Question → Design a Syphon Aqueduct for a the following data :

Discharge of canal = 40 m^3/s .

Bed Width of " = 30 m.

Full Supply depth of canal = 1·6 m

Bed level of canal = 206·4 m

Side slopes of " = 1·5(H) : 1(V)

H.F.D (High Flood discharge) of drainage = 450 m^3/s

H.F.L of drainage = 207 m

Bed level of " = 204·5 m

General Ground Level = 206·5 m

Solution → Here, note that

- Drainage size is large.
- Canal bed level (206·4 m) is slightly below the drainage H.F.L (207 m), Hence Syphon Aqueduct is Required
- Instead of using Earthen banks we will Adopt Concrete Trough.
- For Affecting the economy, the canal shall be flumed.

(Step-1) — Design of Drainage Waterway.

Use lacey's formula: $P = 4.75\sqrt{Q}$

$= 4.75\sqrt{450}$

$P = 100.76$ m

Now, We have find out the number of Piers and no. of bays in such a way that total length of waterway is Approx. equal to Perimeter as obtained above.

Width of Pier = 1.5 m

Using Hit and Trial Method:

Lets say we use: No. of Piers = 10

∴ No. of Span becomes = 11 bays.

Now; length occupied by Piers = 10×1.5 = 15 m

Span b/w Piers = 8 m.

Length Occupied by ~~Piers~~ Spans = 8×11 = 88 (clear width)*

Total length = 88+15

= 103 m

∴ Total length of water way = 88+15

⟹ 103 m

Here We are using "Syphon - Aqueduct"

so limit the value of velocity to 2 m/s (To Prevent Scouring Action).

∴ Height of Barrels required = $\frac{\text{Discharge}}{(\text{Velocity}) \times (\text{clear width})}$*

$$= \frac{450 \ m^3/s}{2 \ \frac{m}{s} \times (11 \times 8)}$$

$$= 2.556 \ m \quad \text{or} \quad 2.56 \ m$$

Hence, Use 11 rectangular barrels, each 8m-wide and 2.56 m-high.

$$\therefore \text{Actual Velocity} = \frac{Q}{A} = \frac{450}{11 \times 8 \times 2.5} = 2.045 \ m/s$$

$$V_{actual} = 2.05 \ m/s$$

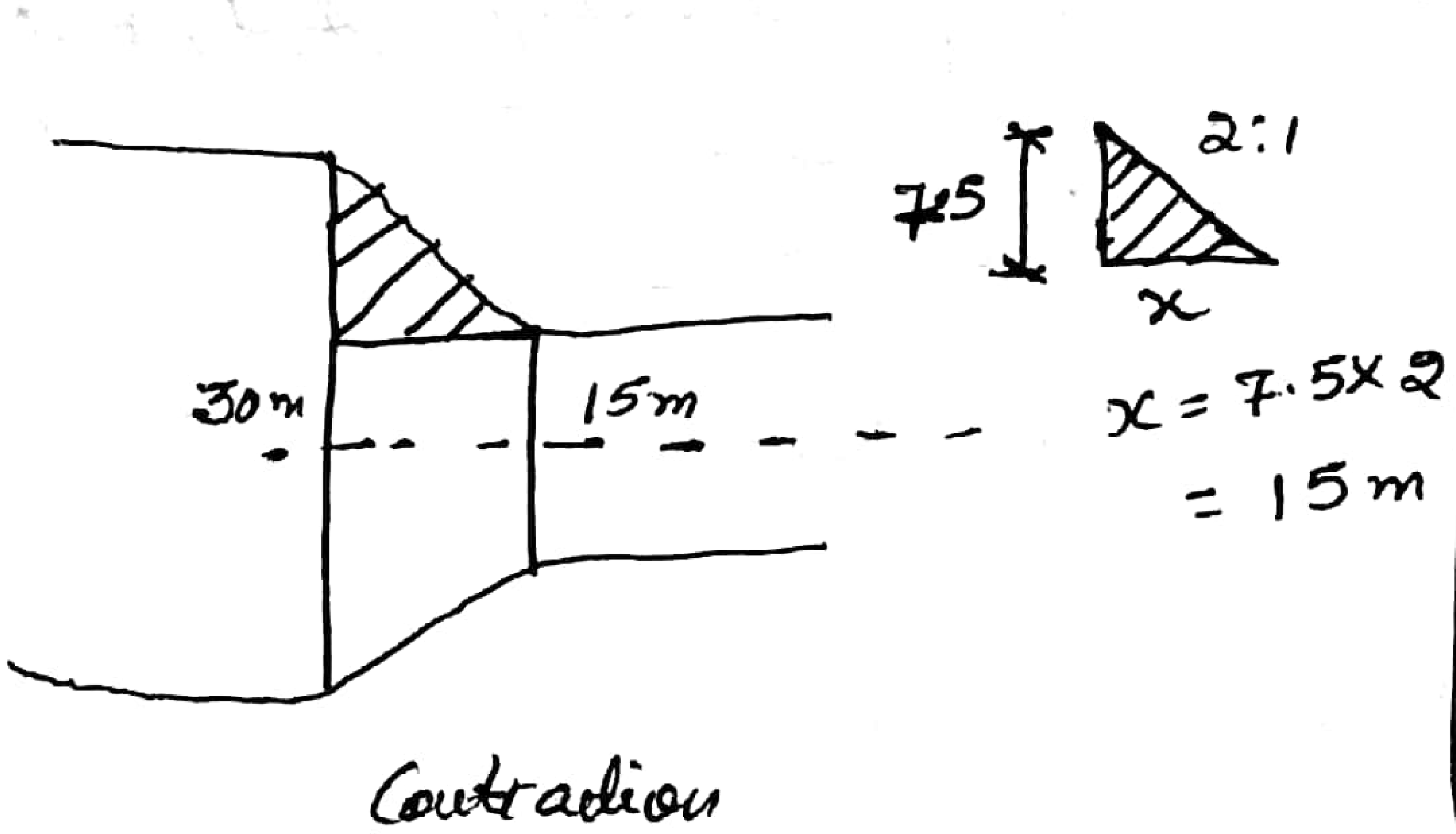
(STEP-2) – Design of Canal Waterway.

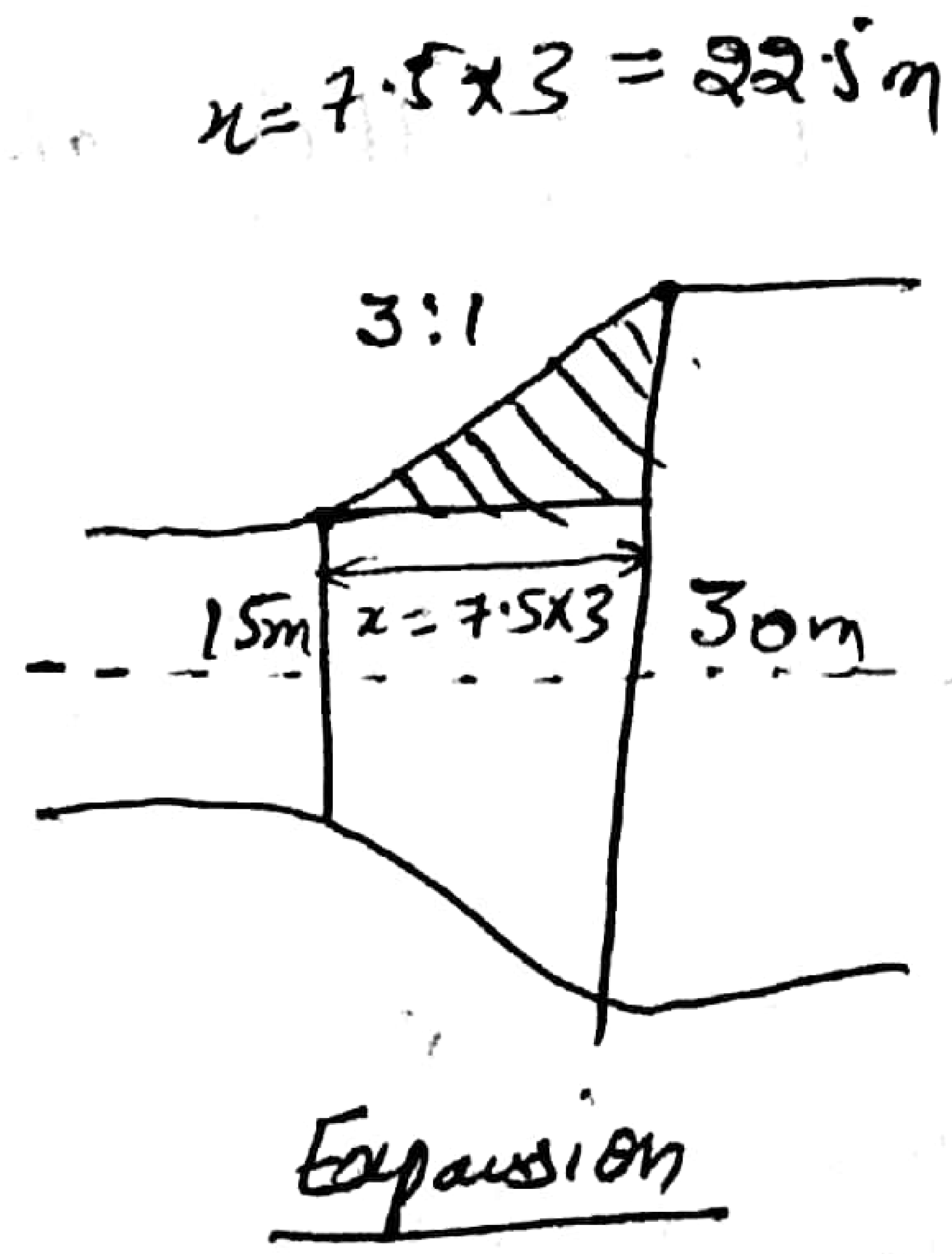
Given, Normal bed Width of canal = 30 m

Let the bed width be reduced to 15 m. (Approx. Half)

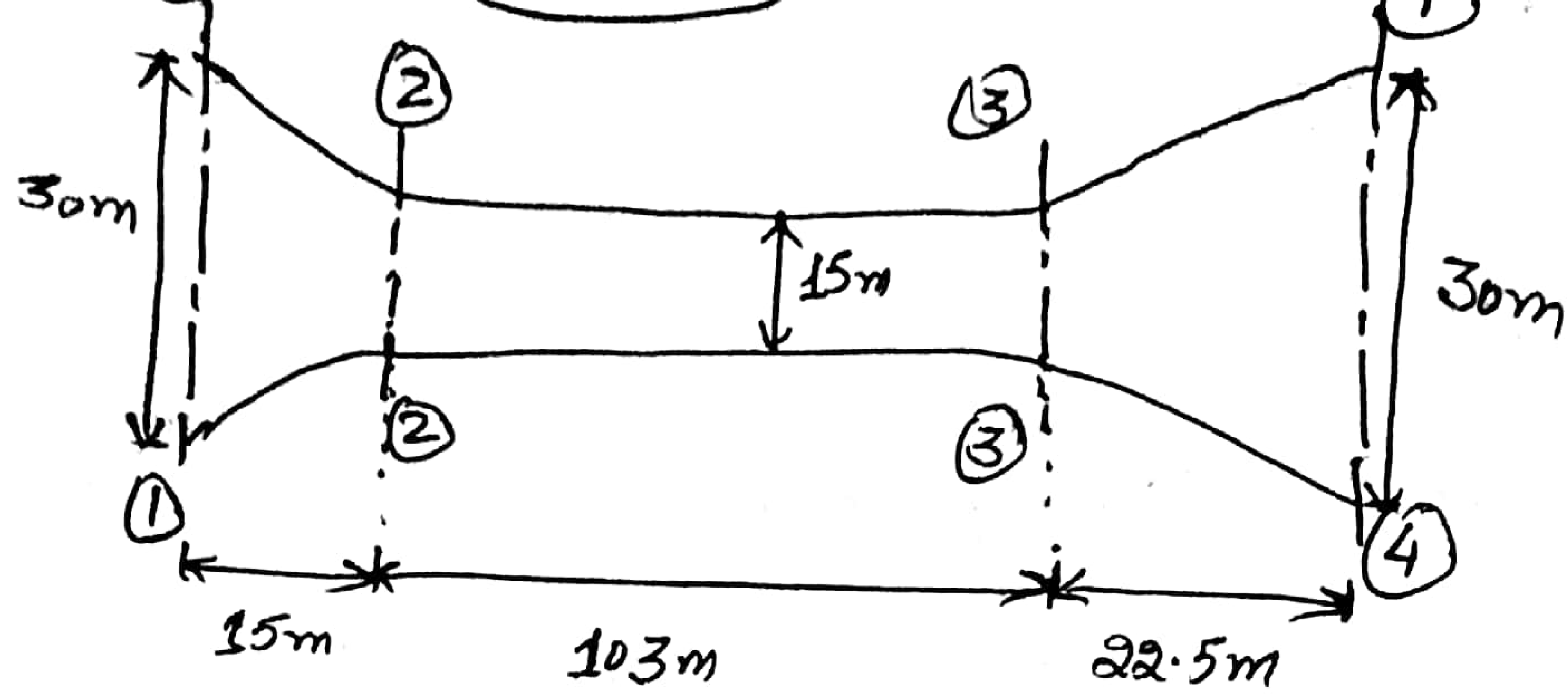
For Contraction, use 2 : 1 and Expansion 3 : 1.

↳ Transition length ⇒ 15 m | Transition length ⇒ 22.5 m





STEP-3



<u>At Section 4-4:</u>

Area of Trapezoidal Canal section $= (B + 1.5y)\,y$

(y = depth = 1.6 m) $= (30 + 1.5 \times 1.6)\,1.6$

$= 51.84\ m^2$

Velocity of flow $(V_4) = \frac{Q}{A} = \frac{40}{51.84} = 0.77\ m/s$

Velocity head $= \frac{V_4^2}{2g} = \frac{(0.77)^2}{2 \times 9.81} = 0.030\ m$

R.L of canal bed (4-4) = 206.4 (Same as Given value)

Water depth = 1.6 m. (given)

R.L. of Water Surface at (4-4) = R.L. of canal bed + water depth

= 206.4 + 1.6

= 208 m.

R.L. of (T.E.L) at (4-4) = R.L. of water surface (4-4) + velocity Head

= 208 + 0.03

= 208.03 m.

At Section 3-3 :

Assuming the constant depth (1·6m) throughout channel

Now, at section 3-3 we have rectangular portion

Bed width = 15m

Depth = 1·6 m

Area = 15×1·6

= 24 m²

Velocity ⇒ $V_3 = \frac{Q}{A} = \frac{40}{24}$ = 1·666 m/s ≃ 1·67 m/s

Velocity head = $\frac{V_3^2}{2g} = \frac{(1.67)^2}{2 \times 9.81}$ = 0·142 m.

As we can observe that Gradual Expansion is Taking place ;

∴ head loss, $h_e = 0.3\left[\frac{V_3^2 - V_4^2}{2g}\right]$

= 0·0335 ≃ 0·034 m.

R·L of T·E·L at (3-3) = R·L of T·E·L (4-4) + Head Loss

= 208·03 + 0·034

= 208·064 m.

R·L of water surface (3-3) = R·L of TEL (3-3) − Velocity head

= 208·064 − 0·142

= 207·922 m

R·L· of Bed at (3-3) = R·L· of water surface (3-3) − depth of flow

= 207·922 − 1·6

= 206·322 m

At Section 2-2 :

Now, from (2-2) → (3-3) Section remains Constant.
∴ Area and Velocity values Same.
But there is friction loss which is computed using : Manning's formula.

$$H_L = \frac{n^2 V^2 L}{R^{4/3}}$$

Area = 15×1.6 = 24 m²
Wetted Perimeter = 15 + 2×1.6
= 18.2 m
Hydraulic mean depth (R)

$$R = \frac{A}{P} = \frac{24}{18.2} = 1.318$$

$R \simeq 1.32\,m$

$$H_L = \frac{(0.016)^2 \times (1.67)^2 \times 103}{(1.32)^{4/3}}$$

$H_L \Rightarrow 0.051\,m$

R.L. of T.E.L at (2-2) = R.L of T.E.L at (3-3) + Head Loss in Trough.

= 208.064 + 0.051

= 208.115 m

R.L of water level (2-2) = R.L of T.E.L (2-2) − Velocity head

= 208.115 − 0.142

= 207.973 m.

R.L of bed (2-2) = R.L of water level (2-2) − depth of flow

= 207.973 − 1.6

= 206.373 m

At Section 1-1 :

Here Contraction is Taking place, thus:

$$0.2\left[\frac{V_2^2 - V_1^2}{2g}\right]$$

{ Velocity at Section 4-4 ⇒ $V_1 = V_4$ = 0.77 m/s

$$h_L = 0.2\left[\frac{(1.67)^2 - (0.77)^2}{2 \times 9.81}\right]$$

h_L = 0.02238 ≃ 0.0224 m ✓

R.L. of T.E.L (1-1) = R.L of T.E.L (2-2) + Head loss (contraction)

= 208.115 + 0.022

= 208.137 m ✓

R.L. of Water Level (1-1) = R.L of T.E.L (1-1) − Velocity head

= 208.137 − 0.030

= 208.107 m. ✓

R.L. of bed (1-1) required to maintain constant depth

= R.L. of water level (1-1) − water depth

= 208.107 − 1.6

= 206.507 m ✓

STEP-4 – Design of Transition.

Contraction Transition : using Mitra's formula

$$B_x = \frac{B_n \cdot B_f \cdot L_f}{B_n L_f - x(B_n - B_f)}$$

B_n = Normal width

B_f = flumed "

L_f = length Transition (15m)

$$B_x = \frac{30 \times 15 \times 15}{(30 \times 15) - x(30 - 15)}$$

$$\boxed{B_x = \frac{6750}{450 - 15x}}$$

x (m)	0	2	4	6	8	10	12	14	15
B_x (m)	15	16.07	17.30	18.75	20.45	22.5	25	28.12	30

Expansion Transition :

$$B_x = \frac{B_n \cdot B_f \cdot L_f}{(B_n \cdot L_f) - x(B_n - B_f)}$$

L_f = Transition Length (22.5m) {calculated in Step-(2)}.

$$B_x = \frac{30 \times 15 \times 22.5}{(30 \times 22.5) - x(30 - 15)}$$

$$\boxed{B_x = \frac{675}{45 - x}}$$

x (m)	0	2	4	6	8	10	12	14	16	18	20	22.5
B_x (m)	15	15.69	16.46	17.30	18.24	19.28	20.45	21.77	23.27	25	27	29.34

STEP - 5 — Design of Trough.

As we know the ~~channel~~ canal width reduced ⇒ 15 m

thus we will divide the Trough into 3 Equal Compartments, 5 m each.

Partion walls thickness ≅ 0.3 m.

At left side partition, we will construct inspection Road (5 m wide)

Provide 0.6 m free-board Above Normal water depth of 1.6 m

thus bottom of Bridge/Road slab = 1.6 + 0.6

= 2.2 m above the Bed level of Trough.

Also the Height of Trough kept equal to 2.2 m ✓.

thickness of outer walls = 0.4 m.

" " Bottom slab of Trough = 0.4 m.

Thus Total Width of Trough Including Partion walls / Side walls = $15 + (2 \times 0.3) + (2 \times 0.4)$

⇒ 16.4 m

It is understood that width of Trough = length of Syphon Barrels.

∴ length of Syphon Barrel = 16.4 m.

STEP-6 - Head loss through Syphon Barrel

Using Unwins formula,

$$h_L = \left[1 + f_1 + f_2 \cdot \frac{L}{R}\right] \frac{V^2}{2g}$$

Here, V = Velocity through barrel (2.05 m/s) → Actual velocity calculated in step 1.

f_1 = Coeff. of head loss at Entry
= 0.505 for unshaped mouth

$f_2 = a\left(1 + \frac{b}{R}\right)$ Value of a & b Taken from Table.
$= 0.00316\left(1 + \frac{0.030}{0.952}\right)$ → a = 0.00316, b = 0.030
= 0.00326

R = hydraulic mean depth for barrel

$= \frac{8 \times 2.5}{2(8+2.5)}$

= 0.952 m

{ Span = 8 m, Height = 2.5 m, Explained = Step 1 }

L = length of barrel (16.4 m)

$$h_L = \left[1 + 0.505 + 0.00326 \times \frac{16.4}{0.952}\right] \times \frac{(2.05)^2}{19.62}$$

h_L = 0.334 m

High Flood level of drainage = 207 m (given)*

∴ Downstream side (d/s) H·F·L· = 207 m.

head loss = Afflux (h) = 0·334 m

thus Upstream side (U/s) H·F·L = d/s H.F.L + Afflux (h)

= 207 + 0·334

= ~~206.66 + 207~~ m

= 207·33 m.

STEP - 7

Uplift Pressure on Roof of Barrel

R.L· of Bottom of trough = R.L· of Canal bed − Slab thickness

= 206·4 − 0·4

= 206 m·

Loss of Head at Entry of Barrel* = $0.505 \frac{V^2}{2g} = 0.505 \frac{(2.05)^2}{2 \times 9.81}$

= 0·108 m ·

Uplift on the Roof = u/s H.F.L − loss at Entry − R.L of Bottom of trough.

= 207·33 − 0·108 − 206.

= 1·22 m

Now, As we know that Unit wt· of water = $10 \frac{kN}{m^3}$.

∴ Pressure exerted due to given head h = h × Unit wt ·

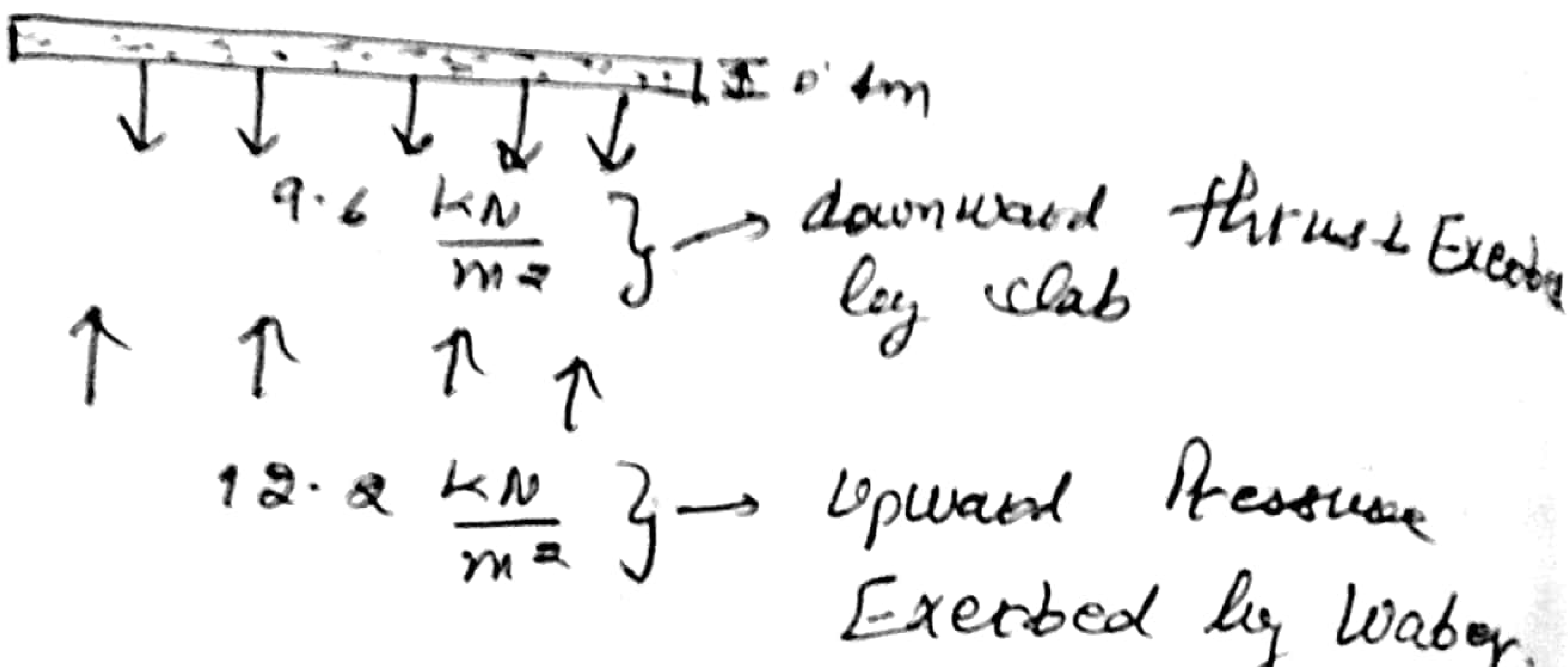
= $10 \times 1.22 \left(\frac{kN}{m^2}\right)$

Uplift Pressure ⇒ $12.2 \left(\frac{kN}{m^2}\right)$

The Roof slab / Trough Bottom is made of concrete having thickness 0.4 m. & thus Roof will Exert a downward thrust of ⇒ thickness × Unit wt. of concrete

$= 0.4 \times 24 \ \frac{kN}{m^3}$

$= 9.6 \ \frac{kN}{m^2}$



∴ Balance ⇒ Net Upward Pressure

$= 12.2 - 9.6$

$\Rightarrow \boxed{2.6 \ \frac{kN}{m^2}}$ ✓

↳ This Has to be resisted by the Top Reinforcement Provided in the Top Roof.

In Addition to this Roof is Also bearing the load of water (1.6m) in the canal + its own dead load.

↳ Bottom R/f.

STEP-8

Design of Roof of Barrel

Uplift pressure $= 2.6\ kN/m^2$

Downward thrust due to Canal water (1.6m)

$= 1.6 \times 10$

$= 16\ \frac{kN}{m^2}$.

dead load / Self wt. $= 0.4 \times 24 = 9.6\ \frac{kN}{m^2}$

∴ (canal water thrust) + (self wt.) $= 16 + 9.6$ ⇒ $25.6\ \frac{kN}{m^2}$.

↳ Total Downward thrust.

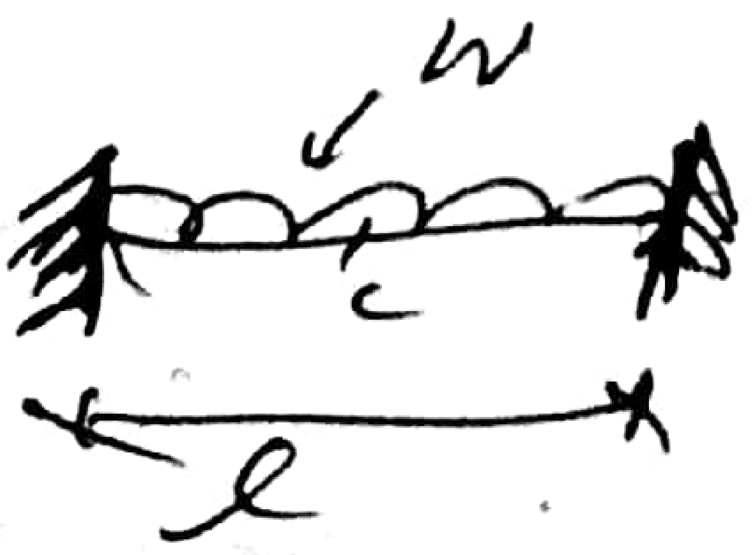
Eff. Span of roof $= 5 + (0.3)$ → thickness of partition.

<u>Effective span of slab</u> $= 5.3\ m$

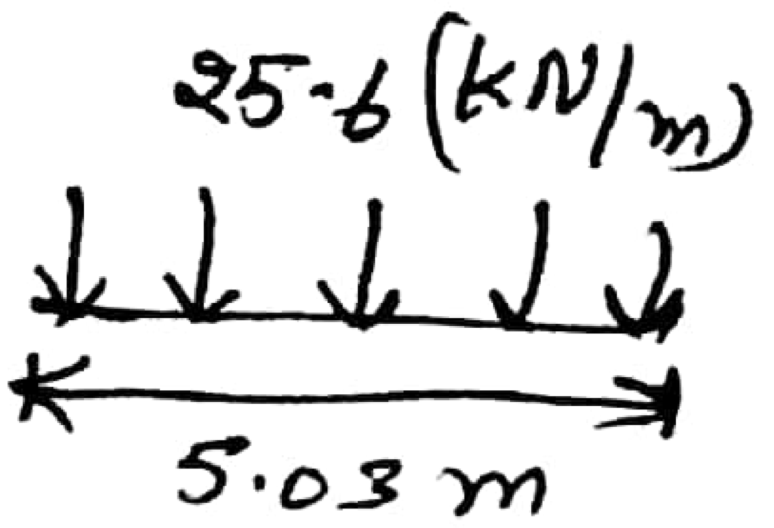
For design of slab we will conside 1m strip and then design for that.

Downward load $= 25.6\ \frac{kN}{m^2} \times 1m = 25.6\ \frac{kN}{m}$ → U.D.L.

Upward load $= 2.6\ \frac{kN}{m^2} \times 1m = 2.6\ \frac{kN}{m}$ → U.D.L.



$(B.M)_{max} = \frac{wl^2}{8}$.



Max. (Sagging) Bending moment ⇒ $\frac{25.6 \times (5.3)^2}{8}$

Here we will use $\frac{wl^2}{10}$ because here the slab is in continuity from one end to other.

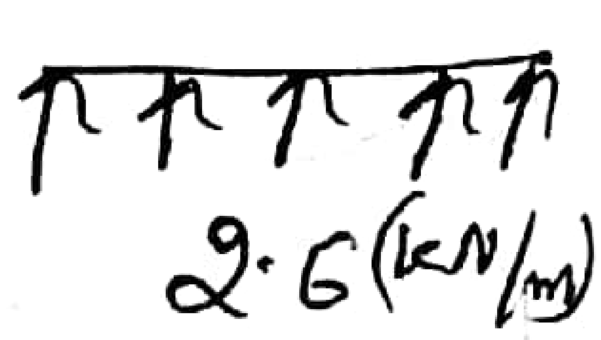
$\frac{wl^2}{8}$ ⇒ Slab simply supported.

$\frac{wl^2}{10}$ ⇒ Slab supported over continuous supports or in framed structures we use this formula.

∴ Max $(B.M)_{(\downarrow)} = \frac{25.6 \times (5.3)^2}{10}$

$= 71.9$ kN-m

Max $(B.M)_{(\uparrow)} = \frac{2.6 \times (5.3)^2}{10}$



$= 7.3$ kN-m.

Max. shear due to 25.6 kN/m load $= \frac{wl}{2}$

$= \frac{25.6 \times (5)}{2}$

$= 64$ kN.

{Here for shear we will use the clear span (5 m)}

Roof is designed same as a Continuous Slab :

As Per IS Code ⇒ $\frac{Span}{depth} = 26$

<u>For Continuous Slab & beam</u>

$$\frac{5.3}{d} = 26$$

$$d = \frac{5.3}{26} \Rightarrow 0.2038\ m$$

$$\boxed{d = 20.38\ cm}$$

Assume Total Thickness of 40 cm and Effective depth of 38 cm.

Cover = 40 − 38 ⇒ 2 cm or 20 mm

∴ d = 38 cm
D = 40 cm

* OK as per Code

Cover to slab = (20 to 30) mm