Hydraulics Structures

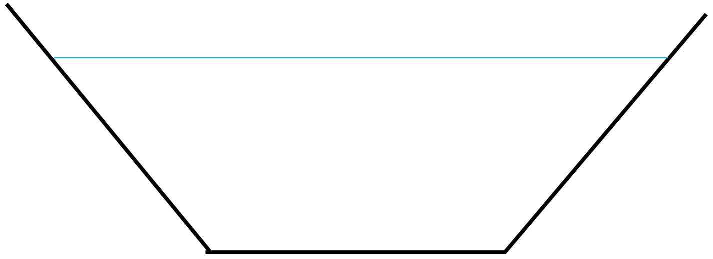
Civil Engineering Department

Tikrit University

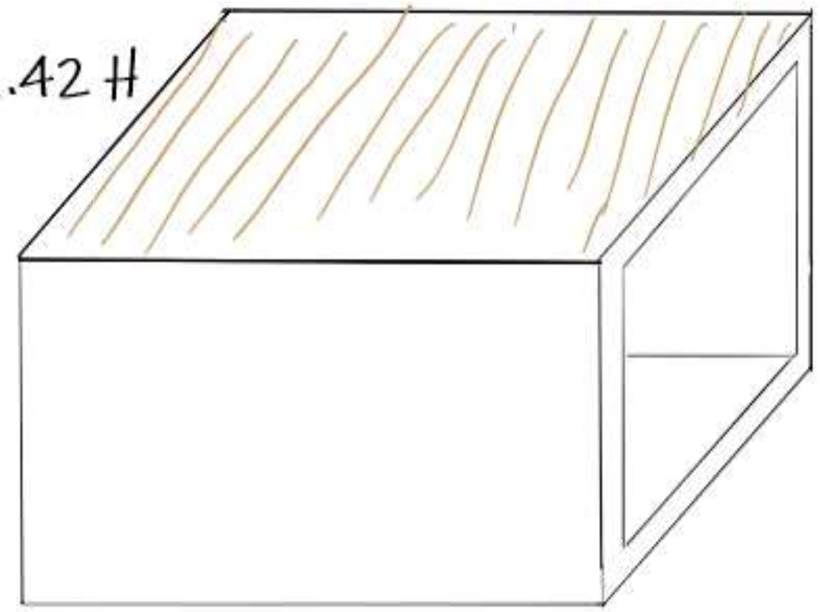
Wesam Sameer Mohammed-Ali

Ph.D., P.E., M.ASCE, M.AWRA

Example: Design box culvert of a 40 m long to pass normal full discharge of trapezoidal channel with 0.15 m head loss. The U/S and D/S parameters of the channel are:



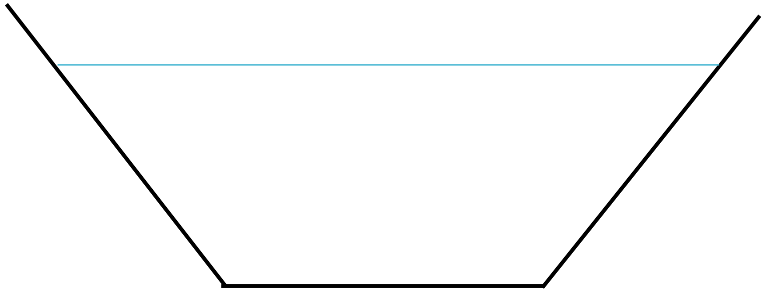
- The depth of flow in the channel = 1.5m.
- Bed width of the channel = 3m.
- Side slope of the channel = 1.5:1.
- Longitudinal slope of the channel = 0.0015.
- Manning's coefficient (*n*) of the channel = 0.023.
- Manning's coefficient (*n*) of the culvert = 0.015.
- K_e = 0.16, and K_o = 1.0.



- $Q = \frac{1}{n}\ A\, R^{\frac{2}{3}}\, S^{\frac{1}{2}}$

$A = By + Zy^2 \qquad \rightarrow\ A = 3 * 1.5 + 1.5 * 1.5^2 \qquad \rightarrow A = 7.875\ m^2.$

$P = B + 2y\sqrt{1 + Z^2} \qquad \rightarrow\ P = 3 + 2 * 1.5\sqrt{1 + 1.5^2} \qquad \rightarrow P = 8.408\ m.$

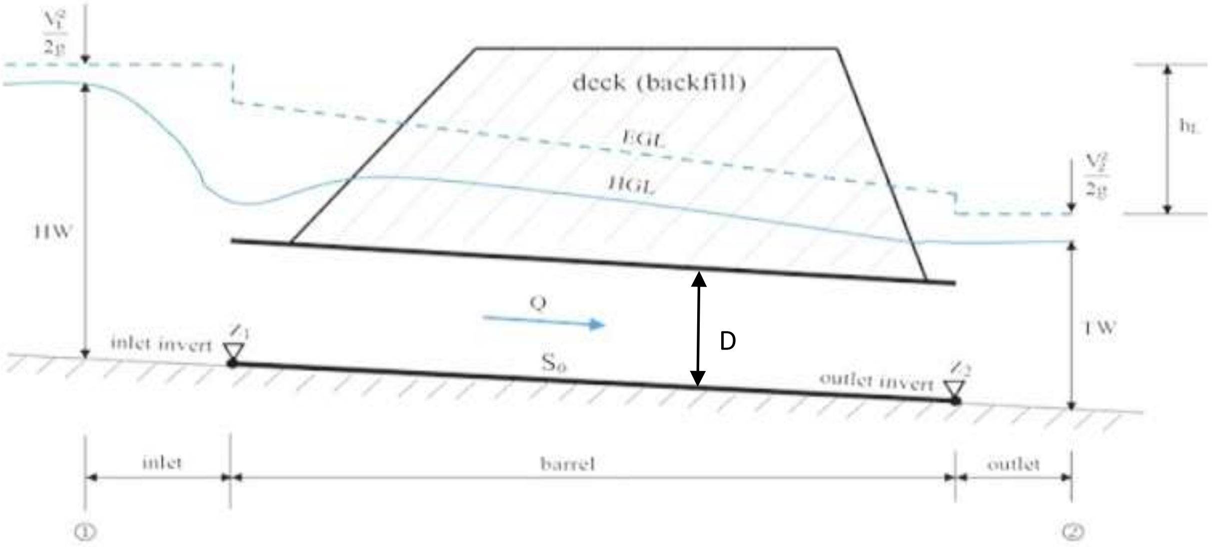


$$R = \frac{A}{P} = \frac{7.875}{8.408} \quad \rightarrow R = 0.937\ m.$$

$$Q = \frac{1}{0.023} * 7.875 *\ (0.937)^{\frac{2}{3}}\,(0.0015)^{\frac{1}{2}}$$

$$\rightarrow Q = 12.7\ \frac{m^3}{S}$$

$$Q = 12.7\ \frac{m^3}{S}$$

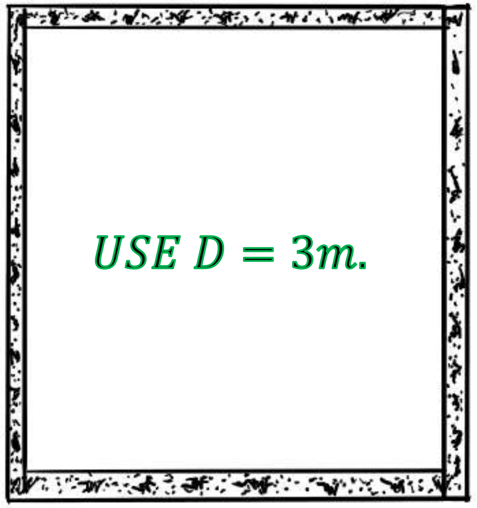


- $\Delta H = \left(k_e + \frac{2gn^2L}{R^{\frac{4}{3}}} + k_o\right)\frac{Q^2}{2gA^2}$

$$0.15 = \left(0.16 + \frac{2*9.81*(0.015)^2*40}{\left(\frac{D}{4}\right)^{\frac{4}{3}}} + 1\right)\frac{(12.7)^2}{2*9.81*D^4}$$

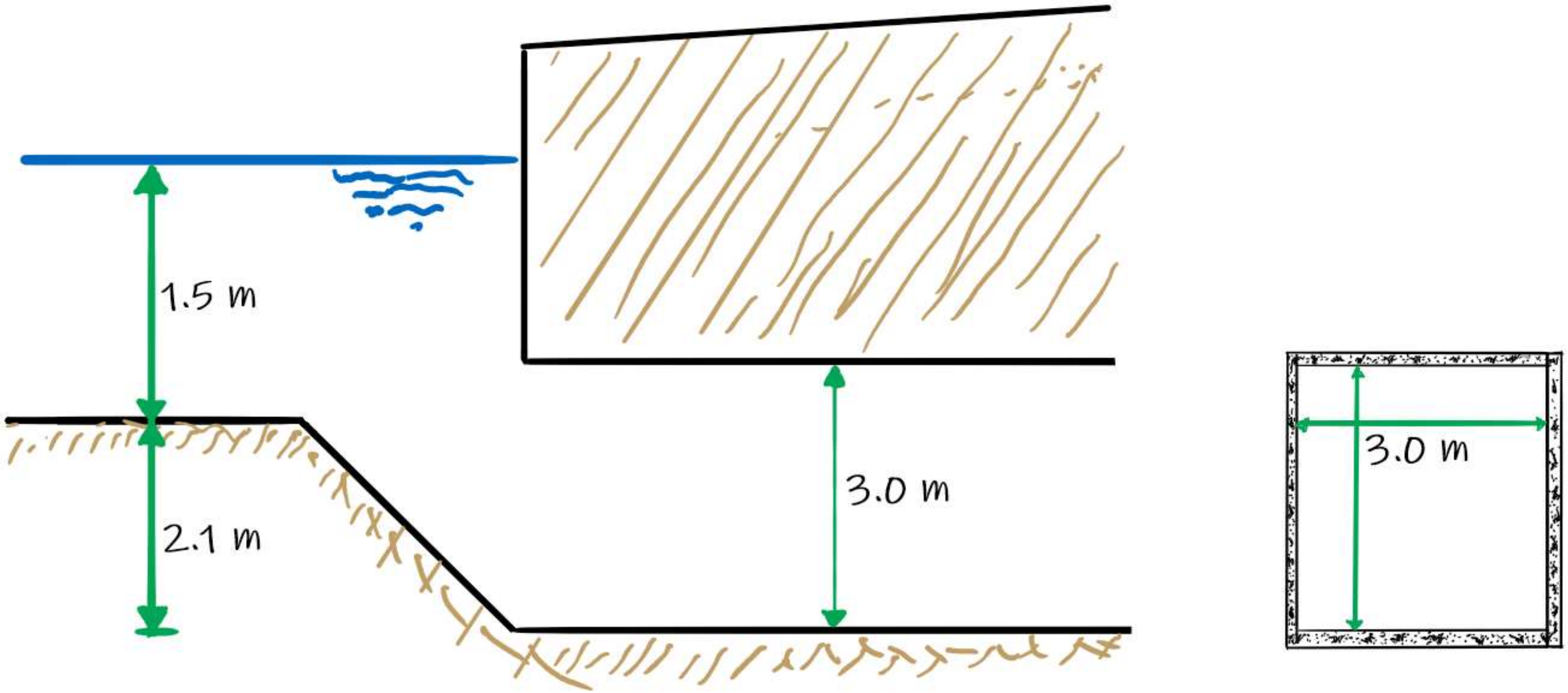
$$0.15 = \left(1.16 + \frac{1.12}{D^{\frac{4}{3}}}\right) * \frac{8.22}{D^4}$$

Solving the equation leads to $D \approx 2.97$.



$\boxed{D = 3m.}$ To get the entrance full submerged, $\frac{H}{D} = 1.2,$

$$\frac{H}{3} = 1.2 \qquad \rightarrow H = 3 * 1.2 = 3.6\ m.$$



Let assume that we have **3** opening: -

For each opening $Q = \frac{12.7}{3} = 4.23\,\frac{m^3}{sec}$

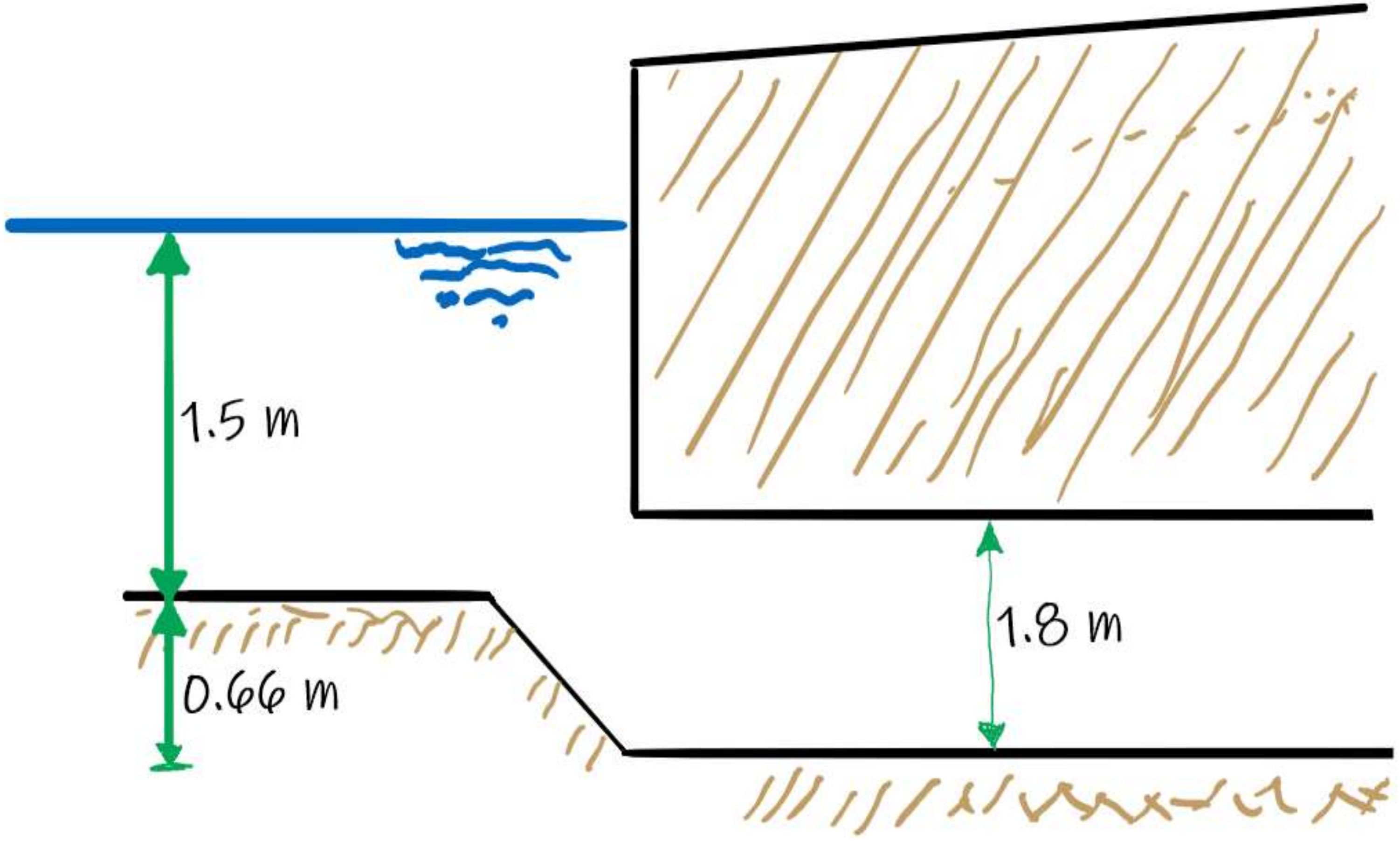
$$0.15 = \left(0.16 + \frac{2 * 9.81 * (0.015)^2 * 40}{\left(\frac{D}{4}\right)^{\frac{4}{3}}} + 1\right)\frac{(4.23)^2}{2 * 9.81 * D^4}$$

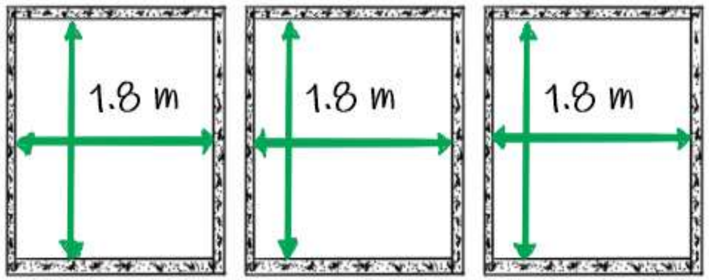
$$\rightarrow D = 1.8m$$

$\boxed{D = 1.8m.}$

To get the entrance full submerged, $\frac{H}{D} = 1.2$,

$$\frac{H}{1.8} = 1.2 \qquad \rightarrow H = 1.8 * 1.2 = 2.16\ m.$$

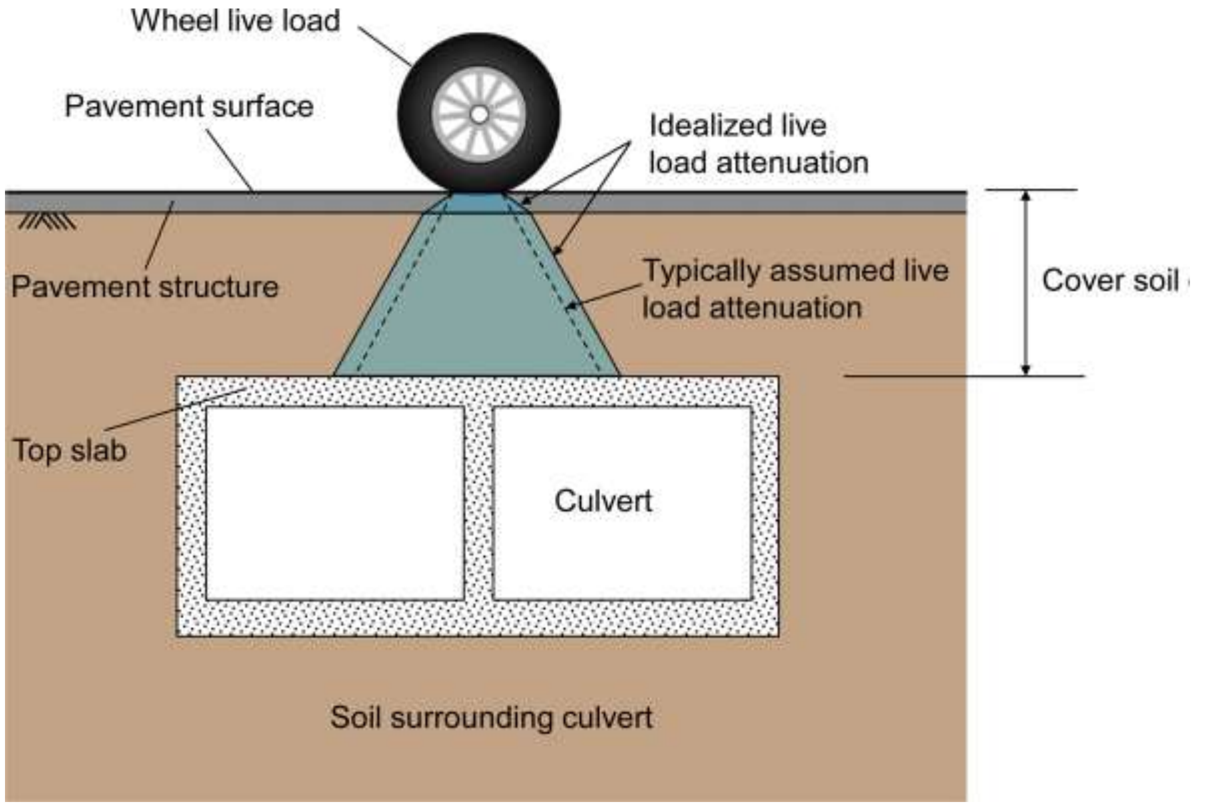




Structure Design of Box Culvert

Buried structures carry vertical loads through a combination of internal capacity and soil arching around the structure; this is termed soil-structure interaction.

AASHTO (The American Association of State Highway and Transportation Officials) has developed empirical equations for different culvert types to allow for a simplified procedure that closely matches 3D soil-structure interaction models.

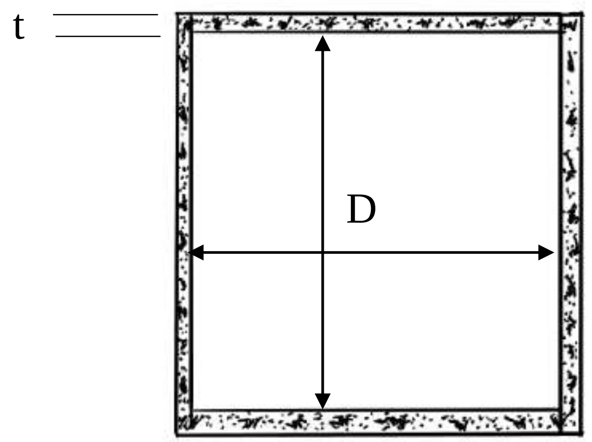


Structure Design of Box Culvert

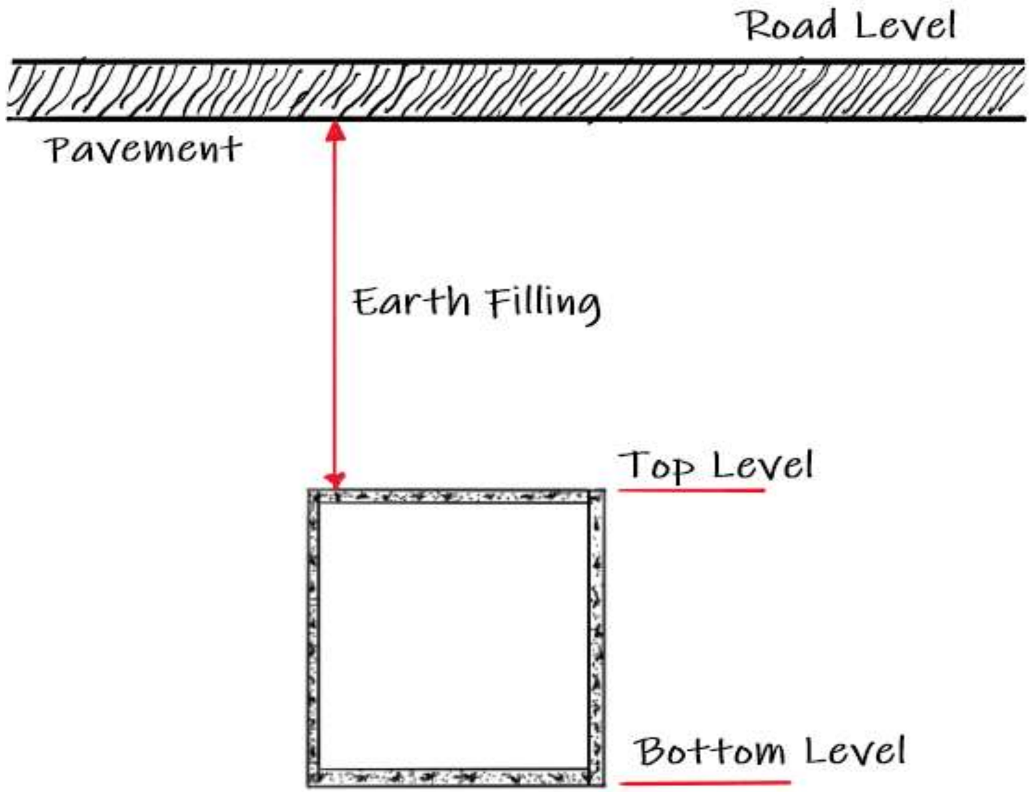
- **Use approximate wall thickness:**

$$t = \frac{D}{6}$$

t: thickness of wall and floor and roof



- **Determine the top level of the culvert road level and the depth of the pavement and earth fill above the top slab of the culvert.**

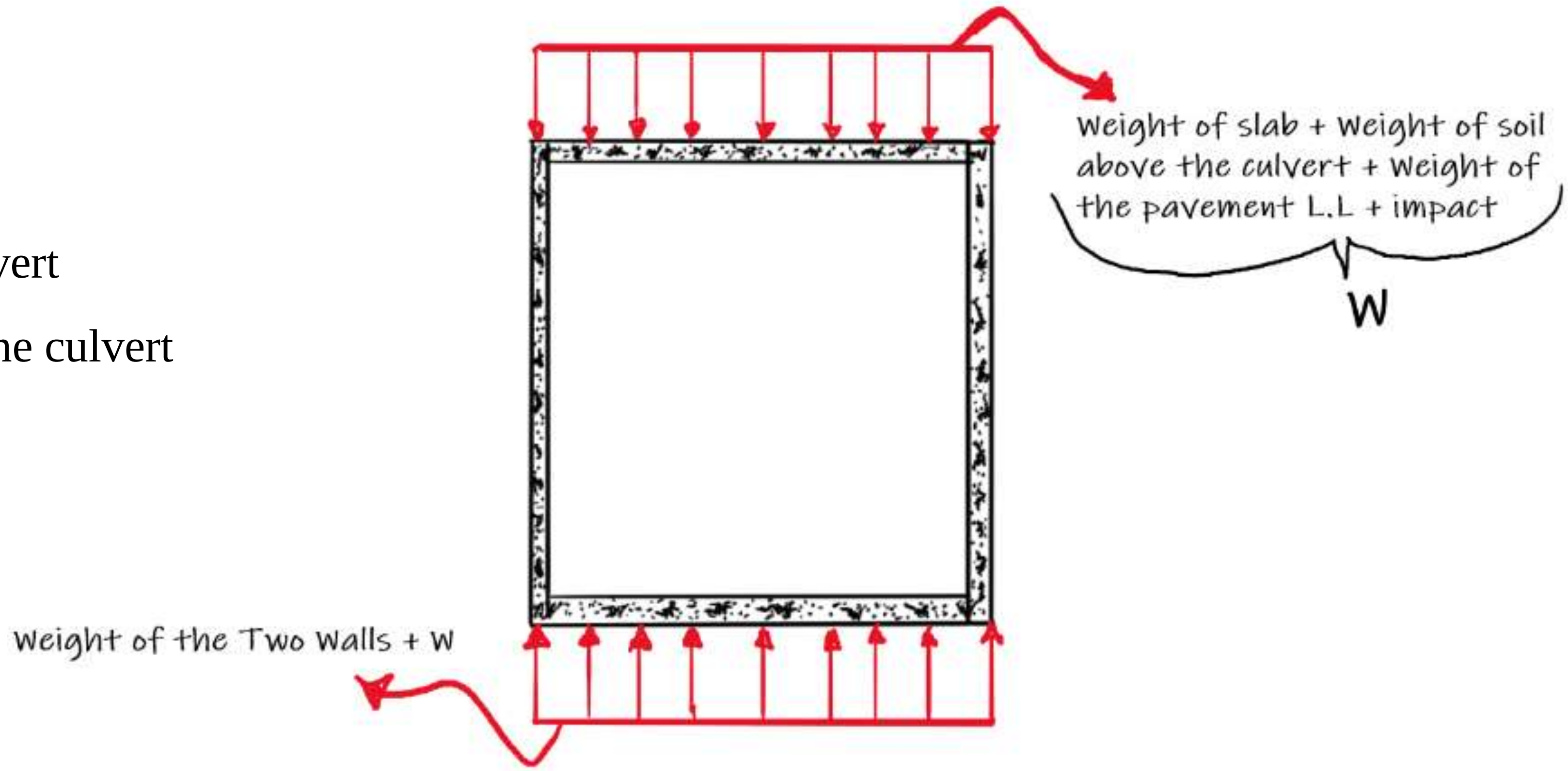


Structure Design of Box Culvert

- **Loadings:**

Uniform vertical external load on the top slab and similar reaction on the bottom slab

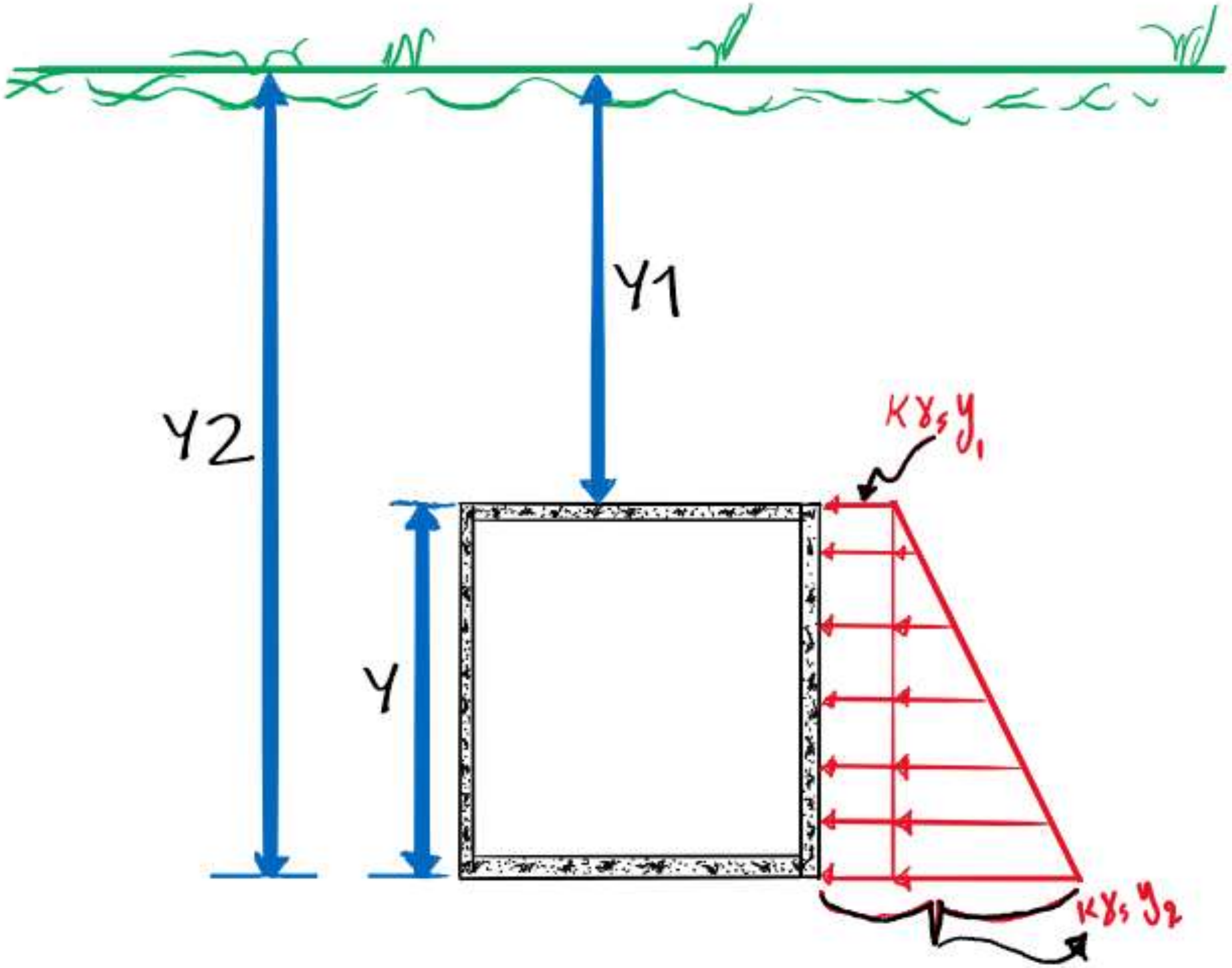
- ✓ Weight of slab
- ✓ Weight of soil above the culvert
- ✓ Weight of pavement above the culvert
- ✓ L.L + impact



Structure Design of Box Culvert

- **Loadings:**

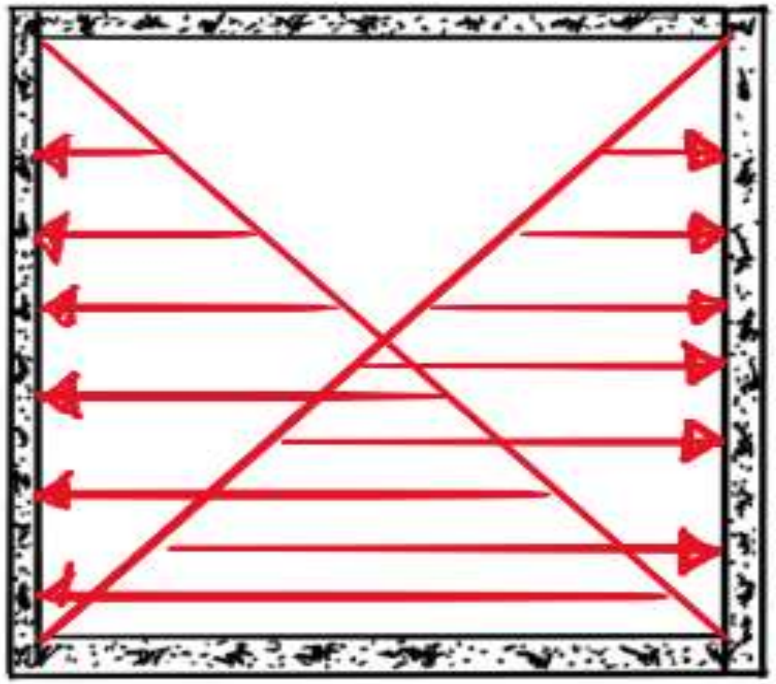
Lateral Soil Pressure on the walls

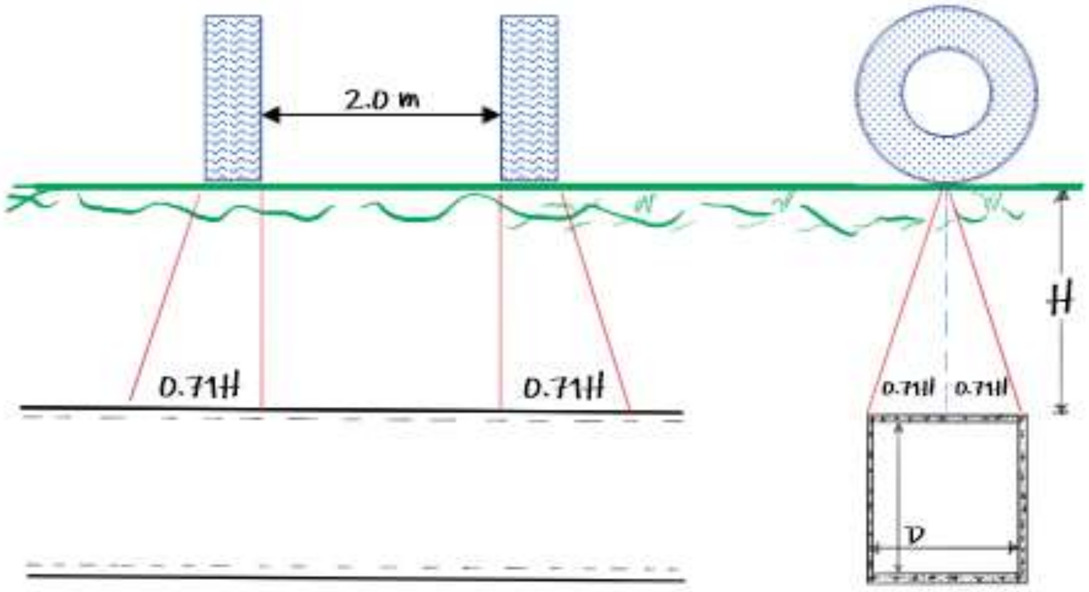


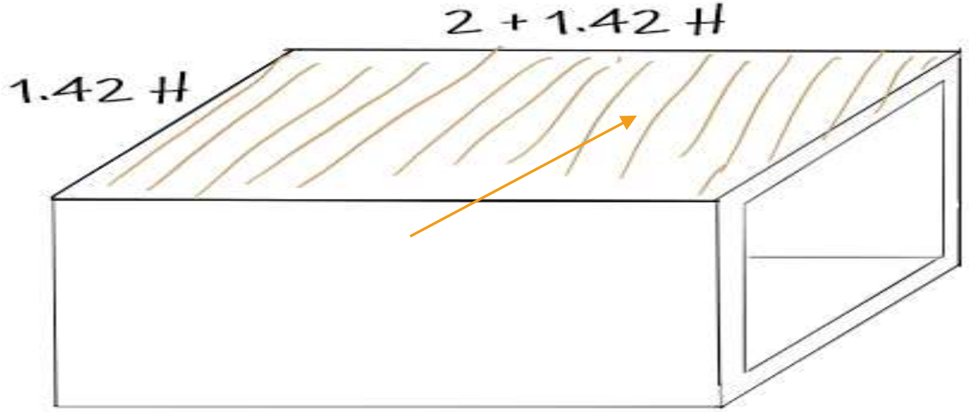
Structure Design of Box Culvert

- **Loadings:**

Lateral Water Pressure




2.0 m
H
0.71H
0.71H
0.71H 0.71H
D


2 + 1.42 H
1.42 H

Example: - Design reinforced concrete box culvert of square dimensions (3.5x3.5m) with the following date:

Depth of earth filling = 1.0 m,

Depth of asphalt =0.1 m,

Road level = 10.0 m

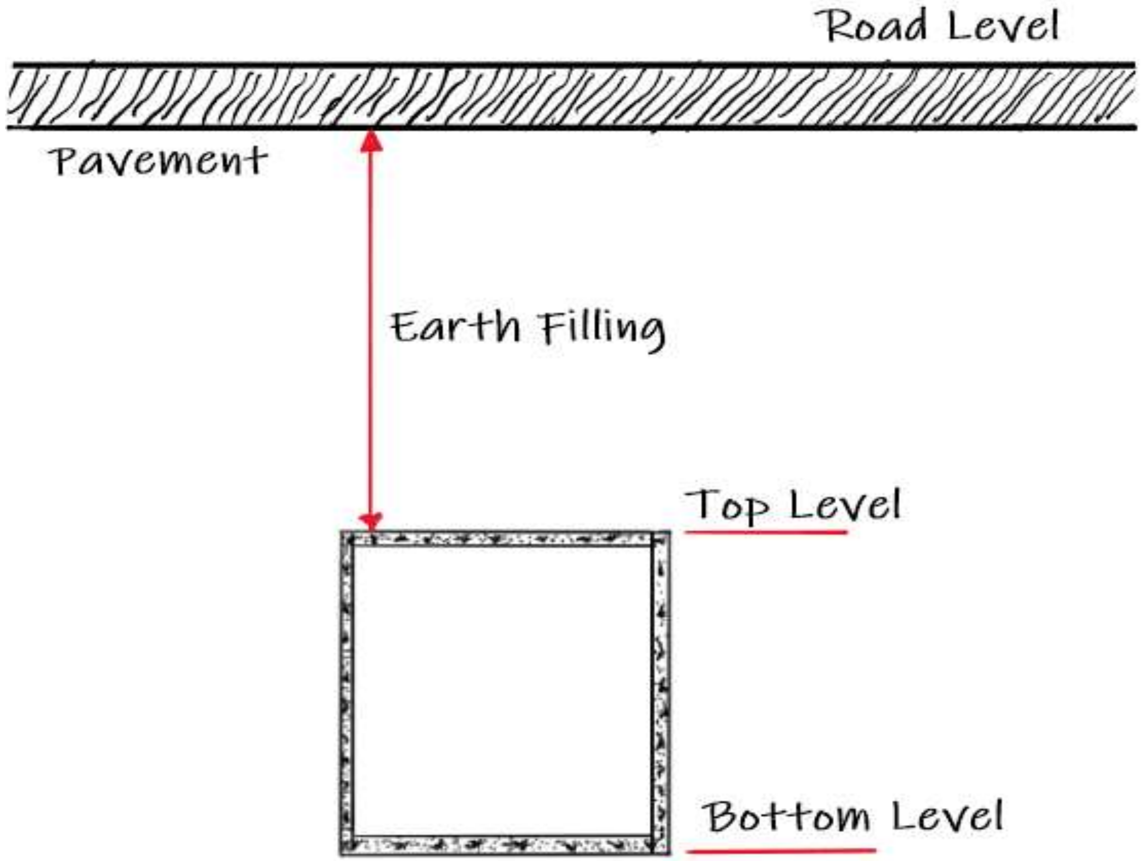
$\gamma\ of\ soil\ \gamma_s = 1.6\ ton/m^3$

$\gamma\ of\ conc.\gamma_c = 2.4\ ton/m^3$

$\gamma\ of\ asphalt\ \gamma_{asf} = 2.3\ ton/m^3$

Use 30 ton for L.L,

K= 0.3



Solution:

$$t = \frac{D}{6} = \frac{3.5}{6} = 0.58\ m \approx 60\ cm$$

Top level= 10 – 0.1 – 1.0 = 8.9 m

Invert level = 8.9- 3.5 – (2 x 0.6) = 4.2m

Weight of asphalt = 0.1 x 2.3 = 0.23 ton/m^2

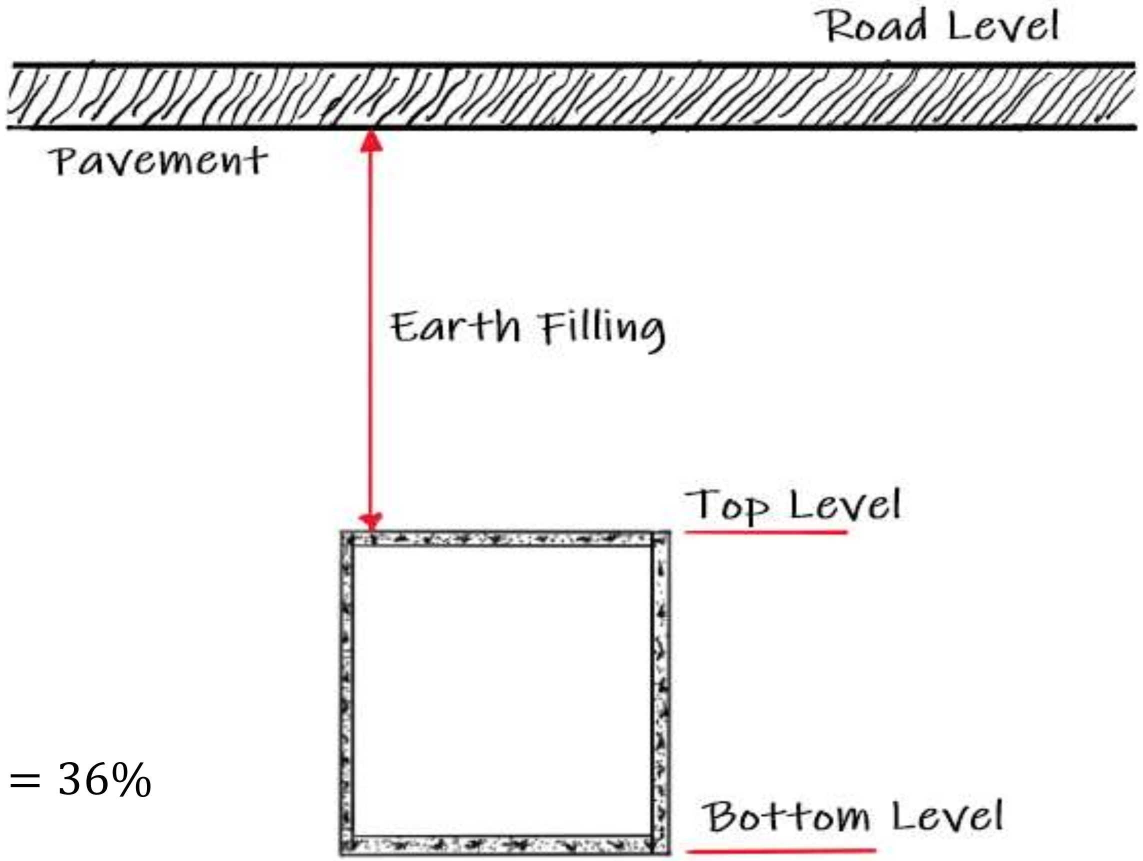
Weight of the soil = 1 x 1.6= 1.6 ton/m^2

Weight of top slab = 0.6 x 2.4= 1.44 ton/m^2

L.L. = 30 x 0.8 = 24 ton

Impact % = $\frac{16}{S+40}$% $\rightarrow$ Impact=$\frac{16}{4.1+40} = 0.36 = 36\%$

Total L.L + Impact = 24 + 0.36 (24) = 32.7 ton



Unit of L.L on the top of the culvert = $\frac{0.8\ of\ L.L+Impact}{(2+1.42\ H)(1.42H)}$

Uniform distributed of L.L = $\frac{32.7}{\left(2+1.42(1.1)\right)(1.42\ (1.1))} = 5.87\ ton/m^2$

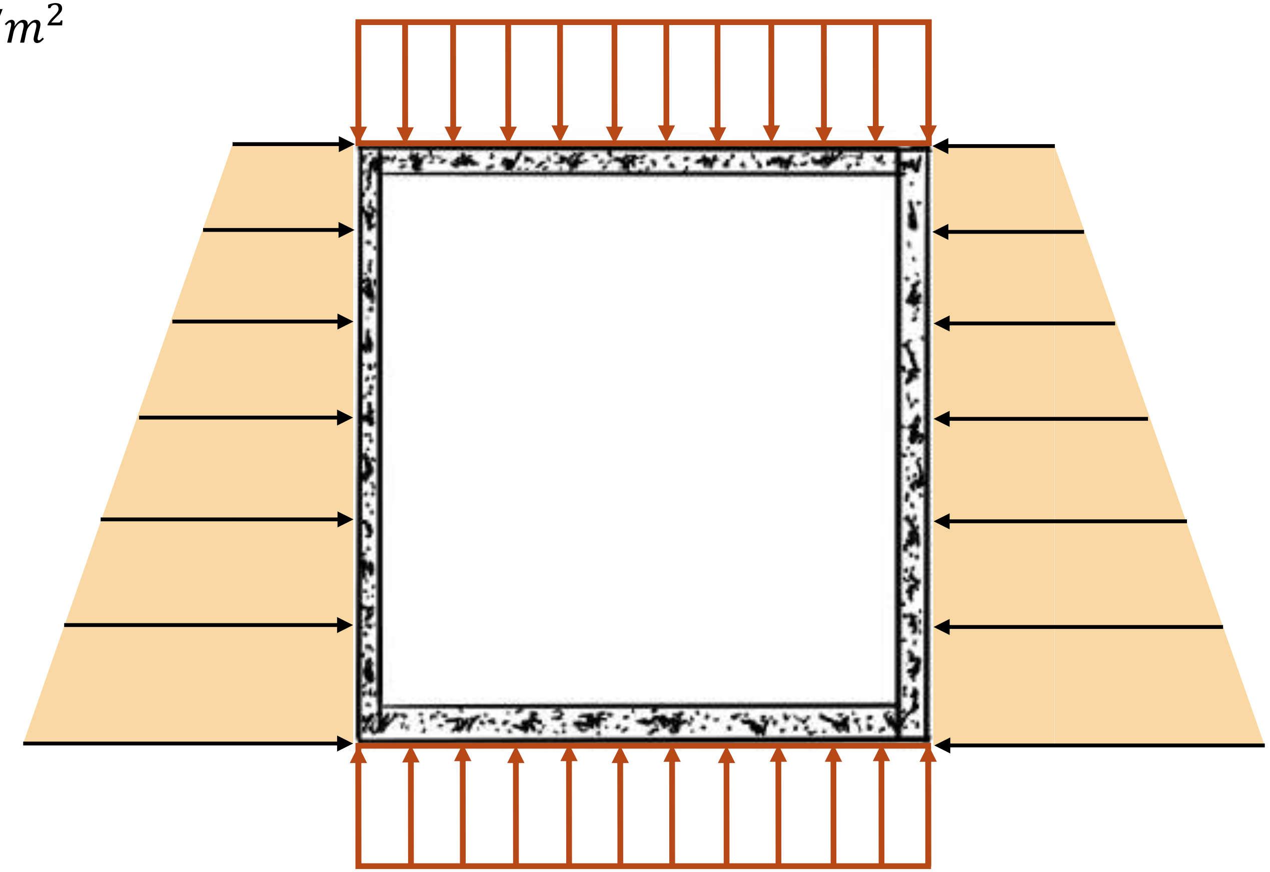
Total uniform load on top slab = 0.23+ 1.6 + 1.44+5.87 = 9.14 ton/m^2

Total uniform load on bottom slab = 9.14+ 2(0.6*2.4) = 12.03 ton/m^2

Lateral load on the walls at the top = K (L.L + weight of asphalt + weight of soil)

= 0.3 (5.87+ 0.23 +1.6)

= 2.31 ton/m^2

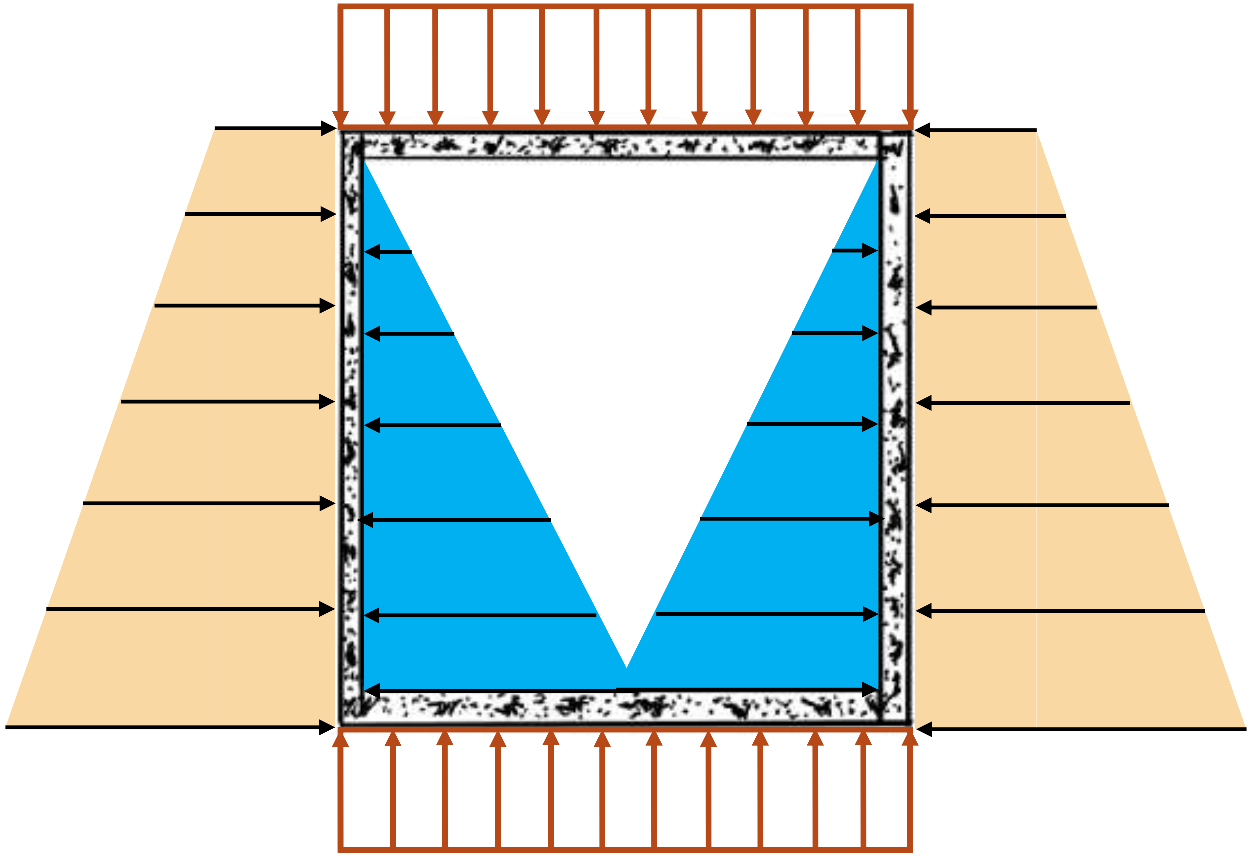


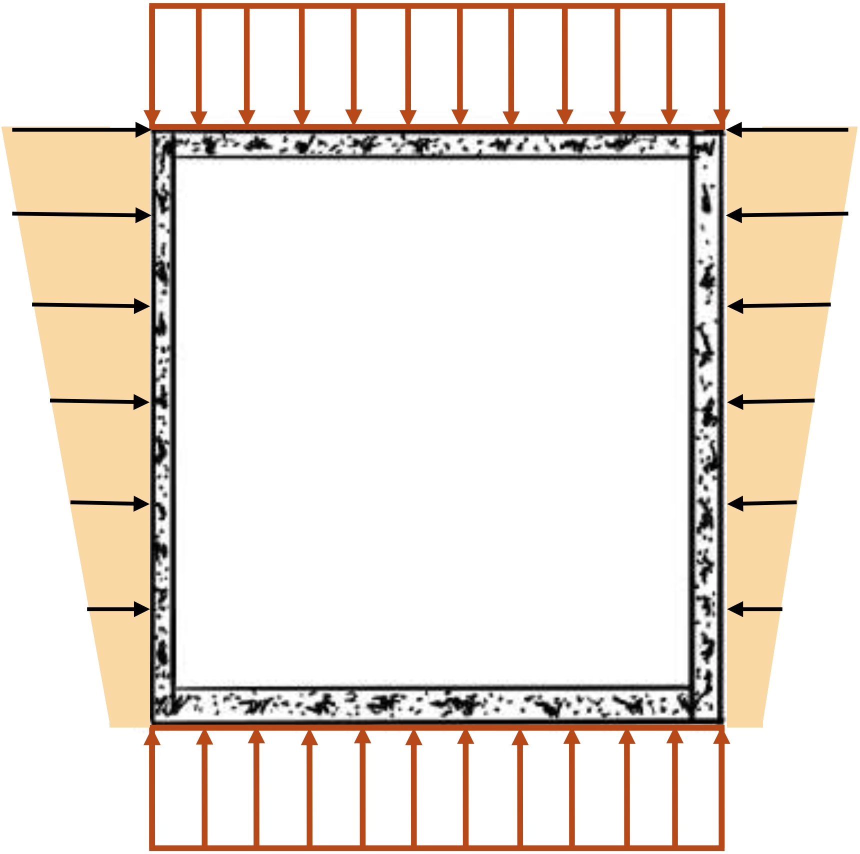
Lateral load on the wall at the bottom = 0.3 (5.87+ 0.23 + 1.6 + 4.1 * 1.6)

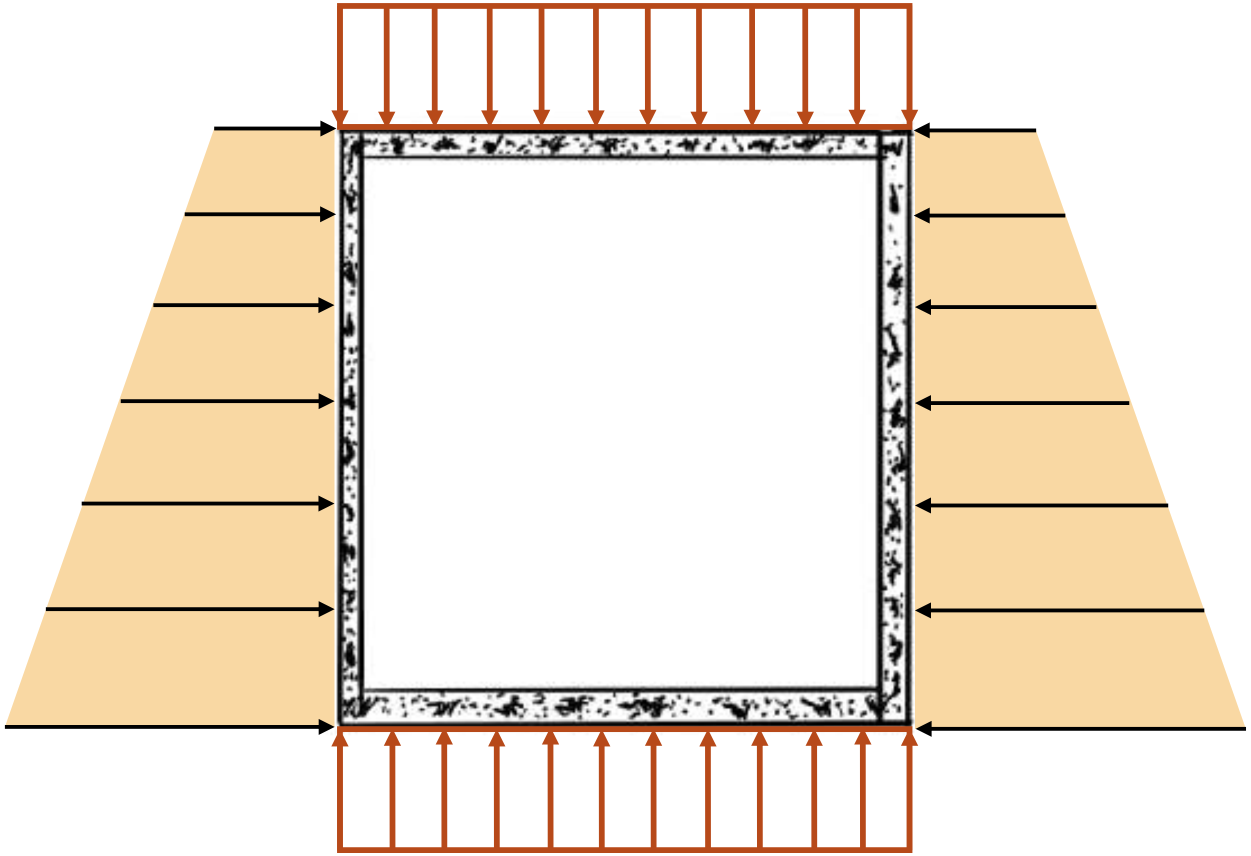
= 4.278 ton/m^2

Load of water on the walls = $\gamma_w * S$

$$= 1 * 4.1 = 4.1\ ton/m^2$$





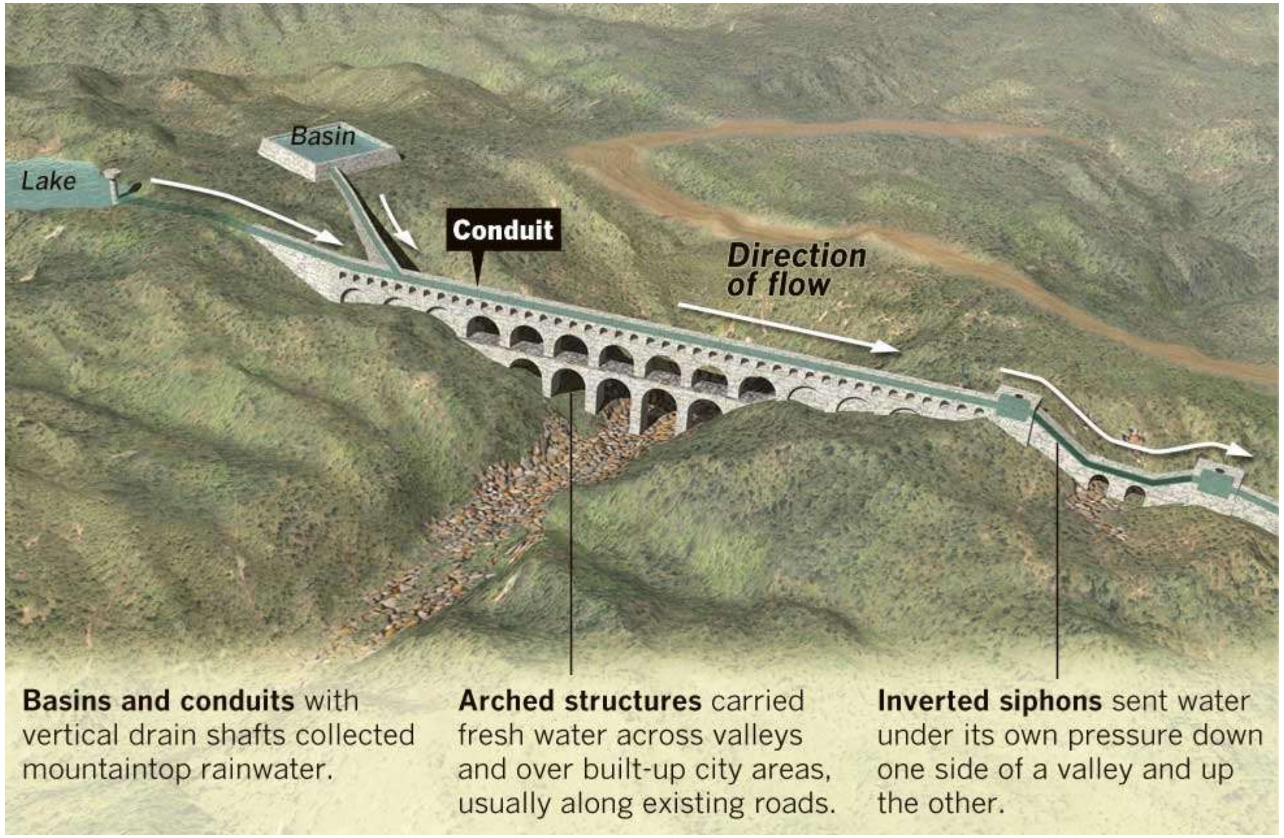


Aqueduct

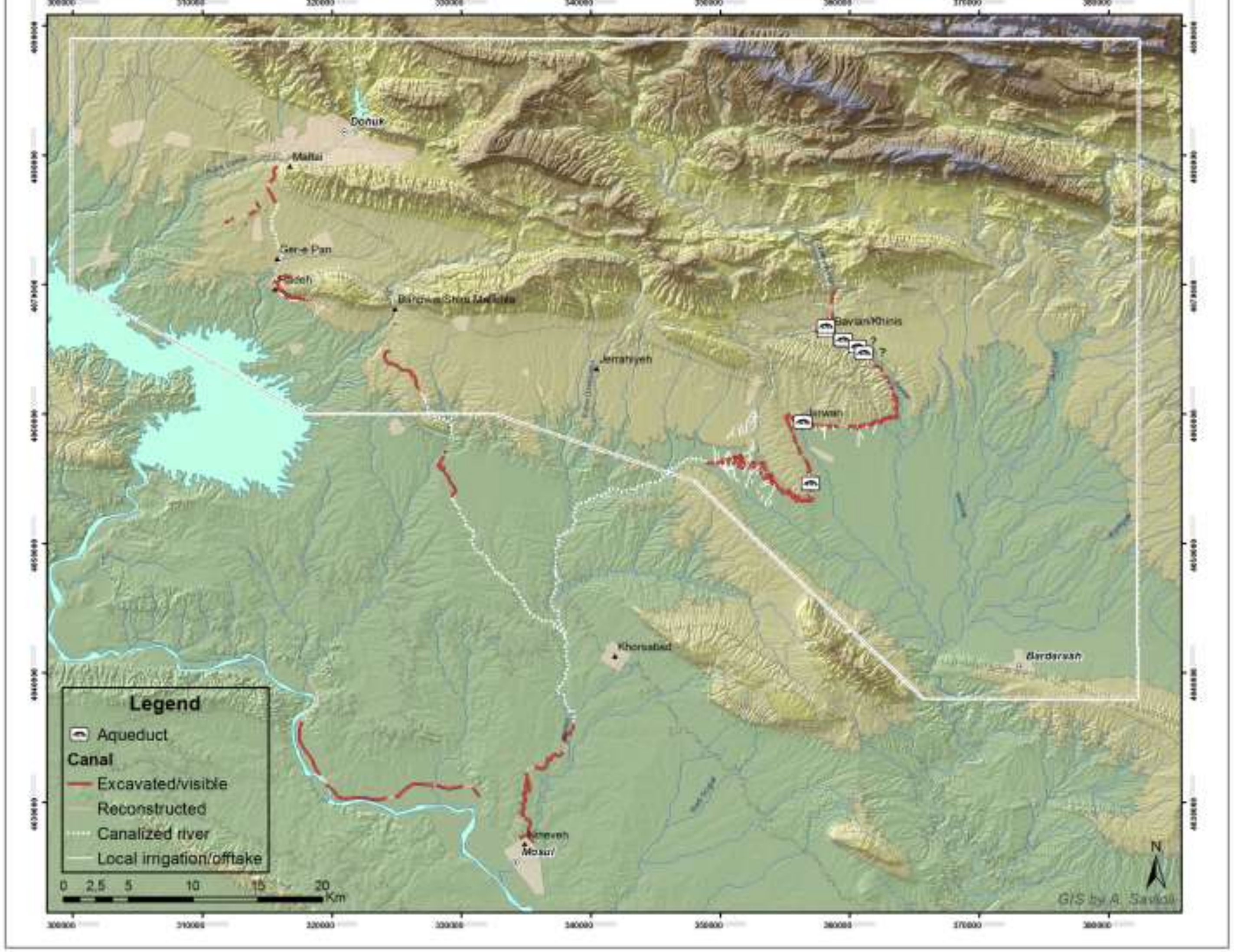
Aqueducts are used to carry a channel water over depression drain, valley, … etc.

These structures consist of an inlet, pipe and flume acting as a bridge, and outlet.

Historical Aqueducts




Assyrian Agricultural Technology
Innovation, adaptation, and just plain showing off.


Dohuk
Maltai
Ger-e Pan
Jerrahiyeh
Jerwan
Khorsabad
Bardarash
Mosul
Legend
Aqueduct
Canal
Excavated/visible
Reconstructed
Canalized river
Local irrigation/offtake
0 2,5 5 10 15 20
Km
N

Los Angeles Aqueduct System

- **Pipe Aqueduct**

Pipe Aqueduct Design

1. Find the discharge (Q) and length of span (L) and overall head loss (ΔH)

2. Choose inlet and outlet and fix the loss coefficients (K_1 and K_2)

3. Calculate the pipe diameter (D) by use the following equation:

$$\Delta H = \left[K_1 + K_2 + \frac{2gn^2L}{(R)^{\frac{4}{3}}}\right]\frac{V^2}{2g} \qquad R = \frac{D}{4}$$

- **Pipe Aqueduct**

Pipe Aqueduct Design

4. Find safe span (L_s) from the following equation:

$$L_s = 0.91\left[\frac{f_s * D}{30 + \frac{D}{t}}\right]^{1/2}$$

where:

L_s: Safe span in meters

f_s: Steel stress= 9300 KN/m^2

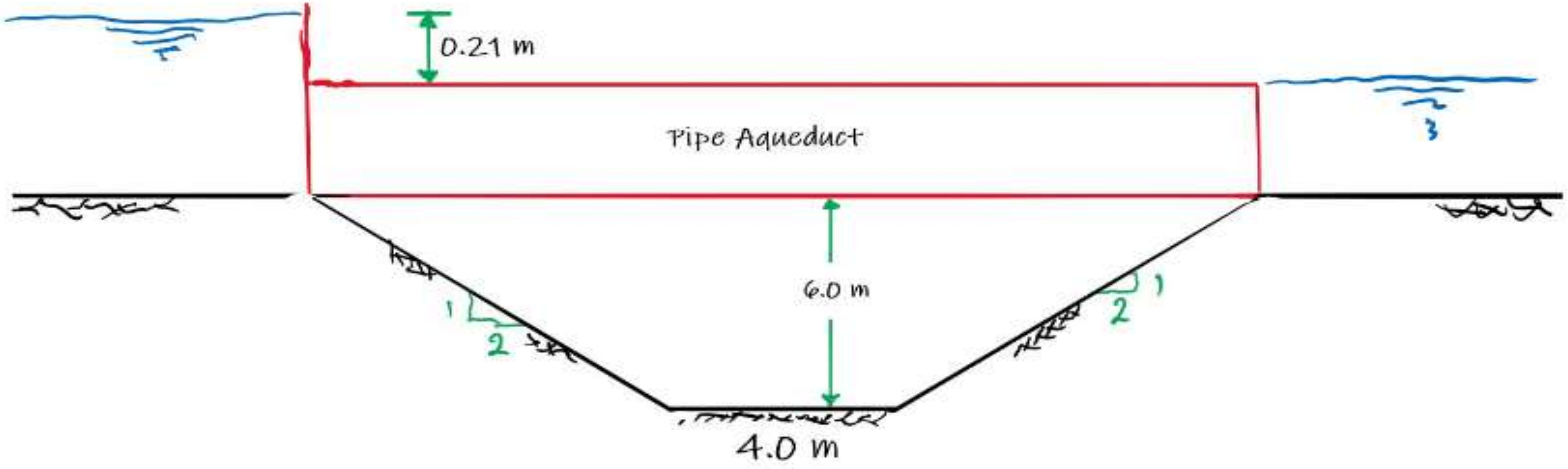
D: Pipe diameter (meter)

t: Thickness of the pipe wall (meter)

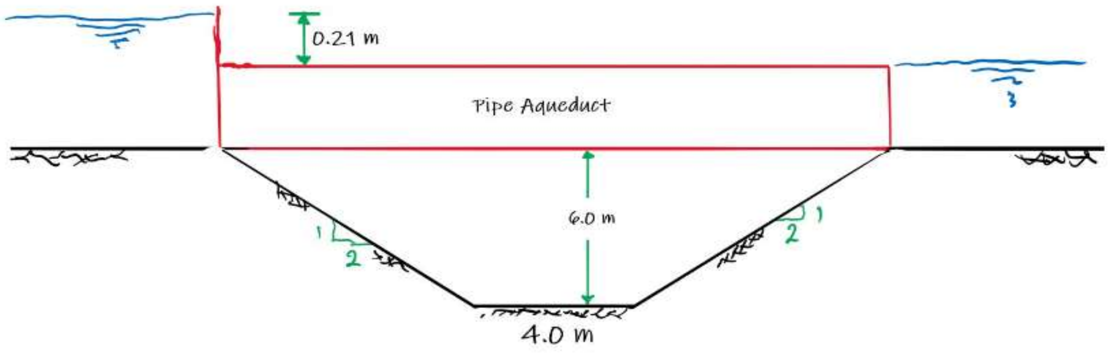
Note: If the required span larger than the safe span (L_s), it should be using supported piers for more economics using.

Example: Design a pipe aqueduct a lined branch canal to across an open drain of 6 m deep, 4 m bed width, and 2:1 side slope. The discharge of the aqueduct is 8 m^3/sec. The overall head loss ΔH not exceed 0.21 m. Assume the thickness of pipe t =9.5 mm

$K_1 = 0.5$, $K_2 = 1.0$, $n_{(steel)} = 0.01$



L= 4 + 2 (2*6) =28 m

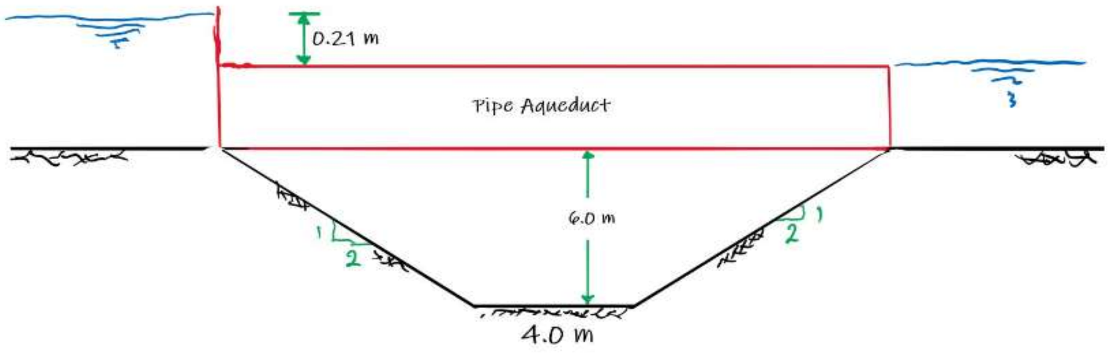


$$\Delta H = \left[K_1 + K_2 + \frac{2gn^2L}{\left(\frac{D}{4}\right)^{\frac{4}{3}}}\right]\frac{V^2}{2g}$$

$$0.21 = \left[0.5 + 1 + \frac{19.62(0.01)^2\ (28)}{\left(\frac{D}{4}\right)^{\frac{4}{3}}}\right]\frac{\left(\frac{1.8}{\frac{\pi}{4}D^2}\right)^2}{19.62}$$

By trial-and-error D=1.2 m

Given that the thickness of the pipe t = 9.5 mm



$$L_s = 0.91\left[\frac{f_s * D}{30 + \frac{D}{t}}\right]^{1/2}$$

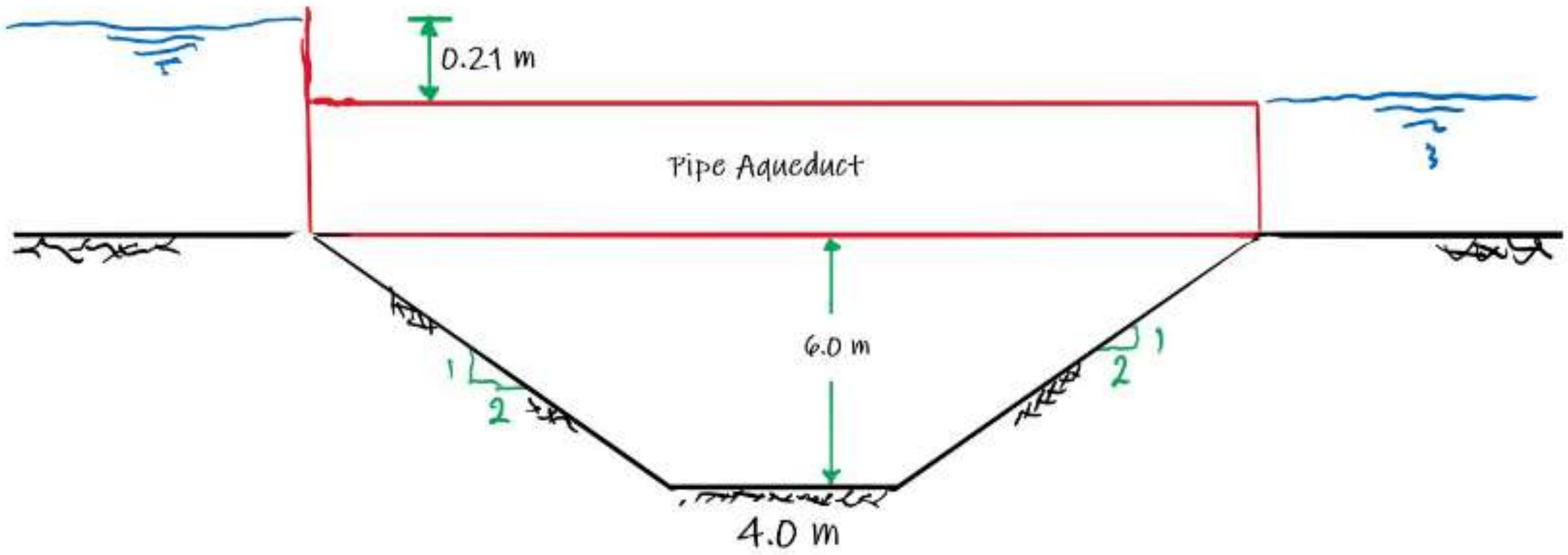
$$L_S = 0.91\left[\frac{93000 * 1.2}{30 + \frac{1.2}{9.3 * 10^{-3}}}\right]^{1/2}$$

$$L_s = 24.31\text{m} < 28\text{m}$$

We need piers at distance 2m from each bank.

$L_s = 24.31\text{m}$

We need piers at distance 2m from each bank.

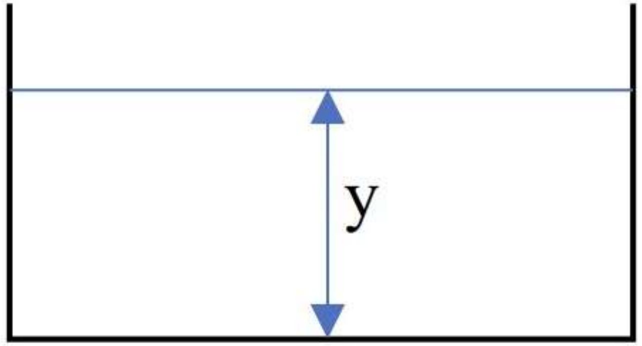


- **Flume Aqueduct**

In flume, the most economical section is a rectangular with half square.

The head loss is the total of inlet and outlet transition and friction loss along the rectangular flume.

$$\Delta H = \left[(K_1 + K_2)\left(\frac{{V_2}^2 - {V_1}^2}{2g}\right) + \frac{{V_2}^2 n^2 L}{\left(\frac{B}{4}\right)^{\frac{4}{3}}} \right]$$



V_2= Velocity of flow in the aqueduct flume

V_1= Velocity of flow in the channel

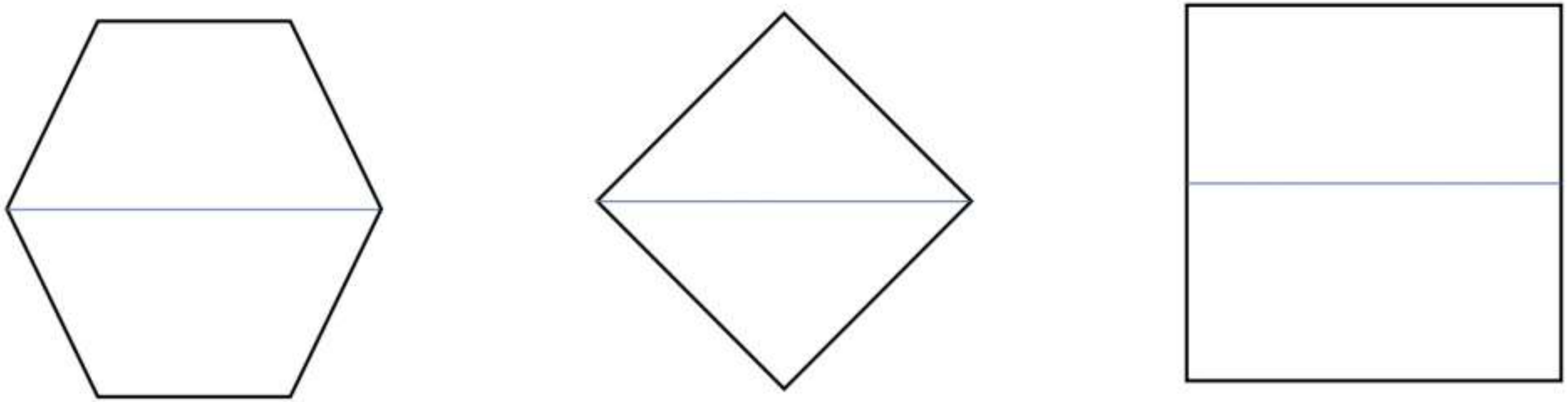
B= Bed width of the flume and channel

The width B is the same at U/S and D/S of Aqueduct

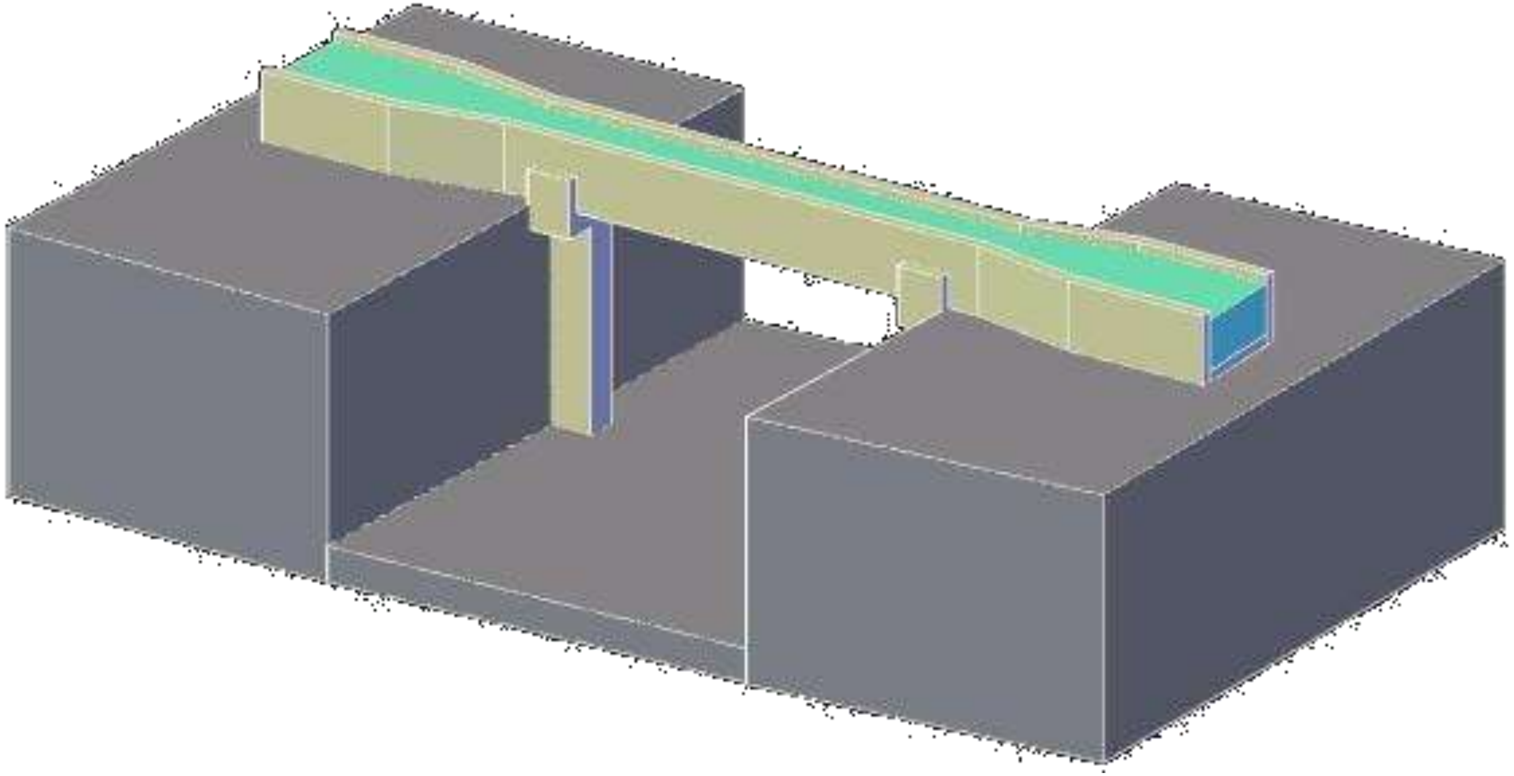
Note: We have to find the depth of flow and then add 20% as a free board

➢ **Flume Aqueduct**

For most economic cross-section shape of open channel, the height is half of the base width.



Example: Design R.C flume aqueduct of effective span equal to 28 m. The aqueduct was used to carry discharge of 1.8 m^3/sec. The bed width of the channel (B) equal to 1.5 m, K_1= 0.5, K_2=1.0. The allowable head loss (ΔH=0.2m) and velocity of flow in the channel V_1= 0.72 m/sec, n_{con}=0.015 (for channel and flume). The longitudinal slop of the channel *S*=200 cm/km



$$\Delta H = \left[(K_1 + K_2) \left(\frac{{V_2}^2 - {V_1}^2}{2g} \right) + \frac{{V_2}^2 n^2 L}{\left(\frac{B}{4} \right)^{\frac{4}{3}}} \right]$$

$$0.2 = \left[(0.5 + 1) \left(\frac{{V_2}^2 - 0.72^2}{19.62} \right) + \frac{{V_2}^2 (0.015)^2 (28)}{\left(\frac{1.5}{4} \right)^{\frac{4}{3}}} \right]$$

V_2=1.543 m/sec

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

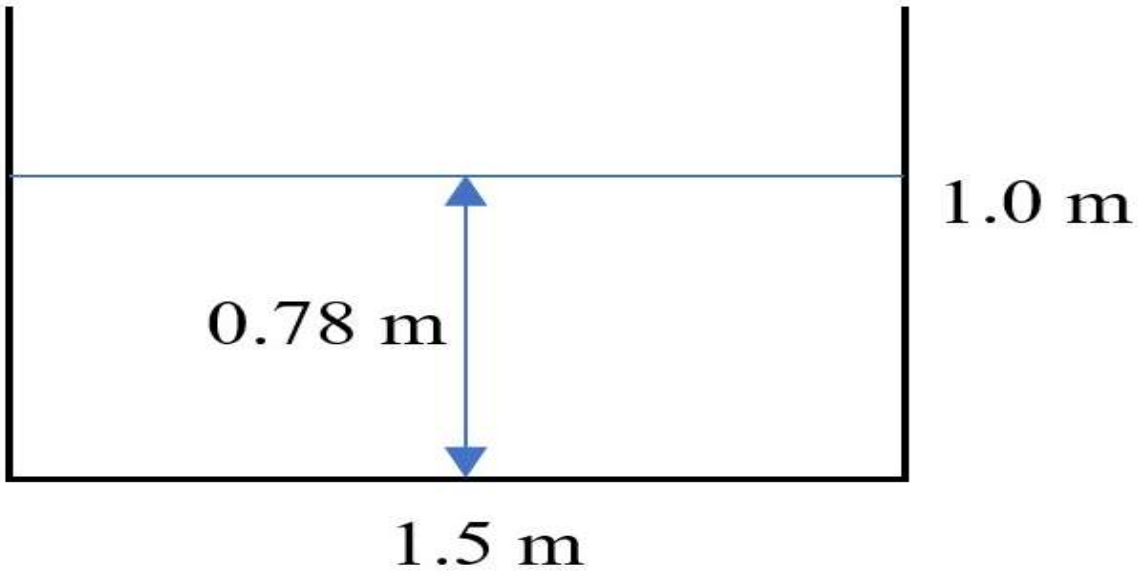
$$1.543 = \frac{1}{0.015} \left(\frac{1.5 * y}{1.5 + 2y} \right)^{2/3} (0.002)^{1/2} \quad \rightarrow$$

By trail and error

y = 0.78 m

Add 20% free board.

The depth of the flume = 0.78+ 0.2 (0.78) ≈ 1m



Hydraulics Structures

Civil Engineering Department

Tikrit University

Wesam Sameer Mohammed-Ali

Ph.D., P.E., M.ASCE, M.AWRA