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Open Channels Design

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Video Lectures https://studio.youtube.com/channel/UC65-ez5Hw0nOildymyn5gzA/videos/upload?filter=%5B%5D&sort=%7B%22columnType%22%3A%22date%22%2C%22sortOrder%22%3A%22DESCENDING%22%7D

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Open Channels Design

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Design Cross-Sections of Trapezoidal Open Channels

1- Trapezoidal Open Channels

The trapezoidal cross-section is the common and best shape for the irrigation and drainage channels (canals and drains), especially for the earth channels.

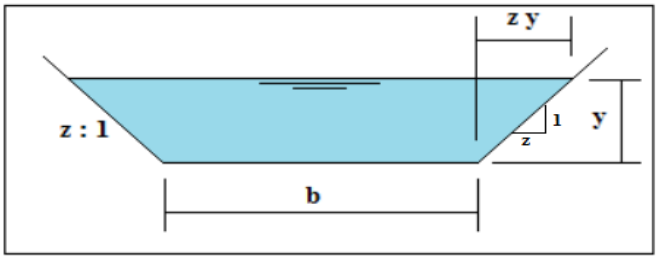
The bed width is (**b**) and (**y**) is the water depth. The sides of the trapezoidal section have a slope of z:1. The slope of z:1 depends on the soil type to keep the stability of the sides of the channels.

In general, the side slopes are:

1:1 for clayey soil,

3:2 for silt soils,

2:1 for sandy soils.



2- Flow in Open Channels

The flow in the open channels is governed by two main equations *as follows:*

1) The continuity equation: **Q = A x v** .... (1)

Where: Q: the discharge, m^3/sec

A: the cross-sectional area, m^2

v: the mean velocity of the flow, m/sec

2) The flow equation: **v = f (n, R, S)**

Where: n: the roughness coefficient.

R: the hydraulic mean radius, m & **R = A / P**

P: the wetted perimeter, m

S: the bed slope, cm/km

3- Manning Equation

There are many formulae to define the function relating the velocity to its parameters.

The commonly used formula is the **Manning equation**, *which is:*

$$v = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} \qquad \text{...} \quad (2)$$

Thus, from the equations (1) and (2):

$$Q = A * v = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A \qquad \text{..} \quad (3)$$

This is the main equation that is used to design the cross-sections of the open channels (such as irrigation and drainage networks).

Each parameter included in this equation will be discussed in the following items.

(1) The discharge (Q):

It is the volume of water passing through the section at a specific time.

Q = A.S. * W.D.

Where: Q: the discharge, m^3/sec

A.S.: the area served, Feddan

W.D.: the water duty of the canal, $m^3/Fed/sec$

(2) The area (A):

It is the area of water in the cross-section (a trapezoidal).

$A = (b * y) + 2 * 1/2 * (z\, y * y)$

$\therefore A = b\, y + z\, y^2$

(3) The velocity (v):

For the earth channels, the maximum permissible velocity depends on the type of soil and the nature of the flowing water. It is recommended that the velocity is 0.45 m/sec for sandy soil, 0.6 m/sec for silt soil, and 0.7 m/sec for clayey soil.

However, the velocity must range between 0.3 and 0.9 m/sec for non-silting and non-scouring conditions.

The non-silting condition means that the velocity of the flow keeps the silts in suspension (does not permit them to fall reducing the area of the section).

While *the non-scouring condition* means that the velocity of the flow keeps the stability of the section (does not push particles from the bed and the sides to move away affecting the stability of the sides and increasing the area of the section).

(4) The roughness coefficient (n):

It is a coefficient determined according to the hydraulic conditions of the channel.

1/n	**Hydraulic Condition**
	Canals
40	Canals of average conditions.
44	New earth canals.
50	Masonry canals.
60	Rough brick canals.
70	Concrete-lined canals.

1/n	**Hydraulic Condition**
	Drains
33	Drains of average conditions.
28	Very weedy drains.

(5) The hydraulic mean radius (R):

R = A / P

Where: P: wetted perimeter.

A: water area.

$P = b + 2\,(y^2 + z^2\,y^2)^{½}$

$\therefore\ P = b + 2\,y\,(1+z^2)^{½}$

$$R = \frac{b\,y + z\,y^2}{b + 2\,y\,\sqrt{1+z^2}}$$

(6) The bed slope (S):

It is the slope of the channel's bed (cm/km). It is assumed to equal the slope of the waterline (i) of the canal (from the final synoptic diagram) to have a uniform flow.

Thus, to design the cross-sections of the open channels, both the bed width (b) and the water depth (y) have to be determined. The employed Manning equation is one equation with the two variables (b) and (y). So, a second equation relating both (b) and (y) is required to get the design values for (b) and (y).

The second equation relating (b) and (y) is assigned according to the required design, which includes either non-silting non-scouring sections, or best hydraulic sections.

4- Design of Non-Silting Non-Scouring Sections

Manning's equation is to be used with one of Buckley's equations, which depends on the required channel (an irrigation canal or a drain).

Cross-sections for Irrigation Canals

Manning equation is to be used with one of *the following Buckley equations:*

$$\boldsymbol{y = \frac{(i+8)^2 * b}{650}}$$ **for y ≤ 1.62 m**...................................... (4)

$$\boldsymbol{y = 0.1\,\left(\frac{i}{2} + 4\right) b^{\frac{1}{2}}}$$ **for y > 1.62 m**....................................... (5)

Where, i: cm/km

Note: Water slope (i) is known, and then the water depth (y) is assumed (≤ 1.62 m OR > 1.62 m). After calculations, if the obtained value of y matched the assumption it is ok. If not, then re-design using the second assumption.

The obtained value of the bed width (b) must be modified to the nearest 0.1 OR 0.5 m and called modified bed width (b_m). So, the corresponding modified value for the water depth (y_m) is calculated *as follows:*

$$\mathbf{A_{calculated} = A_m}$$

$$\therefore \; \mathbf{b\,y + z\,y^2 = b_m\,y_m + z\,y_m^2}$$

Cross-sections for Drainage Networks (Drains)

Manning equation is to be used with one of *the following Buckley equations:*

For i < 10 cm/km

$\mathbf{y = 0.96\,b}$ **for b ≤ 2 m** .... (6)

$\mathbf{y = 1.5\,(b)^{1/3}}$ **for b > 2 m** .... (7)

For i > 10 cm/km

$\mathbf{y = b}$ **for b ≤ 2 m** .... (8)

$\mathbf{y = 1.75\,(b)^{1/3}}$ **for b > 2 m** .... (9)

Note: Water slope (i) is known, then the bed width (b) is assumed (≤ 2 m OR > 2 m). After calculations, if the obtained value of b matched the assumption it is ok. If not, then re-design using the second assumption.

The value of the bed width has to be modified if needed, as stated previously for irrigation networks.

5- <u>Simple Design of Non-Silting Non-Scouring Sections</u>

EL-HAZEK (2019) developed design equations and charts for non-silting non-scouring trapezoidal earthen open channels (canals and drains) [1].

6- <u>Analytical Design via HAZEK Design Equations</u>

For canals (1/n = 40 and y ≤ 1.62 m)

For drains (1/n = 33 and b ≤ 2.0 m)

$$Q = C\, y^{2.666} \qquad \text{(10)}$$

1- According to z and i, get C from Table 1.

2- Knowing Q and C, get y.

3- Substituting in the b-y Buckley equation (equation 4 for canals) – (equation 6 <u>OR</u> 8 for drains according to the values of i), b is determined.

For canals (1/n = 40 and y > 1.62 m)

For drains (1/n = 33 and b > 2.0 m)

$$Q = \alpha\, y^{\beta} \qquad \text{(11)}$$

1- According to z and i, get α and β from Table 2 for canals <u>OR</u> from Table 3 for drains.

2- Knowing Q, α, and β, get y.

3- Substituting in the b-y Buckley equation (equation 5 for canals) – (equation 7 <u>OR</u> 9 for drains according to the values of i), b is determined.

[1] Alaa Nabil El-Hazek (2019). "Design Charts and Design Equations for Trapezoidal Earthen Open Channels". Sumerianz Journal of Scientific Research, Vol. 2, No. 12, pp. 166-182

<u>The paper can be downloaded from Dr. Alaa El-Hazek's page on the Benha University Site</u>

<u>OR Research Gate Site.</u>

Table 1. Coefficient C for HAZEK Design Equation ($Q = C\,y^{2.666}$) (Canals and Drains)

i, cm/km	Canals 1/n = 40 & y ≤ 1.62 m			Drains 1/n = 33 & b ≤ 2.0 m		
	z = 1.0	z = 1.5	z = 2.0	z = 1.0	z = 1.5	z = 2.0
8	0.9595	1.0927	1.2157	0.3931	0.5012	0.6032
9	---	---	---	0.4169	0.5316	0.6398
10	0.8763	1.0252	1.1635	0.4395	0.5603	0.6744
11	---	---	---	0.4492	0.5760	0.6958
12	0.8089	0.9716	1.1235	0.4692	0.6016	0.7267
14	0.7552	0.9302	1.0943	0.5068	0.6498	0.7850
16	0.7126	0.8987	1.0741	0.5418	0.6947	0.8392
18	0.6789	0.8752	1.0609	0.5747	0.7368	0.8901
20	0.6522	0.8580	1.0534	0.6057	0.7766	0.9382
22	0.6311	0.8457	1.0503	0.6353	0.8146	0.9840
24	0.6145	0.8375	1.0507	0.6636	0.8508	1.0278
26	0.6015	0.8325	1.0540	0.6906	0.8855	1.0697

Table 2. Coefficients α and β for HAZEK Design Equation ($Q = \alpha\,y^{\beta}$) (Canals)

i, cm/km	Canals 1/n = 40 & y > 1.62 m					
	z = 1.0		z = 1.5		z = 2.0	
	α	β	α	β	α	β
3	0.7243	3.6606	0.8431	3.5930	0.8431	3.5859
5	0.6847	3.6449	0.8028	3.5882	0.8408	3.5465
7	0.6264	3.6263	0.7641	3.5572	0.8156	3.5026
9	0.5745	3.6030	0.7296	3.5209	0.7934	3.4555
10	0.5535	3.5874	0.7155	3.5017	0.7851	3.4317
12	0.5213	3.5470	0.6923	3.4644	0.7802	3.3747
14	0.4957	3.5078	0.6766	3.4261	0.7896	3.3058
16	0.4776	3.4653	0.6656	3.3918	0.7950	3.2548
18	0.4630	3.4274	0.6581	3.3615	0.8068	3.2027
20	0.4553	3.3816	0.6548	3.3323	0.8198	3.1574

Table 3. Coefficients α and β for HAZEK Design Equation ($Q = \alpha\, y^{\beta}$) (Drains)

i, cm/km	Drains 1/n = 33 & b > 2.0 m					
	z = 1.0		z = 1.5		z = 2.0	
	α	β	α	β	α	β
3	0.0623	4.5644	0.0828	4.4144	0.1007	4.3181
4	0.0742	4.5432	0.1001	4.3829	0.1274	4.2553
5	0.0855	4.5217	0.1224	4.3193	0.1583	4.1807
6	0.0968	4.4980	0.1409	4.2830	0.1836	4.1396
7	0.1086	4.4707	0.1522	4.2830	0.2109	4.0942
8	0.1213	4.4385	0.1721	4.2421	0.2254	4.0942
9	0.1286	4.4385	0.1825	4.2421	0.2391	4.0942
10	0.1345	4.4429	0.1907	4.2460	0.2490	4.1000
11	0.1063	4.3399	0.1636	4.1130	0.2249	3.9518
12	0.1106	4.3412	0.1708	4.1130	0.2348	3.9523
14	0.1182	4.3510	0.1834	4.1167	0.2549	3.9492
16	0.1328	4.3070	0.2012	4.0929	0.2798	3.9250
18	0.1435	4.2889	0.2240	4.0490	0.3047	3.8989
20	0.1549	4.2647	0.2427	4.0212	0.3297	3.8740
22	0.1643	4.2538	0.2594	4.0030	0.3629	3.8264
24	0.1762	4.2275	0.2770	3.9802	0.3866	3.8089
26	0.1855	4.2161	0.2939	3.9611	0.4153	3.7772

Example 1

Mohamed S. Abdelmoaty (2013) reported that the discharge of the Ibrahemia canal in Egypt at km 122.0 is 117.65 m^3/s with z = 1.5, S = 6 cm/km, y = 4.01 m, and b = 35.0 m.

1) Design this cross-section using HAZEK design equations.
2) Design this cross-section using traditional Buckley design equations.

Solution

1) Design the Cross-section using HAZEK Design Equations

Assume y > 1.62 m

1- According to z and i, get α and β from Table 2 for canals.

For z = 1.5 and i = S = 6 cm/km, from Table 2,

α = 0.8431 at i = 5 cm/km & α = 0.7641 at i = 7 cm/km

At i = 6 cm/km, $\therefore \propto = \frac{0.8431+0.7641}{2} = 0.8036$

β = 3.5882 at i = 5 cm/km & β = 3.5572 at i = 7 cm/km

At i = 6 cm/km, $\therefore \beta = \frac{3.5882+3.5572}{2} = 3.5727$

2- Knowing Q, α, and β, get y.

$Q = \alpha\, y^{\beta}$ $y = (Q / \alpha)^{1/\beta}$

$y = (Q / \alpha)^{1/\beta} = (117.65 / 0.8036)^{1/\beta} = (146.4037)^{1/3.5727} = 4.04$ m > 1.62 $\therefore$ assumption ok

3- Substituting in the b-y Buckley equation (equation 5 for canals), b is determined.

$$y = 0.1\ \left(\frac{i}{2} + \ 4\right) b^{\frac{1}{2}}$$

$$4.04 = 0.1\ \left(\frac{6}{2} + \ 4\right) b^{\frac{1}{2}}$$

$(4.04 / 0.7)^2 = b$ b = 33.3 m

Check for Velocity:

$A = b\,y + z\,y^2 = (33.3*4.04) + (1.5*(4.04)^2) = 159.01\ m^2$

v = Q / A = 117.65 / 159.01 = 0.74 m/s ok

2) **Design the Cross-section using Traditional Buckley Design Equations**

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

Assume y > 1.62 m

$y = 0.1\ \left(\frac{i}{2} + 4\right) b^{\frac{1}{2}} \quad = 0.1\ \left(\frac{6}{2} + 4\right) b^{\frac{1}{2}} = 0.7\ b^{1/2}$

$y^2 = 0.49\ b$

$b = 2.04\ y^2$

$A = b\,y + z\,y^2 = 2.04\ y^3 + 1.5\ y^2$

$P = b + 2\,y\,\sqrt{1 + z^2} = b + 2\,y\,\sqrt{1 + 1.5^2} = b + 3.61\,y = 2.04\ y^2 + 3.61\ y$

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

$Q = 40 * \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} * S^{\frac{1}{2}}$

$117.65 = 40 * \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} * (6 * 10^{-5})^{\frac{1}{2}}$

$379.71 = \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}}$

$$379.71 = \frac{(2.04\ y3\ +\ 1.5\ y2)^{5/3}}{(2.04\ y2\ +\ 3.61\ y)^{\ 2/3}}$$

Trial and Error: y = 4 → R.H.S. = 341.42

y = 4.05 → R.H.S. = 357.16

y = 4.1 → R.H.S. = 373.2 ≈ 379.71

$b = 2.04\ y^2 = 2.04 * (4.1)^2 = 34.3$ m

Check for Velocity:

$A = b\,y + z\,y^2 = (34.3*4.1) + (1.5*(4.1)^2) = 165.85\ m^2$

v = Q / A = 117.65 / 165.85 = 0.71 m/s ok

7- Graphical Design via HAZEK Design Charts

31 HAZEK design charts for canals (1 / n = 40) and drains (1 / n = 33) for z = 1, 1.5, and 2 are included in the following published paper.

Alaa Nabil El-Hazek (2019). "Design Charts and Design Equations for Trapezoidal Earthen Open Channels". Sumerianz Journal of Scientific Research, Vol. 2, No. 12, pp. 166-182

The paper can be downloaded from Dr. Alaa El-Hazek's page on the Benha University Site,

OR Alaa El-Hazek's page on the Research Gate Site.

For Canals: 1/n = 40

1- Select the proper design chart according to z and expected y (y ≤ OR > 1.62 m).

2- On the chart, knowing Q, get y according to i.

3- Substituting in the b-y equation (4 OR 5 according to the value of y), b is determined.

For Drains: 1/n = 33

1- Select the proper design chart according to z, i (i ≤ OR > 10 cm/km), and expected b (b ≤ OR > 2.0 m).

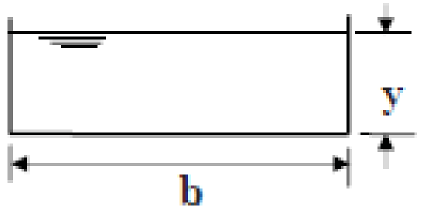
2- On the chart, knowing Q, get y according to i.

3- Substituting in the b-y equation (6 OR 7 OR 8 OR 9 according to the values of i and b), b is determined.

8- Design of Best Hydraulic Sections

The best hydraulic section of an open channel is the section that provides a maximum discharge for a given cross-sectional area (through the least wetted perimeter).

Rectangular cross-section

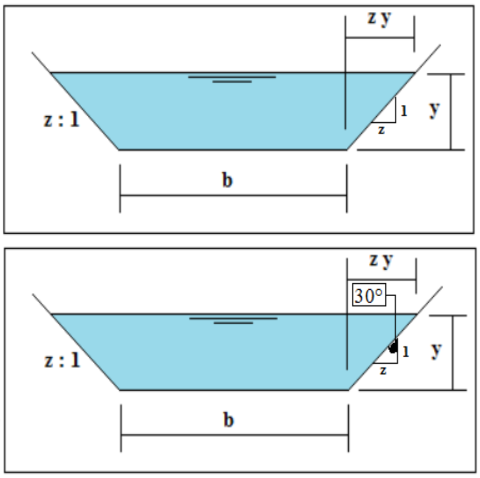


$$P = 2y + \frac{A}{y}$$

$$\frac{dP}{dy} = 0$$

$$\therefore \mathbf{b = 2\,y}$$

Trapezoidal cross-section



$$P = \frac{A}{y} - zy + 2y\sqrt{1 + z^2}$$

$$\frac{\partial P}{\partial y} = 0$$

$$\frac{\partial P}{\partial z} = 0$$

$$\therefore \mathbf{b = 2\,\frac{\sqrt{3}\,y}{3}}$$

The disadvantage of the best hydraulic section is that the water depth (y) is relatively high value concerning the bed width (b), which means more required excavation and consequently more cost.

9- Excel Design of Best Hydraulic Sections

As a spreadsheet, Microsoft Excel software is employed to obtain the required best hydraulic sections for trapezoidal open channels (the following published paper by Dr. Alaa El-Hazek, 2012).

Alaa N. El-Hazek (2012). "Best Hydraulic Sections for Open Channels Employing Spread Sheets". VII - International Conference on Environmental Hydrology with 1st Symposium on Environmental Impacts on the Nile Water Resources, Cairo, Egypt.

The design sheet (method) and the paper can be downloaded from Dr. Alaa El-Hazek's page on the Benha University Site (**www.bu.edu.eg/staff/alaaalhathek3**) OR Alaa El-Hazek's page on Research Gate Site.

Steps for using Excel Design of Best Hydraulic Sections

1- Select the sheet with the required z (z = 1 OR 1.5 OR 2).

2- Enter the data:

Section Number
Water Surface Slope "i" (cm/km)
Bed Slope "$S = i$" (m/m)
Discharge "Q" (m^3/sec)
1 / Manning Coefficient "$1 / n$"

3- Get the answers:

Water Depth "y" (m)
Bed Width "b" (m)

4- Modify b to the nearest 0.5 m and get the modified solution.

Modified Bed Width "b_m" (m)
Modified Water Depth "y_m" *(m)*

Velocity Option

5- Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec)

Modified Water Depth "y_m" (m)
Modified Bed Width "b_m" (m)

10- <u>Examples for Design Cross-section of Canals</u>

<u>Example 1</u>

The discharge of a canal in Egypt is 2.89 m^3/s with 1/n = 40, z = 1.5, S = 10 cm/km.

Design this cross-section using:

1) HAZEK design equations.
2) HAZEK design charts.
3) Traditional Buckley design equations.

<u>Solution</u>

1) <u>Design the Cross-section using HAZEK Design Equations</u>

Assume $y \leq 1.62$ m

1- According to z and i, get C from Table 1.

For z = 1.5 and i = S = 10 cm/km, from Table 1,

C = 1.0252

2- Knowing Q and C, get y.

$Q = C\, y^{2.666}$

$2.89 = 1.0252\, y^{2.666}$

$y^{2.666} = 2.89 / 1.0252 = 2.819$

$y = (2.819)^{1/2.666} = 1.48$ m ≤ 1.62 ∴ assumption ok

3- Substituting in the b-y Buckley equation (equation 4 for canals), b is determined.

$$y = \frac{(i+8)^2 * b}{650}$$

$$1.48 = \frac{(10+8)^2 * b}{650}$$

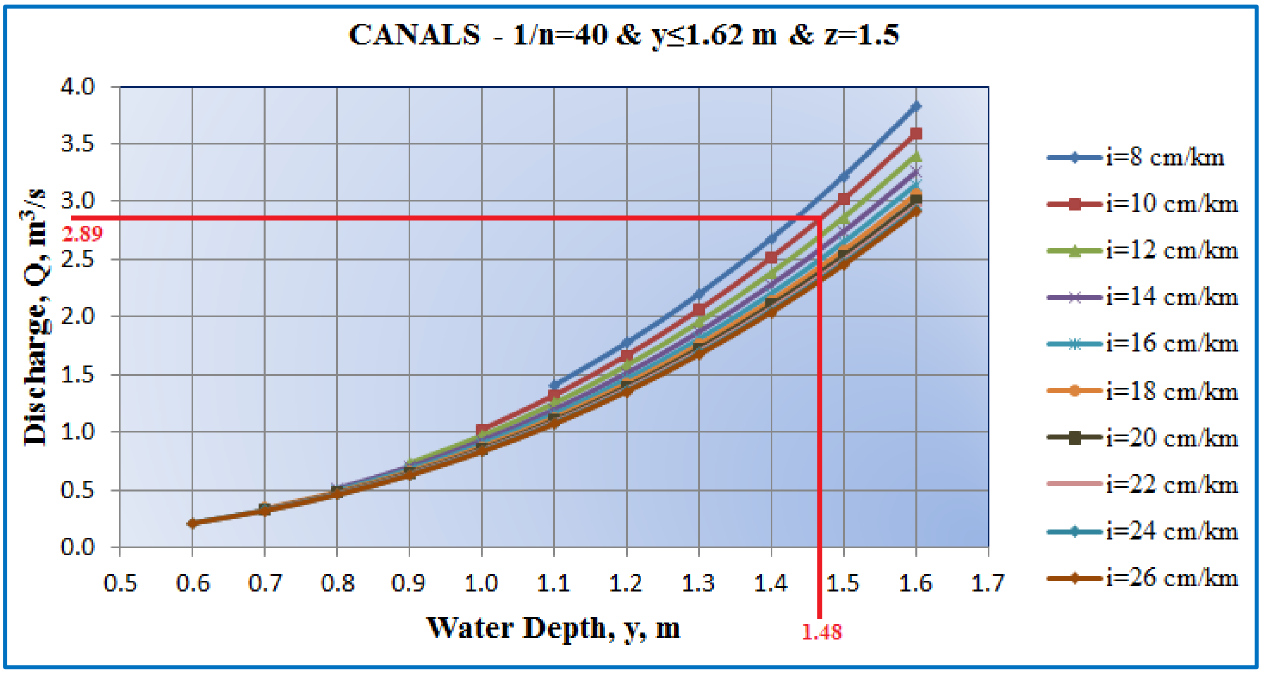
b = 2.97 m

<u>Check for Velocity:</u>

$A = b\,y + z\,y^2 = (2.97*1.48) + (1.5*(1.48)^2) = 7.68\ m^2$

v = Q / A = 2.89 / 7.68 = 0.38 m/s ok

2) Graphical Design via HAZEK Design Charts for Non-Silting Non-Scouring Sections



Q = 2.89 m^3/s

From the curve: y = 1.48 m

To get b:

Buckley design equation for y ≤ 1.62 m,

$$y = \frac{(i+8)^2 * b}{650}$$

$$1.48 = \frac{(10+8)^2 * b}{650}$$

b = 2.97 m

Check for Velocity:

$A = b\,y + z\,y^2 = (2.97*1.48) + (1.5*(1.48)^2) = 7.68\ m^2$

v = Q / A = 2.89 / 7.68 = 0.38 m/s ok

3) <u>Design the Cross-section using Traditional Buckley Design Equations</u>

Assume y ≤ 1.62 m

$y = \frac{(10+8)^2 * b}{650}$ = 0.498 b ≈ 0.5 b

b = 2 y

$A = b\,y + z\,y^2 = 2\,y^2 + 1.5\,y^2 = 3.5\,y^2$

$P = b + 2\,y\,\sqrt{1+z^2} = 2\,y + 2\,y\,\sqrt{1+1.5^2} = 2\,y\,(1+1.8) = 5.6\,y$

R = A / P = 3.5 y2 / 5.6 y = 0.625 y

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

$2.89 = 40 * (0.625\,y)^{2/3} * (10 * 10^{-5})^{\frac{1}{2}} * 3.5\,y^2$

$2.89 = 40 * 0.731\,y^{2/3} * 0.01 * 3.5\,y^2$

$2.824 = y^{8/3}$

$y = (2.824)^{3/8} = 1.48$ m ≤ 1.62 ∴ assumption ok

b = 2 y = 2 * 1.48 = 2.96 m

<u>Check for Velocity:</u>

$A = b\,y + z\,y^2 = (2.96*1.48) + (1.5*(1.48)^2) = 7.67\ m^2$

v = Q / A = 2.89 / 7.67 = 0.38 m/s ok

Example 2

The discharge of a canal in Egypt is 8.1 m^3/s with 1/n = 40, z = 1.5, S = 7 cm/km.

Design this cross-section using:

1) HAZEK design equations.
2) HAZEK design charts.
3) Traditional Buckley design equations.

Solution

1) Design the Cross-section using HAZEK Design Equations

Assume y > 1.62 m

1- According to z and i, get α and β from Table 2 for canals.

For z = 1.5 and i = S = 7 cm/km, from Table 2,

α = 0.7641

β = 3.5572

2- Knowing Q, α, and β, get y.

$Q = \alpha\, y^{\beta}$ $\qquad\qquad$ $y = (Q / \alpha)^{1/\beta}$

$y = (Q / \alpha)^{1/\beta} = (8.1 / 0.7641)^{1/\beta} = (146.4037)^{1/3.5572} = 1.94$ m > 1.62 ∴ assumption ok

3- Substituting in the b-y Buckley equation (equation 5 for canals), b is determined.

$$y = 0.1\ \left(\frac{i}{2} + \ 4\right) b^{\frac{1}{2}}$$

$$1.94 = 0.1\ \left(\frac{7}{2} + \ 4\right) b^{\frac{1}{2}}$$

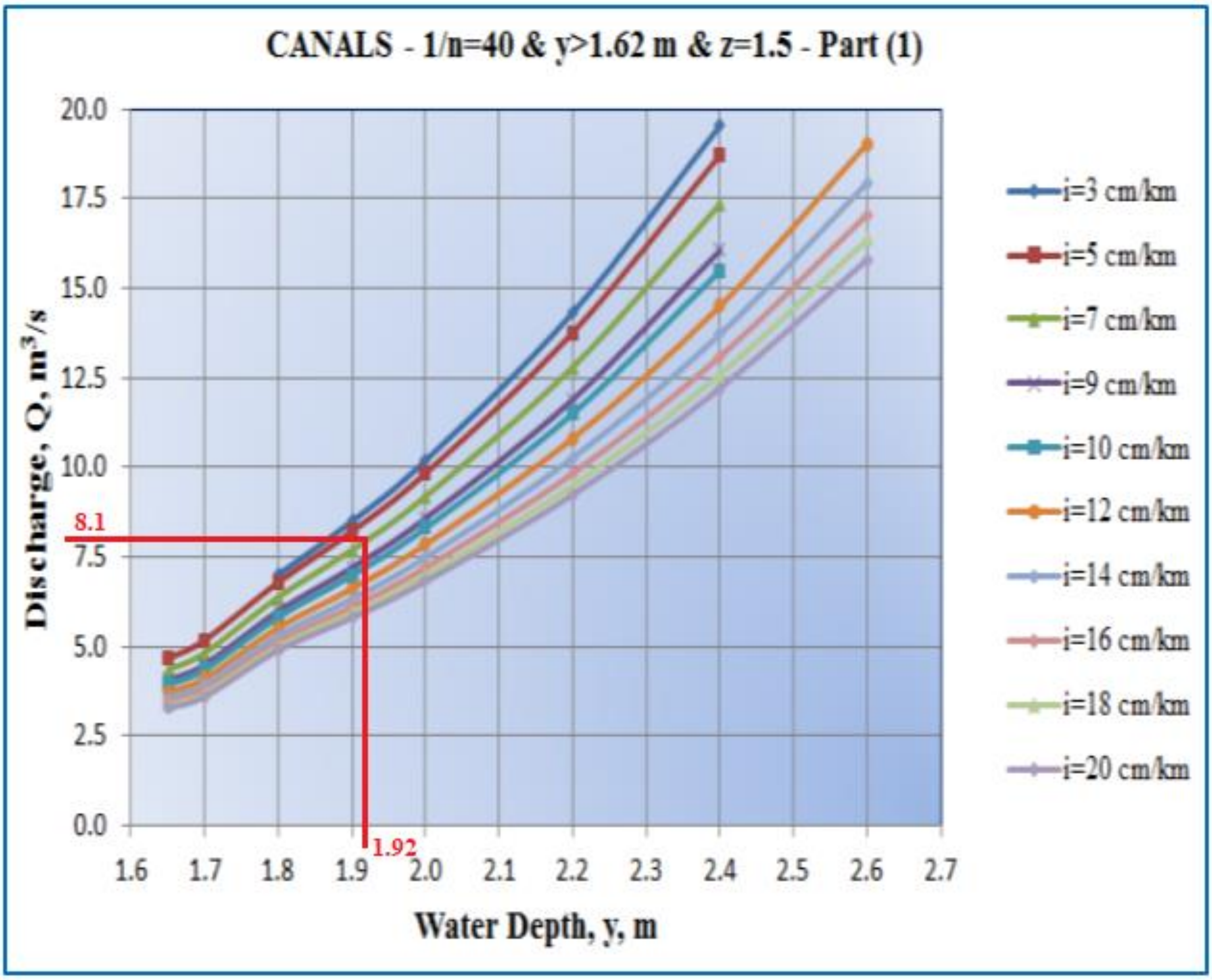
$(2.587)^2 = b$ $\qquad\qquad$ b = 6.7 m

Check for Velocity:

$A = b\,y + z\,y^2 = (6.7*1.94) + (1.5*(1.94)^2) = 18.64\ m^2$

v = Q / A = 8.1 / 18.64 = 0.43 m/s $\qquad$ ok

2) Graphical Design via HAZEK Design Charts for Non-Silting Non-Scouring Sections



Choose the figure concerning Q < 20 m^3/s

Q = 8.1 m^3/s

From the curve: y = 1.94 m

To get b:

$$y = 0.1\left(\frac{i}{2} + 4\right) b^{\frac{1}{2}}$$

$$1.94 = 0.1\left(\frac{7}{2} + 4\right) b^{\frac{1}{2}}$$ b = $(2.587)^2$ = 6.7 m

Check for Velocity:

A = b y + z y^2 = (6.7*1.94) + (1.5*$(1.94)^2$) = 18.64 m^2

v = Q / A = 8.1 / 18.64 = 0.43 m/s ok

3) Design the Cross-section using Traditional Buckley Design Equations

Assume y > 1.62 m

$y = 0.1\ \left(\frac{i}{2} + 4\right) b^{\frac{1}{2}} \quad = 0.1\ \left(\frac{7}{2} + 4\right) b^{\frac{1}{2}} = 0.75\ b^{1/2}$

$y^2 = 0.5625\ b$

$b = 1.78\ y^2$

$A = b\ y + z\ y^2 = 1.78\ y^3 + 1.5\ y^2$

$P = b + 2\,y\,\sqrt{1+z^2} = b + 2\,y\,\sqrt{1+1.5^2} = b + 3.61\,y = 1.78\ y^2 + 3.61\ y$

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

$Q = 40 * \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} * S^{\frac{1}{2}}$

$8.1 = 40 * \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} * (7 * 10^{-5})^{\frac{1}{2}}$

$24.203 = \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}}$

$$24.203 = \frac{(1.78\,y3 + 1.5\,y2)^{5/3}}{(1.78\,y2 + 3.61\,y)^{\,2/3}}$$

Trial and Error: y = 2 → R.H.S. = 25.5

y = 1.9 → R.H.S. = 21.28

y = 1.96 → R.H.S. = 23.73

Take y = 1.97 m

$b = 1.78\ y^2 = 1.78 * (1.97)^2 = 6.91$ m

Check for Velocity:

$A = b\ y + z\ y^2 = (6.91*1.97) + (1.5*(1.97)^2) = 19.43\ m^2$

v = Q / A = 8.1 / 19.43 = 0.42 m/s ok

Example 3 ***Canals***

A canal serves an area of 7,000 Feddan, has a water duty of 50 m^3/Fed/day, and has a trapezoidal cross-section. The canal runs in silt soil.

Design the cross-section of the canal at km 0.0 where the water slope is 10 cm/km.

Solution

1) **Design the Cross-section using Traditional Buckley Design Equations**

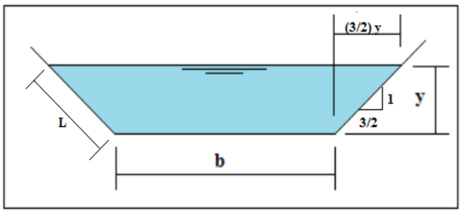
A.S.= 7,000 Feddans W.D. = 50 m^3/Fed/day

Trapezoidal section. Silt soil $\therefore$ z : 1 = 3 : 2

i = 10 cm/km

Q = A.S. x W.D. = (7,000 * 50) / 24 * 60 * 60

$\therefore$ Q = 4.05 m^3/sec



A = b y + 2 * (0.5 * y * 1.5 y)

$\therefore$ A = b y + 1.5 y^2

Assume, y ≤ 1.62 m, *then:*

$$\boldsymbol{y = \frac{(i+8)^2 * b}{650}} \quad \Rightarrow \quad \boldsymbol{y = \frac{(10+8)^2 * b}{650} = 0.5\, b}$$

$\therefore$ b = 2 y

$\therefore A = 2\,y^2 + 1.5\,y^2 = 3.5\,y^2$

$P = b + 2\,(2.25\,y^2 + y^2)^{1/2}$

$\therefore P = 2\,y + 3.6\,y = 5.6\,y$

$\therefore R = A / P = (3.5\,y^2) / (5.6\,y) = 0.625\,y$

$\boldsymbol{Q = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A}$

Assume, S = i = 10 / 10^5 = 10^{-4} & 1 / n = 40

$$4.05 = 40 * (0.625)^{\frac{2}{3}} * (y)^{\frac{2}{3}} * (10^{-4})^{\frac{1}{2}} * 3.5\, y^2$$

$\therefore y^{8/3} = 3.959 \therefore y = 1.675$ m > **1.62 m** **Refused**

<u>Thus, use the other equation</u> for y > 1.62 m

$$y = 0.1\left(\frac{i}{2} + 4\right) b^{\frac{1}{2}} = 0.1\left(\frac{10}{2} + 4\right) b^{\frac{1}{2}}$$

$\therefore y = 0.9\, b^{1/2}$ $\therefore y^2 = 0.81\, b$ $\therefore b = 1.23\, y^2$

$\therefore A = b\, y + 1.5\, y^2 = 1.23\, y^3 + 1.5\, y^2$

& $P = b + 3.6\, y = 1.23\, y^2 + 3.6\, y$

$$Q = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A \qquad Q = \frac{1}{n} * \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} * S^{\frac{1}{2}}$$

$$4.05 = 40 * \frac{(1.23\, y3 + 1.5\, y2)^{\frac{5}{3}}}{(1.23\, y2 + 3.6\, y)^{\frac{2}{3}}} * (10^{-4})^{\frac{1}{2}}$$

$$10.128 = \frac{(1.23\, y3 + 1.5\, y2)^{\frac{5}{3}}}{(1.23\, y2 + 3.6\, y)^{\frac{2}{3}}}$$

<u>Trial and Error:</u> y = 1.7 → R.H.S. = 10.875

y = 1.65 → R.H.S. = 9.828

y = 1.68 → R.H.S. = 10.447

$\therefore y = 1.69$ m > 1.62 m $\therefore$ O.K.

$\therefore b = 1.23\, y^2 = 3.51$ m

Take $b_m = 3.5$ m

$A_{calculated} = A_m$

$\therefore b\,y + 1.5\,y^2 = b_m\,y_m + 1.5\,y_m^2$

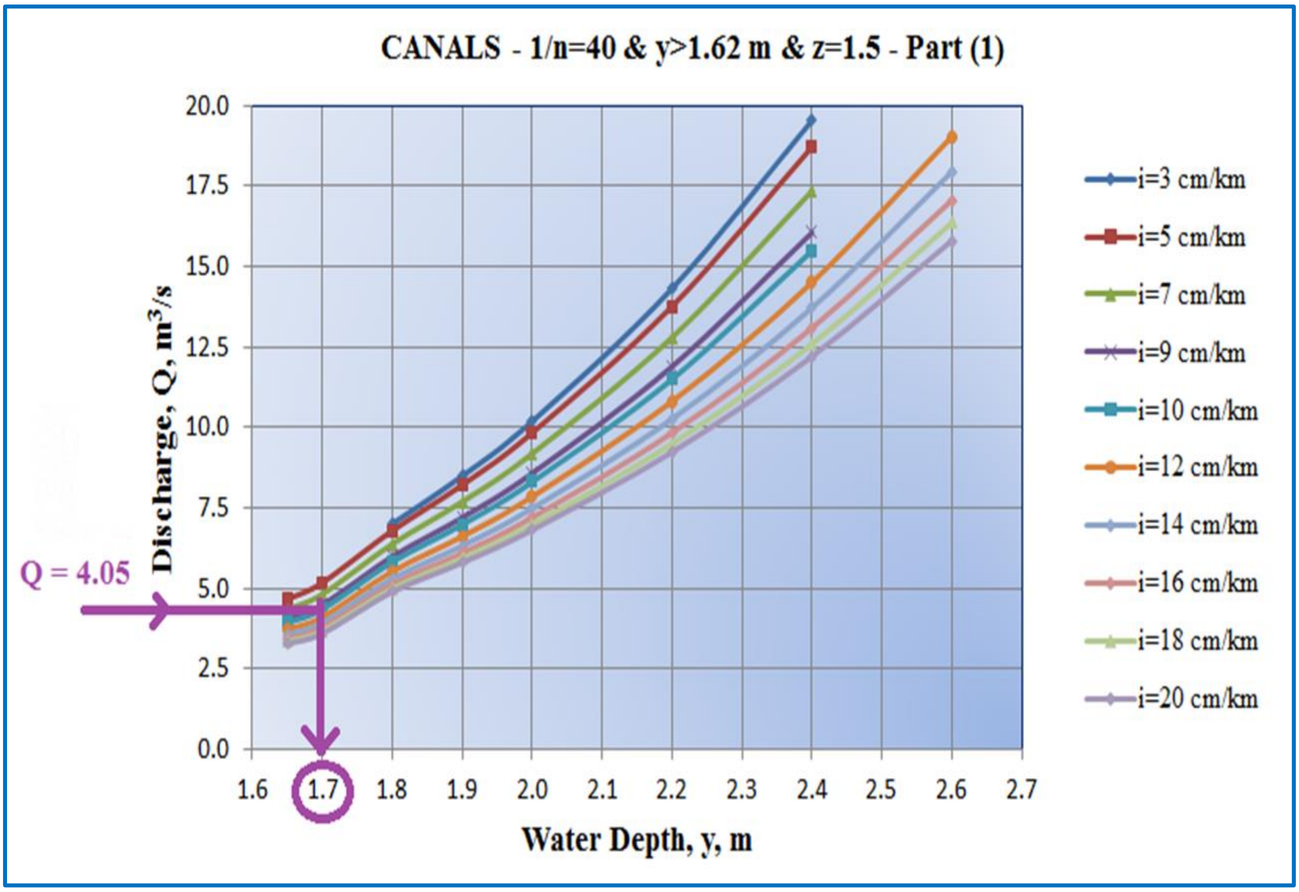
$(3.51 * 1.69) + (1.5 * (1.69)^2) = 3.5\,y_m + 1.5\,y_m^2$

$1.5\,y_m^2 + 3.5\,y_m - 10.22 = 0$

$y_m^2 + 2.33\,y_m - 6.81 = 0$

$$\therefore y_m = \frac{-2.33 \pm [(2.33)^2 - (4 * 1 * -6.81)]^{1/2}}{2 * 1} = 1.7 \text{ m}$$

2) <u>Graphical Design via HAZEK Design Charts for Non-Silting Non-Scouring Sections</u>



From the curve: y = 1.7 m

To get b:

Buckley design equation for y > 1.62 m,

$$\boldsymbol{y = 0.1\ \left(\frac{i}{2} + 4\right) b^{\frac{1}{2}}}$$

$y = 0.1\ (5 + 4)\ b^{1/2}$

$\therefore\ b = (1.7)^2 / 0.81 \approx 3.6$ m

3) Analytical Design via HAZEK Design Equations for Non-Silting Non-Scouring Sections

For canals (1/n = 40 and y > 1.62 m) $\boldsymbol{Q = \alpha\, y^{\beta}}$

α and β: from Table 2 according to z and i.

z = 1.5 and i = 10 cm/km

From Table 2,

$\alpha = 0.7155$ $\beta = 3.5017$

$4.05 = 0.7155\ y^{3.5017}$

$y = (4.05/0.7155)^{1/3.5017} = 1.64$ m

Get b from Buckley's design equation (y > 1.62 m)

$\therefore b = (1.64)^2 / 0.81 = 3.3$ m

4) Excel Design of Best Hydraulic Sections

Steps	***Solution***
1- Select the sheet with the required z (z = 1 OR 1.5 OR 2).	z = 1.5
2- Enter the data: Section Number Water Surface Slope "i" (cm/km) Bed Slope "*S* = *i*" (m/m) Discharge "*Q*" (m^3/sec) 1 / Manning Coefficient "*1 / n*"	Sec No: 1 i = 10 cm/km S = i = 10^{-4} Q = 4.05 m^3/s 1/n = 40
3- Get the answers: Water Depth "y" (m) Bed Width "b" (m)	y = 2.14 m b = 1.31 m
4- Modify b to the nearest 0.5 m and get the modified solution. Modified Bed Width "b_m" (m) Modified Water Depth "y_m" *(m)*	b_m = 1.4 m y_m = 2.12 m
Velocity Option 5- Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec) Modified Water Depth "y_m" (m) Modified Bed Width "b_m" (m)	v = 0.42 m/s OK --- ---

Excel file for design can be downloaded from:

www.bu.edu.eg/staff/alaaalhathek3

Best Hydraulic Trapezoidal Sections for Open Channels

z = 1.5

$Q = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A$	Manning Equation

Given

Section 1	Section Number
10	Water Surface Slope "i" (cm/km)
0.0001	Bed Slope "$S = i$" (m/m)
4.05	Discharge "Q" (m^3/sec)
40	1 / Manning Coefficient "$1/n$"
For Best Hydraulic Section	x' = T / 2 & z = 1.5 & b = 0.61 y

Basic Solution

2.1414	Water Depth "y" (m)
1.3063	Bed Width "b" (m)
9.675757906	Cross Sectional Area "A" (m^2)
9.036780219	Wetted Perimeter "P" (m)
1.070708557	Hydraulic Radius "$R = A / P$" (m)
7.73051578	Top Width "T" (m)

Additional Solution for Modified Bed Width (to nearest 0.05 m)

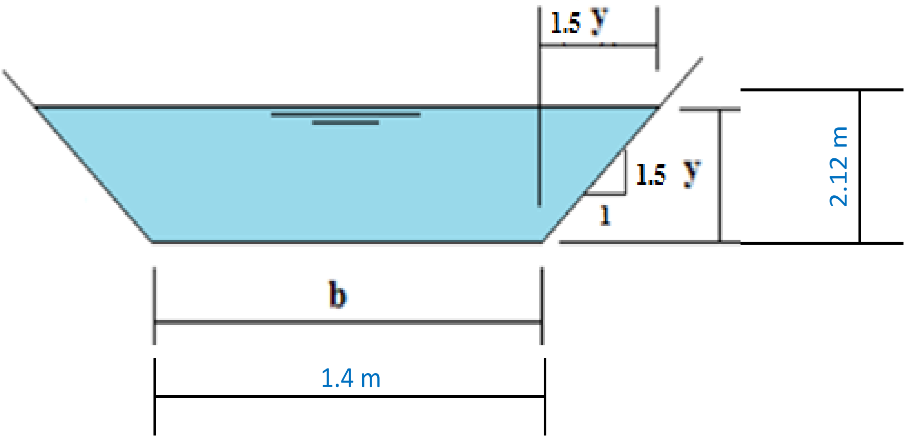
Solution (Modified b)

9.675757906	Cross Sectional Area "A" (m^2)
1.40	Modified Bed Width "b_m" (m)
2.12	Modified Water Depth "y_m" (m)
9.04	Modified Wetted Perimeter "P" (m)
1.07	Modified Hydraulic Radius "$R = A / P$" (m)
7.75	Top Width "T" (m)

OPTION **Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec)**

Solution accounting for the velocity

0.418571862	Velocity "v = Q / A" (m/sec)
	Modified Cross Sectional Area "A = Q / 0.9" (m^2)
	Modified Water Depth "y_m" (m)
	Modified Bed Width "b_m" (m)
	Modified Velocity "v" (m/sec)



Example 4 ***Drains***

A minor drain serves an area of 6,000 Feddan of clayey soil. It has a drainage factor of 25 m^3/Fed/day and its cross-section has the shape of a trapezoidal section.

Design the cross-section of the minor drain at its outfall where the water slope is 20 cm/km.

Solution

1) **Design the Cross-section using Traditional Buckley Design Equations**

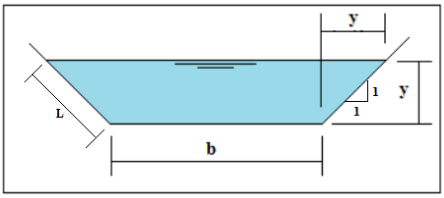
A.S. = 6,000 Feddans D.F. = 25 m^3/Fed/day

Trapezoidal section Clayey soil $\therefore$ z : 1 = 1 : 1

i = 20 cm/km

$$Q = A.S. \times D.F. = \frac{6{,}000 * 25}{24 * 60 * 60} \qquad \therefore Q = 1.736\ m^3/sec$$

$A = b\,y + 2 * (0.5 * y * y)$



$\therefore A = b\,y + y^2$

For i > 10 cm/km, assume b ≤ 2 m, *then:* y = b

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

$\& \ P = b + 2\,(y^2 + y^2)^{½}$

$\therefore P = y + 2.828\,y = 3.828\,y$

$$\therefore R = \frac{A}{P} = \frac{2 * y^2}{3.828\,y} = 0.52\,y$$

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

Assume, $S = i = 20 / 10^{-5} = 2 * 10^{-4}$ & 1 / n = 33

$$1.736 = 33 * (0.52)^{\frac{2}{3}} * y^{\frac{2}{3}} * (2 * 10^{-4})^{\frac{1}{2}} * 2\,y^2$$

$y^{8/3} = 2.876 \qquad \therefore y = 1.49 \text{ m}$

$\therefore b = 1.49 \text{ m} < 2 \text{ m}$ O.K.

Take $b_m = 1.5$ m

$A_{calculated} = A_m$

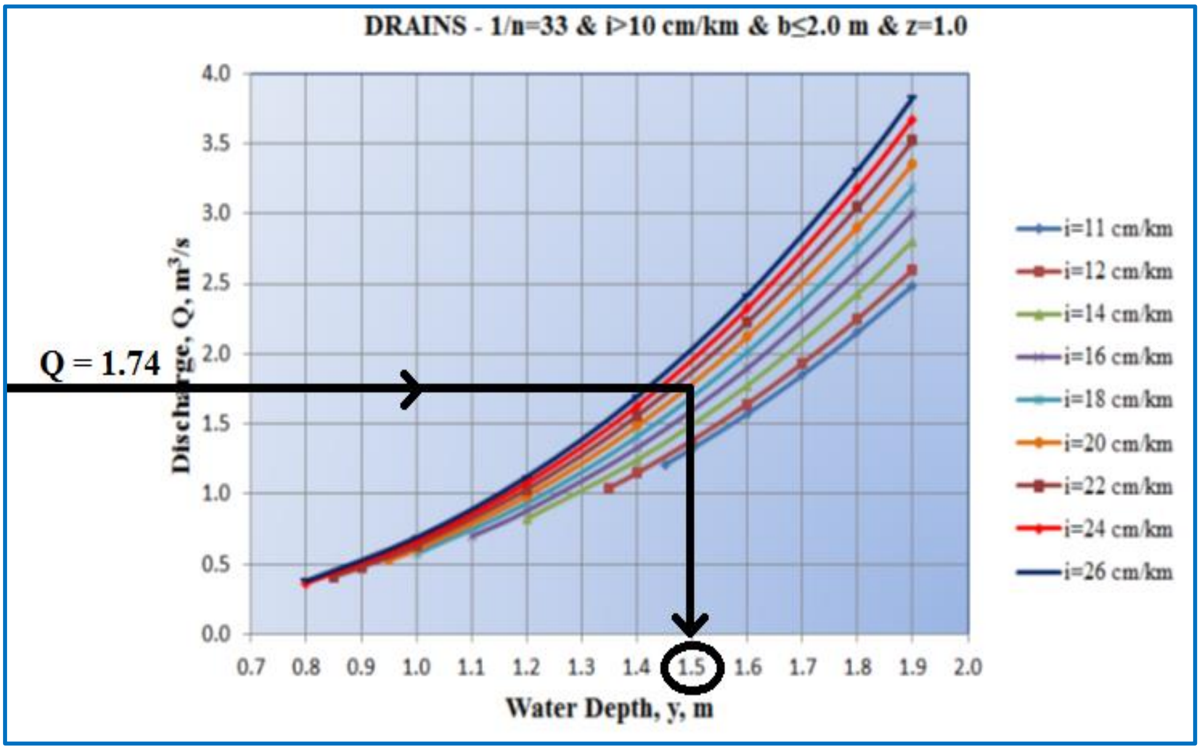
$\therefore b\,y + y^2 = b_m\,y_m + y_m^2$

$\therefore (1.49)^2 + (1.49)^2 = 1.5\,y_m + y_m^2$

$y_m^2 + 1.5\,y_m - 4.44 = 0$

$$\therefore y_m = \frac{-1.5 \pm [(1.5)^2 - (4 * 1 * -4.44)]^{1/2}}{2 * 1} = 1.49 \text{ m}$$

2) <u>Graphical Design via HAZEK Design Charts for Non-Silting Non-Scouring Sections</u>



<u>From the curve:</u> $y = 1.5$ m

For $i > 10$ cm/km, assume $b \leq 2$ m, *<u>then:</u>* $y = b \qquad \therefore b = 1.5$ m

3) Analytical Design via HAZEK Design Equations for Non-Silting Non-Scouring Sections

$$Q = C\, y^{2.666}$$

From Table 1, for drains, b ≤ 2.0 m, z = 1, i = 20 cm/km ∴ C = 0.6057

$1.736 = 0.6057 * y^{2.666}$

$y = (1.736 / 0.6057)^{1/2.666}$

$y = 1.48 \approx 1.5$ m ∴ b = y = 1.5 m

4) Excel Design of Best Hydraulic Sections

Steps	***Solution***
1- Select the sheet with the required z (z = 1 OR 1.5 OR 2).	z = 1
2- Enter the data: Section Number Water Surface Slope "i" (cm/km) Bed Slope "*S = i*" (m/m) Discharge "*Q*" (m^3/sec) 1 / Manning Coefficient "*1 / n*"	Sec No: 1 i = 20 cm/km $S = i = 2*10^{-4}$ Q = 1.736 m^3/s 1/n = 33
3- Get the answers: Water Depth "y" (m) Bed Width "b" (m)	y = 1.56 m b = 1.28 m
4- Modify b to the nearest 0.5 m and get the modified solution. Modified Bed Width "b_m" (m) Modified Water Depth "y_m" *(m)*	b_m = 1.3 m y_m = 1.55 m
Velocity Option 5- Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec) Modified Water Depth "y_m" (m) Modified Bed Width "b_m" (m)	v = 0.39 m/s OK --- ---

The Excel file for design can be downloaded from: www.bu.edu.eg/staff/alaaalhathek3

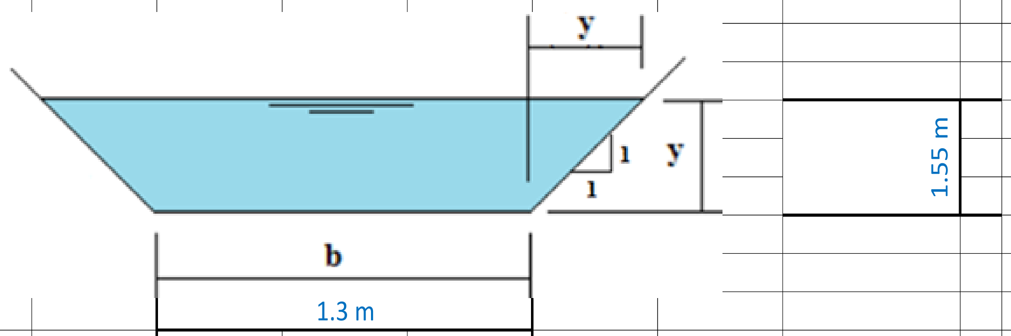
Best Hydraulic Trapezoidal Sections for Open Channels

z = 1

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

Manning Equation

Given	Section 1	Section Number
	20	Water Surface Slope "i" (cm/km)
	0.0002	Bed Slope "$S = i$" (m/m)
	1.736	Discharge "Q" (m^3/sec)
	33	1 / Manning Coefficient "$1/n$"
	For Best Hydraulic Section	x' = T / 2 & z = 1 & b = 0.82 y
	Basic Solution	
Basic Solution	1.5561	Water Depth "y" (m)
	1.2760	Bed Width "b" (m)
	4.406993977	Cross Sectional Area "A" (m^2)
	5.67973926	Wetted Perimeter "P" (m)
	0.77591484	Hydraulic Radius "$R = A / P$" (m)
	4.388182113	Top Width "T" (m)
	Additional Solution for Modified Bed Width (to nearest 0.05 m)	
Solution (Modified b)	4.406993977	Cross Sectional Area "A" (m^2)
	1.30	Modified Bed Width "b_m" (m)
	1.55	Modified Water Depth "y_m" (m)
	5.68	Modified Wetted Perimeter "P" (m)
	0.78	Modified Hydraulic Radius "$R = A / P$" (m)
	4.40	Top Width "T" (m)
OPTION	Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec)	
Solution accounting for the velocity	0.393919304	Velocity "v = Q / A" (m/sec)
		Modified Cross Sectional Area "A = Q / 0.9" (m^2)
		Modified Water Depth "y_m" (m)
		Modified Bed Width "b_m" (m)
		Modified Velocity "v" (m/sec)



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Thank you