هيدروليك ثانية

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هيدروليكا
ثانية مدنـــــي

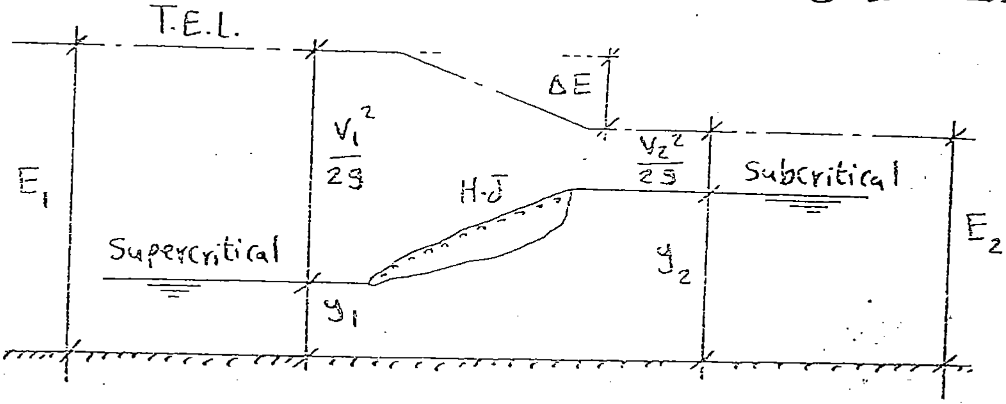
Rapidly Varied Flow (Hydraulic Jump)

2014-2015

Hydraulic Jump

هى ظاهرة يتحول عندها ال flow من Supercritical إلى Subcritical

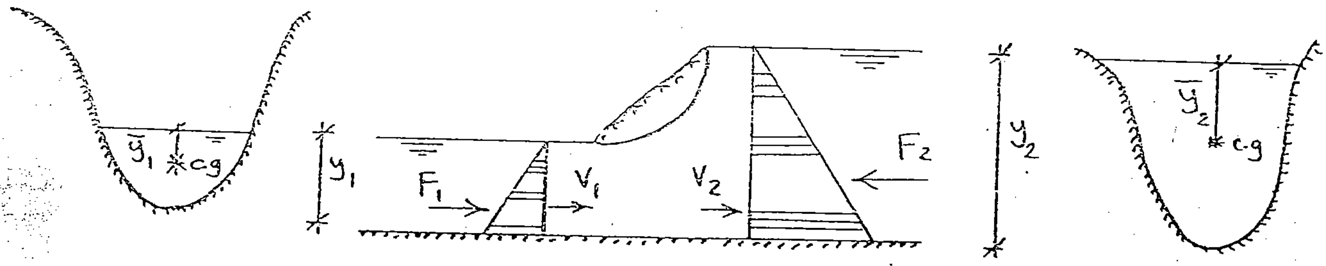
ويحدث عندها فقد فى الطاقة



To get y_1 , y_2

Apply the Momentum equation

$$\boxed{\sum \text{Forces} = \text{Rate of change in Momentum}}$$



$$F_1 - F_2 = \rho Q V_2 - \rho Q V_1$$

$$\gamma A_1 \bar{y}_1 - \gamma A_2 \bar{y}_2 = \frac{\gamma}{g} Q \frac{Q}{A_2} - \frac{\gamma}{g} Q \frac{Q}{A_1}$$

$$A_1 \bar{y}_1 - A_2 \bar{y}_2 = \frac{Q^2}{g A_2} - \frac{Q^2}{g A_1}$$

$$\boxed{A_1 \bar{y}_1 + \frac{Q^2}{g A_1} = A_2 \bar{y}_2 + \frac{Q^2}{g A_2}} = \text{Const} = \text{Specific Force}$$

General case

The Specific Force

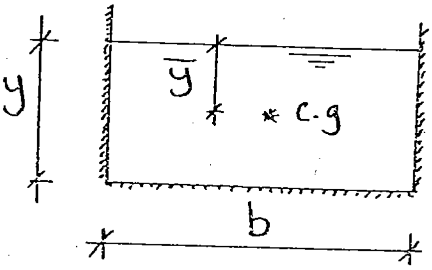
It is the Sum of both the Hydrostatic Force of water per unit Weight and the Momentum of flow passing through the channel per unit time per Unit Weight

$$\boxed{F = \underbrace{A\bar{y}}_{\text{Hydrostatic}} + \underbrace{\frac{Q^2}{gA}}_{\text{Momentum}}}$$

For rectangular section

$A = by \quad , \quad \bar{y} = \frac{y}{2}$

$Q = qb \quad , \quad F = fb$



Where f = Specific force / unit length

$$fb = by \cdot \frac{y}{2} + \frac{q^2 b^2}{gby}$$

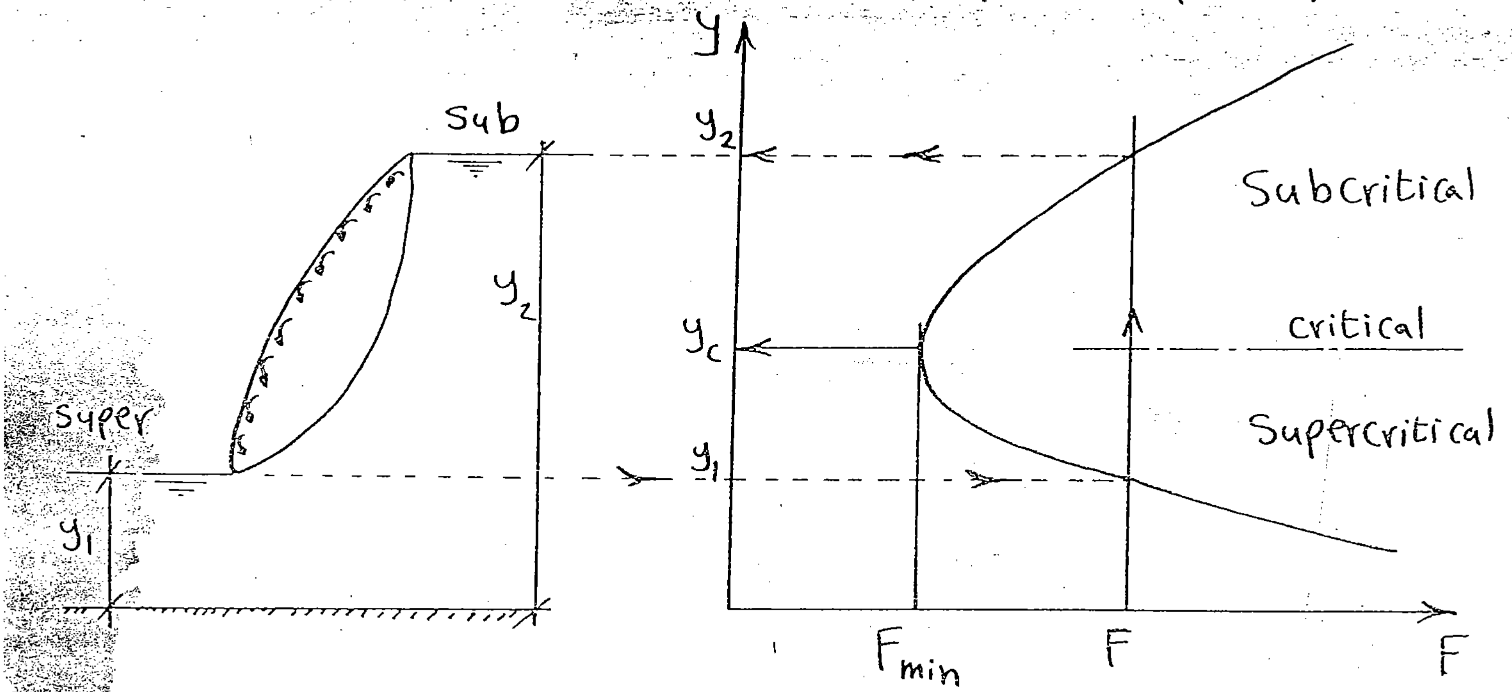
$$\boxed{f = \frac{y^2}{2} + \frac{q^2}{gy}}$$ Rectangular section only

Dimensions

$F : L^3$ $\qquad$ Force $= F\gamma$

$f : L^2$ $\qquad$ Force $= f b \gamma$

The Specific Force Diagram (F-y) ③



y_1, y_2 are two Sequent depths (Conjugate depths

They have the same Specific Force F & Same Discharge Q.

One is Subcritical (y_2) and the other is Supercritical (y_1)

y_1: initial depth

y_2: sequent depth

Minimum Specific Force (f_{min}) for a rectangular section

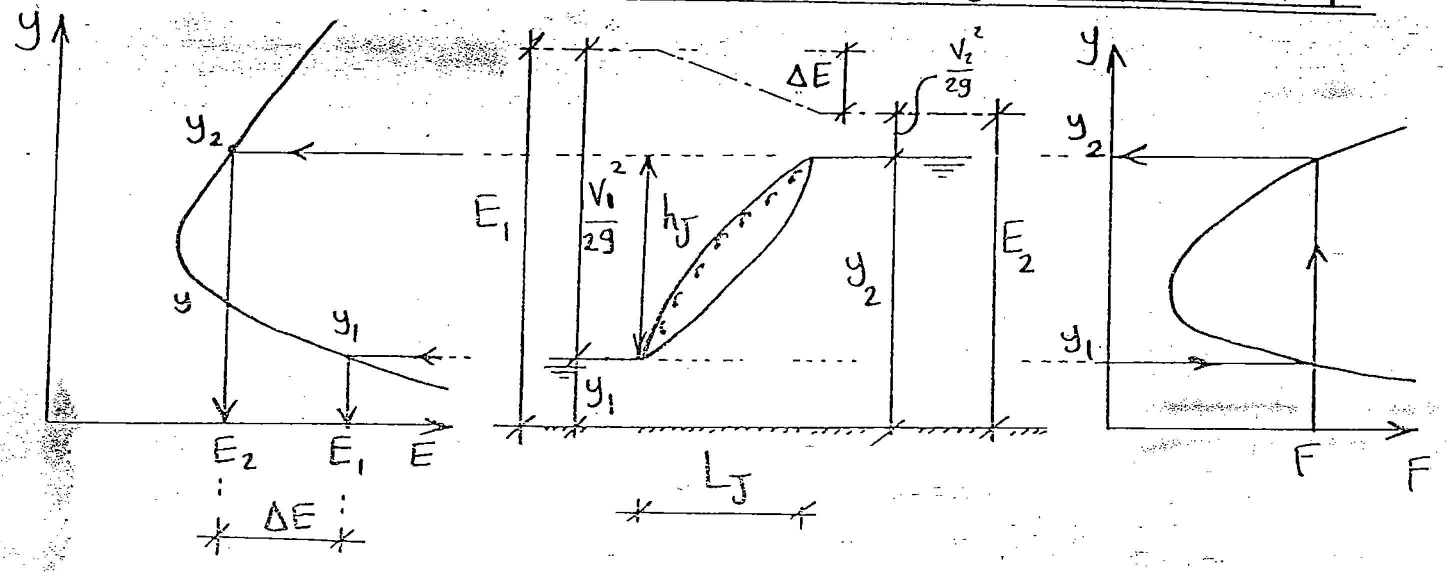
$$f = \frac{y^2}{2} + \frac{q^2}{gy}$$

for f_{min} $\quad \frac{df}{dy} = 0$

$$\frac{df}{dy} = \frac{2y}{2} - \frac{q^2}{gy^2} = 0 \Rightarrow \boxed{y_c = \sqrt[3]{\frac{q^2}{g}}}$$

$$y = \frac{q^2}{gy^2}$$

Characteristics of the Hydraulic Jump



1. y_1 = initial depth
2. y_2 = Sequent depth
3. h_J = height of Jump $\quad h_J = y_2 - y_1$
4. L_J = Length of Jump $\quad L_J = 6y_2$
5. ΔE = Energy loss $\quad \Delta E = E_1 - E_2$

$$E_1 = y_1 + \frac{V_1^2}{2g}$$

$$E_2 = y_2 + \frac{V_2^2}{2g}$$

6. η = Efficiency $\quad \eta = \frac{E_2}{E_1} = \frac{\text{Output}}{\text{input}}$
7. HP = horse power lost $\quad HP = \frac{\gamma Q \Delta E}{K}$

Relative Characteristics of H.J

γ	1000	9810	62.4
K	75	735	550

$\frac{y_1}{E_1}$, $\frac{y_2}{E_1}$, $\frac{h_J}{E_1}$, $\frac{L_J}{E_1}$, $\frac{\Delta E}{E_1}$, $\frac{E_2}{E_1}$, HP

Hydraulic Jump in a rectangular Section

General:

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

$$\cancel{b} y_1 \frac{y_1}{2} + \frac{q^2 b^{\cancel{2}}}{g \cancel{b} y_1} = \cancel{b} y_2 \frac{y_2}{2} + \frac{q^2 b^{\cancel{2}}}{g \cancel{b} y_2}$$

$$\frac{1}{2} y_1^2 + \frac{q^2}{g y_1} = \frac{1}{2} y_2^2 + \frac{q^2}{g y_2}$$

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

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

$$\boxed{\frac{1}{2}(y_1 + y_2) = \frac{q^2}{g y_1 y_2}} \rightarrow (1)$$

As a function of critical depth

$$\therefore y_c^3 = \frac{q^2}{g}$$

$$\therefore \frac{1}{2}(y_1 + y_2) = \frac{y_c^3}{y_1 y_2}$$

$$\boxed{\frac{1}{2} y_1 y_2 (y_1 + y_2) = y_c^3}$$ rect-Sec only

As a function of Froude number 1

$$\boxed{y_1 + y_2 = \frac{2q^2}{g y_1 y_2}} \rightarrow (1) \qquad \therefore q = V_1 y_1$$

$$y_1 + y_2 = \frac{2 V_1^2 y_1^{\cancel{2}}}{g \cancel{y_1} y_2}$$

$$y_1 + y_2 = \frac{2 V_1^2}{g} \frac{y_1}{y_2} \quad * \quad \frac{y_2}{y_1^2}$$

$$\left(\frac{y_2}{y_1}\right)^2 + \left(\frac{y_2}{y_1}\right) = \frac{2 V_1^2}{g y_1^2} = 2 \mathbb{F}_1^2$$

$$\left(\frac{y_2}{y_1}\right)^2 + \left(\frac{y_2}{y_1}\right) - 2 \mathbb{F}_1^2$$

$$\frac{y_2}{y_1} = \frac{-1 \pm \sqrt{1 + 8 \mathbb{F}_1^2}}{2}$$

$$\boxed{\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8 \mathbb{F}_1^2} - 1\right)} \qquad \frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + \frac{8q^2}{g y_1^3}} - 1\right)$$

rect - sec only

As a function of Froude number 2

$$\boxed{y_1 + y_2 = \frac{2q^2}{g y_1 y_2}} \rightarrow (1) \qquad \therefore q = V_2 y_2$$

$$y_1 + y_2 = \frac{2 V_2^2 y_2^{\cancel{2}}}{g y_1 \cancel{y_2}} \quad * \quad \frac{y_1}{y_2^2}$$

$$\left(\frac{y_1}{y_2}\right)^2 + \left(\frac{y_1}{y_2}\right) = \frac{2 V_2^2}{g y_2} = 2 \mathbb{F}_2^2$$

$$\boxed{\frac{y_1}{y_2} = \frac{1}{2}\left(\sqrt{1 + 8 \mathbb{F}_2^2} - 1\right)} \qquad \text{rect - sec only}$$

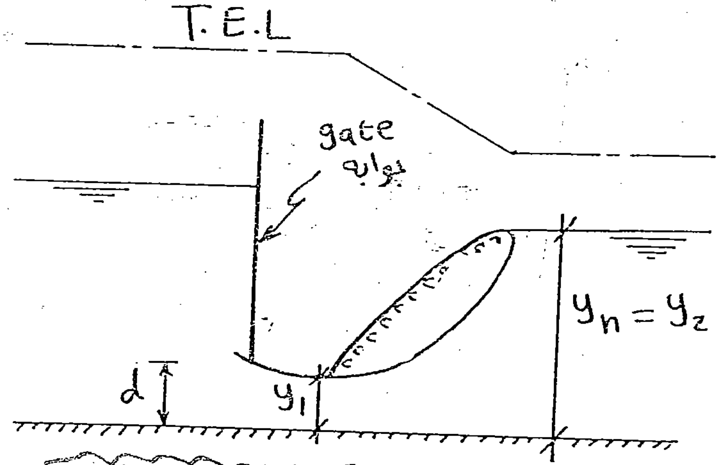
Types of Jumps

According to normal water depth y_n

From Maning or given or measured in lab

$$y_2 = \frac{y_1}{2}\left(\sqrt{1 + 8\mathbb{F}_1^2} - 1\right)$$

$\Rightarrow y_2 = \checkmark$ وهميه



If $y_n = y_2$

Perfect Jump

$y_1 = C_c d$ at Vena Contracta

d = gate opening

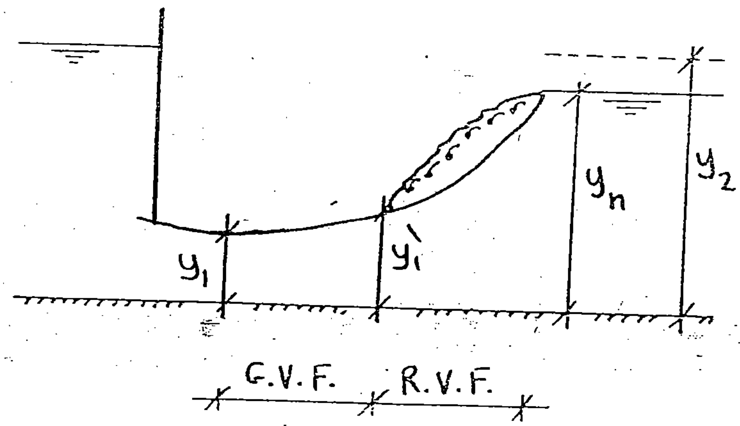
If $y_n < y_2$

Repelled Jump

y_1 تزيد حتى y_1' ثم يحدث Hyd Jump

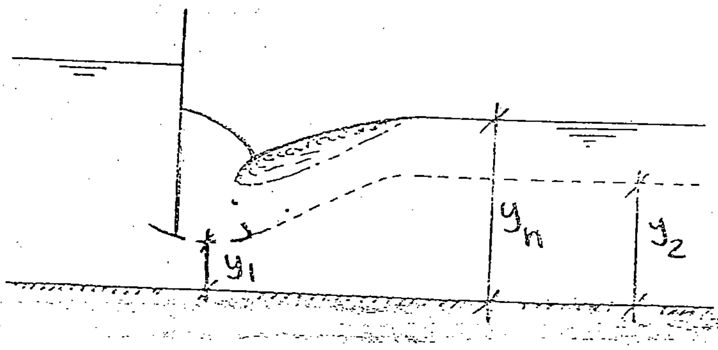
$$\frac{y_1'}{y_n} = \frac{1}{2}\left(\sqrt{1 + 8\mathbb{F}_n^2} - 1\right)$$

$\Rightarrow y_1' = \checkmark$



If $y_n > y_2$

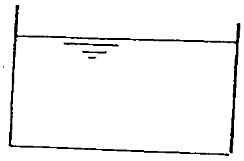
Submerged Jump



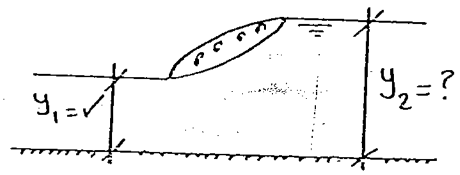
Given : Rectangular Section

If y_1 is given and y_2 is unknown

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1+8\mathbb{F}_1^2} - 1\right)$$



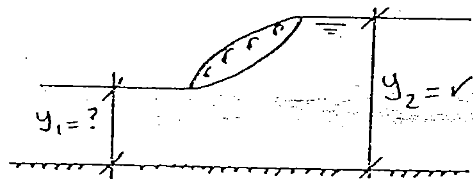
$$\mathbb{F}_1 = \frac{V_1}{\sqrt{g y_1}}$$



If y_2 is given and y_1 is unknown

$$\frac{y_1}{y_2} = \frac{1}{2}\left(\sqrt{1+8\mathbb{F}_2^2} - 1\right)$$

$$\mathbb{F}_2 = \frac{V_2}{\sqrt{g y_2}}$$



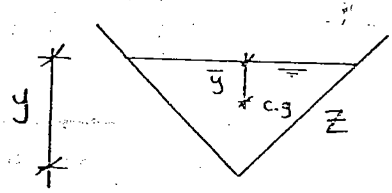
For any Section

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

Triangular Section

$$A = Z y^2$$

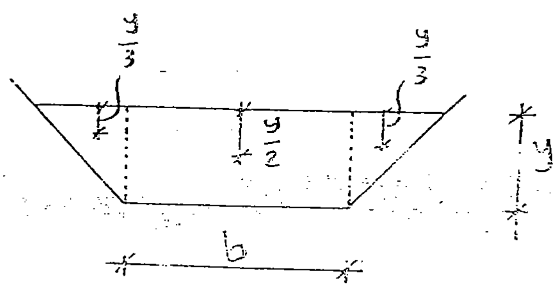
$$\bar{y} = \frac{y}{3}$$



Trapezoidal Section

$$A = by + Zy^2$$

$$A\bar{y} = by\left(\frac{y}{2}\right) + Zy^2\left(\frac{y}{3}\right)$$



AIN SHAMS UNIVERSITY
Faculty of Engineering
Dept. of Irrigation & Hydraulics

2^{nd} Civil Engineering
Hydraulics (CEI 231)
2014/2015

ASSIGNMENT NO. 7
Rapidly Varied Flow

1. Define alternate and sequent depths as used in connection with open channel flow. Plot the specific force diagram and specific energy diagram for a 10 m rectangular channel carrying 15 m^3/sec. Determine the critical depth, the minimum specific energy and minimum specific force. Use both diagrams to determine the initial depth corresponding to a sequent depth 1.5 m, the energy loss in the jump and the height of the jump.

2. A spillway discharge a flood flow at a rate of 7.75 m^3/s/m. At the downstream horizontal apron the depth of flow was found to be 0.50 m. What tailwater depth is needed to form a hydraulic jump? If a jump is formed, find its
   a) Type
   b) Length
   c) Headloss
   d) Energy loss as a percentage of the initial energy

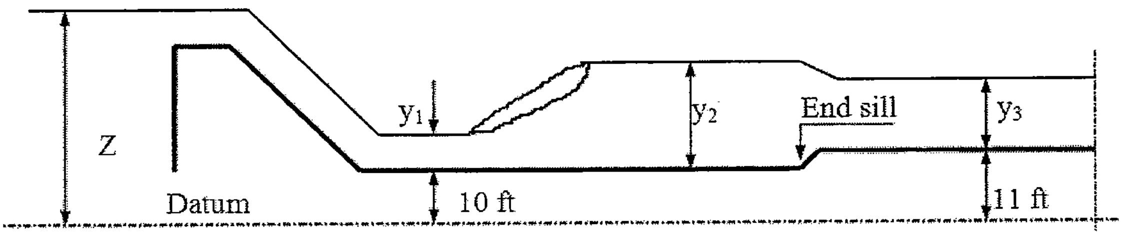
3. **A hydraulic jump occurs in a rectangular open channel. The water depths before and after the jump are 0.6 m and 1.5 m, respectively. Calculate the critical depth and the energy loss.**

4. A sluice gate is 3.0 m wide rectangular horizontal channel releases a discharge of 18.0 m^3/s. The gate opening is 0.67 m and coefficient of contraction can be assumed to be 0.60. Examine the type of hydraulic jump formed when the tailwater depth is 3.60 m, 5.00m, and 4.09 m.

5. Water flows in wide, finished concrete channel with n = 0.014. Such that a hydraulic jump occurs at the transition of the change in slope of the channel bottom. If the upstream Froude number and depth are 4.0 and 6.0 cm, respectively, determine the slopes upstream and downstream of the jump to maintain uniform flows in those regions. Compare these slopes with the critical slope. The jump can be treated as a jump on horizontal surface.

6. **A discharge of 50 m^3/s flows in a trapezoidal channel having a bottom width of 4 m and side slope 1:1, if the sequent depth of the jump is 4 m. Determine the following:**
   a) The initial depth.
   b) The initial Froude number.
   c) The height of the jump.
   d) The energy before and after the jump.
   e) The horsepower lost in the jump.

7. **a)Water discharges at the rate of 8000 ft^3/sec over a spillway 40 ft wide into a stilling basin of the same width. The lake level behind the spillway is 100 ft above datum. The bed level downstream is 10 ft above datum. Assuming no energy dissipated in the flow down the spillway, find the initial depth y_1 and the sequent depth y_2 required for a hydraulic jump to form within the basin. Write down the main characteristics of the jump. Crest, stilling basin and downstream channel all have the same width.**



b) **For a different lake level behind the spillway, for a discharge of 8000 cfs and crest level of 40 ft, y_2 is found to be 30 ft.**

i. **Assume that the end sill is a smooth transition without losses and calculate y_3. Calculate the force on the sill. Specify units.**

ii. **Suppose the sill is not a smooth transition and that laboratory tests indicate that the force on the sill is given by $f = 100\ V_2^2\ h$**
which f = force in pounds per foot width
V_2 = velocity in ft/s
h = sill height in feet
Calculate y3 and find the head loss across the sill

Question(1):- Assignmet(7) 2014/2015

$Q = 15\ m^3/s \qquad B = 10 m$

① $E = y + \dfrac{Q^2}{2gB^2y^2}$ $\qquad F = A\bar{y} + \dfrac{Q^2}{gA}$

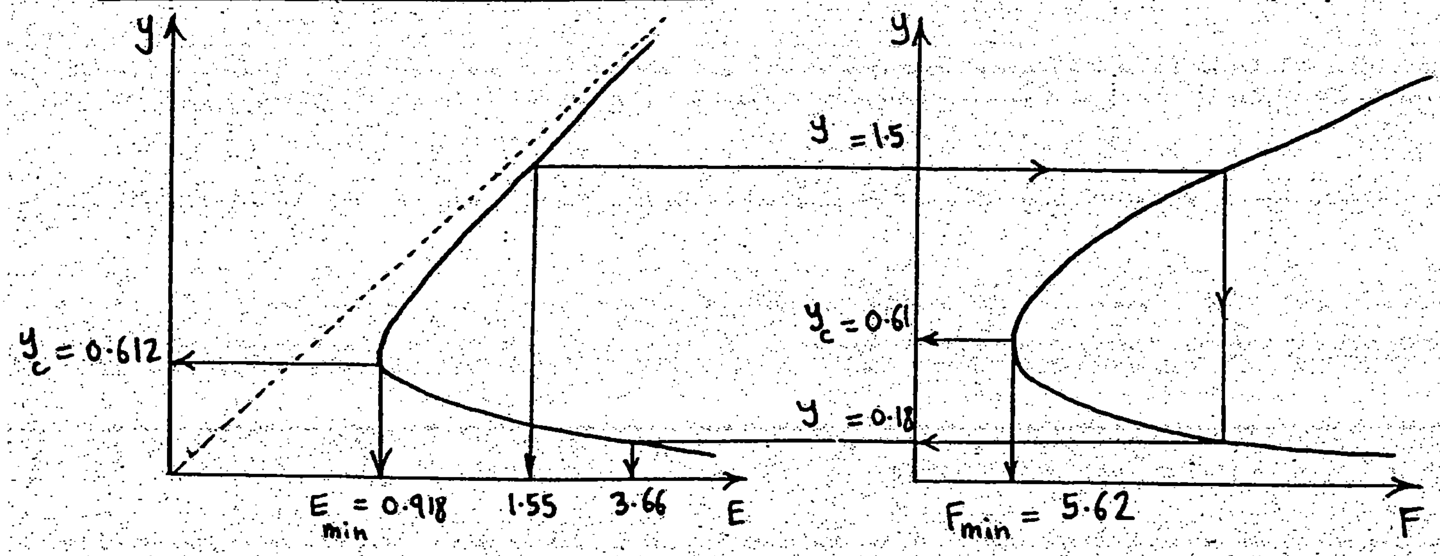
$E = y + \dfrac{(15)^2}{2(9.81)(10)^2 y^2}$ $\qquad F = 10y\dfrac{y}{2} + \dfrac{(15)^2}{9.81(10)y}$

$E = y + \dfrac{1}{8.72\,y^2}$ $\qquad F = 5y^2 + \dfrac{2.293}{y}$

$q = \dfrac{Q}{b} = \dfrac{15}{10} = 1.5$

$y_c = \sqrt[3]{\dfrac{q^2}{g}} = \sqrt{\dfrac{(1.5)^2}{9.81}} = \underline{\underline{0.612\ m}}$

y	0.2	0.4	0.5	0.612	0.7	0.9	1.50	3.00
E	3.06	1.12	0.96	0.918	0.934	1.04	1.55	3.01
F	11.66	6.53	5.83	5.62	5.72	6.6	12.7	45.7

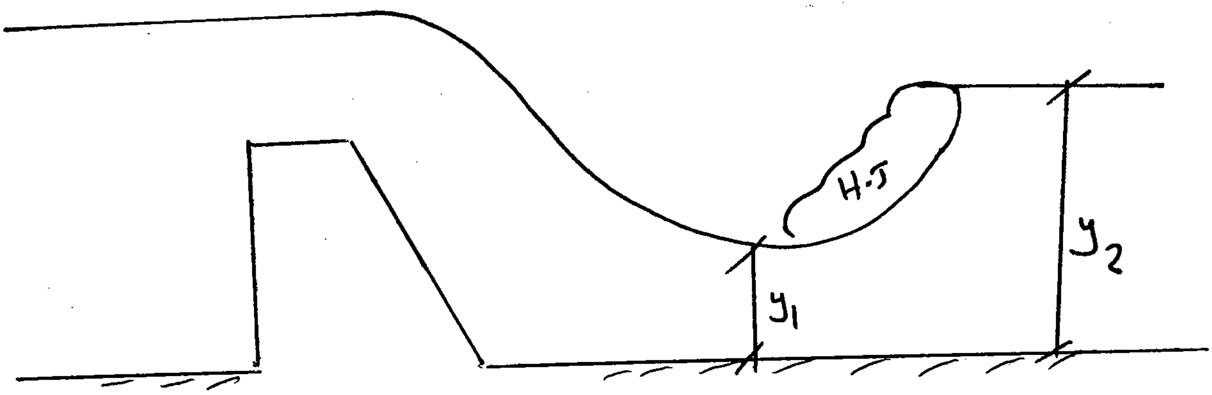


$y = 1.5 \Rightarrow y = \underline{\underline{0.18\ m}}$

$\Delta E = E - E = 3.66 - 1.55 = \underline{\underline{2.11\ m}}$

$h_J = y - y = 1.5 - 0.18 = \underline{\underline{1.32\ m}}$

(2) $q = 7.75\ m^3/s/m$



$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1+8F_{N_1}^2} - 1\right)$$

$$F_{N_1} = \frac{V_1}{\sqrt{g y_1}} \quad , \quad V_1 = \frac{q}{y_1} = \frac{7.75}{0.5} = 15.5\ m/s$$

$$\therefore F_{N_1} = \frac{15.5}{\sqrt{9.81 * 0.5}} = 7 > 1 \quad \text{(Super Critical)}$$

$$\Rightarrow \frac{y_2}{0.5} = \frac{1}{2}\left(\sqrt{1+8(7)^2} - 1\right) \Rightarrow y_2 = 4.7^m$$

$$V_2 = \frac{q}{y_2} = \frac{7.75}{4.7} = 1.65\ m/s$$

$$F_{N_2} = \frac{1.65}{\sqrt{9.81 * 4.7}} = 0.24 < 1 \quad \text{(Sub Critical)}$$

∴ Flow converts from super critical to subcritical

⇒ Hydraulic jump will occur

a) Type of jump is perfect $y_n = y_2$ #

b) $L_j = 6y_2 = 6 * 4.7 = 28.2^m$

c) $h_L = \Delta E = E_1 - E_2$

$$E_1 = y_1 + \frac{V_1^2}{2g} = 0.5 + \frac{(15.5)^2}{2*9.81} = 12.75 \text{ m}$$

$$E_2 = y_2 + \frac{V_2^2}{2g} \quad \& \quad V_2 = \frac{q}{y_2} = \frac{7.75}{4.7} = 1.65 \text{ m}$$

$$E_2 = 4.7 + \frac{(1.65)^2}{2*9.81} = 4.83 \text{ m}$$

$$\therefore h_L = \Delta E = 12.75 - 4.83 = \underline{\underline{7.92^m}}$$

d) $$\frac{h_L}{E_1} = \frac{7.92}{12.75} * 100 = \underline{\underline{62.11\ \%}}$$

③ $y_1 = 0.6^m$

$y_2 = 1.5^m$

<u>Req</u> y_c

$$\frac{y_1}{y_2} = \frac{1}{2}\left(\sqrt{1+8F_{N_2}^2} - 1\right)$$

$$\frac{0.6}{1.5} = \frac{1}{2}\left(\sqrt{1+8F_{N_2}^2} - 1\right)$$

$\therefore F_{N_2} = 0.53$

$\because F_{N_2} = \frac{V_2}{\sqrt{g y_2}} \Rightarrow 0.53 = \frac{V_2}{\sqrt{9.81 * 1.5}}$

$\therefore V_2 = 2 \ m/s$

$$q = y_2 V_2 = 1.5 * 2 = 3 \ m^3/s/m'$$

$$\therefore y_c = \sqrt[3]{\frac{q^2}{g}} = \sqrt[3]{\frac{(3)^2}{9.81}}$$

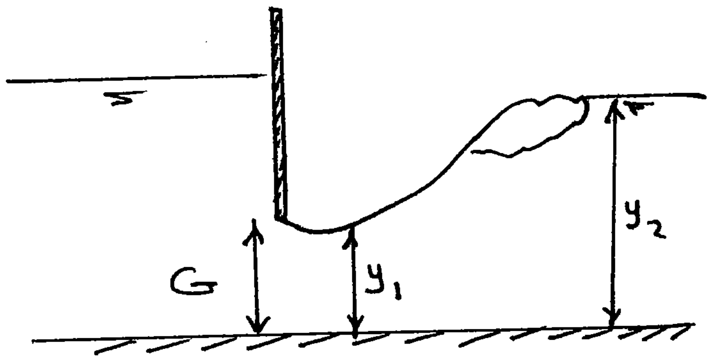
$y_c = 0.97^m$

(4) $b = 3^m$

$Q = 18\ m^3/s$

$G = 0.67^m$

$C_c = 0.6$



$$y_1 = C_c * G = 0.6 * 0.67 = 0.4^m$$

$$q = \frac{Q}{b} = \frac{18}{3} = 6\ m^3/s/m'$$

$$V_1 = \frac{q}{y_1} = \frac{6}{0.4} = 15\ m/s$$

$$F_{N_1} = \frac{V_1}{\sqrt{g y_1}} = \frac{15}{\sqrt{9.81 * 0.4}} = 7.57$$

$$y_2 = \frac{y_1}{2}\left(\sqrt{1+8(7.57)^2} - 1\right) = \underline{\underline{4.09^m}}$$

let the tail race water depth $= y_n$

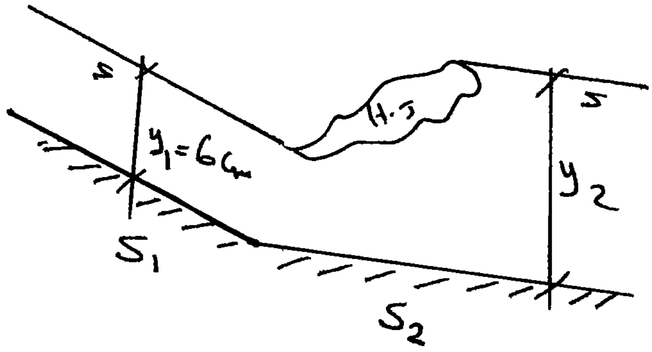
i) $y_n = 3.6^m \Rightarrow y_2 > y_n \Rightarrow$ repelled jump

ii) $y_n = 5^m \Rightarrow y_2 < y_n \Rightarrow$ Submerged jump

iii) $y_n = 4.09^m \Rightarrow y_2 = y_n \Rightarrow$ Perfect jump

⑤ $n = 0.014$, $F_{N_1} = 4$

$S_1 = ?$, $S_2 = ?$ $S_c = ?$



$$F_{N_1} = \frac{V_1}{\sqrt{g y_1}}$$

$$4 = \frac{V_1}{\sqrt{9.81 * 0.06}} \Rightarrow V_1 = 3.07 \text{ m/s}$$

$$q = V_1 y_1 = 3.07 * 0.06 = 0.184 \text{ m}^3/\text{s/m}$$

$$V_1 = \frac{1}{n} R_1^{2/3} S_1^{1/2}$$, for wide channel $R = y$

$$\therefore 3.07 = \frac{1}{0.014}(0.06)^{2/3} S_1^{1/2} \Rightarrow S_1 = 0.0786$$

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1+8F_{N_1}^2} - 1\right)$$

$$y_2 = \frac{0.06}{2}\left(\sqrt{1+8(4)^2} - 1\right) = 0.31^m$$

$$V_2 = \frac{q}{y_2} = \frac{0.184}{0.31} = 0.59 \text{ m/s}$$

$$V_2 = \frac{1}{n} R_2^{2/3} S_2^{1/2}$$

$$0.59 = \frac{1}{0.014}(0.31)^{2/3}(S_2)^{1/2} \Rightarrow S_2 = 3.3*10^{-4}$$

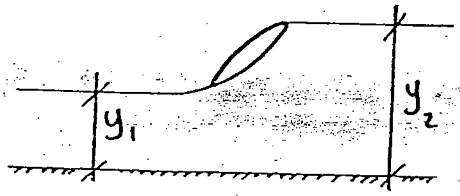
$$y_c = \sqrt[3]{\frac{q^2}{g}} = \sqrt[3]{\frac{(0.184)^2}{9.81}} = 0.15^m$$

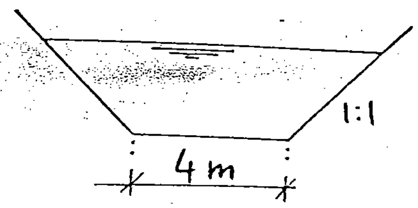
$$S_c = \frac{g n^2}{y_c^{1/3}} = \frac{9.81(0.014)^2}{(0.15)^{1/3}} = 3.6*10^{-3}$$

$S_1 > S_c \Rightarrow$ steep slope & $S_2 < S_c \Rightarrow$ Mild slope

(6) $Q = 50\ m^3/s$

$y_2 = 4m$

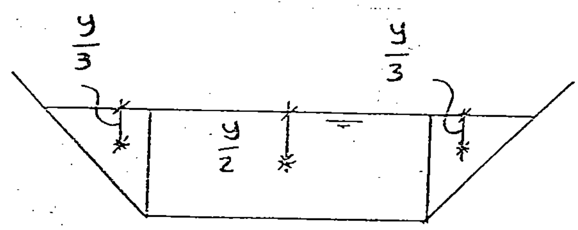




$$A_1 \bar{y}_1 + \frac{Q^2}{g A_1} = A_2 \bar{y}_2 + \frac{Q^2}{g A_2}$$

$A_1 = 4y + y^2$

$A_2 = 4(4) + (4)^2 = 32\ m^2$



$A\bar{y} = Zy^2\left(\frac{y}{3}\right) + by\left(\frac{y}{2}\right)$

$$A_1\bar{y}_1 = \frac{y_1^3}{3} + \frac{4}{2}y_1^2 = \frac{y_1^3}{3} + 2y_1^2$$

$$A_2\bar{y}_2 = \frac{(4)^3}{3} + 2(4)^2 = 53.33\ m^3$$

$$\therefore \frac{y_1^3}{3} + 2y_1^2 + \frac{(50)^2}{9.81(4y_1 + y_1^2)} = 53.33 + \frac{(50)^2}{9.81(32)}$$

$$\frac{y_1^3}{3} + 2y_1^2 + \frac{254.84}{4y_1 + y_1^2} = 61.294$$

also by trial & error

$\Rightarrow y_1 = \underline{\underline{0.878\ m}}$

$\Rightarrow A_1 = 4(0.878) + (0.878)^2 = 4.28\ m^2$

$$V_1 = \frac{Q}{A_1} = \frac{50}{4.28} = 11.67$$

$T_1 = B + 2Zy_1 = 4 + 2(1)(0.878) = 5.756$

$$D_1 = \frac{A_1}{T_1} = \frac{4.28}{5.756} = 0.743$$

$$\mathbb{F}_1 = \frac{V_1}{\sqrt{g D_1}} = \frac{11.67}{\sqrt{9.81(0.743)}} = \underline{\underline{4.32}} > 1 \quad \text{Supercritical}$$

$$h_J = y_2 - y_1 = 4 - 0.878 = \underline{\underline{3.122}}$$

$$E_1 = y_1 + \frac{Q^2}{2gA_1^2} = 0.878 + \frac{(50)^2}{2(9.81)(4.28)^2} = \underline{\underline{7.83}}$$

$$E_2 = y_2 + \frac{Q^2}{2gA_2^2} = 4 + \frac{(50)^2}{2(9.81)(32)^2} = \underline{\underline{4.12}}$$

$$\Delta E = E_1 - E_2 = 7.83 - 4.12 = 3.7\,m$$

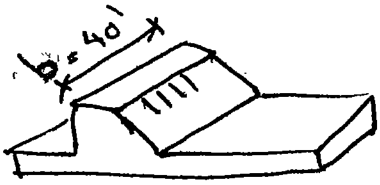
$$HP = \frac{\gamma Q \Delta E}{K} = \frac{1000(50)(3.7)}{75} = \underline{\underline{2470\ HP}}$$

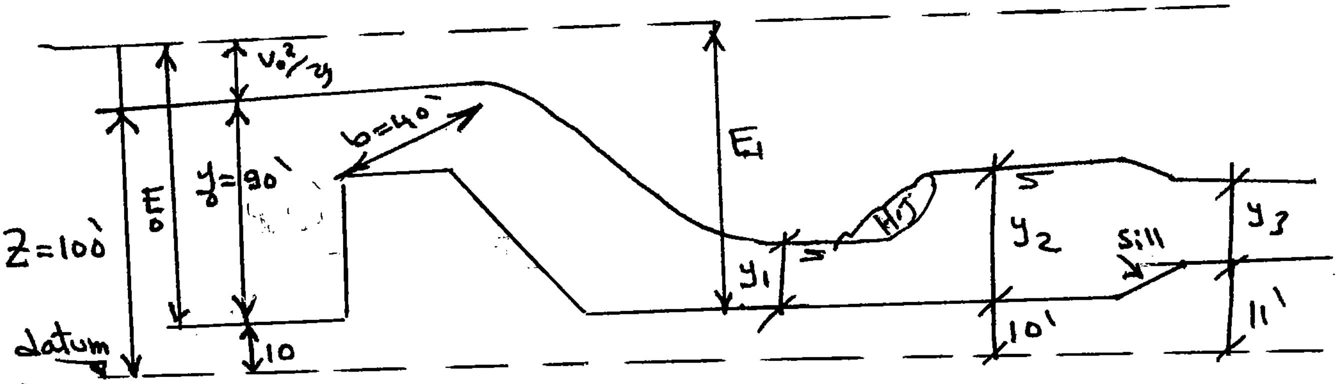
9

(7)

$Q = 8000 \ ft^3/s$

$b = 40 \ ft$





a) $q = \frac{Q}{b} = \frac{8000}{40} = 200 \ ft^3/s/ft$

$\because E_0 = E_1$

$\therefore y_0 + \frac{q^2}{2gy_0^2} = y_1 + \frac{q^2}{2gy_1^2}$

$$90 + \frac{(200)^2}{2*32.2(90)^2} = y_1 + \frac{(200)^2}{2*32.2(y_1^2)}$$

$\therefore y_1 = 2.66 \ ft \Rightarrow V_1 = \frac{q}{y_1} = \frac{200}{2.66} = 75.2 \ ft/s$

$$F_{N_1} = \frac{75.2}{\sqrt{32.2*2.66}} = 8.12$$

$$y_2 = \frac{2.66}{2}\left(\sqrt{1+8(8.12)^2} - 1\right) = 29.26 \ ft$$

$y_2 = 29.26 \ ft$

$h_j = y_2 - y_1 = 29.26 - 2.66 = 26.58 \ ft$

$L_j = 6y_2 = 6*29.26 = 175.7 \ ft$

$h_L = 0 \ \& \ \Delta E = 0$

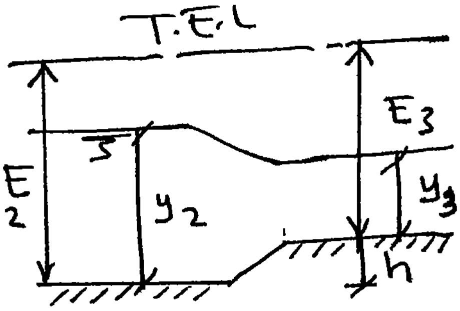
(11)

b) $Q = 8000\ ft^3/s$

$y_2 = 30\ ft$

i) Smooth end sill → No Energy losses on it

* we can assume it as a hump



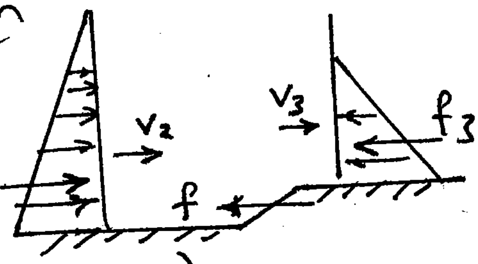
$E_2 = E_3 + h$

$$y_2 + \frac{q^2}{2gy_2^2} = y_3 + \frac{q^2}{2gy_3^2} + 1$$

$$30 + \frac{(200)^2}{2*32.2*(30)^2} = y_3 + \frac{(200)^2}{2*32.2(y_3^2)} + 1$$

$$29.7 = y_3 + \frac{621}{y_3^2} \Rightarrow y_3 = 5\ ft$$

Force on the sill:- apply momentum eqn



$$F_2 - F_3 - F = \rho Q (V_3 - V_2)$$

$$\gamma A_2 \bar{y}_2 - \gamma A_3 \bar{y}_3 - F = 1.94\ Q (V_3 - V_2)$$

we can divide this eqn on b

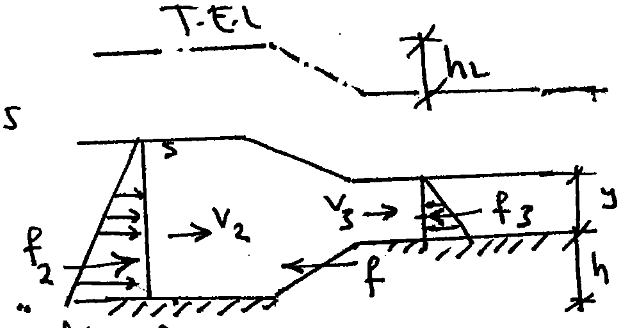
$$\therefore \overbrace{\gamma y_2\left(\frac{y_2}{2}\right)}^{f_2} - \overbrace{\gamma y_3\left(\frac{y_3}{2}\right)}^{f_3} - f = 1.94\, q (V_3 - V_2)$$

$$62.4(30)\left(\frac{30}{2}\right) - 62.4(5)\left(\frac{5}{2}\right) - f = 1.94 * 200\left(\frac{200}{5} - \frac{200}{30}\right)$$

$$\Rightarrow f = 14366.67\ lb/ft$$

(ii) $f = 100\, V_2^2\, h$

Req y_3 , h_L on the sill



$$v_2 = \frac{q}{y_2} = \frac{200}{30} = 6.67 \text{ ft/s}$$

$$h = 11 - 10 = 1 \quad \text{ft}$$

$$\therefore f = 100\,(6.67)^2 * 1 = 4448.9 \text{ lb/ft}$$

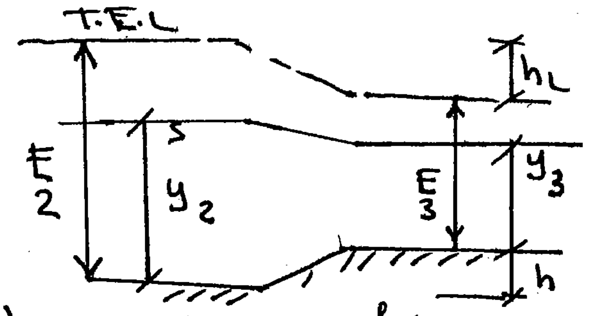
$$f_2 - f_3 - f = \rho q\,(V_3 - V_2)$$

$$\gamma\, y_2\left(\frac{y_2}{2}\right) - \gamma\, y_3\left(\frac{y_3}{2}\right) - 4448.9 = \rho q\left(\frac{200}{y_3} - 6.67\right)$$

$$62.4 * 30 * \frac{30}{2} - 62.4 * \frac{y_3^2}{2} - 4448.9 = 1.94 * 200\left(\frac{200}{y_3} - 6.67\right)$$

$$23631 - 31.2\, y_3^2 = 388\left(\frac{200}{y_3} - 6.67\right)$$

$$\therefore y_3 = \_\_ \text{ ft}$$



$$E_2 = E_3 + h + h_L$$

$$y_2 + \frac{q^2}{2g y_2^2} = y_3 + \frac{q^2}{2g y_3^2} + 1 + h_L \Rightarrow h_L = \_\_ \text{ ft}$$