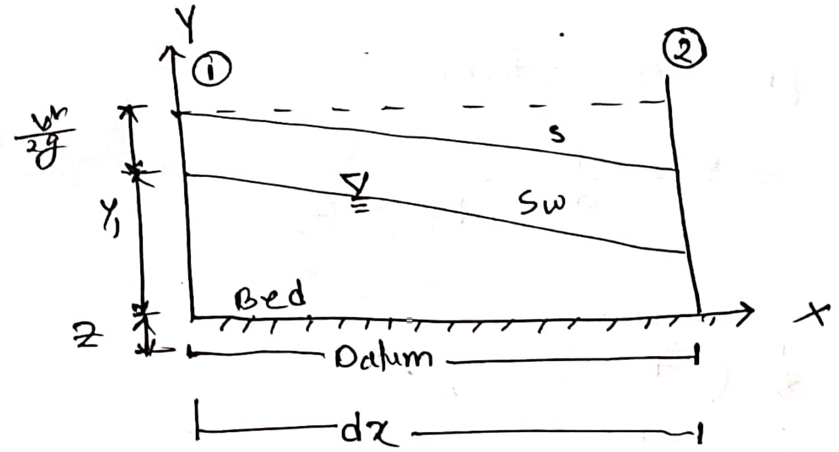
Chp: 09 Gradually-Varied Flow in Open Channels

Definition: A steady non-uniform flow in a prismatic channel with gradual elevation in it's water level elevation.

Derivation of the Dynamic equation of gradually varied Flow:



Considering the profile of a gradually varied flow in the dx length of a channel.

The total head at any section,

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

$$\Rightarrow \frac{dH}{dx} = \frac{dz}{dx} + \frac{dy}{dx} + \frac{d}{dx}\left(\frac{v^2}{2g}\right)$$

Here,

$\frac{dH}{dx} = -S_e$ = Slope of Energy line

$\frac{dz}{dx} = S_0$ = bed slope

$$\therefore -S_e = -S_0 + \frac{dy}{dx} + \frac{d}{dx}\left(\frac{v^2}{2g}\right)$$

$$\Rightarrow S_0 - S_e = \frac{dy}{dx} + \frac{dy}{dy} \cdot \frac{d}{dx}\left(\frac{v^2}{2g}\right)$$

$$\Rightarrow S_0 - S_e = \frac{dy}{dx}\left(1 + \frac{d}{dy}\left(\frac{v^2}{2g}\right)\right)$$

$$\Rightarrow \frac{dy}{dx} = \frac{S_o - S_e}{1 + \frac{d}{dy}\left(\frac{v^2}{2g}\right)} \quad \text{(Proved)}$$

Derivation of the Differential Equation for the Gradually Varied Flow:

Solution: After previous section,

$$D.E.G = \cancel{S_o - S_e} \quad \frac{dy}{dx} = \frac{S_o - S_e}{1 + \frac{d}{dy}\left(\frac{V^2}{2g}\right)} \longleftarrow (1)$$

Now,
$$\frac{d}{dy}\left(\frac{V^2}{2g}\right) = \frac{d}{dy}\left(\left(\frac{Q}{A}\right)^2 \times \frac{1}{2g}\right)$$

$$= \frac{d}{dy} \frac{Q^2}{A^2 2g}$$

$$= \frac{Q^2}{2g} \frac{d}{dy}(A^{-2})$$

$$= -\frac{Q^2}{gA^3} \frac{dA}{dy} \qquad \left[D = \frac{A}{T} = \text{hydraulic depth} \right]$$

$$= \frac{-Q^2 T}{gA^3}$$

$$= \frac{-V^2 A^2 T}{gA^3}$$

$$= \frac{-V^2 T}{gA}$$

$$= \frac{-V^2}{gD}$$

$$= -\left(\frac{V}{\sqrt{gD}}\right)^2 \qquad \left[\because F_r = \frac{V}{\sqrt{gD}} \right]$$

$$= -F_r^2$$

$\therefore$ D.E.G becomes,

$$\boxed{\frac{dy}{dx} = \frac{S_o - S_e}{1 - F_r^2}}$$

Classification of flow profiles:

Q = Discharge

n = manning coefficient

S_o = Channel Bed Slope

S_e = " energy slope

y_o = uniform flow depth
= normal depth

y_c = critical depth.

y = Non uniform flow depth

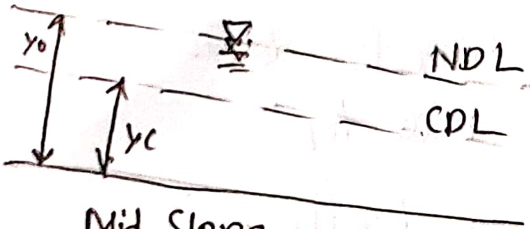
* Manning's Equation for discharge, [emperical formulae]

$$Q = \left(\frac{1}{n}\right) A R^{2/3} \sqrt{S_o} \quad ; n = \text{roughness of friction}$$

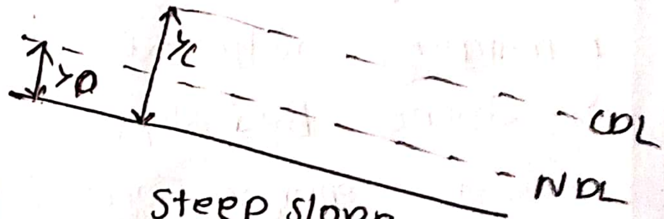
For horizontal channel, $S_o = 0$ $\therefore Q = 0$

" adverse " , $S_o < 0$ $\therefore Q$ can't be calculated.

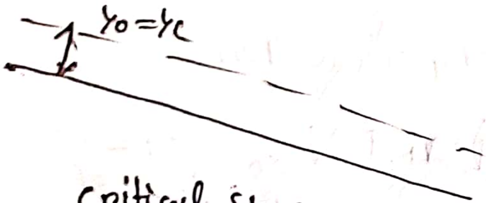
No.	Channel Catagory	Symbol	Condition	Remark
1.	Mild Slope	M	$y_o > y_c$	Subcritical flow at normal depth
2.	Steep slope	S	$y_c > y_o$	Supercritical flow at normal depth
3.	Critical Slope	C	$y_c = y_o$	Critical flow at normal depth
4.	Horizontal bed	H	$S_o = 0$	Can't sustain Uniform flow
5.	Adverse Slope	A	$S_o < 0$	Can not sustain uniform flow.



Mid Slope , So=+



Steep slope



Critical slope

Horizontal bed

Behaviour of dy/dx:

If depth of flow is $= y$,

then we know, if

$y > y_c \rightarrow$ Subcritical $\rightarrow F_r < 1$

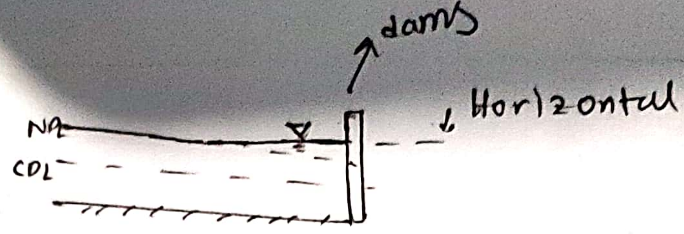
$y = y_c \rightarrow$ Critical $\rightarrow F_r = 1$

$y < y_c \rightarrow$ supercritical $\rightarrow F_r > 1$

Now, using $\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2}$ for these three,

Channel	Region	Condition	Type	Flow	$\frac{dy}{dx}$
Mild Slope ($S_e > S_0$)	1	$y > y_0 > y_c$	M1 - Backwater	Subcritical	
	2	$y_0 > y > y_c$	M2 - Drawdown	subcritical	
	3	$y_0 > y_c > y$	M3 - Backwater	supercritical	
Steep slope ($S_0 > S_e$)	1	$y > y_c > y_0$	S1 - Backwater	Subcritical	
	2	$y_c > y > y_0$	S2 - Drawdown	Supercritical	
	3	$y_c > y_0 > y$	S3 - Backwater	"	
Critical Slope ($S_0 = S_e$)	1.	$y > (y_c = y_0)$	C1 - Backwater	Subcritical	
	2	$y = y_c = y_0$	C2 - Uniform Parallel to bottom	Uniformly critical	
	3	$y < (y_c = y_0)$	C3 - Backwater	supercritical	
Horizontal $S_0 = 0$	none	none	none	none	
	2	$y_0 = \infty$ and $y > y_c$ Draw ~~Back~~	H2 - Draw	subcritical	
	3	$y_0 = \infty$ and $y < y_c$ Back	H3 - Back	supercritical	
Adverse $S_0 < 0$	None	None	—	—	
	~~H1~~ 2	$y > y_c$ - Draw	H2 - Draw	subcritical	
	3	$y < y_c$ - Back	H3 - Back	supercritical	

01. M1



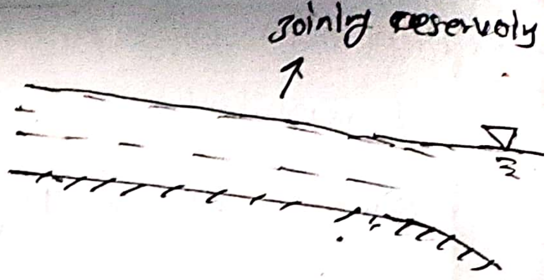


Fig. M1 ($y > y_0 > y_c$)

* Most important
* The downstream end of a mild channel is submerged in a reservoir of a greater depth than normal depth
* Example: Behind a dam of a natural river. and a cannal joining two reservoirs.

M2 :

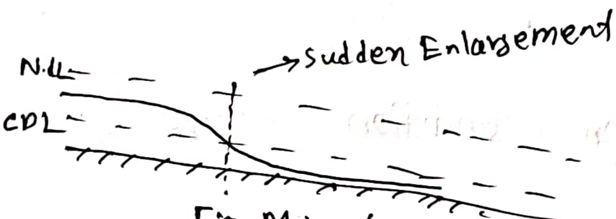
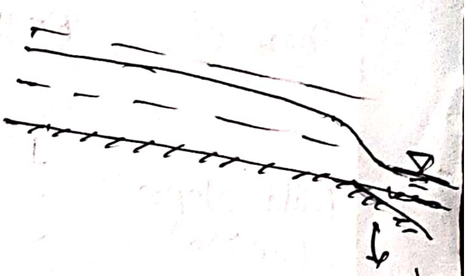


Fig. M2 ($y_0 > y > y_c$)

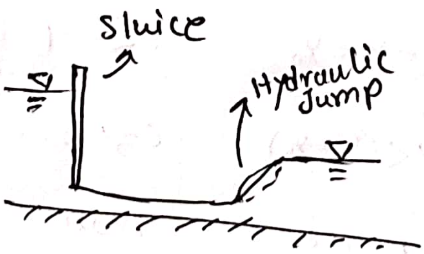


* The downstream end is submerged to a depth less than the normal depth.

* If it's even less than the critical depth then it'll stop abruptly meaning a "Hydraulic Drop"

* Ex: Sudden enlargement, cannal joining a reservoir

M3:



* Occurs when a supercritical flow enters a mild channel

* ~~Can never exist physically~~

* Ex: Stream below a sluice, after the chang of slope from steep to mild

Aupom Sir

M-Profiles

a) M1 /

Fig: Flow behind a weir

* Region 1

* Here,

$y > y_0 > y_c$

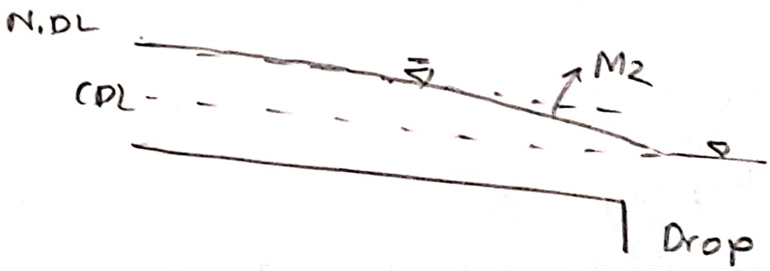
$S_e > S_0$

* subcritical flow as $y_0 > y_c$ and $F_r < 1$
* From, $\frac{dy}{dx} = \frac{S_0(1-(K_0/K)^2)}{1-(Z_c/Z)^2}$, $\frac{dy}{dx} = \frac{+}{+} > 0$ ∴ Water depth will increase in flow direction

* Most common of all profiles
* Weirs, dams, control structures, natural features like bends produce M1 curves.

* Backwater curve.

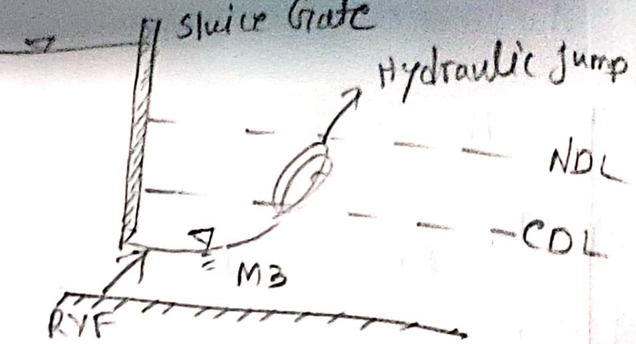
b) M2 /



* Region two
* $y_0 > y > y_c$, subcritical
* Backwater
* $S_e > S_0$
* From, $\frac{dy}{dx} = \frac{S_0(1-(K_0/K)^2)}{1-(Z_c/Z)^2}$; $\frac{dy}{dx} = \frac{-}{+} < 0$ ∴ Water depth will decrease

* Occures at a sudden drop of a channel and at the canal outputs into pools.

c) M_3 - Curve:

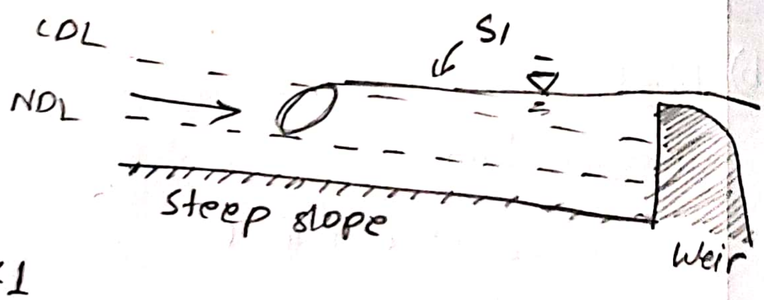


* Water will be in Region 3
* $y_o > y_c > y$, supercritical, $Fr > 1$
* $S_e > S_o$
* $\frac{dy}{dx} = \frac{-}{-} > 0$ ∴ Backwater, water depth will increase
* Backwater

* When a supercritical flow enters a mild slope channel.
* the flow leading from a spillway or sluice gate to a mild slope channel.
* The beginning of m3 is followed by a RVF and a hydraulic jump.
* M3 curves are short of length.

S- Curves

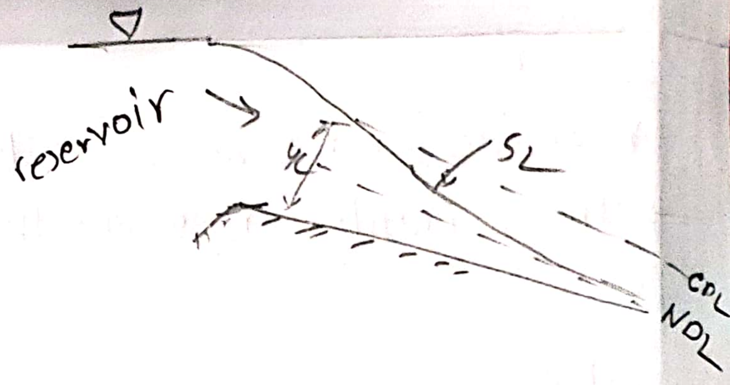
a) S_1 - Curve:



* Steep slope, $S_o > S_e$
* $y > y_c > y_o$, subcritical, $Fr < 1$
* region 1
* $\frac{dy}{dx} = \frac{+}{+} = + > 0$, water depth will increase
* Backwater

* It's produced when the flow from a steep channel is terminated by a deep pool created by a weir, dam. At the beginning flow changes from supercritical to subcritical flow by a hydraulic jump.

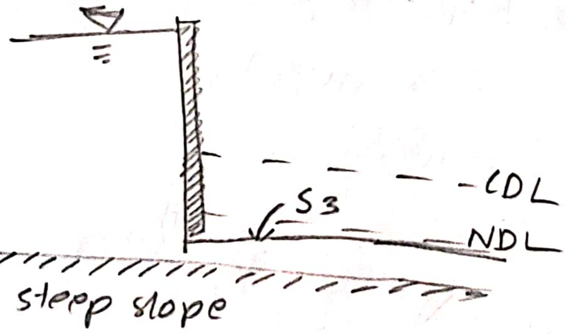
b) S-2 Curve:

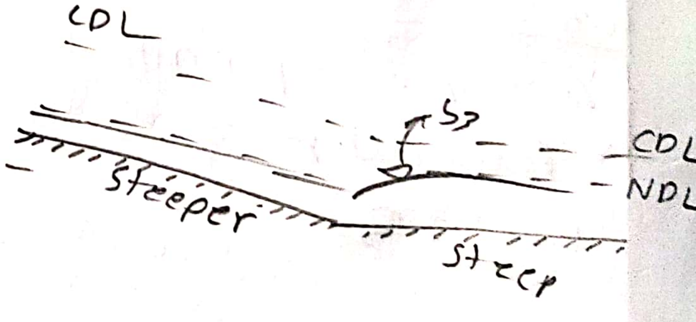


* Region 2
* $y_c > y > y_0$, supercritical, $Fr > 1$
* $S_e > S_0$
* $\frac{dy}{dx} = \frac{+}{-} = - < 0$, Draw down, water depth derease
* Occur at the entrance of a steep channel leading from a reservoir
* Short of length

c) S-3 Curve

* region 3
* $y_c > y_0 > y$, Super critical, $Fr > 1$.
* $S_e > S_0$
* $\frac{dy}{dx} = \frac{-}{-} = + > 0$, water depth will increse
* Backwater



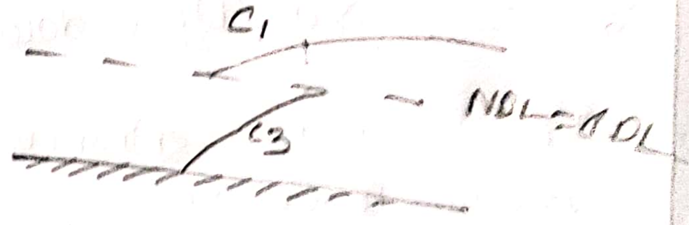


* Occurs at sluice gate with a steep slope
* And a steeper slope to a steep slope.

C-Curves:

* $S_0 = S_c$ and $y_0 = y_c$ ∴ No region 2
* These profiles represent the transition between M & S
*

C1 curve:



* $y > y_0 = y_c$ ∴ subcritical
* Horizontal asymtote curve
* Region - 1
* Backwater

C-2:

* $y = y_0 = y_c$ ∴ Uniformly critical flow
* $Fr = 1$
* paralled to channel slope

C3

$y_0 = y_c > y$ ∴ super critical
* Backwater
* Region-3

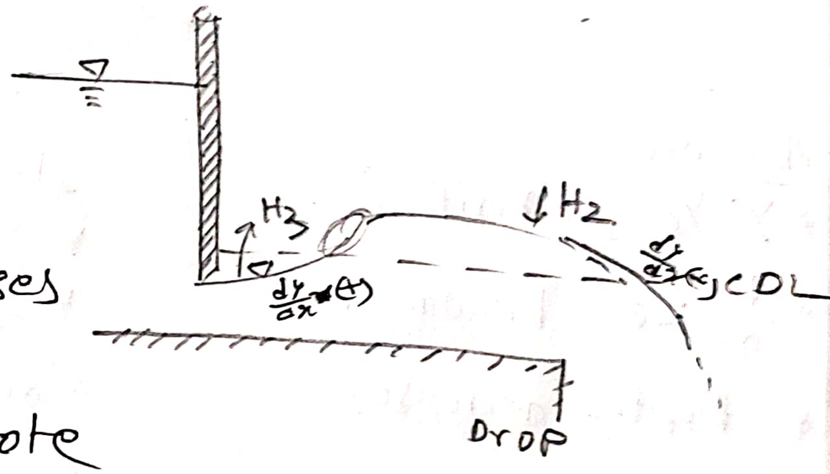
H - curves:

* Uniform flow depth y_0 does not exist, ∴ there's no region 1. ∴ H1 profile doesnot exist.

* $S_0 = 0$, $y_0 = \infty$

* H2, H3 profile correspond to M2 & M3 profiles

H-2 curve:



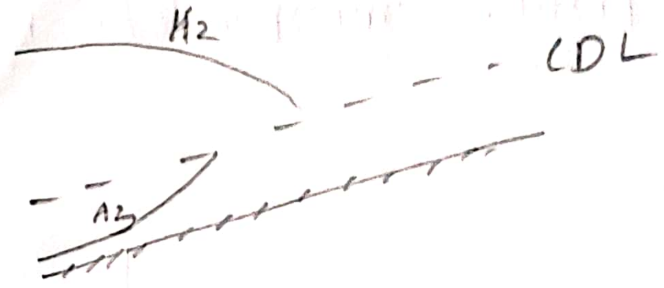
* $y_0 = \infty$
* region 2
* $y > y_c$, Subcritical
* $\frac{dy}{dx} < 0$, Depth Decreases
* ~~Back~~ Draw down
* Horizontal Asymptote

H3 - Curve:

* $y_0 = \infty$
* $y_c > y$
* Supercritical
* $\frac{dy}{dx} > 0$, water depth increases
* Backwater

A Profiles

* $S_0 < 0$
* Uniform flow depth y_0 does not exist
* ∴ like H, there's no region one or NDL
* A_2, A_3 similar to H_2, H_3
*



A2 Curve:
* $y > y_c$, subcritical,
* $\frac{dy}{dx} < 0$, Drawdown
* Depth decreases

A3 curves:
* $y_c > y$, supercritical
* $\frac{dy}{dx} > 0$, Backwater
* depth increases
*

Backwater

when $\frac{dy}{dx}$ is ~~negative~~ positive. Happens in upstream due to rising of water.

Drawdown:

when $\frac{dy}{dx} < 0$ negative

Chapter | Gradually Varied Flow Profile computation

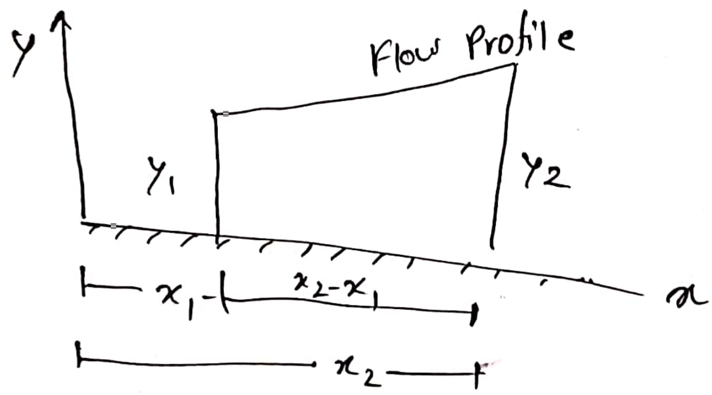
The main objective is to compute and determine the shape of the flow profile.

<u>Methods:</u>

1. Graphical Integration Method
2. Direct Integration "
3. Direct Step Method
4. Standard step method

01. Graphical Integration Method:

This method is to integrate the dynamic equation by a graphical procedure.



The distance along the channel floor is,

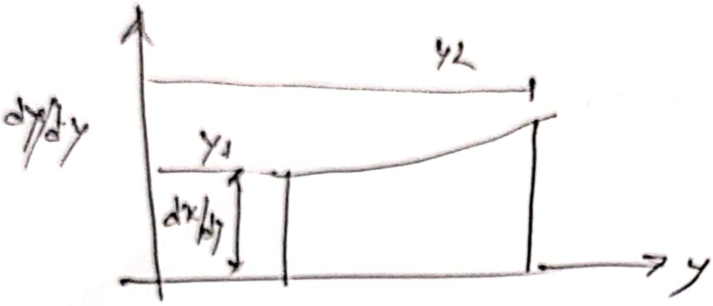
$$x = x_2 - x_1$$

$$= \int_{x_1}^{x_2} dx$$

$$= \int_{y_1}^{y_2} \frac{dx}{dy}\, dy \quad \text{———} (1)$$

Now, $\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{S_0\left[1 - \left(\frac{K_n}{K}\right)^2\right]}{1 - \left(Z_c/Z\right)^2}$

A curve of y aginst dx/dy is then constructed. from eqn (1) it's apparant that the value of x is equal the shaded area



For uniform flow/ Normal depth:

Conveyance, $K = \dfrac{1\cdot49\, AR^{2/3}}{n}$

Discharge, $Q = \dfrac{1\cdot49\, AR^{2/3}}{n} S^{1/2}$

$\therefore K = \dfrac{Q}{\sqrt{S}}$

And

$\cancel{\dfrac{V^2}{2g} = \dfrac{D}{2}}$

for Critical flow:

$Z_c = \dfrac{Q}{\sqrt{g/\alpha}}$

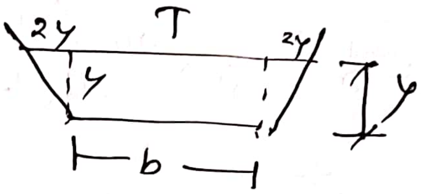
$\dfrac{V^2}{2g} = D/2$

Ex: 10.1 - Vente chow

* A trapezoidal channel having $b = 20'$, $z = 2$, $S_0 = 0.0016$ and $n = 0.025$ carries a discharge of 400 cfs. Compute the backwater profile created by a dam which backs up the water to a depth of 5' immediately behind the dam. The upstream end of profile is assumed at a depth equal to 1% greater than the normal depth. The energy co-efficient $\alpha = 1.10$

Solution:

Here,



$z = 2$

$b = 20$

$S_0 = 0.016$

$n = 0.025$

$Q = 400$

$\therefore$ Top width $T = 2y + 2y + b = 20 + 4y$

$\therefore$ Area, $A = \frac{1}{2} y (20 + 4y + 20)$

$\therefore A = 20y + 2y^2$

$\therefore$ Hydraulic Depth, $D = \frac{A}{T} = \frac{20y + 2y^2}{20 + 4y} = \frac{10y + y^2}{10 + 2y}$

$V = \frac{Q}{A} = \frac{400}{20y + 2y^2}$

Determination of critical Depth:

From condition of critical condition we know,

$$\frac{V^2}{2g} = \frac{D}{2}$$

$$\Rightarrow \frac{400^2}{\cancel{2} \times 9.8 \times (20y + 2y^2)^2} = \left(\frac{10y + y^2}{10 + 2y}\right) \times \frac{1}{\cancel{2}}$$

Simplifying, $y_c = 2.14$ ft

Determination of Normal Depth:

Here,

$P = y\sqrt{5} + 20 + y\sqrt{5}$

$\therefore P = 2y\sqrt{5} + 20$

$\therefore$ Hydraulic Radius, $R = \frac{A}{P} = \frac{2y(10+y)}{2(y\sqrt{5}+10)}$

$\therefore R = \frac{y(10+y)}{y\sqrt{5}+10}$

$\therefore$ from manning's formulae,

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

$$\Rightarrow \frac{400}{20y + 2y^2} = \frac{1.49}{0.025} \times \left(\frac{y(10+y)}{y\sqrt{5}+10}\right)^{2/3} 0.0016^{1/2}$$

$$\Rightarrow \frac{200 \times 2.34}{10y + y^2} = \frac{(y(10+y))^{2/3}}{(y\sqrt{5}+10)^{2/3}}$$

[illegible] Calculator এ

$\therefore y_n = 3.35'$

[$y_0 = y_n$ = normal depth = Uniform depth]

As $y_n > y_c$ $\therefore$ The flow is subcritical And the flow behind the dam is greater than y_n

$\therefore$ y_0 or $y_n > y_c$ Which is ~~in~~ M-type.

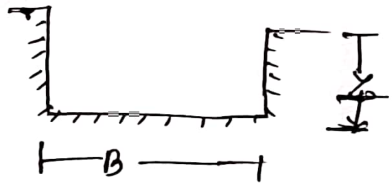
And $y = 5'$ behind dam

$\therefore y > y_0 > y_c$ $\therefore$ M1 type profile

* CT Question:

Detenmine the gradually varied profile of a ~~g~~ rectangular Channel with a bottom width of 5m and a bottom Solpe of 0·0007 has a discharge of 2·5 m3/sec. In a gradually varied flow in this channel, the depth at a certain location is found to be 0·5m. Assume, n=0·016 Also sketch the qualitative sketch

Solution:



Here,

$B=5$, $T=B=5$

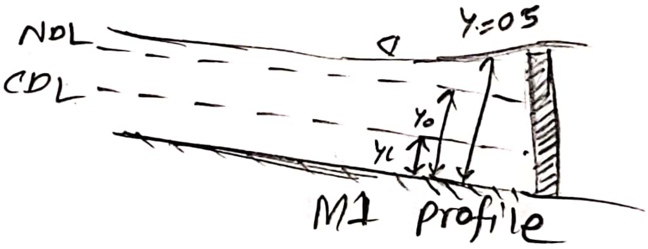
$S_0=0.0007$

$Q=2.5$

$A=5y$

$D=\frac{A}{T}=\frac{5y}{5}=y$

$R=\frac{5y}{5+2y}$



Critical Depth:

$\frac{V^2}{2g}=\frac{D}{2}$

$\Rightarrow \frac{Q^2}{A^2 2g}=\frac{D}{2}$

$\Rightarrow \frac{2.5^2}{25y^2\times 19.6}=\frac{y}{2}$

$\therefore y_c=0.27$

$\therefore y=0.5m$

$\therefore y>y_0>y_c$ $\therefore$ Thus M1 Curve

Normal Depth:

$V=\frac{1.49}{n}R^{2/3}\sqrt{S}$

$\Rightarrow \frac{Q}{A}=\frac{1.49}{n}R^{2/3}\sqrt{S}$

$\Rightarrow \frac{2.5}{5y}=\frac{1.49}{0.016}\left(\frac{5y}{5+2y}\right)^{2/3}\sqrt{0.0007}$

$\therefore y_0=0.4$

$g = 32\ ft/s^2$

section factor, $Z_c = \dfrac{Q}{\sqrt{\frac{g}{\alpha}}} = \dfrac{400}{\sqrt{\frac{\cancel{32}\,32}{1.1}}} = \cancel{134}\ 74.16$

conveyance, $K = \dfrac{Q}{\sqrt{S}} = \dfrac{400}{\sqrt{0.0016}} = 10000$

CT

Chapter 1

* Short notes on (i) Backwater curve (ii) Drawdown Curve
* Flow Profiles: flow from reservoir into mild slope channel → M2
  " " " " steep " "

* Derive the basic differential equation for the gradually varied flows water surface profile. What are the assumptions.

* Sketch the possible flow profile in the following serial arrangement of channels.

(i) Reservoir - Mild — M2
(ii) Reservoir - steep — S2 20 mins
(iii) Mild - Milder - steep
(iv) Steep - mild - milder
(v) Mild - Critical - Steep

Hydraulic Jump:

* Define Hydraulic jump when it's occurred? Write down - significant applications of hydraulic jumps

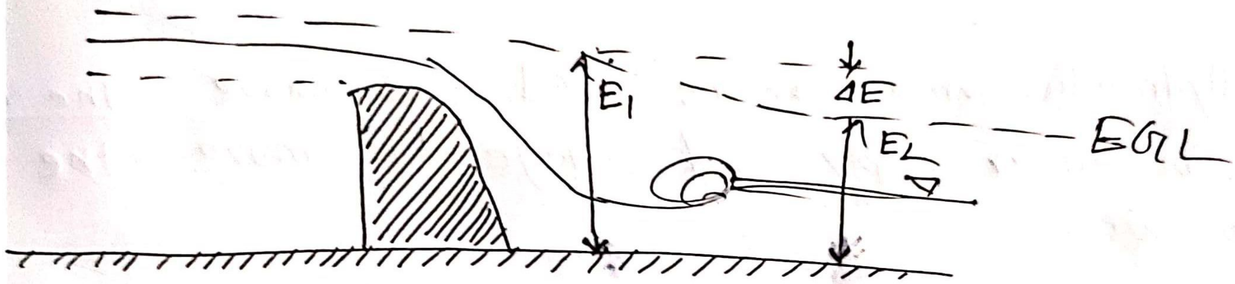
* When and how hydraulic jump is formed? Classify hydraulic jump based on ~~hydraulic jump~~ and sketch them. Write practical applications.

* Water is flo

Chapter: Hydraulic Jump

Definition: In open channels when a supercritical flow is made to change abruptly to subcritical flow, the result is usually an abrupt rise of the water surface. This feature is known as hydraulic jump

Energy dissipation at the toe of overflow spillway:



Actually hydraulic jump usually acts as the energy dissipater. It distributes the surplus energy of water. It happens due to change from supercritical to subcritical with considerrable energy dissipation

Effects :

- Acts as the energy dissipator
- Many ~~&~~ noticeable disturbances occur like eddies, reverse flow
- Air get trapped. It can help remove the wastes which cas pollution.
- Hydraulic jump also makes the work of different hydraulic structures effective: like weirs and flumes

Applications:

01. Usually reverses the flow of water. This can be used to mix chemicals for water purification.

02. Hydraulic jump usually maintains high water level on downstream side. This high water level can be used for irrigation purposes.

03. Hydraulic jump can be used to remove the debris from water supply and sewage to remove the blocking.

04. It prevents the scouring in the downstream side of the dam by dissipating energy.

05. The reduction of uplift pressure under a structure by increasing it's weight on it's apron.

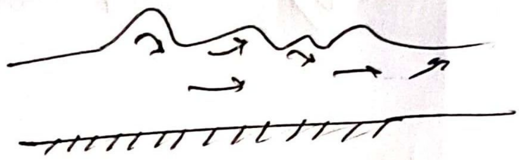
06. To remove air pockets from water-supply system and thus preventing air locking.

07. To increase the discharge of a sluice by holding back tailwater.

Types of Jump:

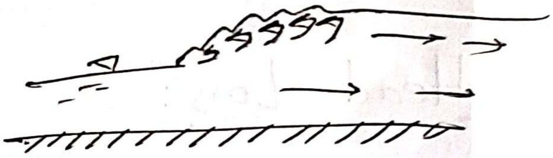
Hydraulic jumps can be classified based on initial Froude number as

(i) Undular Jump:



* $1 < F_r < 1.7$
* Water surface shows Undulations

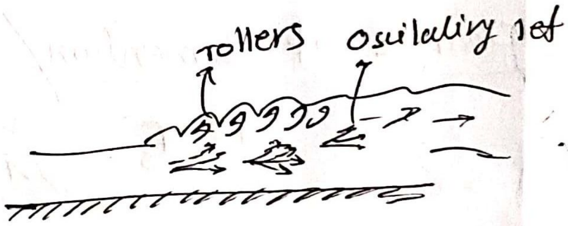
(ii) ~~Oscilating Jump:~~ Weak Jump:



$1.7 < F_r < 2.5$

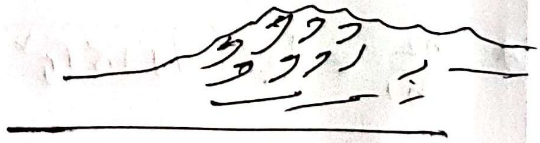
* a series of small rollers develop on the surface of the jump, but the downstream water surface remains smooth.

(iii) Oscillating Jump:



* $2.5 < F_1 < 4.5$
* There's an oscillating jet entering the jump bottom to surface and back again with no periodicity.
* Very common in canals
* Can damage earth banks and rip-raps
* Wave suppressors may be designed

(iv) Steady Jump:



* $4.5 < F_1 < 9.0$
* Least sensitive to tailwater depth
* Well balanced and performance at its best
* The energy dissipation or efficiency 45 to 70%.

(v) Strong Jump:

* $F_1 > 9$
* The jump action is rough but effective since the energy dissipation may reach 85%.

Basic Charecteristics

Head Loss:

$$h_L = \frac{(h_2-h_1)^3}{4h_2h_1}$$

Change of ~~Momentum~~ Momentum/Specific Force:

$$M = F_s = \frac{Q^2}{gA} + \bar{y}A$$

sequent depth:

* $\cancel{\bar{y}_1 A_1 + \frac{V_1^2}{2g} A_1 = \bar{y}_2 A_2 + \frac{V_2^2}{2g} A_2}$

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

$\bar{y}_2 = \frac{h_2}{2}$

$\bar{y}_1 = \frac{h_1}{2}$

* $\frac{h_1}{h_2} = \frac{1}{2}\left(\sqrt{1+8F_{r_2}^2} - 1\right)$
* $\frac{h_2}{h_1} = \frac{1}{2}\left(\sqrt{1+8F_{r_1}^2} - 1\right)$

Height/Depth of the jump:

$h_j = h_2 - h_1$

Power Dissipation:

$$P = \gamma Q h_L$$

$$P = \rho g Q h_L \quad \text{— in (watts)}$$

Math

* A rectangular horizontal channel 2m wide, carries a flow of $4 m^3/s$. The depth of water on the downstream side of the hydraulic jump is 1m.

(i) What is the depth upstream?

(ii) Wat is " loss of head?

Solution:

(i) Here,

$h_2 = 1m \quad \therefore \bar{y}_2 = \frac{h_2}{2} \quad A_1 = 2h_1$

$h_1 = ? \quad \bar{y}_1 = \frac{h_1}{2} \quad A_2 = 2\times1 = 2$

$\therefore$ We unow,

$F_1 = F_2$

$$\Rightarrow \bar{y}_1 A_1 + \cancel{\frac{v_1^2}{2g} A_1} = \bar{y}_2 A_2 + \cancel{\frac{v_2^2}{2g} \times A_2}$$

$$\Rightarrow \frac{h_1}{2} A_1 + \cancel{\frac{Q^2}{2gA_1}} = \frac{h_2}{2} A_2 + \frac{Q^2}{2gA_2}$$

$$\Rightarrow \cancel{h_1 A_1 + \frac{Q^2}{gA_1}} =$$

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

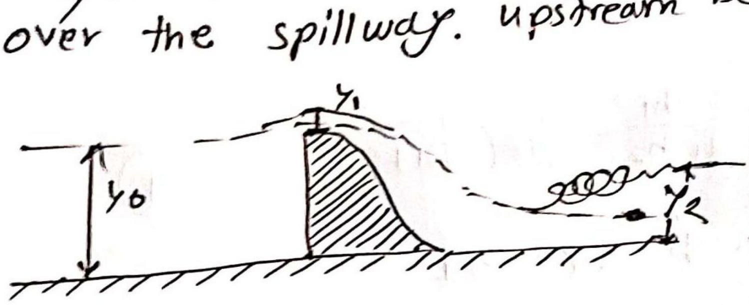
$$\Rightarrow \frac{h_1}{2} A_1 + \frac{Q^2}{gA_1} = \frac{Q^2}{gA_2} + \frac{h_2}{2} A_2$$

$$\Rightarrow \frac{h_1}{\cancel{2}} \times \cancel{2} h_1 + \frac{4^2}{g \times 2h_1} = \frac{4^2}{g\times2} + \frac{1}{\cancel{2}} \cancel{\times 2}$$

$$\therefore h_1^2 + \frac{16}{19.6 h_1} = \frac{16}{19.6} + 1$$

$\therefore h_1 = 0.53 m$

The spillway has shown discharge of $1.2\ m^3/s$ meter width occuring over it. What depth y_2 will exist downstream of the hydraulic jump? Assume negligible energy loss over the spillway. upstream De[pth] 5m



Solution:

Here, $H_L = 0$

Benroulli at y_0 and y_1,

$$y_0 + \frac{v_0^2}{2g y_0} = y_1 + \frac{v_1^2}{2g y_1}$$

$$\Rightarrow y_0 + \frac{Q_0^2}{2g y_0 A_0} = y_1 + \frac{Q^2}{2g y_1 A_1}$$

$A_0 = y_0 \times 1 = y_0$

$A_1 = y_1 \times 1 = y_1$

$$\Rightarrow y_0 + \frac{Q^2}{2g y_0^2} = y_1 + \frac{Q^2}{2g y_1^2}$$

$$\Rightarrow 5 + \frac{1.2^2}{2\times 9.8 \times 5^2} = y_1 + \frac{1.2^2}{19.6 \times y_1}$$

$\therefore y_1 = 0.123$

or, $Fr_2 = \frac{V_2}{\sqrt{g h_2}} = \frac{Q}{A_2\sqrt{g h_2}} = \frac{4}{2\sqrt{9.8 \times 1}}$

$= 0.638$

$\therefore \frac{h_1}{h_2} = \frac{1}{2}\left(\sqrt{1+8Fr_2^2} - 1\right)$

$\therefore h_1 = 0.531$

(ii) head loss

$h_L = \frac{(h_2-h_1)^3}{4h_2h_1}$

$= \frac{(1-0.531)^3}{4\times1\times0.531}$

$= 0.048$

$\simeq 0.05m$

$\approx 5cm$

or,

$V_2 = \frac{Q}{A_2} = \frac{4}{2\times1} = 2\ ms^{-1}$

$V_1 = \frac{Q}{A_1} = \frac{4}{2\times0.53} = 3.77\ ms^{-1}$

$\therefore y_1 + \frac{v_1^2}{2g} = y_2 + \frac{v_2^2}{2g} + h_L$

$\Rightarrow h_L = 0.53 - 1 + \frac{3.77^2}{19.6} - \frac{2^2}{19.6}$

$= 0.05\ m$

$\approx 5\ cm$

A: