Notes by-

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Open Channel Flows

Questions of Examination :- Q10(a) Sketch the specific energy diagram for a constant flow through open channel. (5). 10(b) Explain the principle and working of current meter (5).
(1992) (Q8) Design a concrete lined trapezoidal channel section to carry a discharge of 200 m^3/s through a terrain where the longitudinal slope is 0.004. Assume side slopes of 1:1 and take Manning's n as 0.14 for design. Draw a sketch of the section with usual details needed for a canal. Use formula $B = 0.7\sqrt{Q}$ for bottom width. (15) (1981): (7(c)) 20 m^3/s of water flows through a 6m wide rectangular channel at a velocity of 2m/s. Calculate the sp. energy of flowing water. Also calculate minimum sp. energy and critical depth for this discharge. (4) 9(a) Sketch the water surface profile in a long rectangular channel for the following two situations. (i) the bed slope changes from mild to steep (ii) the bed slope changes from steep to mild. (6) (9(b)) A wide rectangular channel carries a discharge of 3 m^3/s per m width of channel. It has a bed slope of 1:10,000 If at a section in this channel the depth is 1.6m how far upstream or downstream from this section will the depth be 2.0m? Assume Manning's n = 0.015. (9) (1999) 3(a) (i) Explain the hydraulically efficient channel section. Derive the conditions for a most efficient trapezoidal section in open channel flow (5) (ii) Distinguish between sp. energy and sp. force in an open channel. (5) (b) A river 45m wide has a normal depth of flow of 4m and average bed slope of 1:12000. A weir is built across the river raising the water surface level at the weir site to 5.5m above the bottom of the river. Assuming that the backwater curve is an arc of a circle, calculate the approximate length of the back water curve. Consider that the river is prismatic. Take the value of η in Manning's formula as 0.025. (10) 1996 3(a) What are M_1 & M_2 curves in an open channel? Discuss the condition under which they occur. (10) (3(b)) A hydraulic jump occurs in a rectangular channel. The details are as follows. (i) Width of channel = 5m, Discharge = 5 m^3/s, Depth of water before jump = 0.2m. Find (1) Froude number before jump. (2) Depth after jump (3) Froude number after jump (4) Length of jump (5) Height of jump. (10)

1) * Determine the efficient section of a trapezoidal channel with side slopes 1:2 carrying a discharge of 11.25 m^3/s with a velocity of 0.75 m/s. What should be the bed slope of the channel? n = 0.025 [$y = 2.46$m ; $B = 1.16$m $S_o = 0.0001$]

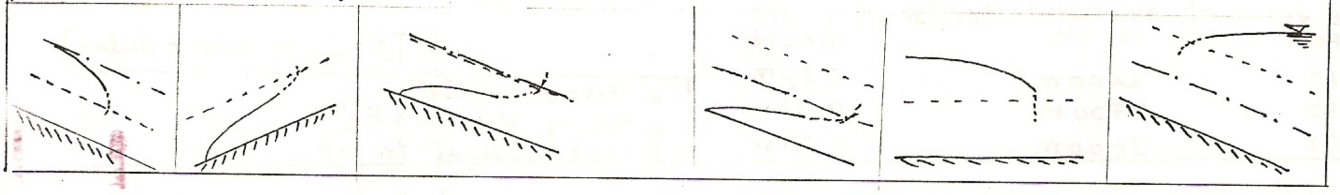
2) Uniform flow occurs at a depth of 1.5m in a long rectangular channel 3m wide and laid at a slope of 0.0009. If the Manning's n is given as 0.015, calculate the width of contraction which will produce critical depth without increasing u/s depth of flow [2.08m]

3) A rectangular channel 10m wide carries a discharge of 40 m^3/s. If at a section in this channel the depth is 1.5m, how far u/s or d/s from this section will the depth be 2.0m Take $S_o = 0.00009$ and $n = 0.017$ [367m upstream]

4) A rectangular channel carries a discharge of 3 m^3/s per m width. If the loss of energy in the hydraulic jump is found to be 3.2m, determine the conjugate depths before and after the jump. [Hint: $\Delta E = (y_2 - y_1)^3 / 4y_1y_2$ & $y_2/y = \frac{1}{2}(-1+\sqrt{1-8F_1})$ Solve by trial & error Ans: [0.293m, 2.36m]

5) A rectangular channel 7.5m wide carries 12 m^3 of water per second with a velocity of 1.5 m/s. Compute the sp. energy. Also find the depth of flow in the channel when the sp. energy would be minimum. What will be the value of critical velocity as well as minimum sp. energy. [1.18m, 0.639m, 2.503 m/s, 0.959 m]

6) Identify the flow profiles :-



Pro: Design a concrete lined trapezoidal channel ~~et~~ section to carry a discharge of 200 m^3/s through a terrain where the longitudinal slope is 0.004. Assume side slopes of 1:1 & take manning n = 0.14. for design. Draw a sketch of the section with usual details needed for a chanal. Use formula, $B = 0.7\sqrt{Q}$ for ~~wate~~ bottom width. (15M)

1992

Sol^n:-

$Q = 200 m^3/s$

$S = 0.004$

$Z = 1:1 = 1$ Horizontal.

$n = 0.14$

$B = 0.7\sqrt{Q}$

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

Max. per. vel. for concrete channel = 6 m/s.

Min. per. vel. ~~for~~ = 3 m/s.

$$\therefore V = \frac{1}{n} \cdot R^{2/3} \cdot S^{1/2}$$

$$\therefore 6 = \frac{1}{0.14} \times R^{2/3} \times \sqrt{0.004}$$

$$R = 48.4 m$$

But $R = \frac{A}{P}$

$$Q = A \cdot V \Rightarrow A = \frac{Q}{V} = \frac{2000}{6} = 33.33 m^2$$

$$\therefore P = \frac{A}{R} = \frac{48.4}{33.33} = 0.69 m \quad \left[= \frac{33.33}{48.4}\right]$$

$$\boxed{P = B + \sqrt{Z^2+1}\ (2y)}$$

$$\therefore 0.69 = B + 2\sqrt{2} \times y. \quad \text{— (i)} \quad \Rightarrow B + 2.828y = 0.69$$

~~A = B + 2y~~

~~$\therefore 33.33 = B + 2y$~~ $\Rightarrow B + 2y = 33.33$

$\therefore B = 112.12$

$$B = 0.7\sqrt{Q}$$

$$= 0.7 \times \sqrt{200} = 9.899 m$$

$$\therefore \boxed{B = 9.899 m}$$

Pro:- $20 m^3/s$ of water flows through a 6m wide rectangular channel at a velocity of 2m/s. Calculate the specific energy of flowing water. Also calculate min. sp. energy & critical depth for this discharge.

(4M)

Sol^n :- $Q = 20 m^3/s$

$B = 6 m$, $R = y$

$V = 2 m/s$

Calculate
E,
Emin = Ec
y_c

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

① $Q = A \cdot V$

$$\therefore A = \frac{Q}{V} = \frac{20}{2} = 10 m^2$$

$\therefore 6 \times y = 10 m^2$

$\therefore y = 1.67 m$

② $$E = y + \frac{Q^2}{2g (A^2)}$$

$$= 1.67 + \frac{20^2}{2 \times 9.81 \times (6 \times 1.67)^2}$$

$E = 1.87$

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

$$= \left[\frac{(Q/B)^2}{g}\right]^{1/3}$$

$$= \left(\frac{(20/6)^2}{9.81}\right)^{1/3}$$

~~$y_c = 0.698 m$~~ $y_c = 1.042 m$

④ $E_c = \frac{3}{2} y_c$

~~$E_c = 1.0467$~~ $E_c = 1.563$

②

Pro :- A hydraulic jump occurs in a rectangular channel. The details are as follows :-

① Width of channel = 5m

② Discharge = $5 m^3/s$

③ Depth of water before jump = 0.2m

④ Find -

① Fr. No. Before jump

② Depth after Jump

③

Soln :-

$B = 5m$

$Q = 5 m^3/s$

$y_1 = 0.2 m$

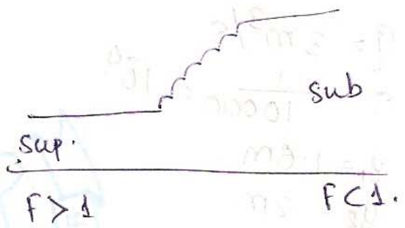
$F_1 = ?$

$y_2 = ?$

$F_2 = ?$

$L_j = ?$

$H_j = ?$



$$F_1 = \frac{V}{\sqrt{g \cdot D}}$$

$$= \frac{Q}{\sqrt{g \cdot (A/T)} \times A}$$

$$= \frac{5}{\sqrt{9.81 \times \left(\frac{5 \times 0.2}{5}\right)} \times 5 \times 0.2}$$

$$\boxed{F_1 = 3.57}$$

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

$$\therefore y_2 = \frac{0.2}{2}\left(-1 + \sqrt{1 + 8 \times 3.57^2}\right)$$

~~$y_2 = 0.9m$~~ $\boxed{y_2 = 0.91 m}$

$$F_2 = \frac{Q/A}{\sqrt{g \cdot (A/T)}}$$

$$= \frac{5/(5 \times 0.91)}{\sqrt{9.81 \times \frac{5 \times 0.91}{5}}}$$

$$\boxed{F_2 = 0.368 m}$$

$\therefore F_1 = 3.57,\ F_2 = 0.37 \quad \therefore$ O.K.

$> 1 \qquad < 1.$

Ht of jump = $y_2 - y_1$
= 0.91 − 0.2
= 0.71 m

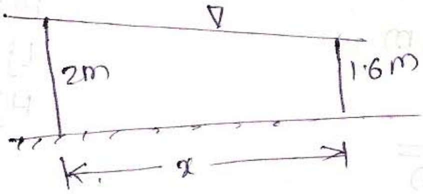
Length of jump = 5 hj
= 5×0.71
= 3.55 m

9(b)
[1991]

STEP BY STEP MTD

Pro: A wide rectangular channel carries a discharge of 3 m^3/s per m width of channel. It has a bed slope as 1:10000. If at a section in this channel, the depth is 1.6 m how far u/s or d/s from this sect^n will the depth be 2m.
Assume n = 0.015

9M



Soln:-
$q = 3\ m^3/s$
$S = \frac{1}{10000} = 10^{-4}$
$y_1 = 1.6m$
$y_2 = 2m$
$n = 0.015$

Assume B = 1m.

$V = \frac{1}{n} \cdot R^{2/3} S^{1/2}$

Depth y	Area A (B×y)	Perimeter P (B+2y)	Hydra. mean Radius (R) (A/P)	velocity V	$\frac{V^2}{2g}$	E $y+\frac{V^2}{2g}$	ΔE $E_1 - E_2$	Sf	$\bar{Sf}$	$So - \bar{Sf}$	Δx
1.6m	1.6	4.2	0.38	0.35	6.23×10^{-3} ~~0.01598~~	~~1.61598~~ 1.6062	—	1.0014×10^{-4}	—	—	—
1.7m	1.7	4.4	0.386	0.3534	6.3665×10^{-3}	1.7064	0.10016	9.998×10^{-5}	1.0006×10^{-4}	6.223×10^{-8}	1609423
1.8m	1.8	4.6	0.3913	0.3566	6.4833×10^{-3}	1.8064	0.10008	9.997×10^{-5}	9.997×10^{-5}	2.5494×10^{-8}	39250-5
1.9m											
2.0											

ΣΔx =

$$V = \frac{1}{n} \cdot R^{2/3} \cdot S^{1/2}$$

$$Sf = \left[\frac{V \cdot n}{R^{2/3}}\right]^2$$

$$Sf_1 = 1.0014\times10^{-4}$$

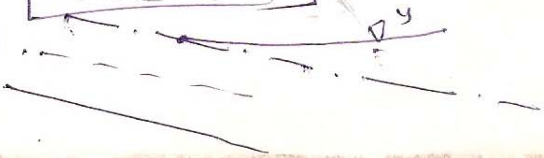
$$\bar{Sf} = \frac{Sf_1 + Sf_2}{2}$$

$$\Delta x = \frac{\Delta E}{So - \bar{Sf}}$$

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

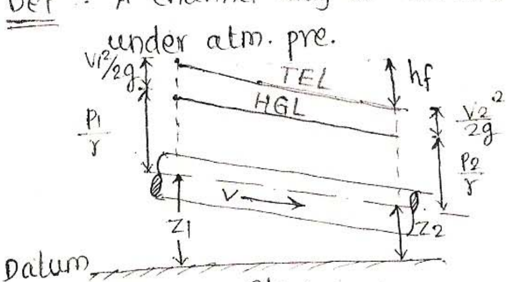
$$y_n = \left(\frac{q \cdot r}{\sqrt{So}}\right)^{3/5}$$

If $y_n > y_c$ ⇒ mild slopping channel
$y > y_n > y_c$ ⇒ M_1 Profile

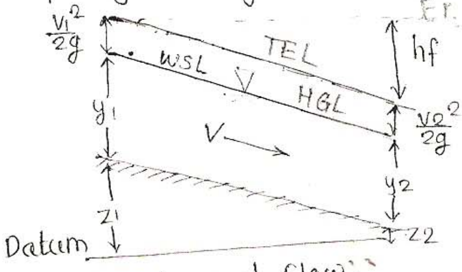


Flow in Open Channels

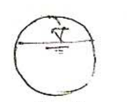
Def^n. A channel may be defined as, a passage through which water flows under atm. pre.



Pipe Flow

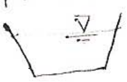
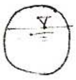


Open Channel Flow

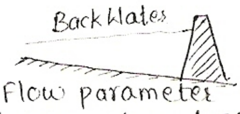


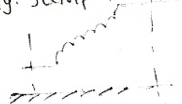
closed channel flow

* Types of Channels :-

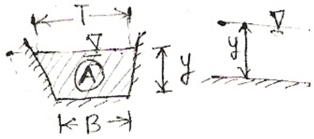
- Acc. to c/s form
  - Natural (Irregular shape)
  - Artificial (Regular)
    1) Rectangular
    2) Trapezoidal
    3) Triangular
    4) Parabolic
    5) Circular
- Open Channel 
- Closed channel 
- Prismatic: shape & size remains const. along the length. (Artificial)
- Non prismatic: shape & size does not remains const. across the length. (Natural)

Types of Flow

- On the basis of time
  - Steady
  - Unsteady
- On the basis of space
  - Uniform
  - Non-Uniform (Varied)
    - Gradually varied: Flow parameter changes along long distances. 

    - Rapidly varied: eg- Hy. Jump / Drop. Flow parameter varies along short dist. 
    - Specially varied. Discharge also varies. eg: seepage along canal, spillway along canal.
- On the basis of Layers
  - Laminar $Re < 500$
  - Transition $Re = 500$ to 2000
  - Turbulent $(Re > 2000)$
- Subcritical $[F_r < 1]$
  Supercritical $[F_r > 1]$
  Critical $[F_r = 1]$

Geometrical Properties of channel section :-

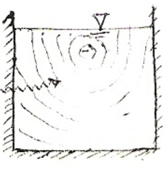


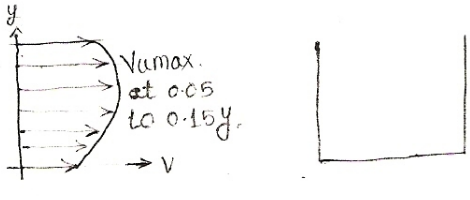
1) y = Depth of flow : Vertical dist. from WS to channel ~~depth~~ bed free surface.
2) T = Top width: Width of channel sect^n at the free surface.
3) A = Wetted Area: c/s area normal to the flow direct^n (Hatched)
4) P = Wetted Perimeter: Length of channel boundary in contact with the flowing water at any section.
5) B = Bottom Width: Width across the channel at bed level.
6) R = Hydraulic Mean Radius = A/P = (Wetted area)/(Wetted perimeter)
7) D = Hydraulic mean depth = A/T = (Wetted area)/(Top width)
8) Z = Section factor :

   For critical flow, $Z = A\sqrt{D} = A\sqrt{(A/T)} = \sqrt{A^3/T}$

   For Uniform Flow, $Z = AR^{2/3}$

9) Velocity Distribution in channel section :-

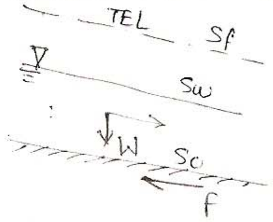




10) α = Kinetic Energy correction factor (~~Ceno~~ Coriolis coeff.) → (1.03 to 1.36)

11) β = Momentum correction factor (Boussinesq coeff.) → (1.01 to 1.12)

Uniform Flow : $\boxed{S_o = S_w = S_f}$ & Gravitational Forces = Resisting force.



* Uniform Flow formulae:-

① Chezys Eq^n :- $V = C\sqrt{RS_f} = C\cdot\sqrt{RS_o} \Rightarrow C = \sqrt{\frac{8g}{f}}$ where f = friction factor.

② Mannings eq^n :- $V = \frac{1}{n} R^{2/3} S_o^{1/2}$

③ Relation bect^n C & n :- $C = \frac{1}{n} R^{1/6}$

④ Sticklers Eq^n :- $n = \frac{d_{50}^{1/6}}{24}$ → d_{50} = Mean particle size.

⑤ Normal Depth :- $y_o = y_n$

* Most Economical Channel Section:-

① Rectangular Section:-

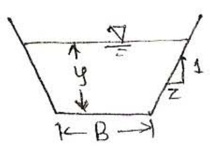
$R = y/2$

$y = B/2$

② Trapezoidal Section:-

$R = y/2$

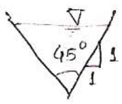
$\frac{B+2yZ}{2} = y\sqrt{1+Z^2}$



③ Triangular Section:-

$\theta = 45° \Rightarrow Z = 1$

$R = \frac{y}{2\sqrt{2}}$



* Normal Depth for rectangular section:- $y_o = \left[\frac{q\cdot n}{\sqrt{S_o}}\right]^{3/5} \Rightarrow \left[q = \frac{Q}{B}\right]$

> Computational Problem:-

Basic ~~B~~ Eq^n :- ① 1D continuity Eq^n ② Uniform flow formulae / Resistance eq^n

$Q = A_1V_1 = A_2V_2$ $\quad V = C\sqrt{RS_o}$; $V = \frac{1}{n} R^{2/3} S_o^{1/2}$

* Conveyance factor: $(K) = \frac{1}{n} A\cdot R^{2/3} = \frac{Q}{\sqrt{S_o}}$

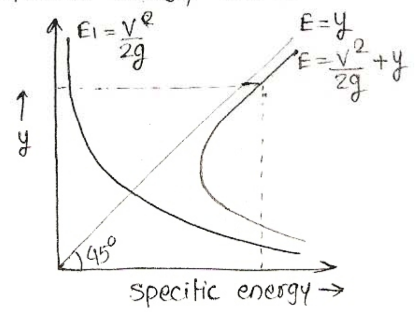
* Specific Energy:-

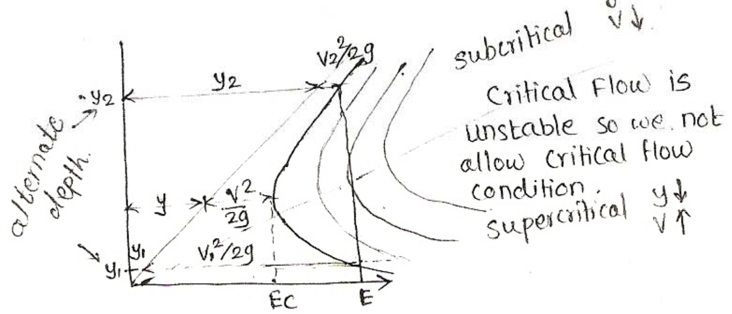
Total energy = $z + \frac{P}{\gamma} + \frac{V^2}{2g}$ = Datum head + Pre. head + vel. head (m) (Nm/N)

Specific energy is energy per unit wt. measured w.r.t. channel bed.

$\Rightarrow S = \frac{P}{\gamma} + \frac{V^2}{2g}$ (Nm/N) $= \frac{P}{\gamma} + \frac{Q^2}{2gA^2}$

* Specific Energy Curve:-





Critical Flow:- for a given discharge flow at min sp. energy.

Froude No:- $F = \frac{V}{\sqrt{g.D}} = \frac{\text{Inertia force}}{\text{Gravity force}} = \frac{\text{Velocity of Flow}}{C = \text{Celerity of wave}}$

F = 1 Critical
F < 1 Subcritical
F > 1 Supercritical

If stone is drop on water, waves are moving in all direct^n is U/S side also, i.e. flow is subcritical. If waves are not seen on upstream side (i.e. vel. is more & depth is less) flow is supercritical.

Critical Flow Condition:- ① $F = \frac{V}{\sqrt{gD}} = 1$

② $\frac{Q^2}{g} = \frac{A^3}{T}$

③ $\frac{V^2}{2g} = \frac{D}{2}$

④ for given sp. energy Discharge is max.
⑤ for given discharge sp. energy is min.
⑥ for given discharge, sp. force is min.

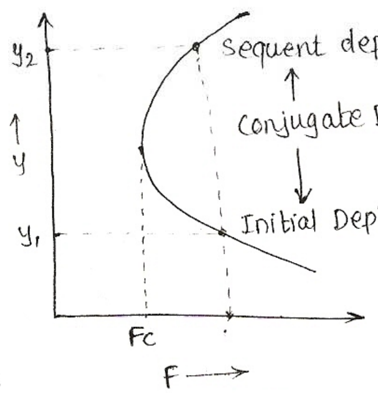
For Wide Rectangular Channel:

$D = \frac{A}{T} \simeq y$

$R = \frac{A}{P} \simeq y$

* Specific force: Force per unit wt. of water.

$$F = \frac{Q^2}{g \cdot A} + A\bar{Z}$$



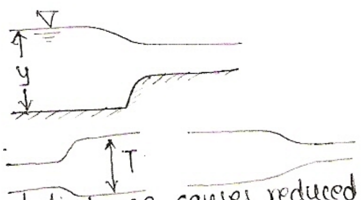
* Critical flow calculations for ① Rectangular Section:

$y_c = \left[\frac{q^2}{g}\right]^{1/3}$ $y_n = \left(\frac{q \cdot n}{\sqrt{S_0}}\right)^{3/5}$ $E = \frac{3}{2} y_c$

② Triangular Section:-

$y_c = \left[\frac{2Q^2}{g \cdot m^2}\right]^{1/5}$; $E = 1.25\, y_c$

V. Imp
Channel Transition:-
① Depth transition
② Width transition.



Necessity:- ① As reduced discharge causes reduced dim.
② Practical difficulties.
③ To flume the channel to critical flow.

Types of flume: 1) Venturi flume
2) Standing wave flume
3) Parshall flume
} Discharge measuring devices in channel.

① Venturi flume: Depth const. $Q = \frac{k \cdot A\, a \sqrt{2g}\, (\sqrt{H-h})}{\sqrt{A^2 - a^2}}$

② Standing Wave flum: Depth & Width transition. $Q = c \cdot b \cdot H^{3/2}$

③ Parshall flume: Width transition $Q = c \cdot b \cdot H^n$

Imp
Velocity measuring devices:- ① Pitot tube
② Current meter → Cup type / Propeller type } Moving boat technique.
③ Floats.

* Gradually Varied Flow:- (GVF)

① Dynamic eq^n GVF,

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - F^2} = \frac{S_0 - S_f}{1 - \left(\frac{Q^2 T}{g A^3}\right)}$$

where, $\frac{dy}{dx}$ = slope of water surface
S_0 = Bed slope
S_f = slope of Energy line.
F = Froude's No.

② Dynamic eq^n of GVF for wide rectangular channel:-

$$\frac{dy}{dx} = S_0 \cdot \left[\frac{1 - \left(\frac{y_n}{y}\right)^{10/3}}{1 - \left(\frac{y_c}{y}\right)^3}\right]$$ → Derived from Manning's eq^n

$$= S_0 \left[\frac{1 - \left(\frac{y_n}{y}\right)^3}{1 - \left(\frac{y_c}{y}\right)^3}\right]$$ → Using Chezy's Eq^n

$y_c = \left(\frac{q^2}{g}\right)^{1/3}$; $y_n = \left(\frac{qn}{\sqrt{S_0}}\right)^{3/5}$

* classification of canal bottom Slope :-

① Critical Slope :	$S_o = S_c$	⇒	$y_n = y_c$
② Mild slope :	$S_o < S_c$	⇒	$y_n > y_c$
③ Steep slope :	$S_o > S_c$	⇒	$y_n < y_c$
④ Horizontal :	$S_o = 0$	⇒	$y_n = \infty$
⑤ Adverse slope :	$S_o < 0$	⇒	$y_n =$ imaginary.

* classification of surface Profiles:-

zone 1	above top line.
zone 2	bet^n top & middle line
zone 3	below middle line.

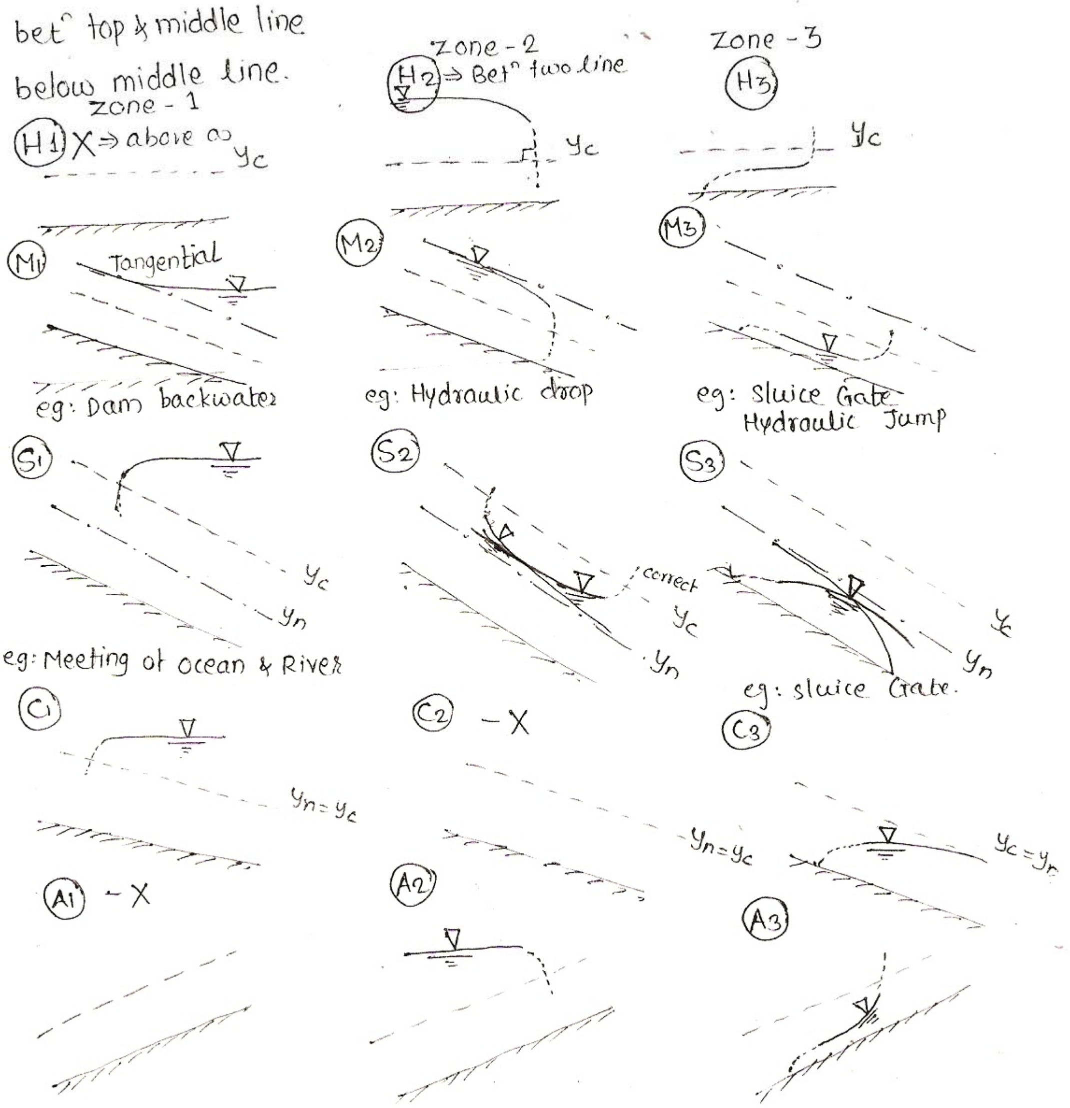
① Horizontal
$S_o = 0$
$y_n = \infty$

② Mild Slope
$S_o < S_c$
$y_n > y_c$

③ Steep slope :
$S_o > S_c$
$y_n < y_c$

④ Critical slope
$S_o = S_c$
$y_n = y_c$

⑤ Adverse slope
$S_o < 0$
$y_n =$ Imaginary



* Computation of flow Profiles :-
① Step Mtd :
② Graphical integration mtd.
③ Direct integration mtd.

① Step Mtd :- Step by step procedure :
① Compute area of flow section 'A', Wetted perimeter 'P' & Hydraulic radius 'R' corresponding to known 'y'.
② Compute the mean velocity 'V', the vel. head ($V^2/2g$) & sp. energy 'E' energy line slope 'S_f' at the channel section where 'y' is known. (Use Manning's or Chezy's eq^n for calculating S_f)
③ Assume new depth for another section lying very close to the previous one, & from the assumed depth of flow 'y' compute the various quantites as indicated in step ① & ②.
④ Obtain the value of ΔE from the computed values of sp. energies E_1 & E_2 at the two adjacent sections.

(5) $\overline{Sf} = \frac{(Sf_1 + Sf_2)}{2}$

(6) Substitute the values of ΔE, So & $\overline{Sf}$ to compute dx as,

$dx = \frac{\Delta E}{So - \overline{Sf}}$ which represents the length of the portion of the surface profile lying betn two adjacent sections.

(7) Repeat the process by assuming diff. values of depths of flow 'y' at the adjacent sections until the reqd. section is reached. at the resulting dx to obtain reqd. length 'x' of the flow profile.

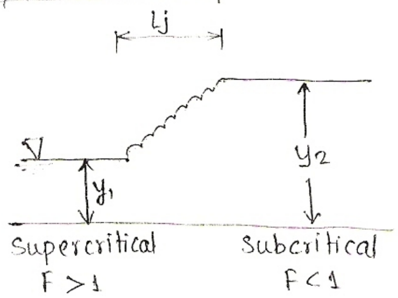
(2) Graphical Mtd. of integration :-

$$\frac{dy}{dx} = \frac{So - Sf}{1 - \frac{Q^2 T}{g A^3}} \quad ; \quad dx = f(y) \cdot dy \quad \text{where } f(y) = \frac{1 - \left(\frac{Q^2 T}{g A^3}\right)}{So - Sf}$$

$$\therefore \int dx = \int f(y)\, dy \Rightarrow (x_2 - x_1) = \int_{x_1}^{x_2} dx = \int_{y_1}^{y_2} f(y)\, dy$$

(3) Direct integration mtd :- (Very complicated).

* Hydraulic Jump :-



[Local phenomenon]

y_1 = Pre jump depth / Initial depth

y_2 = post jump depth / Sequent depth

For rectangular channel,

$$\frac{y_2}{y_1} = \frac{1}{2}\left[-1 + \sqrt{1 + 8 F_1^2}\right]$$

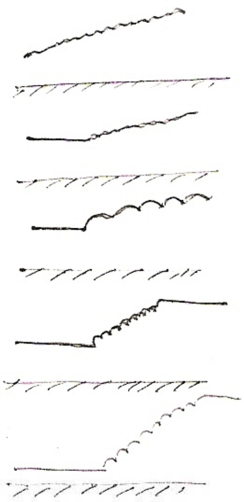
$$\frac{y_1}{y_2} = \frac{1}{2}\left[-1 + \sqrt{1 + 8 F_2^2}\right]$$

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

$h_j = y_2 - y_1$

L_j = (5 to 7 times) h_j

Types of Jumps :-



(1)	undular	F_1 = 1 to 1.7
(2)	weak	F_1 = 1.7 to 2.5
(3)	Oscillating	F_1 = 2.5 to 4.5
(4)	steady	F_1 = 4.5 to 9
(5)	strong	$F_1 > 9.0$

Uses of Jump :-

1. Energy Discipation.
2. Increasing WL in irrigatn channels.
3. To increase wt. of on apron.
4. To increase discharge thr sluice
5. Mixing chemicals in water & other liquids.

— END —