BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY .

WRE - 302
Open-Channel Hydraulics

Experiment No. : 07

Name of the Experiment: Hydraulic Jump.

Date of Performance : 22-02-14
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Level : 3 ; Term : I
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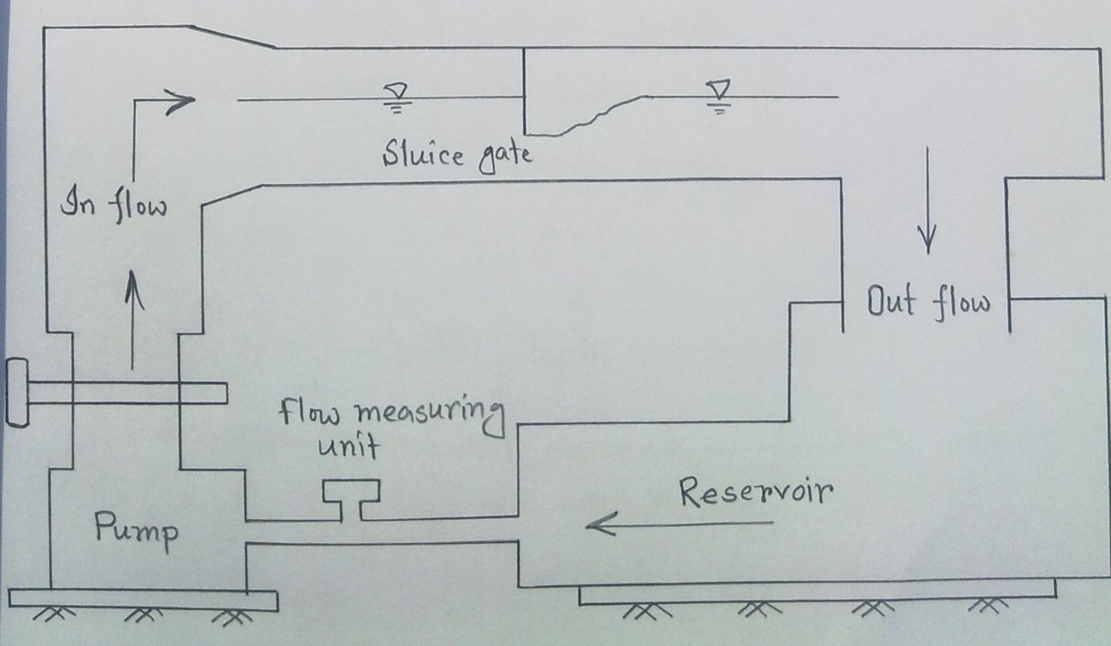
Objective:

- To determine the type of the jump according to the United States of Bureau of Reclamation (USBR) classification.
- To measure the initial depth, y_1, sequent depth (y_2), Length (L), height (h_j) of the jump and compare them with the theoretical value.
- To determine the total energy loss, kinetic energy loss and efficiency of the jump and compare them with the theoretical value.
- To develop the theoretical characteristics curve of hydraulic jump.

Experimental Set up:



Related formula :

Froude Number (F_1) before the hydraulic jump is given by

$$F_1 = \frac{V}{\sqrt{gD}}$$

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

where, V_1 = velocity of the flow just before the jump

y_1 = depth of flow just before the jump

g = acceleration due to gravity

Depending on the value of F_1 jump (hydraulic) is classified as follows :

$F_1 = 1 \sim 1.7$; Undular Jump

$F_1 = 1.7 \sim 2.50$; Weak jump

$F_1 = 2.5 \sim 4.5$; Oscillating jump

$F_1 = 4.5 \sim 9.0$; Steady jump

$F_1 \geq 9.0$; Strong jump

* Initial and sequent depth :

Considering moment correction factor is equal to unity (i.e $\beta_1 = \beta_2 = 1.0$) we can assume hydrostatic force on section before the jump and after the jump as

$$f_{P_1} = \gamma \bar{z}_1 A_1 \quad \text{and} \quad f_{P_2} = \gamma \bar{z}_2 A_2$$

where, $\bar{z}_1, \bar{z}_2$ = Vertical distance of the centroids from free surface.

A_1, A_2 = Area of the corresponding section.

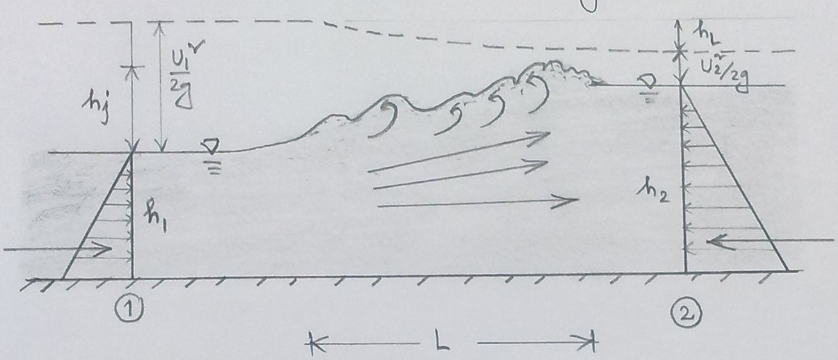


figure: Hydraulic Jump in horizontal rectangular channel

Applying momentum equation between section 1 and 2 we get,

$$\frac{Q^2}{gA_1} + \bar{z}_1 A_1 = \frac{Q^2}{gA_2} + \bar{z}_2 A_2$$

$$\Rightarrow \frac{q^2B^2}{gBy_1} + \frac{y_1}{2}\cdot By_1 = \frac{q^2B^2}{gBy_2} + \frac{y_2}{2}By_2$$

$$\left[\because q = \frac{Q}{B};\ \bar{z}_1 = \frac{y_1}{2};\ \bar{z}_2 = \frac{y_2}{2}\right]$$

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

$$\Rightarrow \frac{u^2y_2^2}{g} = \frac{\frac{1}{2}y_2^2\left(1 - \frac{y_1^2}{y_2^2}\right)}{\frac{y_2 - y_1}{y_1y_2}}$$

$$\Rightarrow \frac{u^2}{gy_1} = F_1^2 = \frac{1}{2}\frac{y_2}{y_1}\left(\frac{y_2}{y_1} + 1\right)$$

$$\Rightarrow \frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8F_1^2} - 1\right)$$

where, y_1 = depth of flow before the jump

y_2 = depth of flow after the jump

* Length of the jump :

According to Silverster the length of for free hydraulic jump in horizontal rectangular channel is given by the following equation.

$$L/y_1 = 9.75(F_1-1)^{1.01}$$

where, L = Length of the jump

F_1 = froude Number measured before the jump

y_1 = depth of flow before the jump.

* Energy loss in jump :

The loss of total energy in the jump is equal to the difference in specific energies before and after the jump which is given by the following formula

$$\Delta E_{total} = E_1 - E_2$$

$$= \frac{(y_2-y_1)^3}{4y_1y_2}$$

Where, E_1 = Specific energy at initial section

E_2 = Specific energy at sequent section or after the jump

Kinetic energy loss is the difference in velocity head before and after the jump. Thus

$$\Delta E_{K.E} = \frac{1}{2g}\left(V_1^2 - V_2^2\right)$$

where, V_1 = Velocity before the jump
V_2 = Velocity after the jump

* Efficiency of jump:

It is the ratio of the specific energy after the jump to before the jump. It is given by

$$E_2/E_1 = \frac{(8F_1^2+1)^{3/2} - 4F_1^2 + 1}{8F_1^2(2+F_1^2)}$$

* Height of Jump:

It is the difference between the depths after and before the jump. Thus,

$$h_j = y_2 - y_1$$

Relative height of the jump is the ratio of height of jump to the specific energy before jump. So,

$$\frac{h_j}{E_1} = \frac{\sqrt{1+8F_1^2} - 3}{F_1^2 + 2}$$

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7.8 Data sheet:

Flume width, B= 0.3048 m   Discharge, Q= 0.0181 m^3/s

Depth				Velocity		F_1	Type of jump
y_1 (m)		y_2 (m)		V_1 (m/s)	V_2 (m/s)		
0.0305 0.0290 0.0296	0.0297	0.1313 0.1337 0.1336	0.1329	1.999	0.4468	3.705	Oscillating jump

Verification of total energy loss					Kinetic energy loss (m)	Verification of efficiency		
E_1 (m)	E_2 (m)	E_1-E_2 (m)	RHS of Eq.(7.6) (m)	Comment		E_2/E_1	RHS of Eq.(7.8)	Comment
0.233	0.143	0.089	0.0696	Experiment value is greater	0.193	0.614	0.645	Theoritical value governs

Verification of length of jump				Verification of height of jump			
L (m)	L/y_1	RHS of Eq.(7.5)	Comment	h_j (m)	h_j/E_1	RHS of Eq.(7.10)	Comment
1.0	33.67	26.59	Experimental value is greater	0.1032	0.443	0.479	Theoretical value governs

Characteristic curve:

F_1	$\frac{E_2}{E_1}$	$\frac{h_j}{E_1}$	$\frac{y_1}{E_1}$	$\frac{y_2}{E_1}$
2.73	0.78	0.505	0.21125	0.716
3.68	0.623	0.453	0.129	0.581
4.01	0.58	0.420	0.11	0.53
3.705	0.614	0.443	0.1275	0.570
2.869	0.74221	0.479	0.1955	0.6747

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Sample Calculation :

Upstream depth of flow, $y_1 = \frac{0.0305 + 0.029 + 0.0296}{3}$

$= 0.0297$ m

Downstream depth of flow, $y_2 = \frac{0.1313 + 0.1337 + 0.1336}{3}$

$= 0.1329$ m

Velocity at upstream, $V_1 = \frac{Q}{A_1} = \frac{Q}{By_1}$

$= \frac{0.0181}{0.3048 * 0.0297}$

$= 1.999 \; ms^{-1}$

Velocity at downstream, $V_2 = \frac{Q}{By_2} = \frac{0.0181}{0.3048 * 0.1329}$

$= 0.4468 \; ms^{-1}$

Froude Number at upstream, $F_1 = \frac{V_1}{\sqrt{g y_1}}$

$= \frac{1.999}{\sqrt{9.81 * 0.0297}}$

$= 3.705$

Energy loss (Experimentally), $\Delta E = E_1 - E_2$

$= \left(y_1 + \frac{V_1^2}{2g}\right) - \left(y_2 + \frac{V_2^2}{2g}\right)$

$= \left(0.0297 + \frac{1.999^2}{2 \times 9.81}\right) - \left(0.1329 + \frac{0.4468^2}{2 \times 9.81}\right)$

$= 0.089$

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

$$= \frac{(0.1329 - 0.0297)^3}{4 * 0.0297 * 0.1329}$$

$$= 0.0696$$

Kinetic Energy loss, $\Delta E_{K.E} = \frac{1}{2g}(v_1^2 - v_2^2)$

$$= \frac{1.999^2 - 0.4468^2}{2 \times 9.81}$$

$$= 0.193$$

Ratio of specific Energy, $E_2/E_1 = \frac{0.143}{0.233}$

$$= 0.614$$

Ratio of specific Energy (Theoretically),

$$E_2/E_1 = \frac{(8F_1^2 + 1)^{3/2} - 4F_1^2 + 1}{8F_1^2(2 + F_1^2)}$$

$$= \frac{(8 * 3.705^2 + 1)^{3/2} - 4 * 3.705^2 + 1}{8 * 3.705^2 (2 + 3.705^2)}$$

$$= 0.645$$

Ratio of hydraulic length to upstream depth,

$L/y_1 = 1/0.0297 = 33.67$ (Experimentally)

Ratio L/y_1 (Theoretically) $= 9.75(F_1 - 1)^{1.01}$

$= 9.75(3.705 - 1)^{1.01}$

$= 26.59$

Height of Jump, $h_j = y_2 - y_1$

$= (0.1329 - 0.0297)$ m

$= 0.1032$ m

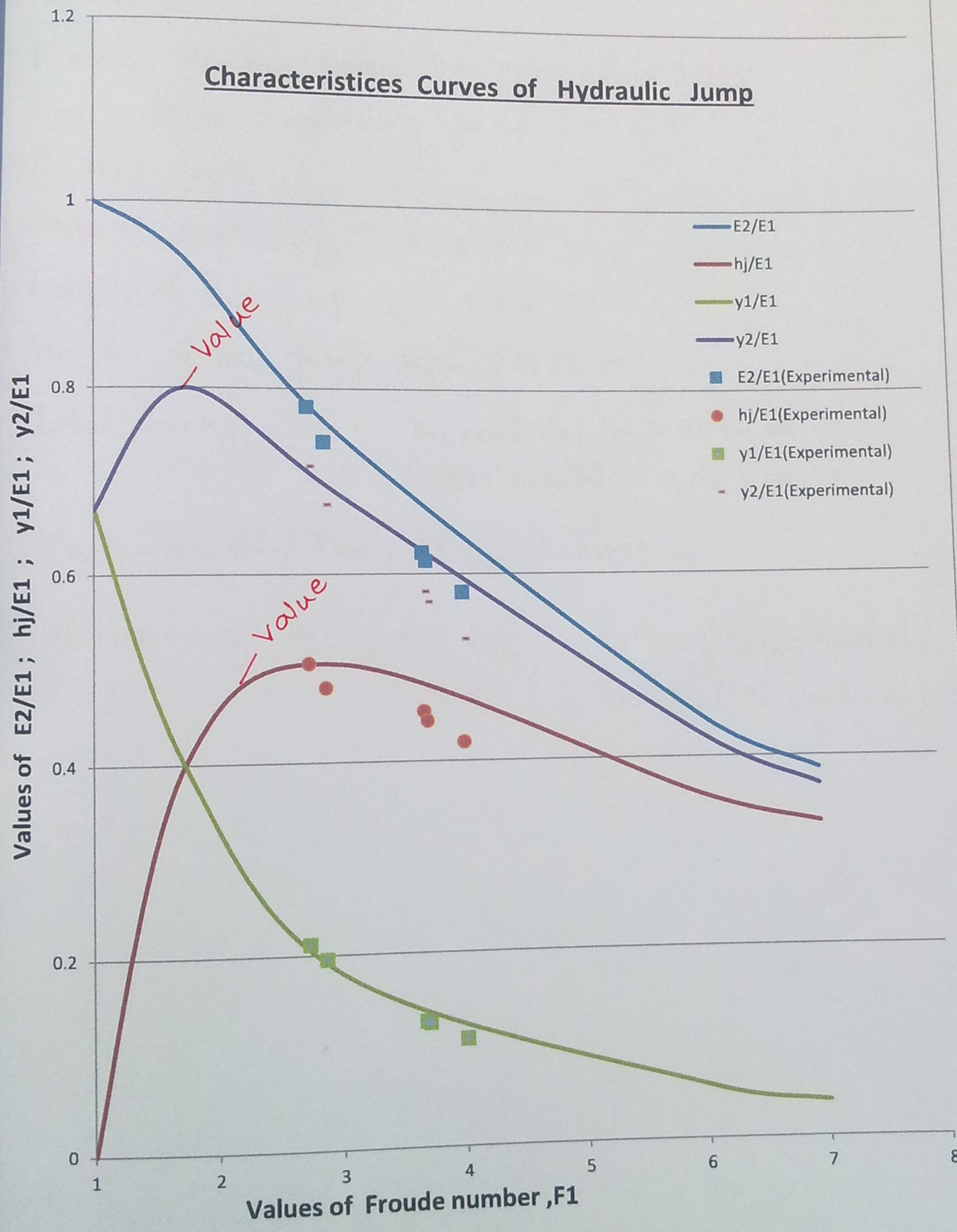
Ratio of height of jump to specific energy (Experimentally), $h_j/E_1 = \frac{0.1032}{0.233}$

$= 0.443$

Ratio h_j/E_1 (theoretically) $= \frac{\sqrt{1+8F_1^2} - 3}{F_1^2 + 2}$

$= \frac{\sqrt{1+8 * 3.705^2} - 3}{3.705^2 + 2}$

$= 0.479$


Characteristices Curves of Hydraulic Jump
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
Values of E2/E1 ; hj/E1 ; y1/E1 ; y2/E1
Values of Froude number ,F1
E2/E1
hj/E1
y1/E1
y2/E1
E2/E1(Experimental)
hj/E1(Experimental)
y1/E1(Experimental)
y2/E1(Experimental)
Value
Value

Result :

- Froude Number before the jump, $F_1 = 3.705$
- Type : It is oscillating jump
- Initial depth, $y_1 = 0.0297$ m
- Sequent depth, $y_2 = 0.1329$ m
- Length of the jump, $L = 1.0$ m
- Height of the jump, $h_j = 0.1032$ m
- Total energy loss : Theoretical = 0.0696 m
  Experimental = 0.089 m
- Kinetic energy loss ; $\Delta E_{K.E} = 0.193$ m
- Efficiency of the jump, h_j/E_1 = 0.443 (Experimental)
  = 0.479 (Theoretical)

Discussion:

- The depth of flow before the jump and after the jump was found to be 0.0297 m and 0.1329 m respectively. This increase in depth (i.e occurring of hydraulic jump) results in subcritical flow which was initially followed by supercritical flow. The difference of this two depth is the height of hydraulic jump. Therefor the height of the jump was 0.1032 m.

- The velocity before the jump (i.e $V_1 = 1.999\ ms^{-1}$) and corresponding depth of flow (i.e $y_1 = 0.0297$ m) exhibits froude number to be 3.705. So, before occuring the jump velocity of the flow was 3.705 times greater the celerity.

- The value of froude number ($F_1 = 3.705$) represents the jump to be an Oscillating jump according to the classification of USBR. Therefore, it was observed that an oscillating jet was entering the jump bottom to surface and back again with no periodicity. This type of wave having irregular period causes unlimited damage to earth banks.

- The length of the jump was 1.0 m. Therefore, the abrupt change in the depth of flow was occured within this length.

- Energy loss for the jump is measured as 0.089 m. This loss of energy is due to the formation of eddy or head dissipation through turbulent flow. The theoretical loss for this setup is found 0.0696 m. Thus experimental measurement of energy loss gives higher value than that of the theoretical.

- The ratio of the specific energy after the jump to the specific energy before the jump i.e E_2/E_1 is found 0.614. If there occur no energy loss this ratio will be 1.0. Therefore nearly 29% of the specific energy before the jump is lost due to the formation of this jump. Again theoretically measured value is 0.645 which is slightly greater than the experimental value.

- Kinetic energy loss is found 0.193 m. This is the difference of velocity head between the two section. The velocity head before the jump is 0.204 m and after the jump is 0.01 m. It is because the part of velocity head of the upstream section is being converted the static head after the jump and also some coversion of head dissipation.

- The ratio of the height of jump to the specific energy before the jump i.e h_j/E_1 is found 0.443. It significantly express that 44.3% of the specific energy (static head + velocity head) before the jump is converted to abrupt change in ~~the~~ depth of flow due to the formation of jump. Besides theoretically measured value is 0.479.

- Characteristics curves of hydraulic jump shows that values of E_2/E_1; h_j/E_1; y_1/E_1; y_2/E_1 all are the only function of froude number measured before the jump.

- "E_2/E_1 vs F_1" curve is downward slopping giving maximum value of 1 at froude number equal to unity. Therefore, if critical section occur just before the jump there will be no difference in specific energy before and after the jump.

- Curve representing the relation between y_2/E_1 and F_1 is initially upward slopping, changing its curvature at $F_1 = 1.70$ (maximum point) and then gradually decrease (downward slopping). Experimental values showing ~~on~~ as scattered point are not lie within the curve.

– "h_j/E_1 vs F_1" curve passes through the point (1,0) i.e at point $F_1 = 1.0$ the value h_j/E_1 is zero. Therefore if critical section or critical depth occur ~~befor~~ the assumed jump there will no jump actually.

☐ Assignment Question :

Q.1 What are the different types of hydraulic jumps according to the United States Bureau of Reclamation (USBR) classification ?

Depending the value of froude number before the jump the United States Bureau of Reclamation (USBR) classified the hydraulic jump in horizontal channel into the following categories:

1. Under jump : when $F_r = 1 \sim 1.70$
2. Weak jump : when, $F_r = 1.70 \sim 2.50$
3. Oscillating jump : when $F_r = 2.50 \sim 4.50$
4. Steady jump : when, $F_r = 4.50 \sim 9.0$
5. Strong Jump : when $F_r > 9.0$

Q.2 Why does the energy loss occur in hydraulic jumps ? Is it really an energy loss ?

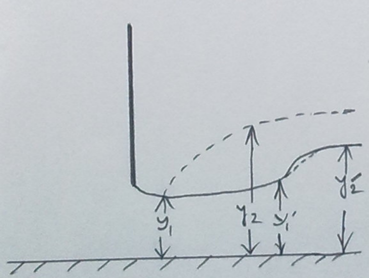
When liquid at high velocity discharge into a zone of lower velocity, a rather abrupt rize occurs in the liquid surface. The rapid flowing liquid is abruptly slowed and increase in height, converting some of the flow's initial kinetic energy into an increase in potential energy. At the same time some energy irreversibly lost through turbulent to heat. This is the reason why energy dissipation occur in hydraulic jump.

The phenomenon of hydraulic jump is dependent upon the initial fluid speed. For initial flow speed which is not significantly above the critical speed, the transition appears as an undulating waves. As the initial flow speed increases further, the transition becomes more abrupt, untill at high speeds, the transition front will break and curl back upon itself. When this happens, the jump can be accompanied by violent turbulence, eddying, air entrainment and surface undulation or waves which will result in more dissipation of energy.

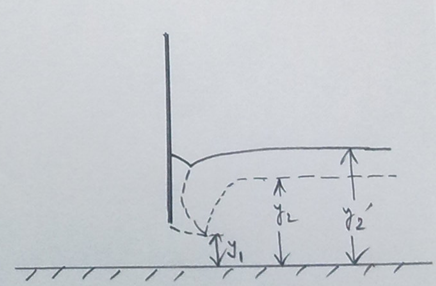
Q.3 What is tail water depth? Explain why a hydraulic jump moves upstream or downstream when the tail water depth is greater or smallere than the sequent depth.

Tail water depth reffers the depth of water located immediately drownstream from a hydraulic structure, such as a dam, bridge, or culvert.

In case of having tail water depth (y_2') less than the sequent depth (y_2), the jump will reduce or recede downstream to a point where, $y_2/y_1 = \frac{1}{2}(\sqrt{1+8F_1^2}-1)$ equation is valid.



Case: $y_2' < y_2$



Case: $y_2' > y_2$

When the tailwater depth y_2' is greater than sequent depth y_2, the jump will be forced upstream and may finally be drowned out at the sources and become a submerged jump