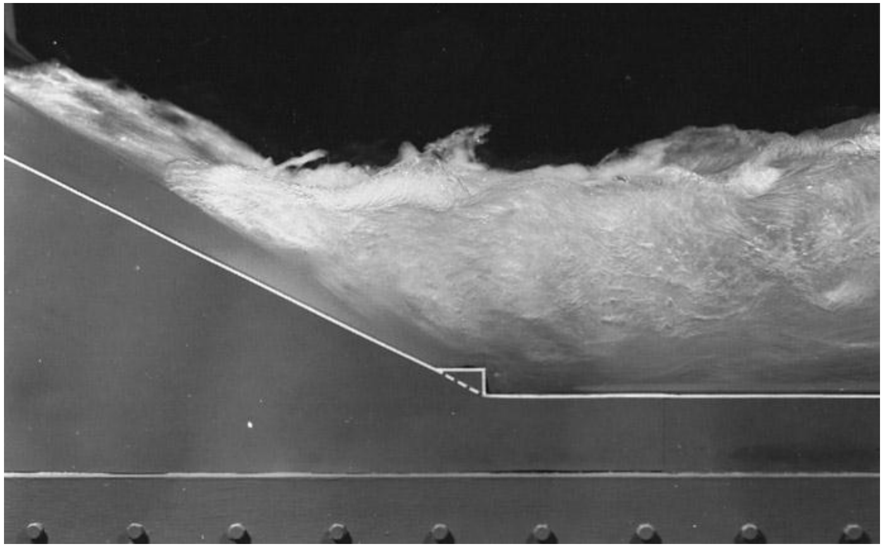
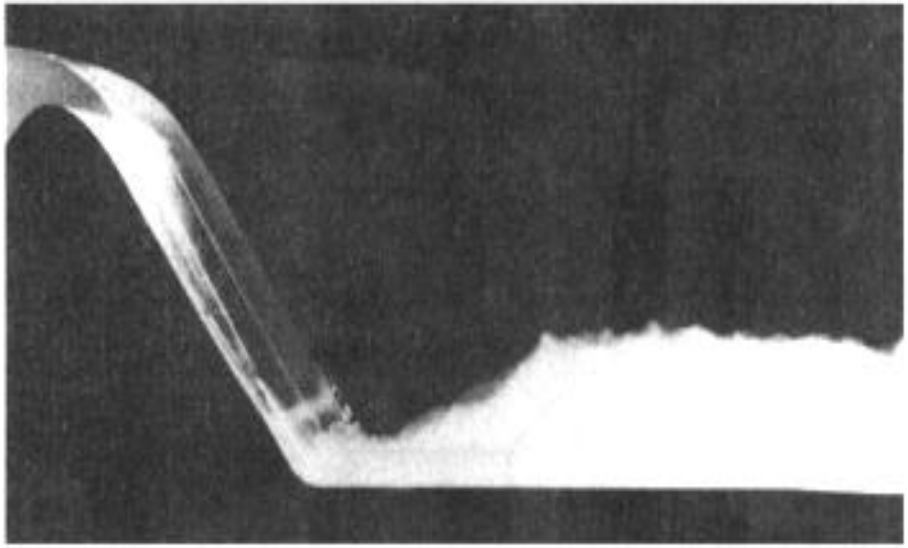
Steady Flow in Open Channels

- Specific Energy and Critical Depth
- Surface Profiles and Backwater Curves in Channels of Uniform sections
- Flow over Humps and through Constrictions
- Hydraulics jump and its practical applications.
- Broad Crested Weirs and Venturi Flumes

Hydraulic jump



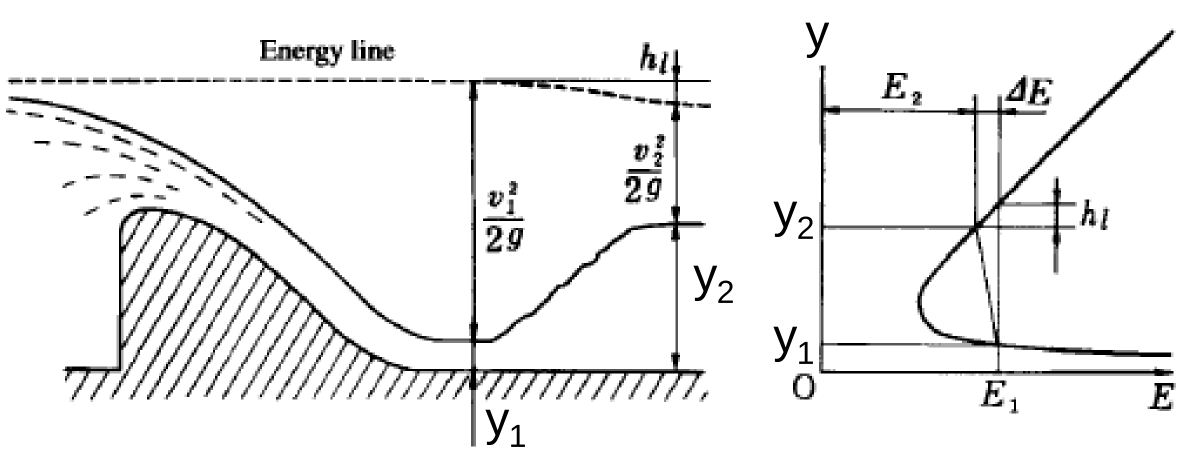
Hydraulic jump formed on a spillway model for the Karna-fuli Dam in Bangladesh.



Rapid flow **and** hydraulic jump on a dam

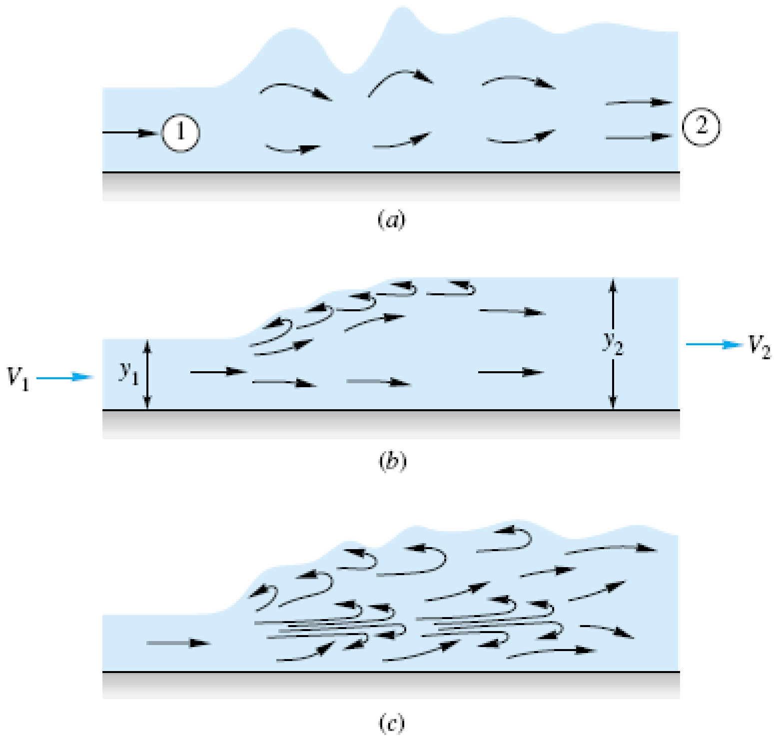
Hydraulics Jump or Standing Wave

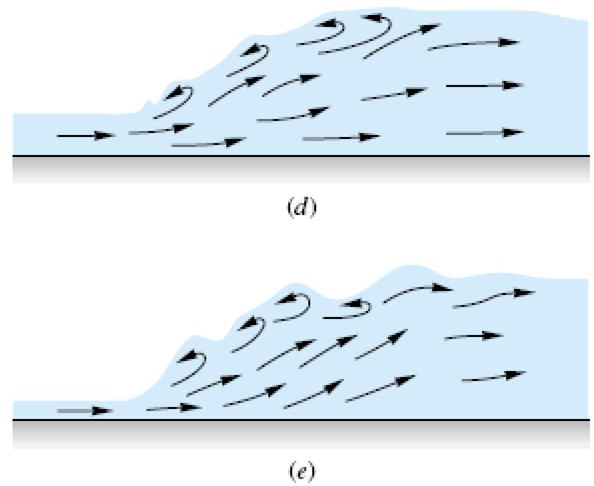
- Hydraulics jump is local non-uniform flow phenomenon resulting from the change in flow from super critical to sub critical. In such as case, the water level passes through the critical depth and according to the theory dy/dx=infinity or water surface profile should be vertical. This off course physically cannot happen and the result is discontinuity in the surface characterized by a steep upward slope of the profile accompanied by lot of turbulence and eddies. The eddies cause energy loss and depth after the jump is slightly less than the corresponding alternate depth. The depth before and after the hydraulic jump are known as conjugate depths or sequent depths.



y_1 & y_2 are called conjugate depths

Classification of Hydraulic jump





Classification of hydraulic

jumps: (*a*) Fr =1.0 to 1.7: undular jumps;
(*b*) Fr =1.7 to 2.5: weak jump;

(*c*) Fr =2.5 to 4.5: oscillating jump;

(*d*) Fr =4.5 to 9.0: steady jump;

(*e*) Fr =9.0: strong jump.

Classification of Hydraulic jump

- F_{r1} <1.0: Jump impossible, violates second law of thermodynamics.
- F_{r1}=1.0 to 1.7: Standing-wave, or *undular, jump* about 4y_2 long; low dissipation, less than 5 percent.
- Fr1=1.7 to 2.5: Smooth surface rise with small rollers, known as a *weak jump*; dissipation 5 to 15 percent.
- F_{r1}=2.5 to 4.5: Unstable, *oscillating jump*; each irregular pulsation creates a large wave which can travel downstream for miles, damaging earth banks and other structures. Not recommended for design conditions. Dissipation 15 to 45 percent.
- F_{r1}=4.5 to 9.0: Stable, well-balanced, *steady jump*; best performance and action, insensitive to downstream conditions. Best design range. Dissipation 45 to 70 percent.
- F_{r1}>9.0: Rough, somewhat intermittent *strong jump*, but good performance. Dissipation 70 to 85 percent.

Uses of Hydraulic Jump

- Hydraulic jump is used to dissipate or destroy the energy of water where it is not needed otherwise it may cause damage to hydraulic structures.
- It may be used for mixing of certain chemicals like in case of water treatment plants.
- It may also be used as a discharge measuring device.

Equation for Conjugate Depths

Momentum Equation

$$F_1 - F_2 + F_g - F_f = \rho Q(V_2 - V_1)$$

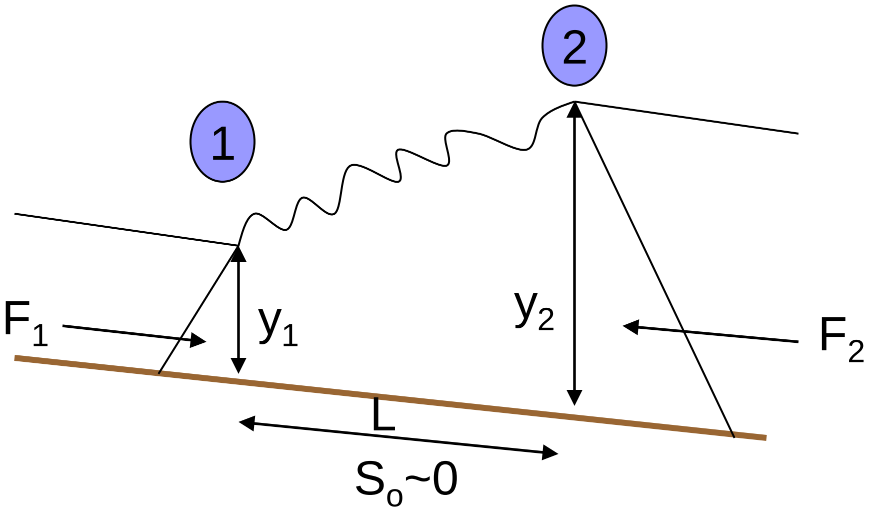
Where

$F_1 = Force\ helping\ flow$

$F_2 = Force\ resisting\ flow$

$F_f = Frictional$ Resistance

$Fg = Gravitational\ component\ of\ flow$



Assumptions:

1. If length is very small frictional resistance may be neglected. i.e (F_f=0)
2. Assume S_o=0; Fg=0

Note: Momentum equation may be stated as sum of all external forces is equal to rate of change of momentum.

Equation for Conjugate Depths

Let the height of jump = y_2-y_1

Length of hydraulic jump = Lj

$$F1 - F2 = \frac{\gamma}{g} Q(V_2 - V_1)$$

$$\gamma h_{c1} A_1 - \gamma h_{c2} A_2 = \frac{\gamma}{g} Q(V_2 - V_1)$$

h_c = Depth to centriod as measured from upper WS

$$\frac{\gamma}{g} QV_1 + \gamma h_{c1} A_1 = \frac{\gamma}{g} QV_2 + \gamma h_{c2} A_2 \Rightarrow eq.1$$

Eq. 1 stated that the momentum flow rate plus hydrostatic force is the same at both sections 1 and 2.

Dividing Equation 1 by γ and changing V to Q/A

$$\frac{Q^2}{A_1 g} + A_1 h_{c1} = \frac{Q^2}{A_2 g} + A_2 h_{c2} = F_m \Rightarrow eq.2$$

Where;

$$\text{Specific Force} = F_m = \frac{Q^2}{Ag} + Ahc$$

Note: Specific force remains same at section at start of hydraulic jump and at end of hydraulic jump which means at two conjugate depths the specific force is constant.

Now lets consider a rectangular channel

$$\therefore \frac{q^2 B^2}{By_1 g} + By_1 \frac{y_1}{2} = \frac{q^2 B^2}{By_2 g} + By_2 \frac{y_2}{2}$$

$$\frac{q^2}{y_1 g} + \frac{y_1^2}{2} = \frac{q^2}{y_2 g} + \frac{y_2^2}{2} \Rightarrow eq.3$$

$$\frac{q^2}{g}\left(\frac{1}{y_1} - \frac{1}{y_2}\right) = \frac{1}{2}\left(y_2^2 - y_1^2\right)$$

or

$$\frac{q^2}{g}\left(\frac{y_2 - y_1}{y_1 y_2}\right) = \frac{1}{2}\left(y_2 - y_1\right)\left(y_2 + y_1\right)$$

Equation for Conjugate Depths

$$\frac{q^2}{g} = y_1 y_2 \left(\frac{y_2 + y_1}{2} \right) \Rightarrow eq.4$$

Eq. 4 shows that hydraulic jumps can be used as discharge measuring device.

Since $q = V_1 y_1 = V_2 y_2$

$$\therefore \frac{V_1^2 y_1^2}{g} = y_1 y_2 \left(\frac{y_2 + y_1}{2} \right)$$

$\div\, by\ y_1^3$

$$\frac{2V_1^2}{gy_1} = \frac{y_2}{y_1} + \left(\frac{y_2}{y_1} \right)^2$$

$$0 = \left(\frac{y_2}{y_1} \right)^2 + \frac{y_2}{y_1} - 2F_{N1}^2$$

$$\frac{y_2}{y_1} = \frac{-1 \pm \sqrt{1 + 4(1)(2)F_{N1}^2}}{2(1)}$$

$$y_2 = \frac{y_1}{2}\left(-1 \pm \sqrt{1 + 8F_{N1}^2} \right)$$

Practically -Ve depth is not possible

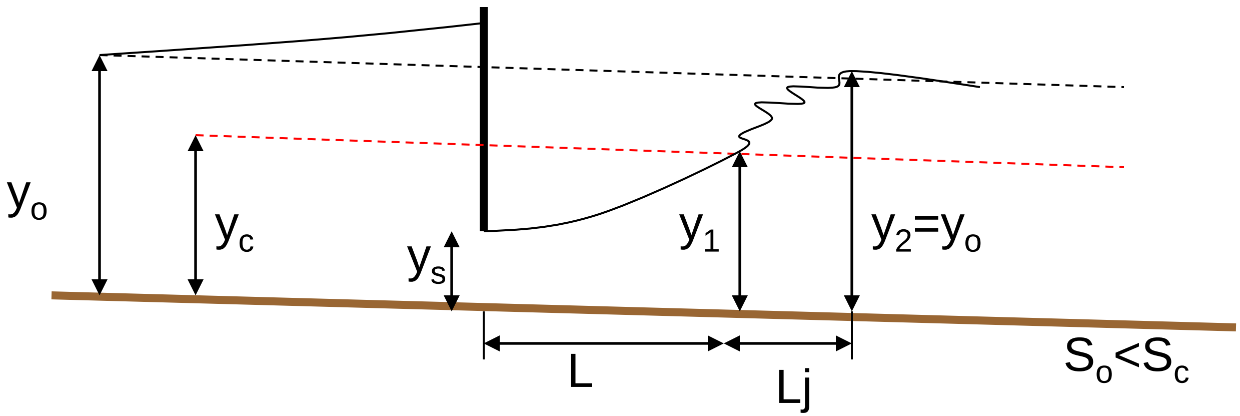
$$\therefore\ y_2 = \frac{y_1}{2}\left(-1 + \sqrt{1 + 8F_{N1}^2} \right) \Rightarrow eq.5$$

Similarly

$$y_1 = \frac{y_2}{2}\left(-1 + \sqrt{1 + 8F_{N2}^2} \right) \Rightarrow eq.5a$$

Location of Hydraulic Jumps

- Flow Under a Sluice Gate



Location of hydraulic jump where it starts is

$$L=(E_s-E_1)/(S-S_o)$$

Condition for Hydraulic Jump to occur

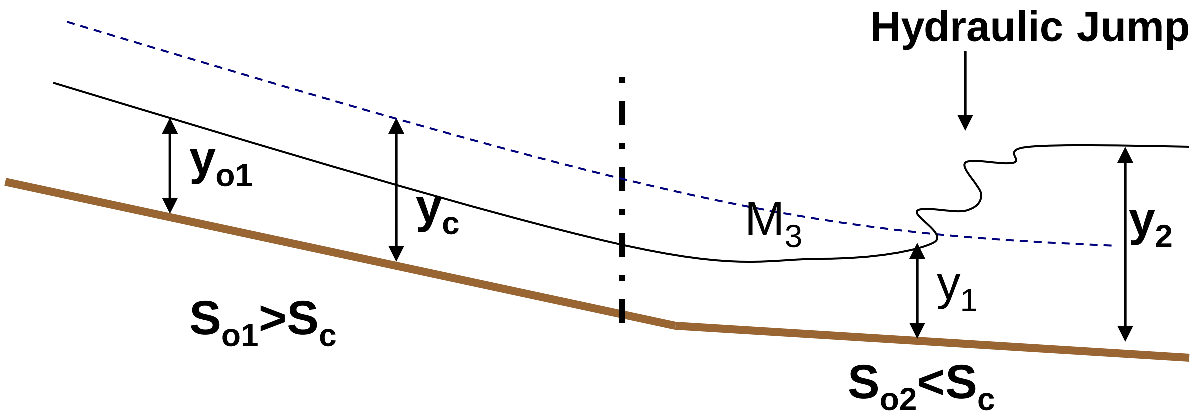
$$y_s<y_1<y_c<y_2$$

Flow becomes uniform at a distance L+Lj from sluice gate where

Length of Hydraulic jump = Lj = $5y_2$ or $7(y_2-y_1)$

Location of Hydraulic Jumps

- Change of Slope from Steep to Mild



Hydraulic Jump may take place

1. D/S of the Break point in slope $y_1>y_{o1}$
2. The Break in point $y_1=y_{o1}$
3. The U/S of the break in slope $y_1<y_{o1}$

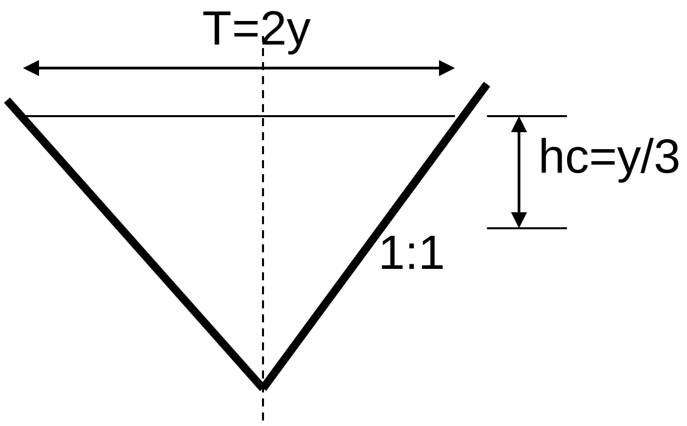
Problem 11. 87

- A hydraulic Jump occurs in a triangular flume having side slopes 1:1. The flow rate is 0.45 m^3/sec and depth before jump is 0.3m. Find the depth after the jump and power loss in jump?
- **Solution**

Q= 0.45 m^3/sec

y_1=0.3m

y_2=?



$$\frac{Q^2}{A_1 g} + A_1 hc_1 = \frac{Q^2}{A_2 g} + A_2 hc_2$$

$$hc = y/3$$

$$y_2 = 0.858m$$

$$\Delta E = E_1 - E_2$$

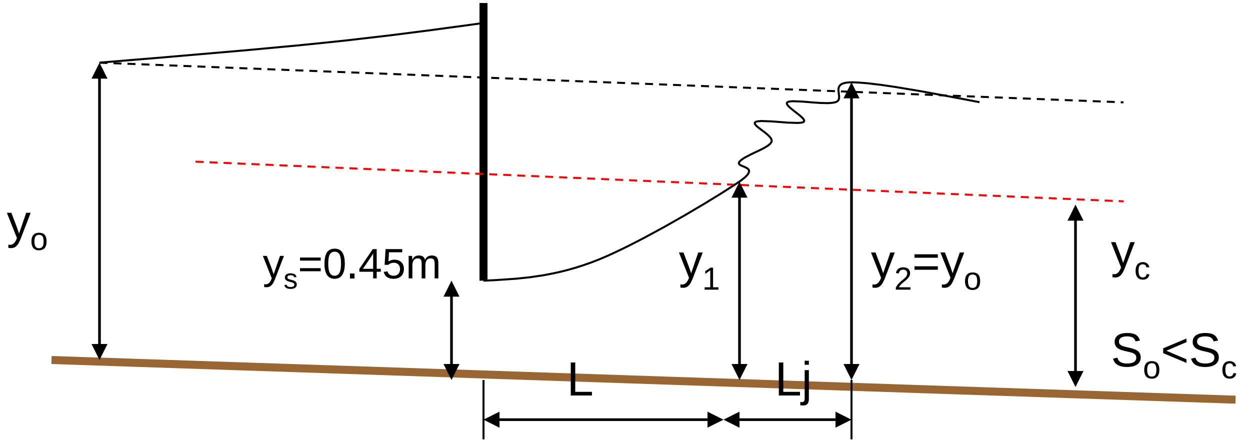
$$\Delta E = 0.679$$

$$Power\ Loss = \gamma Q \Delta E$$

$$Power\ Loss = 2.997 Kwatt$$

Problem 11. 89

- A very wide rectangular channel with bed slope = 0.0003 and roughness n = 0.020 carries a steady flow of 5 m^3/sec/m If a sluice gates is so adjusted as to produce a minimum depth of 0.45 m in the channel, determine whether a hydraulic jump will form downstream, and if so, find (using one reach) the distance from the gate to the jump.
- **Solution**



Problem 11. 89

$$y_c = \left(\frac{q^2}{g} \right)^{1/3} = 1.366 > 0.45 \Rightarrow Super\ Critical\ Flow$$

$$Q = \frac{A}{n} R^{2/3} S_o^{1/2}$$

$$y_o \approx y_2$$

$$y_1 = f(y_2)$$

$$S = \frac{V_m^2 n^2}{R_m^{4/3}}$$

$$L = \frac{E_s - E_1}{S - S_o}$$

Assignment

- Problem:
  - 11.83, 11.84, 11.85, 11.87, 11.88, 11.89
- Date of Submission:

Questions