EWCE 362

S01 26/11

OCF - Open Channel Flow

State of flow

Re → <500 laminar
>12500 turbulent

Critical, supercritical, subcritical

1 >1 <1

Froude number

very turbulent less turbulent

G4 G5

Black Ash

Lab report

Top sheet → Index
Cover page ↙
↓

who on prac. app.
↙

Exp. No, Exp Name, Obj, Signific/Scope, Apparatus, Datasheet, calc (details), Result, Disc., Assignment

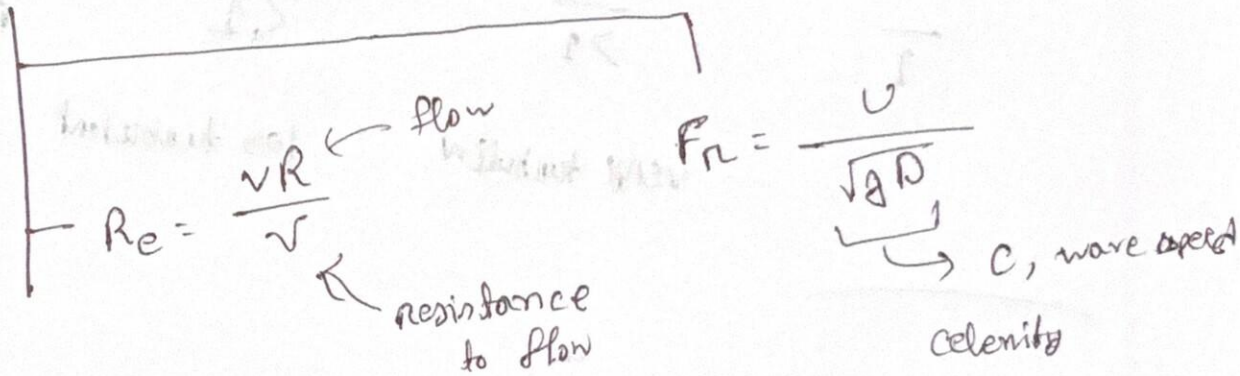
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~~Det~~

Exp 01 Determination of state of flow and critical depth in open channel

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State of flow



$Re < 500 \rightarrow$ laminar

$Re > 12500 \rightarrow$ turbulent ✓

else $\rightarrow$ transitional

For OEF, v is ↓↓ as less x-section area in contact to offer resistance



Fr

$C > V \rightarrow$ subcritical ✓

$Q = AV$

$= B_y V$

$= B_y \uparrow V \downarrow$

$d \uparrow$

$C < V \rightarrow$ super

$C = V \rightarrow$ critical

Critical depth

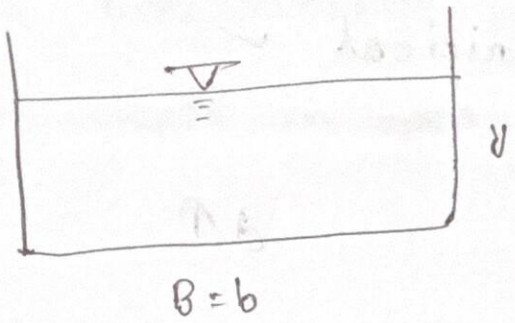
$$y_c = \sqrt[3]{\frac{Q^2}{g B^2}}$$

$$= \sqrt[3]{\frac{q^2}{g}}$$

B = top width

q = discharge per unit w

$= \frac{Q}{B}$



Exp. NO

Exp. Name

Obj: 1. defn critical depth

2. State

Apparatus

Sample calc, Result

Datasheet

Discussion → exp. result | $y > y_c$ →
practical app | $y < y_c$ →
$y = y_c$ →

Q/A

$Q = 2850$ ~~2868~~ L/min

Slope = 0.062 %

width = 0.6 m (top, btm)

u/s = 51.5, 51.6, 51.4 cm

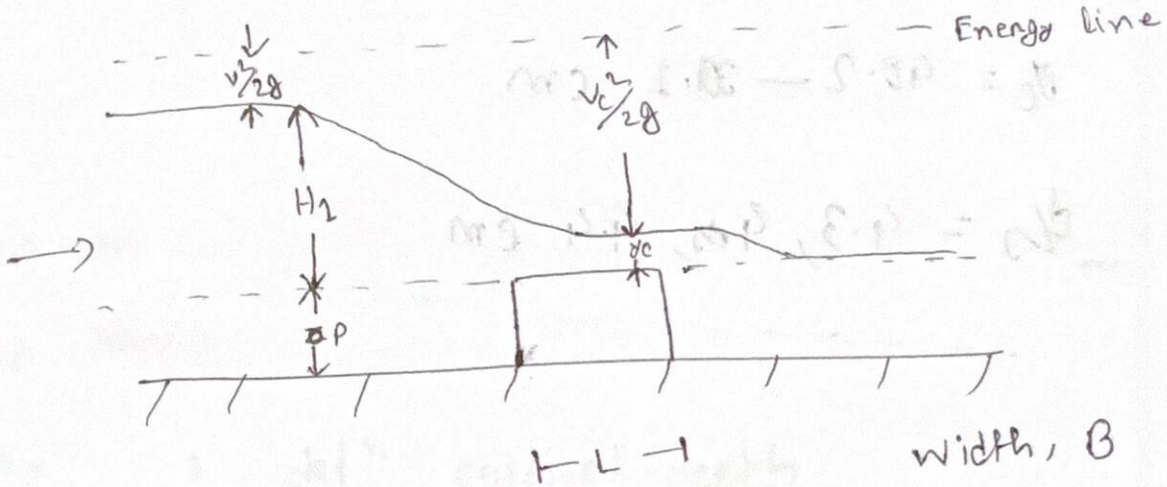
d_c = 48.2 — 39.1 cm

d/s = 4.3, 4.3, 4.4 cm

Flow Over a Broad Crested Weir

Weir — overflow structure

Broad-crested weir → made of wide concrete / timber



Use case

discharge measure on field, irrigation

Disadvantage

more energy loss

Sec 1 = Sec 2

$$\frac{P_1}{\gamma}^{0} + \frac{V_1}{2g} + Z_1^{P_1} = \frac{P_2}{\gamma}^{0} + \frac{V_2}{2g} + Z_2^{P_2}$$

$$\Rightarrow P + H_1 = \frac{V_2^2}{2g} + d + P$$

$$\Rightarrow V_2 = \sqrt{2g(H_1 - d)}$$

$$Q = AV = B \times d \times \sqrt{2g(H_1 - d)}$$

$$\Rightarrow H = {}^{*}\tfrac{3}{2} d_c$$

$$Q_t = \left(\frac{2}{3}\right)^{1.5} \sqrt{g}\, B H^{1.5}$$

→ indicates efficiency of actual discharge

$$C_d = \frac{Q_a}{Q_t}$$

$$\Rightarrow Q_a = C_d Q_t$$

$$= C_d \left(\tfrac{2}{3}\right)^{1.5} \sqrt{g}\, B H^{1.5}$$

d	Q_a
=	
=	

$Q = k d^n$

Calibration

$C_d \approx 0.8 - 0.85$

2nd method:

$$Q = ky^n$$

$$\Rightarrow \log Q = \log k + n \log y$$

$$Y = k + nX$$

$$n = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{N(\Sigma X^2) - (\Sigma X)^2}$$; $N \rightarrow$ # of data

$$k = \frac{(\Sigma Y) - n(\Sigma X)}{N}$$

$$r = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{N(\Sigma X^2) - (\Sigma X)^2} \sqrt{N(\Sigma Y^2) - (\Sigma Y)^2}}$$

$n \longrightarrow 0.6 \sim$

Discussion

1. C_d, range, why not (1cm)

   C_d diff, efficien, — Q diff (actual, graph, theo)

2. calibration, graph related disc., linear, compare

3. regression

   real life

Regression table:

S/N	Q	v	Y $= \log Q$	X $= \log v$	XY	X^2	Y^2

$B = 0.31\ m$

$H, d = 14.1\ cm = 0.141\ m$

$Q_a = 99.25\ m^3/hr$

$= 0.02757\ m^3/s$

$Q_t = \left(\frac{2}{3}\right)^{1.5} \times \sqrt{9.81} \times 0.31 \times 0.141^{1.5}\ m^3/s$

$= 0.02798\ m^3/s$

0.989

Advantages

Concrete material can be
in expensive
easy & installation
used for irrigation field

disadvantages

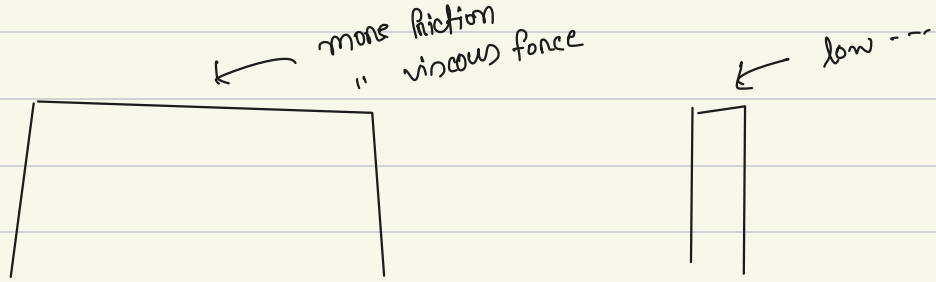
used water level
not to high

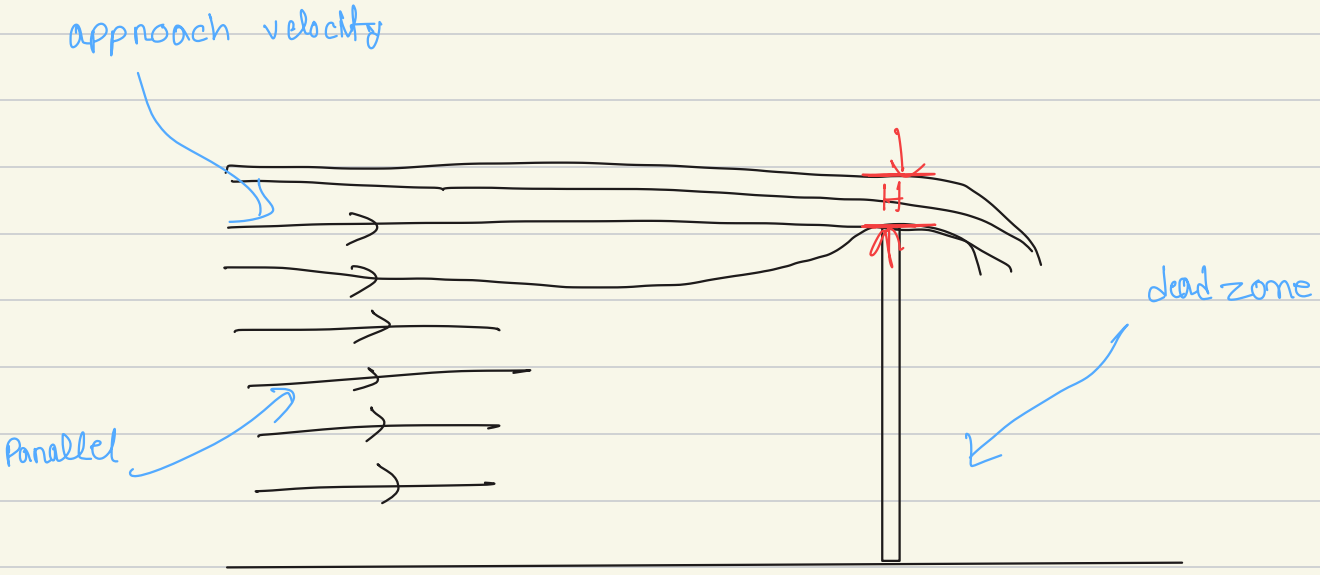
need low high
dead zone
used water
extreme
high

and calibrate
2 hour
not in

Flow over a sharp crested rectangular weir

Broad-crested — loss of than sharp crested





Main purpose → flow measure

Usage → irrigation canals

dams (can be used as; to store during dry season)

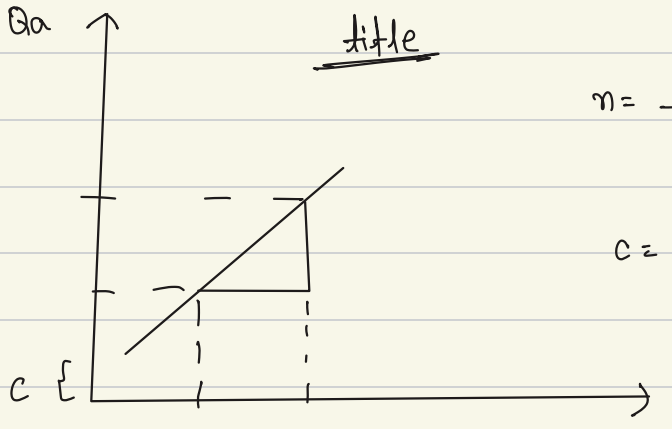
Qf → assumptions (5)

Calculation

$$Q_t = \frac{2}{3}\sqrt{2g}\, B H^{3/2}$$

$$Q_t = K H^n$$

$$Q_a = \frac{2}{3} C_d \sqrt{2g}\, B H^{3/2}$$



title

$$n = \frac{\log \frac{Q_2}{Q_1}}{\log \frac{H_2}{H_1}}$$

C = - - -

Assignment

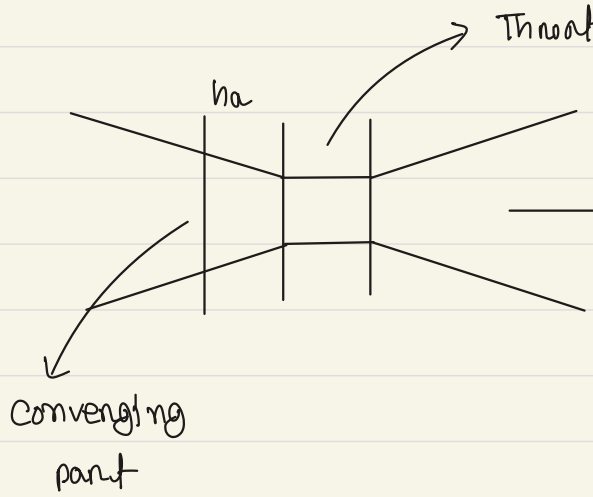
4 → H, P, B given

Rehbock formula → $C_d = 0.611 + 0.08 \frac{H}{P}$

$Q_a = \frac{2}{3} C_d \sqrt{2g}\, B H^{3/2}$ } $\frac{H}{P} \leq 5$

$C_d \rightarrow 0.58 - 0.62$

Flow through a Parshall Flume

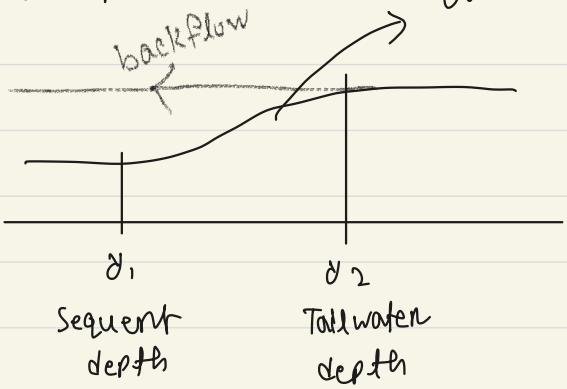


no deposition
self cleaning

Use → small irrigation no longer used as much

why do we want to develop critical flow
→ one less variable

hydraulic jump → causes energy loss



then diverging section to recover energy loss

if too high, can backflow blocking discharge

Discharge → two

free water flow

Submerged flow

Supercritical flow — doesn't affect u/s flow

advantage of Parshall flume

can measure at u/s and still get accurate result

⊛⊛⊛ why give upward slope at diverging slope & downward slope at throat

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expected values

$Q_f = K H_a^n$

$Q_{ff} = 0.3812 H_a^{1.58}$ — 4.2 ← free flow

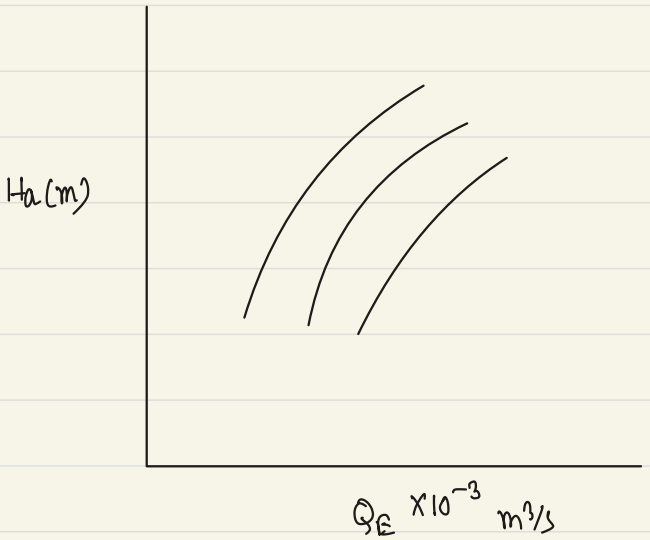
Submerged → Q_{ff} again from new Ha

Submergence ratio H_b/H_a → if < 60%

then $Q_{fs} = Q_{ff}$

else, from graph

$Q_{fs} = Q_{ff} - Q_E$



Assignment

Discussion → value

why not exact



Flow Trough a venturi Flume

Used in very large flow rate [fill in the gaps]

Measured in metre^3

At critical flow $Q = A_c\sqrt{g D_c}$ ← y_c

Weir disadv. sediment accumulation . . .

Venturi adv. - - -

adv. head diff low

Formula:

$$Q_{ff} = \left(\frac{2}{3}\right)^{1.5}\sqrt{g}\, b\, H^{1.5} \longrightarrow \text{free flow}$$ (H ← y)

Submerged: [no critical section hence two formula]

$a = b y_2$

$A = B y_1$

$m = \frac{a}{A}$

$$Q_{fs} = a v_2 = a\sqrt{\frac{2g(y_1 - y_2)}{1 - m^2}}$$

C_v calc not needed

Calc C_d

Graph for free flow $Q = k y_1^{\,n}$

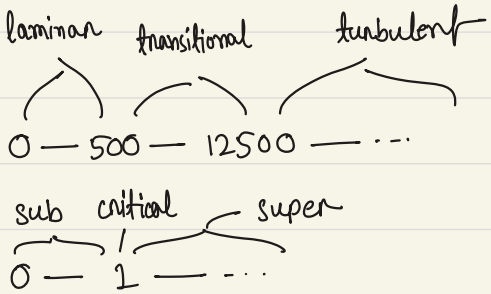
Rough / Midquiz

21/01

Exp. 01 State of flow

$Re = \frac{VR}{\nu}$; $\nu = 10^{-6}\ m^2/s$; $R = \frac{A}{P}$

$Fr = \frac{V}{\sqrt{gD}}$; $D = \frac{A}{T}$



Sample calc:

$Q = 47500\ cm^2/s$ $B = 60\ cm$ $y_c = 9.1\ cm$ $\nu = 10^{-6}\ m^2/s = 10^{-2}\ cm^2/s$

(1) $y = 51.5\ cm$; $V = \frac{47500}{60 \times 51.5} = 15.4\ cm/s$; $R = \frac{60 \times 51.5}{60 + 2 \times 51.5} = 19\ cm$

$D = \frac{60 \times 51.5}{60} = 51.5\ cm$

$\therefore Re = \frac{15.4 \times 19}{10^{-2}} = 2.9 \times 10^4$

$Fr = \frac{15.4}{\sqrt{981 \times 51.5}} = 0.069$

$y_c = \sqrt[3]{\frac{Q^2}{gB^2}} = \sqrt[3]{\frac{47500^2}{981 \times 60^2}} = 8.61\ cm$

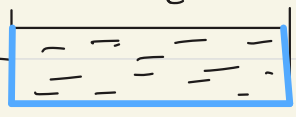
Kinematic viscosity : $\nu \rightarrow m^2/sec$

$\rightarrow cm^2/sec$ (1 stoke)

Why Froude Number is more significant:

Re always $\sim 10^6$; only variable Fr

$\frac{inertia}{viscosity}$ ← less x-section area in contact for resistance



Exp. 02 Broad crested weir

Formula: $Q_t = \left(\frac{2}{3}\right)^{1.5} \sqrt{g}\, B y_1^{1.5}$ ← depth of water over weir crest

Disadv.
i) Dead water zone at u/s → sedimentation
ii) Higher head loss
iii) u/s water lvl can get very high if not properly installed

Adv.
i) Can be constructed from concrete, timber
ii) mats locally available
iii) User friendly, easy to operate/install
iv) Less maintenance
v) Used in irrigation canals

Exp. 03 Sharp crested wein

Formula: $Q = \frac{2}{3}\sqrt{2g}\, B H^{1.5}$

Assumptions:

(i) Flow uniform, pressure = $\rho g h$

(ii) Free surface is hon. as for as wein plane goes. Particles move horizontally

(iii) water pressure at nappe is atm

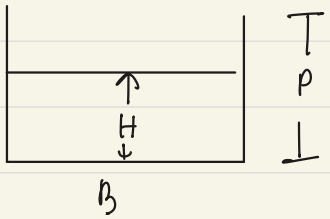
(iv) Effects of viscosity is negligible (and surface tension)

(v) U/s approach vel is "

Rehbock formula

$$C_d = 0.611 + 0.08 \frac{H}{P} \; ; \quad \frac{H}{P} \geq 5$$

$$Q_a = C_d \left(\frac{2}{3}\right) \sqrt{2g}\, B H^{1.5}$$



Exp. 04 Parshall flume

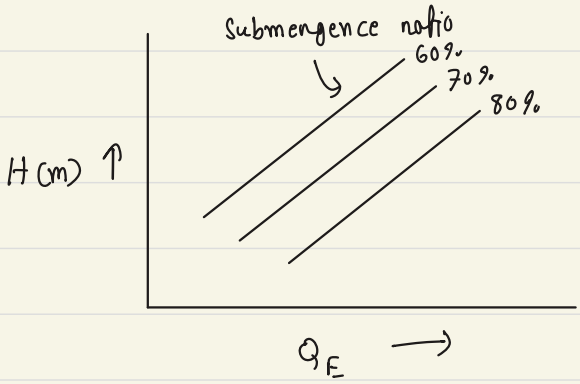
$Q_a = k H_a^n$

for 6" throat, $Q_a = 0.3812 H_a^{1.58}$; $Q_a \rightarrow m^3/s$, $H_a \rightarrow m$

$$\% \text{ Submergence} = \frac{H_b}{H_a} \times 100 \%$$

$> 60\%$

$Q_{fs} = Q_{ff} - Q_E$



Advantages:

i) self cleaning device
ii) more accurate flow measurement than others
iii) suitable for wide range of discharges
iv) can measure under both free & submerge cond.

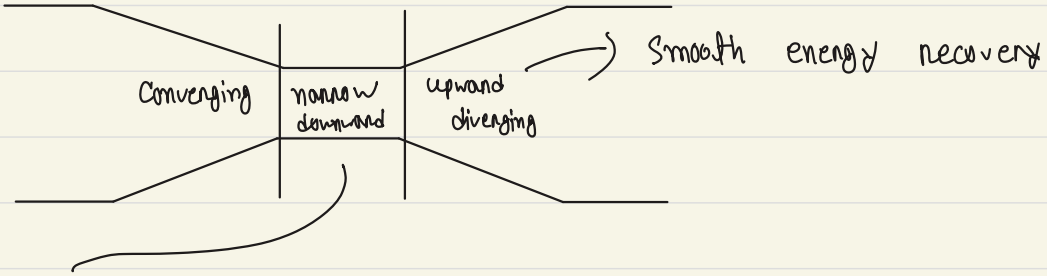
Disadv

i) costly, difficult to construct
(ii) Requires precise dimension and installation; fabrication is tough
(iii) Not suitable for small discharges

Uses

i) Measurement of irrigation canals
ii) Sewer and wastewater treatment plant
iii) where sediments are present

Downward narrow section & upward diverging section:



ensures critical flow; Q depends only on u/s depth

Exp. 05 venturi flume

Formula: $Q_{tf} = \left(\frac{2}{3}\right)^{1.5} \sqrt{g}\, b\, y_1^{1.5}$

$$Q_{ts} = a v_2 = a \sqrt{\frac{2g(y_1 - y_2)}{1 - m^2}} \; ; \; m = \frac{a}{A} = \frac{b y_2}{B y_1}$$

Adv.

(i) Smaller head loss than weirs
(ii) No dead water zone
(iii) Suitable for large flows
(iv) Single measurement at throat

Disadv.

(i) Small head diff u/s vs d/s → reduced measurement sensitivity
(ii) not for very small discharges

Use

(i) Measurement at irrigation channel distribution channel
(ii) Outlet control structures of irrigation system
(iii) Large channel where head loss to be minimized

Free flow vs. submerged flow

(i) critical depth at throat
doesn't occur at throat

(ii) Discharge depends only on u/s head (y_1)
on both u/s & d/s head (y_1, y_2)

(iii) Simple, more accurate
Requires two equations

Creation of submerged flow:

→ By obstructing d/s flow → partially closing tail gate or placing an obstruction at d/s end

Regression :

$$Q = k y^{n}$$

$$\Rightarrow \log Q = \log k + n \log y$$

$$Y = K + nX$$

$$n = \frac{N(\Sigma XY) - \Sigma X \Sigma Y}{N(\Sigma X^2) - (\Sigma X)^2}$$

$$K = \frac{\Sigma Y - n \Sigma X}{N}$$

$$k = 10^{K}$$

Rough

$$Re = \frac{VR}{\nu} = \frac{V\frac{A}{P}}{\nu} \Rightarrow 54700 = \frac{V \times \frac{0.3 \times h}{0.3 + 2h}}{1.002 \times 10^{-6}}$$

$$Fr = \frac{V}{\sqrt{gD}} \Rightarrow 1.5 = \frac{V}{\sqrt{9.81 \times h}}$$

$$\Rightarrow V = 1.5\sqrt{9.81\,h}$$

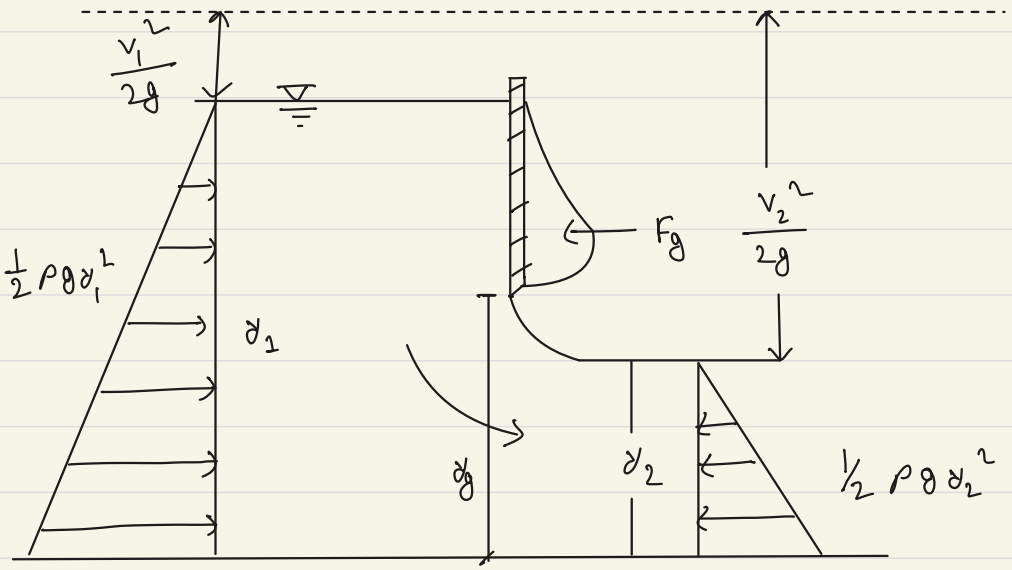
$$54700 = \frac{1.5\sqrt{9.81h}\ \frac{0.3h}{0.3+2h}}{1.002}$$

Flow Beneath a Sluice Gate

To regulate u/s flow ; control water level, discharge ...

Types [details not needed]

- Flap sluice gate → common
- vertical rising sluice gate → most common



$$Q = b y_2 \sqrt{\frac{2g y_1}{\frac{y_2}{y_1} + 1}}$$

[derivation not needed]

$$= C_v b y_2 \sqrt{\frac{2g y_1}{\frac{y_2}{y_1} + 1}}$$

$$y_2 = C_c y_g$$

$$C_c = \frac{y_2}{y_g}$$

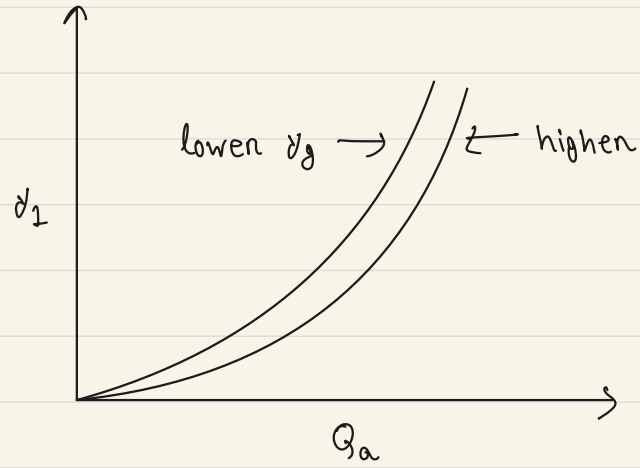
$$C_v = \frac{y_g}{y_1}$$

Use full formula to det^n C_c, C_v

~~$Q = C_d b y_g \sqrt{2g y_1}$~~

$$F_g = \frac{1}{2} \rho g \frac{(y_1 - y_2)^3}{y_1 + y_2}$$

$$F_H = \frac{1}{2} \rho g (y_1 - y_g)^2$$



normal plot

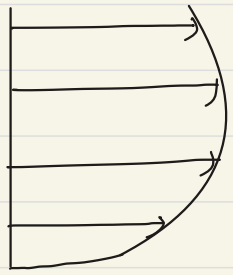
Assignment

2. → would remain subcritical always
u/s ht not independent

S08

18/02

Determination of discharge & mean velocity of an open channel



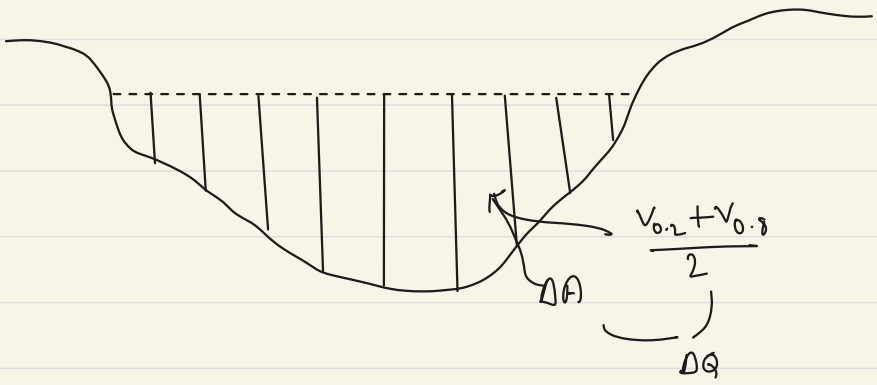
velocity distribution

0.61 m > depth ⟶ 0.6 h

< ⟶ 0.2h ↓ V_1 0.8 h ↓ V_2

$$\frac{V_{0.2h} + V_{0.8h}}{2}$$

Area-velocity method:

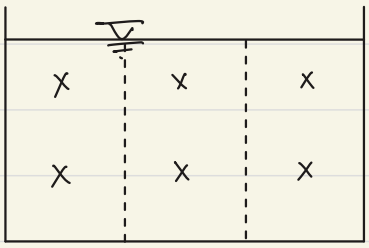


$$Q = \sum_{i=1}^{n} \Delta Q$$

$$V = \frac{Q}{\Sigma \Delta A}$$

Apparatus: Boat, current meter
Staff gauge, GPS ⟶ $v = aN + b$

Experiment: min 3 strip



Find out → n, C ← Chezy's C (~100)

$$n = \frac{(x-1)\,R^{1/6}}{6.78\,(x+0.95)} \longrightarrow \text{avg of 3}$$

$$C = \frac{1}{n} R^{1/6} \longrightarrow \text{avg of 3}$$

$$x = v_{0.2}/v_{0.8}$$





S09 25/02

Determination of change in Water Level due to Raised Channel Bottom

$$y_c = 3\sqrt{\frac{Q^2}{gB^2}}$$

Velocity → calculated (Q/A) Current meter

$$\Delta y = y_1 - y_2 - \Delta z$$

State → sub/super lam/turb

Assignment

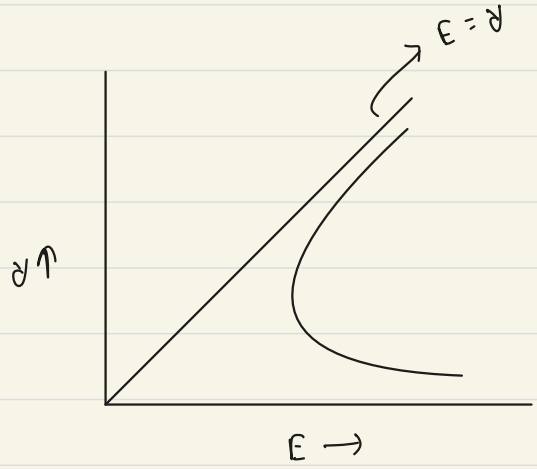
Specific energy curve → for Δy

~09:00

S10 04/03

Generalized specific energy curve

Generalized specific force curve



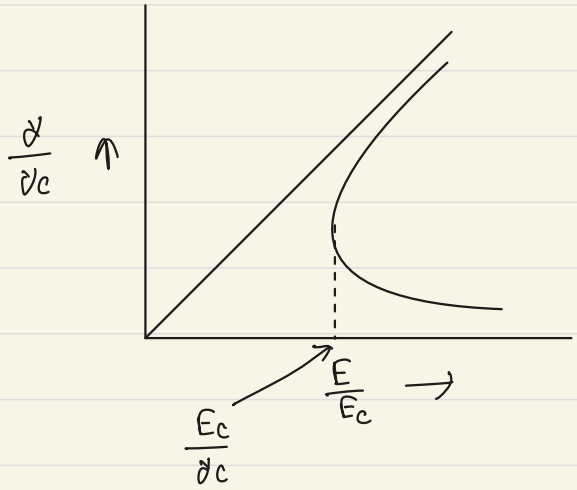
$E = y + \frac{v^2}{2g}$

when $y \to 0$, $v \uparrow$

$E \to \infty$

when $v \to 0$, $y \uparrow$

$E \to y$



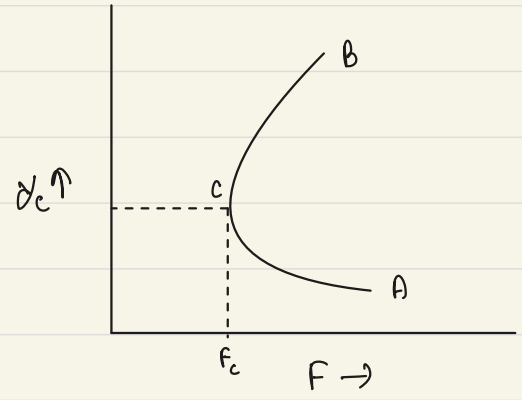
Datasheet:

$Q =$ ☐ $\qquad y =$ ☐

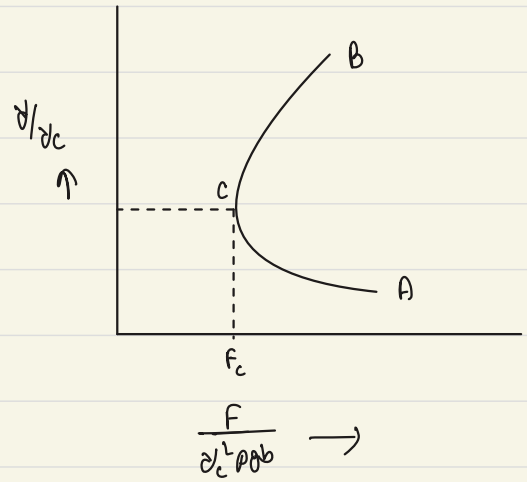
$y_c = \sqrt[3]{\frac{Q^2}{gb^2}}$

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

Specific force curve



$$\frac{F}{y_c^2 \rho g b} = \frac{y_c}{y} + \frac{1}{2}\left(\frac{y}{y_c}\right)^2$$



Discussion: whether $1 + \epsilon$ turns on $y/y_c = 1$

S11

31/03

Study of hydraulic jump

Why → reduce vel → less scouring

- - -

Counter uplift pressure

<3:30

Changes → - - -

efficiency of jump [ratio of E)

<5

Practical applications

- - -

Take eqns from book (not manual)

Objective

4. 4 graphs (see "Typical shape of graph")

Datasheet

~22

- - -

$E_2 - E_1 \rightarrow h_L$ (use formula from book on connected)

Comment → whether two same

RHS of eqn → theoretical

Other measured

Except E_1, E_2 (equip not avail) : $E = y + \frac{u^2}{2g}$

Rough / Final

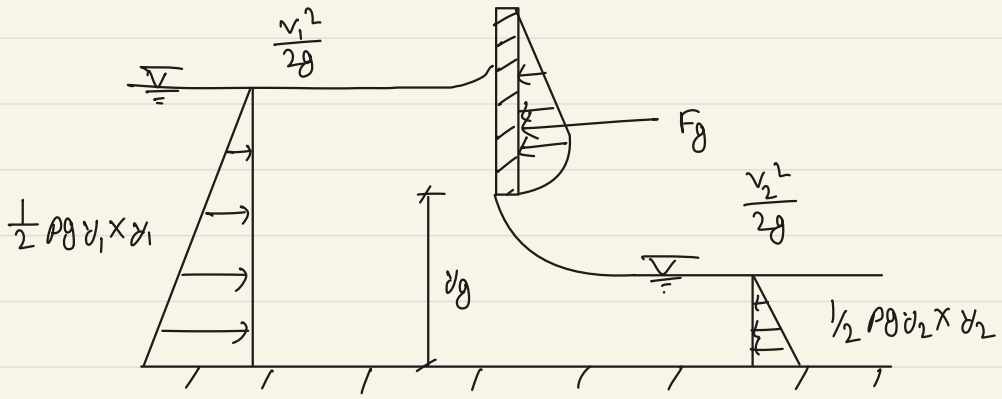
08104

Flow beneath a sluice gate

- Control & regulate water flow
- Measure discharge
- Raise or maintain water lvl
- Drain water

Types
- Flap
- vertical rising
- Radial sluice
- Needle sluice
- Rising section sluice

Process:



$$Q_t = b y_g \sqrt{2g y_1}$$

$$Q_a = C_v b y_2 \sqrt{\frac{2g y_1}{\frac{y_2}{y_1} + 2}} \quad ; \quad y_2 = C_c y_g$$

$$F_H = \frac{1}{2} \rho g (y_1 - y_g)^2$$

$$F_g = \frac{1}{2} \rho g \frac{(y_1 - y_2)^3}{y_1 + y_2}$$

Sample calc :

$y_1 = 0.42\ m$; $y_2 = 0.053\ m$; $y_g = 0.08\ m$; $b = 0.6\ m$; $Q_a = 0.077\ m^3/s$

$$Q_t = b y_g \sqrt{2g y_1} = 0.6 \times 0.08 \times \sqrt{2 \times 9.81 \times 0.42} = 0.138\ m^3/s$$

For C_v, C_d :

$$Q_a = C_v\, b\, y_2 \sqrt{\frac{2g y_1}{y_2/y_1 + 1}} \quad ; \quad y_2 = C_c y_g \Rightarrow C_c = \frac{y_2}{y_g} = 0.663$$

$$= C_v\, b\, C_c y_g \sqrt{\frac{2g y_1}{\frac{C_c y_g}{y_1} + 1}}$$

$$\Rightarrow 0.077 = C_v \times 0.6 \times 0.663 \times 0.08 \sqrt{\frac{2 \times 9.81 \times 0.42}{\frac{0.663 \times 0.08}{0.42} + 1}}$$

$$\Rightarrow C_v = 0.895$$

$$C_d = \frac{Q_a}{Q_t} = 0.558$$

$$F_H = \frac{1}{2} \rho g (y_1 - y_g)^2 = 567\ N$$

$$F_g = \frac{1}{2} \rho g \frac{(y_1 - y_2)^3}{y_1 + y_2} = 513\ N$$

when gate opening is gt than critical depth:

Always subcritical, u/s no longer independent

Submergence

d/s water lvl high enough to push back water coming underneath.

Discharge & mean vel.

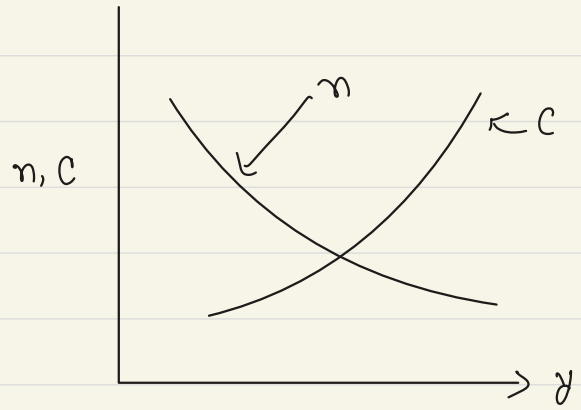
$V = aN + b$

$$x = \frac{V_{0.2}}{V_{0.8}}$$

$$R = A/P$$

$$n = \frac{(x-1)R^{1/6}}{6.78(x+0.95)}$$

$$C = \frac{1}{n} R^{1/6}$$



Sample calc:

$V_{0.2} = 0.4$ m/s; $V_{0.8} = 0.32$ m/s; $Y = 0.39$ m; $b = 0.2$m; $B = 0.6$m

$$x = \frac{V_{0.2}}{V_{0.8}} = 1.25; \qquad R = \frac{A}{P} = \frac{0.39 \times 0.6}{0.6 + 0.39 \times 2} = 0.170$$

$$n = \frac{(x-1)R^{1/6}}{6.78(x+0.95)} = \frac{(1.25-1) \times 0.17^{1/6}}{6.78(1.25+0.95)} = 0.0125$$

$$C = \frac{1}{n} R^{1/6} = 60$$

— — —

Change in water level due to raised bottom

Example 3.8: $V = 1\ m/s$; $d = 1.50\ m$; $B = 3\ m$

a) $F_R = \frac{V}{\sqrt{gD}} = \frac{1}{\sqrt{9.81 \times 1.50}} = 0.26$ [subcritical]

$Q = AV = 3 \times 1.5 \times 1 = 4.5\ m^3/s$

$h_c = \sqrt[3]{\frac{Q^2}{gB^2}} = 0.61\ m$

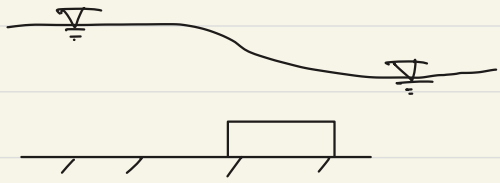


$E_1 = h_1 + \frac{v_1^2}{2g} = 1.55\ m$

$E_c = 1.5 h_c = 0.92\ m$

$E_1 = E_c + \Delta z_c \Rightarrow \Delta z_c = 0.63\ m$

b) (i) Step of $0.45\ m$



$E_1 = 1.55\ m$

$E_2 + 0.45 = 1.55$

$\Rightarrow \frac{v_2^2}{2g} + h_2 + 0.45 = 1.55$; $v = \frac{Q}{A}$

$\Rightarrow \frac{\frac{(4.5)^2}{(3 \times h_2)^2}}{2 \times 9.81} + h_2 + 0.45 = 1.55$

$\Rightarrow h = 0.41\ m,\ 0.98\ m$ ✓

(ii) Upward step of 0.80 m

$h_c = 0.61\ m$

$E_c = 1.5\, h_c = 0.92\ m$

$E_1 = 1.55\ m$

$E_1 = E_2 + (\Delta z_c = 0.80)$

$\Rightarrow E_2 = 0.75\ m \quad (< E_c)$

$\therefore E_1' = h_1' + \frac{v_1'^2}{2g}$

$\Rightarrow E_c + 0.8 = h_1' + \frac{Q^2}{2g\, h_1'^2 \times b^2}$

$\Rightarrow 0.92 + 0.8 = h_1' + \frac{4.5^2}{2 \times 9.81 \times h_1'^2 \times 3^2}$

$\Rightarrow h_1' = 0.28\ m,\ 1.68\ m \longrightarrow 1.68\ m$

$\therefore \Delta h = 1.68 - (0.61 + 0.8) = 0.27\ m$

#2 $B = 2.5\,m$; $Q = 6\ m^3/s$; $h = 0.5\,m$

$h_L = 0.1 \times \frac{v_1^2}{2g}$; $v_1 = \frac{Q}{A} = 4.8\ m/s$

$h_c = \sqrt[3]{\frac{Q^2}{gB^2}} = 0.84$

$E_1 = h_1 + \frac{v_1^2}{2g} = 1.67$

$E_c = 1.5 h_c = 1.26\ m$

$E_1 = E_2 + \Delta h_2 + h_L$

$\Rightarrow 1.67 = 1.26 + \Delta h_2 + 0.2\ \frac{4.8^2}{2 \times 9.81}$

$\Rightarrow \Delta h_2 = 0.29\ m$

$F_{r1} = \frac{v}{\sqrt{gD}} = \frac{4.8}{\sqrt{9.81 \times 0.5}}$

$= 2.16$

Study on hydraulic jump

Sample calc: $y_1 = 0.0513\,m$; $y_2 = 0.212\,m$; $v_1 = 2.2\,m/s$; $v_2 = 0.7\,m/s$

$$F_1 = \frac{v}{\sqrt{gD}} = 3.1$$

$$E_1 = y_1 + \frac{v_1^2}{2g} = 0.298; \quad E_2 = 0.237; \quad E_1 - E_2 = 0.061$$

$$E_2 - E_1 = \frac{(h_2 - h_1)^3}{4 h_1 h_2} = 0.0954$$

$$E_2/E_1 = 0.795$$

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

$$= 0.728$$

$$\frac{L_j}{h_1} = 9.75(F_n - 1)^{1.01} = 20.63$$

$$\frac{h_j}{E_1} = \frac{\sqrt{1+8F_n^2} - 3}{2+F_n^2} = 0.502$$