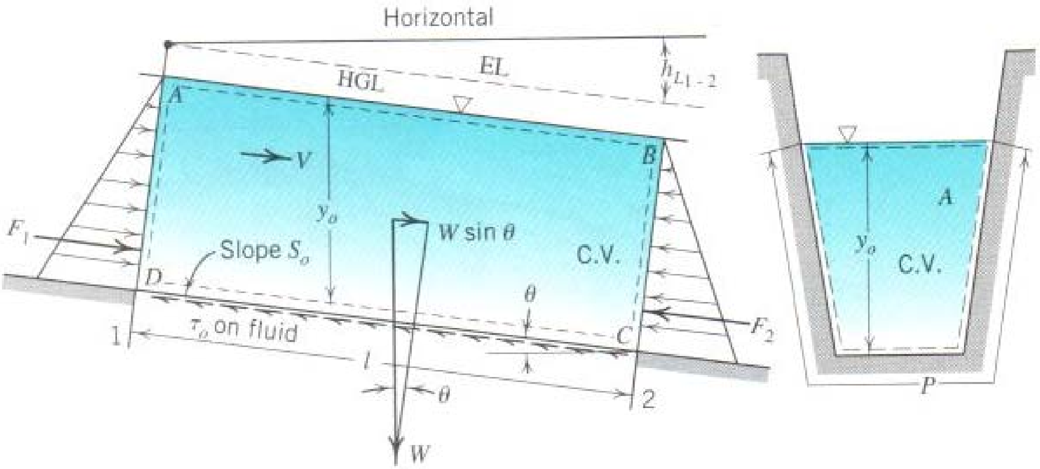
Ch. 7 Uniform Flow in Open Channels

7-2 Uniform Flow Equation



Contents

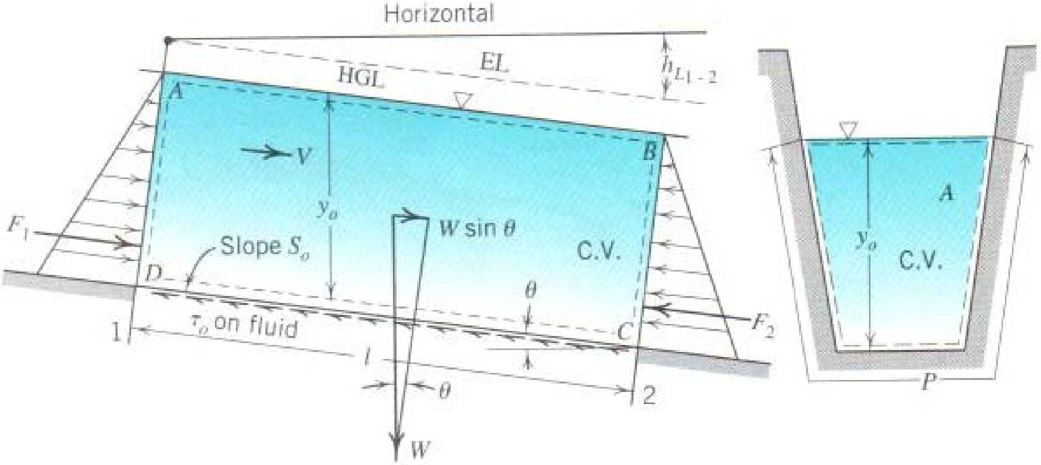
Class objectives

- Apply the Chezy and Manning’s to the uniform open channel flow problems
- Understand how to determine the channel efficiency

7.2 Uniform Flow – Chezy Equation

- Apply impulse-momentum eq. (Antonine de Chezy, 1775)

- For uniform flow, there is no change in momentum



- The force balance is given as

$$F_1 + W\sin\theta - F_2 - Pl\overline{\tau}_0 = 0$$

(P is wetted perimeter and l is length of channel)

Uniform flow – The Chezy equation

- Pressure forces on the cross sections are the same ($F_1 = F_2$)

Therefore, $W \sin\theta = Pl\bar{\tau}_0$

$W = A\gamma l; \sin\theta = h_L / l \approx \tan\theta = S_0$ (For unifrom flow and small slope)

$A\gamma l S_0 = Pl\bar{\tau}_0$

$$\boxed{\bar{\tau}_0 = \gamma \frac{A}{P} S_0 = \gamma R_h S_0}$$

$where\, R_h = \frac{A}{P}$ (hydraulic radius)

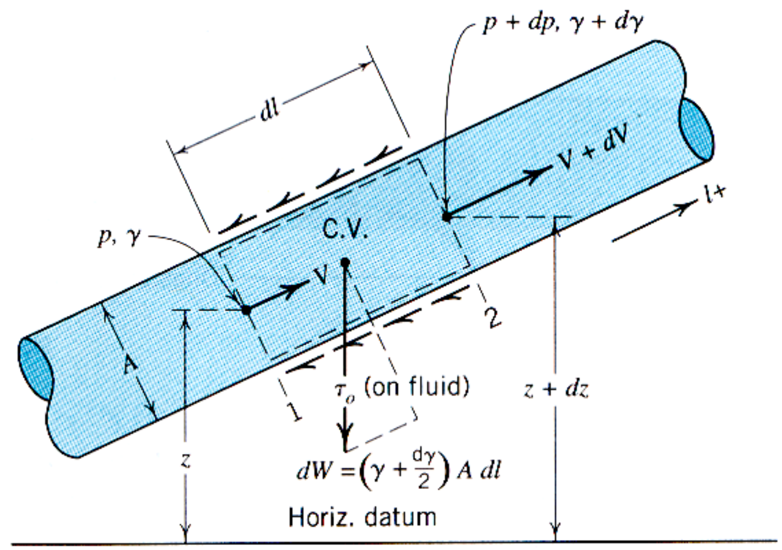
- In pipe flow, $\tau_0 = \frac{f}{8}\rho V^2$ (the shear stresses are same to above)
- Combining two

$$V = \sqrt{\frac{8g_n}{f}}\sqrt{R_h S_0}$$

$$\boxed{V = C\sqrt{R_h S_0}; \quad Q = CA\sqrt{R_h S_0} \quad \text{where } C = \sqrt{\frac{8g_n}{f}}}$$

[Re] Shear stress in pipe flow

(Ch. 7 & 9)



Apply impulse-momentum equation

between ① & ② (momentum changes)

$$\sum \vec{F} = Q\rho\left(\vec{V}_2 - \vec{V}_1\right)$$

Pressure force

$$pA - (p+dp)A - \tau_0 P dl - \left(\gamma + \frac{d\gamma}{2}\right) A dl \frac{dz}{dl}$$

$$= (V+dV)^2 A(\rho + d\rho) - V^2 A\rho$$

Shear force is included for real fluid.

Gravity force

in which $P =$ perimeter of the streamtube

For established incompressible flow, g is constant; $d\left(1/\gamma\right)=0$

$$d\left(\frac{p}{\gamma}+\frac{V^2}{2g}+z\right)=-\left(\frac{\tau_0 dl}{\gamma R_h}\right)$$

Integrating this between points 1 and 2 yields

$$\left(\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1\right)-\left(\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2\right)=\frac{\tau_0\left(l_2-l_1\right)}{\gamma R_h} \qquad (7.8)$$

Now, note that the difference between total heads is the drop in the energy line between points 1 and 2. Work-energy equation for real fluid flow is

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+h_{L_{1-2}} \qquad (7.9)$$

Comparing (7.8) and (7.9) gives

$$\boxed{h_{L_{1-2}} = \frac{\tau_0 \left(l_2 - l_1 \right)}{\gamma R_h}} \qquad (7.10)$$

BTW, Darcy-Weisbach's head loss equation is

$$\boxed{h_L = f \frac{l}{d} \frac{V^2}{2g}} \qquad (9.2)$$

Equations (7.10) and (9.2) are combined to give a basic relation between friction stress and friction factor; this is

$$\boxed{\tau_0 = \frac{f}{8} \rho V^2} \qquad (9.3)$$

7.3 Chezy Coefficient and the Manning's *n*

- Many laboratory and field experiments have been done so far to determine the magnitude of the Chezy coefficient *C*.
- The simplest relation and the most widely used is the result of the work of Manning (Robert Manning, UK engineer, 1890)
- The results may be summarized by the empirical relation

$$C = \frac{R_h^{1/6}}{n}$$

- Chezy-Manning equation (n's unit is $t^1 L^{-1/3}$)

$$V = \left(\frac{1}{n}\right) R_h^{2/3} S_0^{1/2}$$

- In general form (SI or US Customary)

$$\boxed{C = \frac{u R_h^{1/6}}{n} \qquad Q = \left(\frac{u}{n}\right) A R_h^{2/3} S_0^{1/2} \qquad (u = 1\ \ (SI),\ u = 1.49\ (U.S.))}$$

The Chezy Coefficient and the Manning's *n*

- The Manning *n* is obtained from the channel type and properties and some typical values are given in Table 5 in text book, pp. 438-439.
- There are no clear physical explanation for Chezy C or Manning *n*.
- Related with the friction factor *f* with *n*

$$C = \sqrt{\frac{8g_n}{f}}$$

$$\boxed{n = R_h^{1/6}\sqrt{\frac{f}{8g_n}}} \qquad n = fn(R_h, f) = fn(R_h, \mathrm{Re}, \frac{e}{d})$$

- In the channel, ***n*** is not an absolute roughness coefficient because it depends on the hydraulic radius, and must exhibit the same characteristics as the friction factor, which in turn depends on relative roughness and Reynolds number.

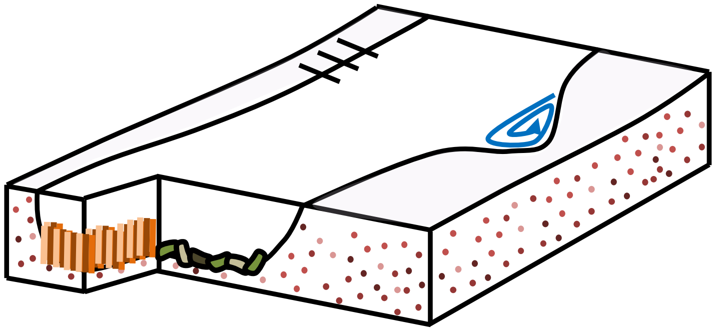
The Chezy Coefficient and the Manning's *n*

- For wholly rough channel, as R_h increases, f decreases, so that $\boldsymbol{n}$ may change gradually for a given boundary surface for increasing depths and flow rates.
- This coefficient is **empirical** to be determined with the theoretical explanation.

The Manning's *n*

Cowan (1956)

$$n = m_5(n_0 + n_1 + n_2 + n_3 + n_4)$$



A. Conduits

TABLE 5-6. VALUES OF THE ROUGHNESS COEFFICIENT n
(Boldface figures are values generally recommended in design)

Type of channel and description	Minimum	Normal	Maximum
A. CLOSED CONDUITS FLOWING PARTLY FULL			
A-1. Metal			
a. Brass, smooth	0.009	0.010	0.013
b. Steel			
1. Lockbar and welded	0.010	0.012	0.014
2. Riveted and spiral	0.013	0.016	0.017
c. Cast iron			
1. Coated	0.010	0.013	0.014
2. Uncoated	0.011	0.014	0.016
d. Wrought iron			
1. Black	0.012	0.014	0.015
2. Galvanized	0.013	0.016	0.017
e. Corrugated metal			
1. Subdrain	0.017	0.019	0.021
2. Storm drain	0.021	0.024	0.030
A-2. Nonmetal			
a. Lucite	0.008	0.009	0.010
b. Glass	0.009	0.010	0.013
c. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
d. Concrete			
1. Culvert, straight and free of debris	0.010	0.011	0.013
2. Culvert with bends, connections, and some debris	0.011	0.013	0.014
3. Finished	0.011	0.012	0.014
4. Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
5. Unfinished, steel form	0.012	0.013	0.014
6. Unfinished, smooth wood form	0.012	0.014	0.016
7. Unfinished, rough wood form	0.015	0.017	0.020
e. Wood			
1. Stave	0.010	0.012	0.014
2. Laminated, treated	0.015	0.017	0.020
f. Clay			
1. Common drainage tile	0.011	0.013	0.017
2. Vitrified sewer	0.011	0.014	0.017
3. Vitrified sewer with manholes, inlet, etc.	0.013	0.015	0.017
4. Vitrified subdrain with open joint	0.014	0.016	0.018
g. Brickwork			
1. Glazed	0.011	0.013	0.015
2. Lined with cement mortar	0.012	0.015	0.017
h. Sanitary sewers coated with sewage slimes, with bends and connections	0.012	0.013	0.016
i. Paved invert, sewer, smooth bottom	0.016	0.019	0.020
j. Rubble masonry, cemented	0.018	0.025	0.030

B. Lined channels

C. Excavated channel

D. Natural streams

TABLE 5-6. VALUES OF THE ROUGHNESS COEFFICIENT *n* (*continued*)

Type of channel and description	Minimum	Normal	Maximum
C. EXCAVATED OR DREDGED			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
D. NATURAL STREAMS			
D-1. Minor streams (top width at flood stage <100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Natural streams

TABLE 5 Manning n-values[9]

Type of Conduit	Minimum	Normal	Maximu
Pipes flowing partly full			
Welded steel	0.010	0.012	0.014
Coated cast iron	0.010	0.013	0.014
Corrugated metal	0.021	0.024	0.030
Cement mortar lined (neat)	0.010	0.011	0.013
Concrete culvert (finished)	0.011	0.012	0.014
Concrete pipe (steel form)	0.012	0.013	0.014
Vitrified clay	0.011	0.014	0.017
Drainage tile	0.011	0.013	0.017

TABLE 5 (Continued)

Type of Conduit	Minimum	Normal	Maximum
Lined open channels			
Smooth steel	0.011	0.012	0.014
Wood (planed)	0.010	0.012	0.014
Wood (unplaned)	0.011	0.013	0.015
Cement (neat)	0.010	0.011	0.013
Concrete (troweled)	0.011	0.013	0.015
Concrete (float finish)	0.013	0.015	0.016
Concrete (unfinished)	0.014	0.017	0.020
Gunite	0.016	0.019	0.023
Brick	0.012	0.015	0.018
Rubble masonry	0.017	0.025	0.030
Asphalt (smooth)	—	0.013	—
Asphalt (rough)	—	0.016	—
Unlined open channels			
Earth, straight and uniform, clean	0.016	0.018	0.020
Earth, straight and uniform, short vegetation	0.022	0.027	0.033
Earth, winding and sluggish, clean	0.023	0.025	0.030
Earth, winding, sluggish, short vegetation	0.025	0.030	0.033
Gravel, straight and uniform, clean	0.022	0.025	0.030
Dredged, clean	0.025	0.028	0.033
Rock cuts, smooth and uniform	0.025	0.035	0.040
Rock cuts, jagged and irregular	0.035	0.040	0.050
Natural channels			
Clean, straight, no riffles or pools	0.025	0.030	0.033
Clean, winding, some pools and shoals	0.033	0.040	0.045
Sluggish, weedy, deep pools	0.050	0.070	0.080
Mountain streams, gravel, cobbles	0.030	0.040	0.050
Mountain streams, cobbles, large boulders	0.040	0.050	0.070
Flood plains, pasture	0.025	0.030	0.035
Flood plains, light brush and trees	0.035	0.050	0.060
Flood plains, heavy stand of timber	0.080	0.100	0.120

IP 10.1 (p. 440)

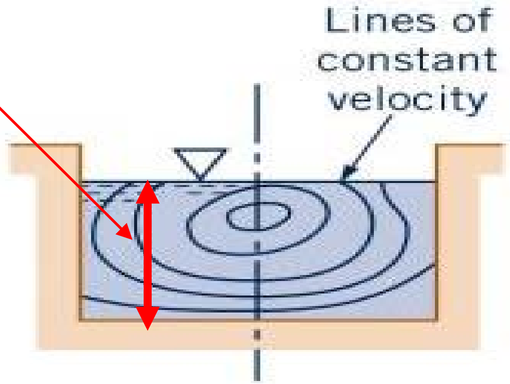
- Rectangular channel lined with asphalt is 20 ft wide and laid on a slope of 0.0001. Calculate the depth of uniform flow (normal depth) in this channel when the flowrate is 400 ft³/s.

$$Q = \left(\frac{1.49}{n}\right) A R_h^{2/3} S_0^{1/2}$$

$$B = 20\,ft \quad S_0 = 0.0001\,ft/ft \quad Q = 400\,ft^3/s$$

$$P = 20 + 2y_0\,ft \quad A = 20y_0\,ft^2$$

$$R_h = \frac{A}{P} = \frac{20y_0}{20+2y_0}\,ft$$



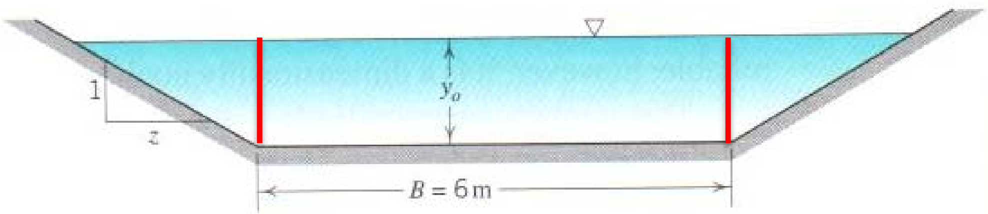
$$400 = \left(\frac{1.49}{0.013}\right)(20y_0)\left(\frac{20y_0}{20+2y_0}\right)^{2/3}(0.0001)^{1/2}$$ (n in Table 5)

$$y_0\left(\frac{20y_0}{20+2y_0}\right)^{2/3} = 17.45 \qquad y_0 = 6.85\,ft$$

y_0 is different depending on the roughness and slope for a given discharge

I.P. 10.2 (pp.440-441)

- A concrete-lined canal with an *n*-value of 0.014 is constructed on a slope 0.33 m/km and conveys 23 m^3/s of water. Find the uniform flow depth if the canal is trapezoidal in cross section with a bottom with of *B*=6 m and side slopes of *z* =1.5.



$$Q = \left(\frac{1}{n}\right) A R_h^{2/3} S_0^{1/2}$$

$$B = 6\,m \quad S_0 = 0.00033 \quad Q = 23\,m^3/s$$

$$P = 6 + 2\sqrt{1+1.5^2}\; y_0 = 6 + 3.61 y_0\; m$$

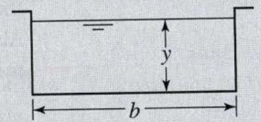
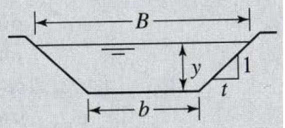
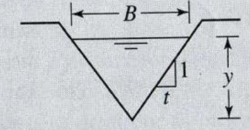
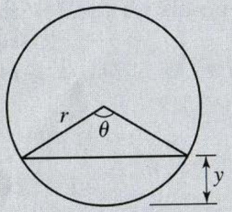
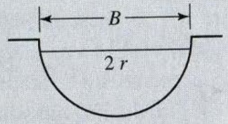
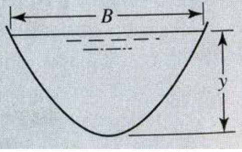
$$A = 6y_0 + 2\left[\frac{1}{2}\left(y_0 \times 1.5 y_0\right)\right] = 6y_0 + 1.5y_0^2\; m^2$$

$$R_h = \frac{A}{P} = \left(\frac{6y_0 + 1.5y_0^2}{6 + 3.61y_0}\right) m$$

$$23 = \left(\frac{1}{0.014}\right)\left(6y_0 + 1.5y_0^2\right)\left(\frac{6y_0 + 1.5y_0^2}{6 + 3.61y_0}\right)^{2/3} 0.00033^{1/2}$$

$$y_0 = 1.77\,m$$

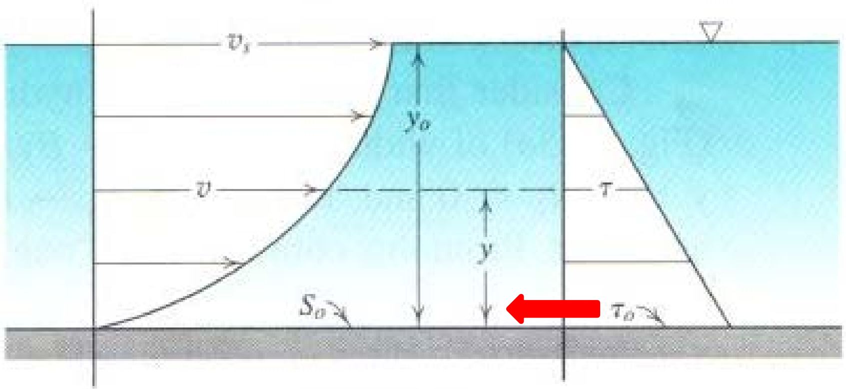
TABLE 10.1 Properties and Geometric Elements of Typical Channel Cross Sections

Section	Area, A	Wetted Perimeter, P	Hydraulic Radius, R	Top Width, B	Hydraulic Depth, D	Cross Section
Rectangular	by	$b + 2y$	$by/(b + 2y)$	b	y	
Trapezoidal	$(b + ty)y$	$b + 2yw$, $w = (1 + t^2)^{0.5}$	A/P	$b + 2ty$	A/B	
Triangular	ty^2	$2yw$	$ty/(2w)$	$2ty$	A/B	
Circular	$(\theta - \sin\theta)\dfrac{d^2}{8}$	$r\theta$	$\left(1 - \dfrac{\sin\theta}{\theta}\right)d/4$	$2r\sin(\theta/2)$	A/B	 $\theta = 2\cos^{-1}\left(1 - 2\dfrac{y}{d}\right)$
Semicircular	$\pi r^2/2$	πr	$r/2$	$2r$	$\pi r/4$	
Parabolic Section	$2/3By$	$B + (8/3)y^2/B$*	$2B^2y/(3B^2 + 8y^2)$	$3A/(2y)$	$2/3y$	

*Approximation for the interval $0 < \frac{4y}{B} \leq 1$

7.4 Uniform Laminar Flow

- Laminar flow ($\mathrm{Re} = \dfrac{V y_0}{\nu} < 500$) in open channels occurs in drainage from streets, airport runaways, parking areas, and so forth.
- Infinite width with resistance only at the bottom of the sheet flow.
- The flow is a two-dimensional one.



- Parabolic velocity profile and linear shear stress profile.
- The hydraulic radius consists only with bottom.

$$Eq.(9.6):\ \frac{v}{v_*}=\frac{v_*}{\nu}\left(y-\frac{y^2}{2y_0}\right)$$

$$R_h = A/P = by_0/b = y_0$$

$$\tau_0=\gamma y_0 S_0=\mu\left.\frac{dv}{dy}\right|_{y=0}=2\mu\frac{v_s}{y_0}$$

$$V=\frac{2}{3}v_s=\frac{gy_0^2S_0}{3\nu}$$

$$v_s=v|_{y=y_0}=\frac{v_*^2}{2\nu}y_0=\frac{1}{2\nu}gy_0^2S_0$$

$$\frac{dv}{dy}=\frac{v_*^2}{\nu}\left(1-\frac{y}{y_0}\right)$$

$$v_*=\sqrt{\frac{\tau_0}{\rho}}=\sqrt{gy_0S_0}$$

$$\left.\frac{dv}{dy}\right|_{y=0}=\frac{v_*^2}{\nu}=\frac{2v_s}{y_0}$$

- The limit of laminar flow is determined by an experimentally determined critical Reynolds number (~500).

$$\mathrm{Re}=\frac{Vy_0}{\nu}=\frac{g_n y_0^3 S_0}{3\nu^2}\quad and\quad \boxed{V=\frac{g_n\sqrt{S_0}\,y_0^{3/2}}{3\nu}\sqrt{y_0S_0}}$$

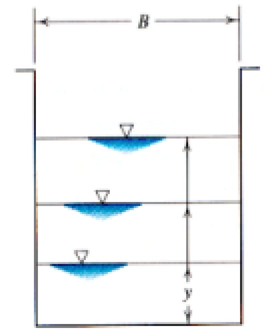
Therefore, $\boxed{C=\sqrt{g_n\,\mathrm{Re}/3}}$

Laminar case

7.5 Hydraulic Radius Considerations

- The <u>variation of hydraulic radius with depth</u> is important in open channel flow.

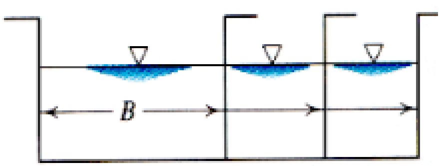
1) Rectangular section



– In the case of <u>narrow deep sections</u>,

$$R_h = \frac{By}{\cancel{B} + 2y} \cong \frac{B}{2}$$

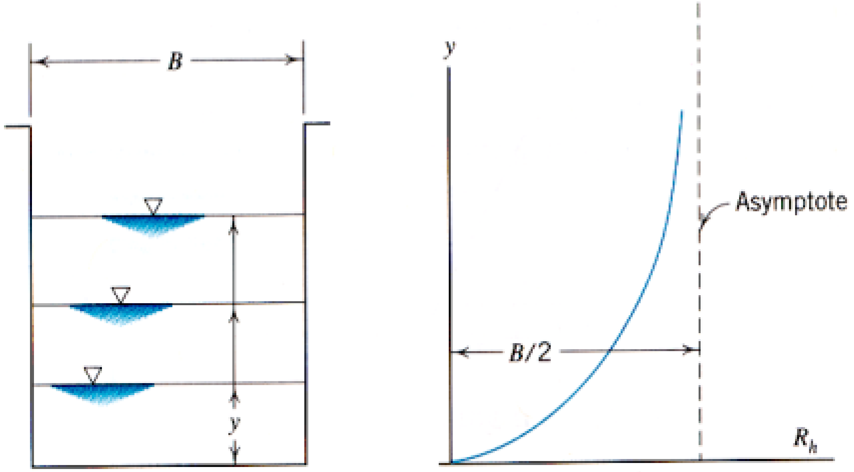
– In the case of <u>wide shallow sections</u>,



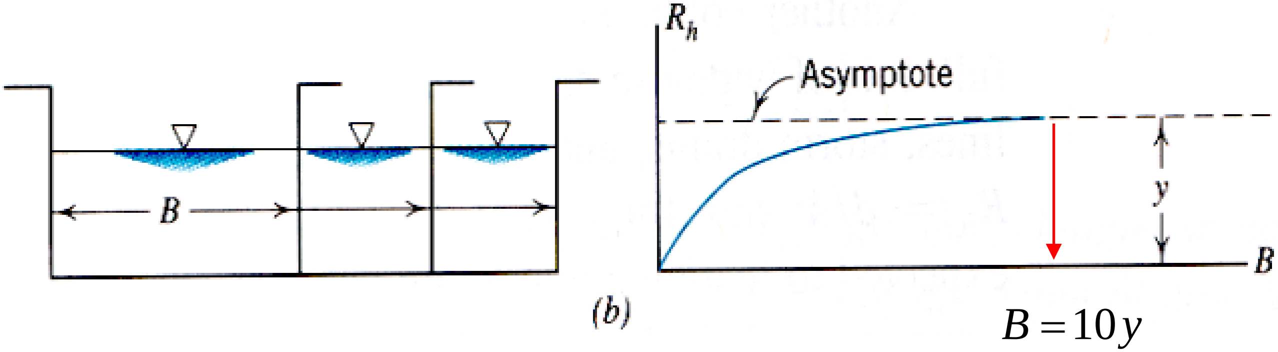
$$R_h = \frac{By}{B + \cancel{2y}} \cong y$$

– The assumption of a wide section is valid only when $\boxed{\frac{B}{y} > 10}$

i) Narrow deep section



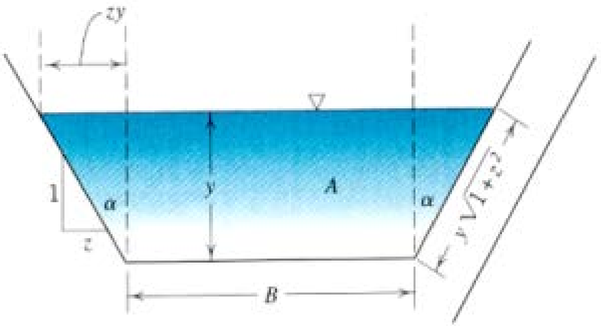
ii) Wide shallow section



$$B = 10y$$

2) Trapezoidal section

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

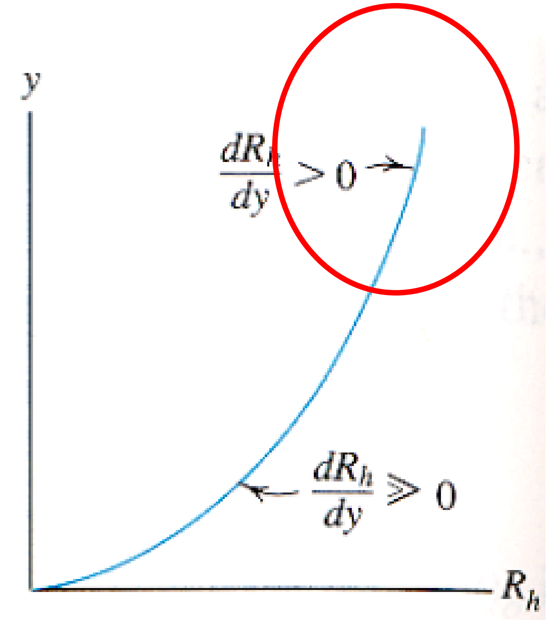


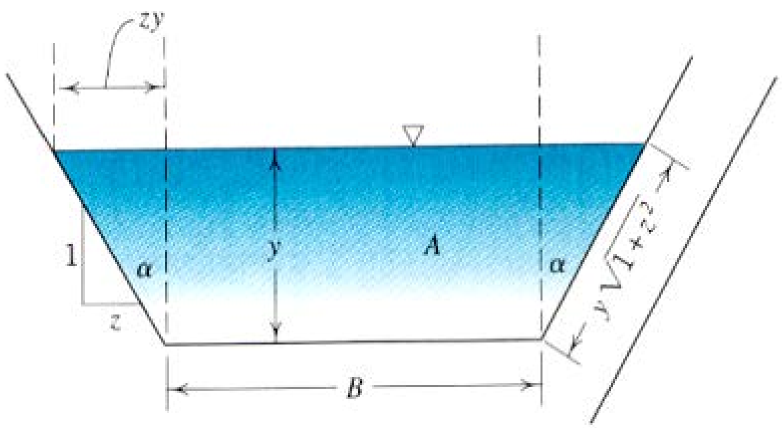
– The derivative of R_h with respect to y will allow the relationship between R_h and y

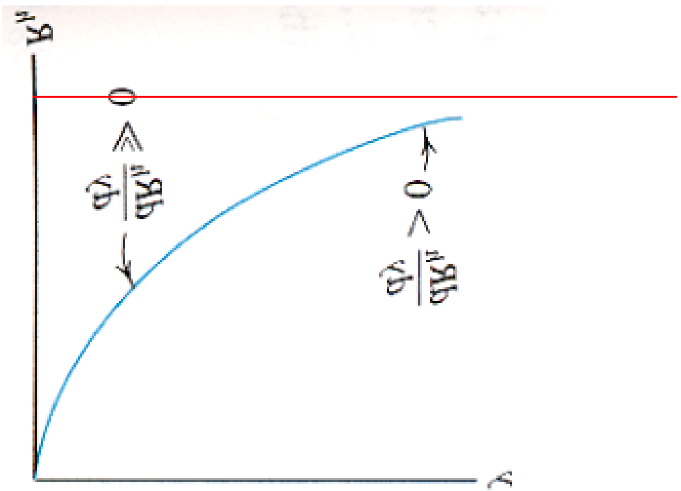
$$\frac{dR_h}{dy} = \frac{1 + 2z(y/B)\left[1 + (y/B)\sqrt{1+z^2}\right]}{1 + 4\sqrt{1+z^2}(y/B)\left[1 + (y/B)\sqrt{1+z^2}\right]}$$

– The denominator is larger than the numerator $\rightarrow \frac{dR_h}{dy} < 1$

- $\frac{dR_h}{dy}$ diminishes with increasing *y*
- $\frac{dR_h}{dy}$ does not approach zero as *y* approaches infinity $\rightarrow$ no asymptote







3) Circular pipe flowing partially full

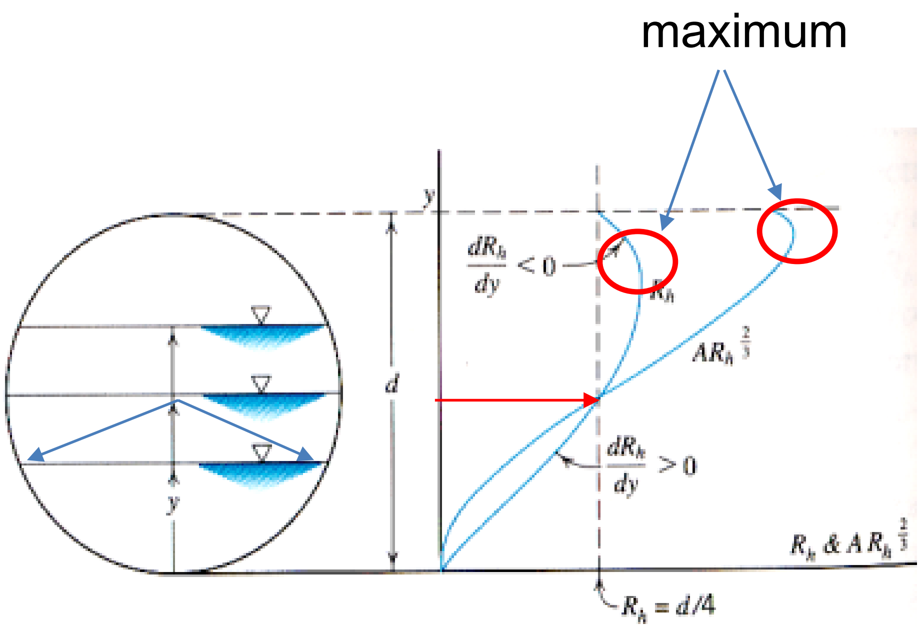
- Sewer pipes, storm drains, culverts

$$R_h = \frac{A}{P} = \frac{d}{4} \text{(y=d/2 or completely full)}$$

$$For\ y = 0, R_h = 0$$

- Continuous variation of R_h with y is expected to feature a maximum value

- Variation of $AR_h^{2/3}$ with y is also important → maximum flowrate is achieved before pipe is full

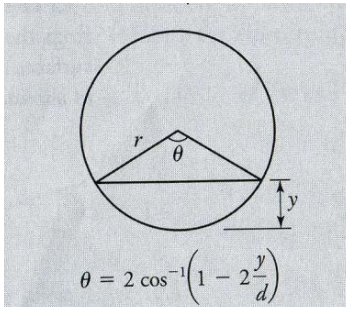


Hydraulic characteristic curve

$$Q = \left(\frac{1}{n}\right) AR_h^{2/3} S_0^{1/2}$$

$$R_h = \frac{d}{4}\left(1 - \frac{\sin\theta}{\theta}\right)$$

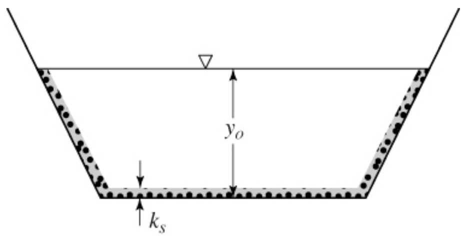
$$P = \frac{d}{2}\theta;\ A = (\theta - \sin\theta)\frac{d^2}{8}$$



Best hydraulic section (channel efficiency)

$$Q = \left(\frac{1}{n}\right) A R_h^{2/3} S_0^{1/2};\ R_h = \frac{A}{P}$$

$$\boxed{P \downarrow \rightarrow R_h \uparrow \rightarrow Q \uparrow}$$

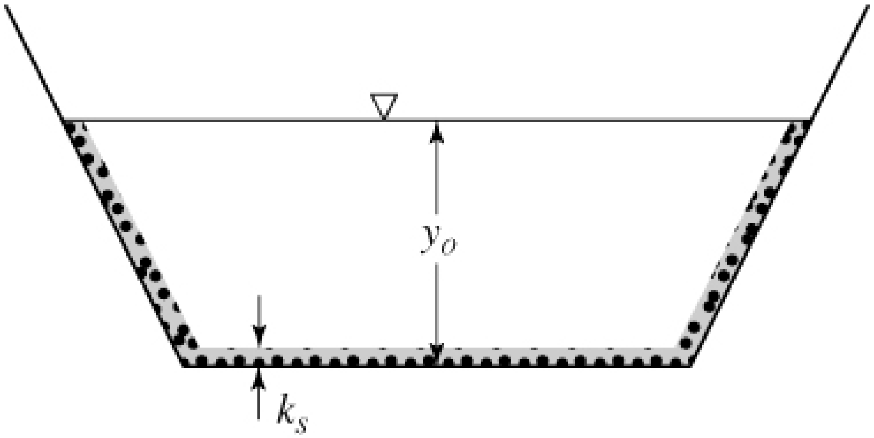


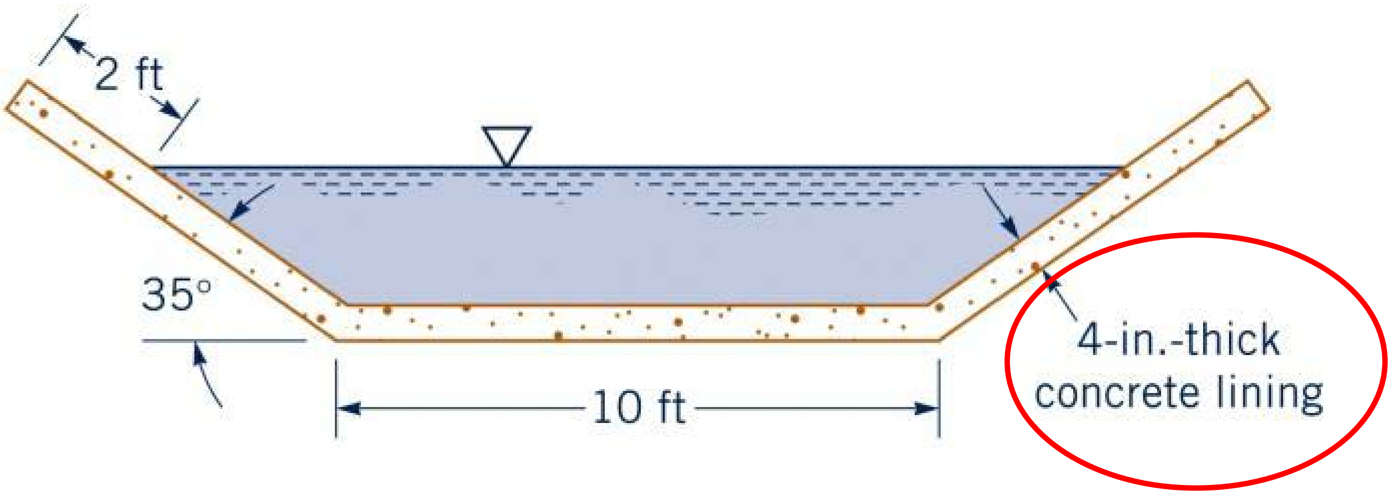
- For open channels, another important engineering problem of section geometry is the reduction of boundary resistance by minimizing of the wetted perimeter for a given area of flow section.
- With A fixed, $R_h = A/P$, and, with P to be minimized, this may be considered a problem of maximization of the hydraulic radius.
- This reduces the cost of lining (most economical section), and maximizes the flowrate.
- For this reason, a section of maximum hydraulic efficiency is known as the **most efficient section** or the **best hydraulic section**.

- There is no generalized solution for all possible section shapes.

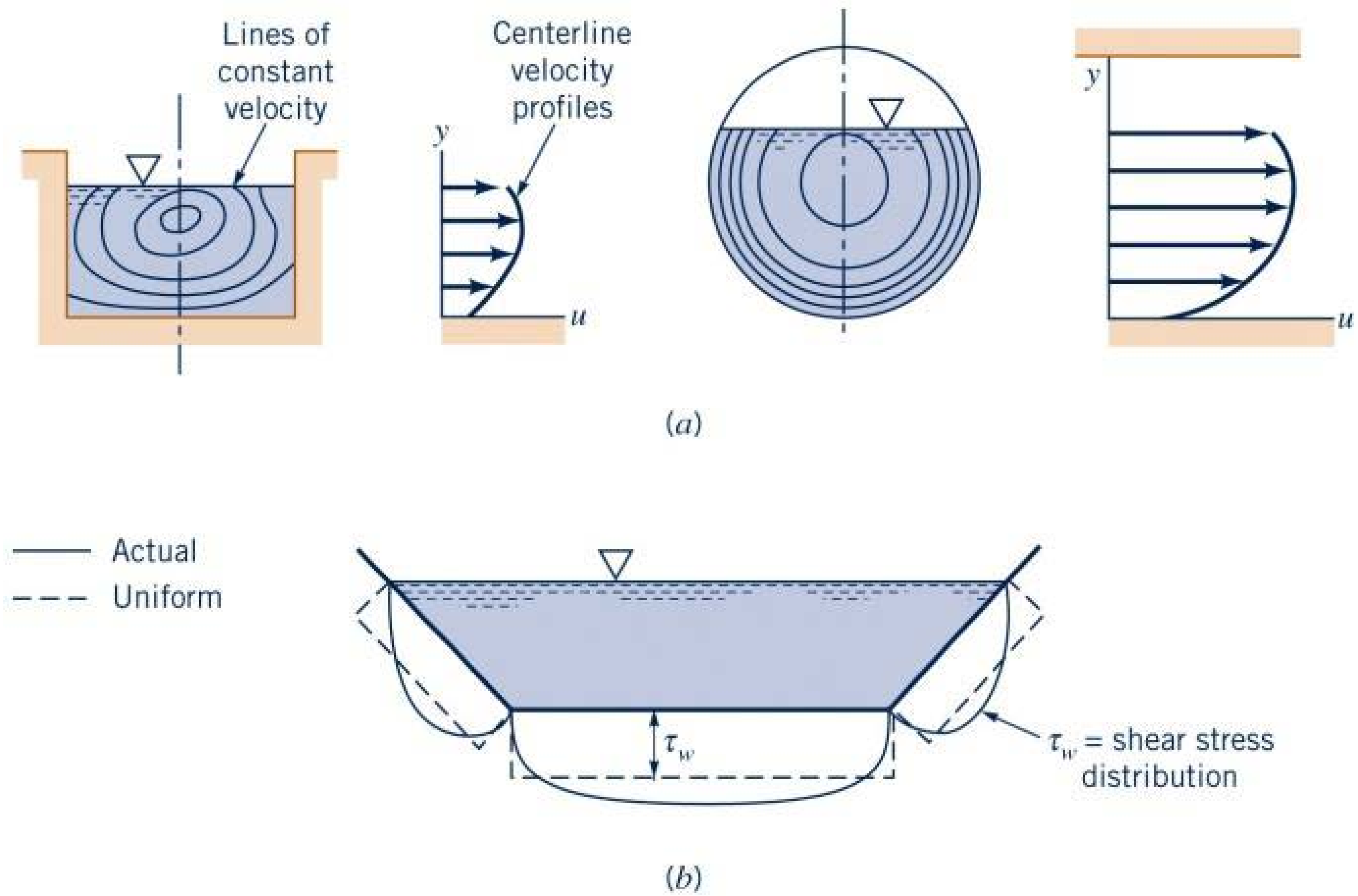
Friction in open channel

- Open channel flow has **free surface (no friction)** and **walls (friction),** this unbalance produces velocity distribution in channel





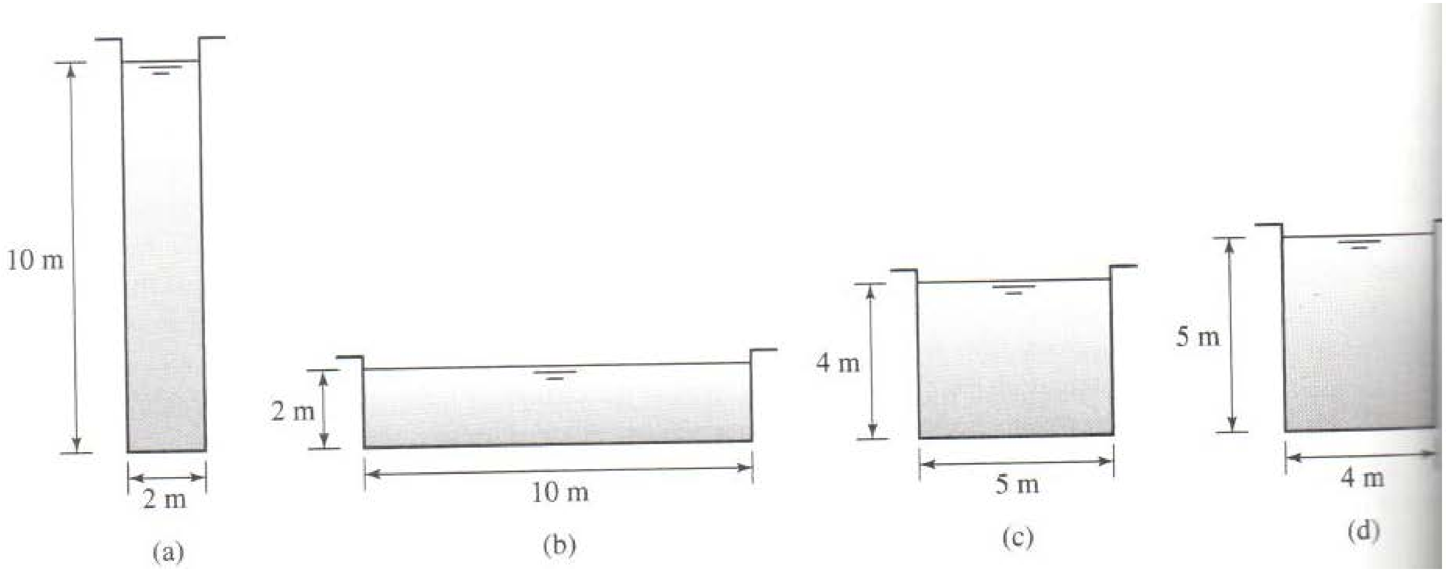
Friction in open channel



Channel Efficiency

- The following channels have <u>the same cross-sectional area of 20 m^2</u>. But, they have **<u>different wetted perimeter</u>**. Maybe the <u>case of (c)</u> has the <u>minimum wetted perimeter</u> and hence will encounter <u>least energy loss.</u>

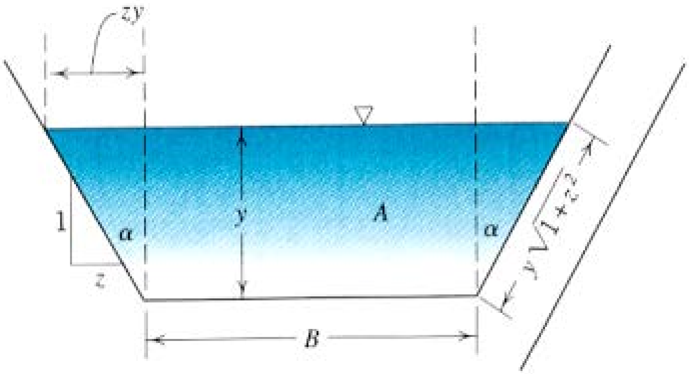
P=22 m P=14 m P=13 m P=14 m



Channel Efficiency

- **Trapezoidal sections**

- It is a simple matter to develop geometric relationships to minimize the wetted perimeter.



$$A = By + zy^2 \rightarrow B = \frac{A - zy^2}{y} = \frac{A}{y} - zy \leftarrow \text{eleminate B}$$

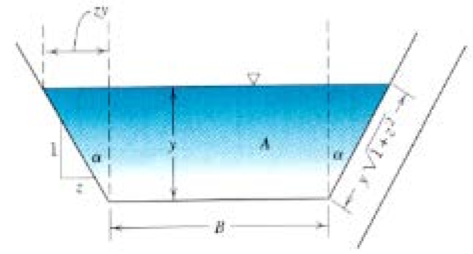
$$P = B + 2y\left(1+z^2\right)^{1/2} = \frac{A}{y} - zy + 2y\left(1+z^2\right)^{1/2}$$

$$R_h = \frac{A}{P} = \frac{A}{\frac{A}{y} - zy + 2y\left(1+z^2\right)^{1/2}}$$

A is constant

Differentiating R_h wrt y and equating the result to zero gives

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



$$A = y^2\left(2\sqrt{1+z^2} - z\right); B = 2y\left(\sqrt{1+z^2} - z\right)$$

$$\Rightarrow \boxed{R_{h_{\max}} = \frac{y}{2}}$$

→ For best hydraulic section of trapezoidal channel, its hydraulic radius is close to one-half of the flow depth.

In the case of **rectangular sections** ($z = 0$)

$$R_{h_{\max}} = \frac{y}{2}$$

$$A = 2y^2$$

$$\boxed{B = 2y}$$

→ For best hydraulic section of rectangular channel, its flow depth is one-half of the width of the channel.

IP 10.3 (pp. 445-446)

Find the dimensions of the most-efficient cross section for a rectangular channel that is to convey a uniform flow of 10m^3/s if the channel is lined with Gunite concrete and is laid on a slope of 0.0001.

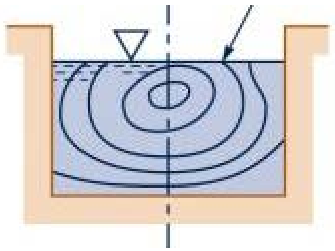
[Sol] For the most efficient cross section, the hydraulic radius R_h is one-half the depth, and, the area is given by $2y_0^2$. Substituting this information into Chezy and Manning equation

$$Q = \left(\frac{u}{n}\right) A R_h^{2/3} S_0^{1/2} = \left(\frac{u}{n}\right)\left(2y_0^2\right)\left(\frac{y_0}{2}\right)^{2/3} S_0^{1/2}$$

- From the Table 5 (in text book), the *n*-value for a Gunite-lined channel is 0.019 and for SI *u*=1.

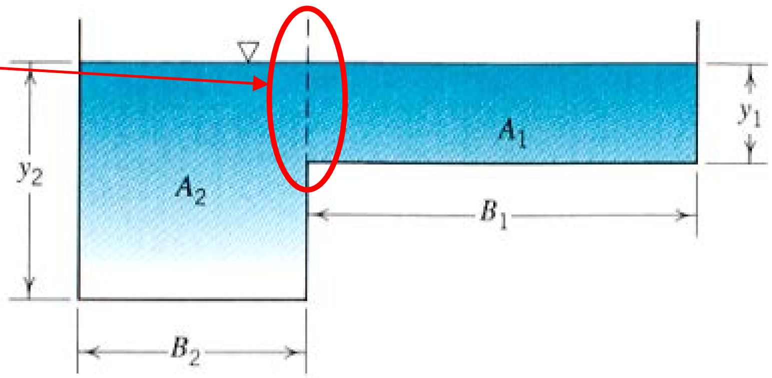
$$10 = \left(\frac{1.0}{0.019}\right)\left(2y_0^2\right)\left(\frac{y_0}{2}\right)^{2/3} (0.0001)^{1/2}$$

$$y_0^{8/3} = 15.1 \qquad y_0 = 2.77 \quad B = 2y_0 = 5.54$$



Compound channel

- Consider them composed of parallel channels separated by the vertical dashed line (with zero resistance)



$$Q = Q_1 + Q_2$$

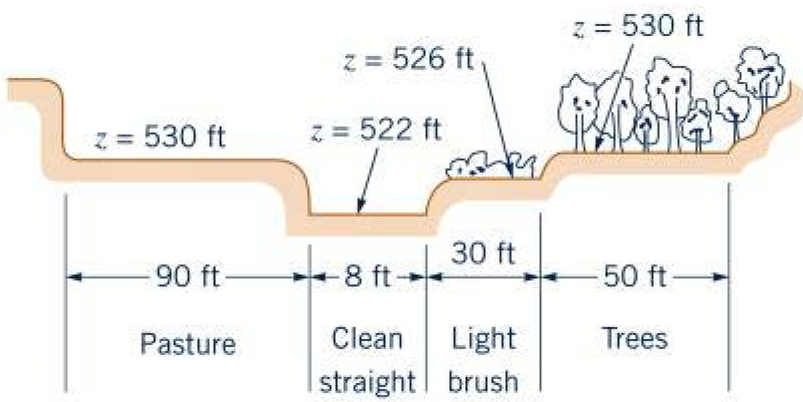
$$Q = \left(\frac{u}{n_1}\right) A_1 R_{h_1}^{2/3} S_0^{1/2} + \left(\frac{u}{n_2}\right) A_2 R_{h_2}^{2/3} S_0^{1/2}$$

$$A_1 = B_1 y_{0_1}$$

$$A_2 = B_2 y_{02}$$

$$P_1 = B_1 + y_{0_1}$$

$$P_2 = B_2 + 2y_{0_2} - y_{0_1}$$



z = 530 ft
z = 526 ft
z = 530 ft
z = 522 ft
90 ft
8 ft
30 ft
50 ft
Pasture
Clean straight
Light brush
Trees

관목 vs 교목

Homework Assignment No. 5

Due: 1 week from today

Answer questions either in Korean or in English

1. (10-2) Water flows uniformly at a depth of 1.2 *m* in a rectangular canal 3 *m* wide, laid on a slope of 1 *m* per 1,000 *m*. What is the mean shear stress on the sides and bottom of the canal?

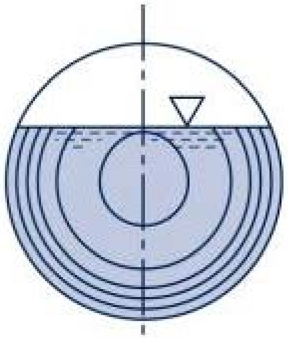
2. (10-8) Calculate the uniform flowrate in an earth-lined (n = 0.020) trapezoidal canal having bottom width 3 *m*, sides sloping 1 (vert.) on 2 (horiz.), laid on a slope of 0.0001, and having a depth of 1.8 *m*.

3. (10-15) At what depth will 4.25 m^3/s flow uniformly in a rectangular channel 3.6 m wide lined with rubble masonry and laid on a slope of 1 in 4000?

4. (10-20) A trapezoidal canal of side slopes 1 (vert.) on 2 (horiz.) and having $n = 0.017$ is to carry a uniform flow of 37 m^3/s on a slope of 0.005 at a depth of 1.5 m. What base width is required?

5. (10-25) Water (20 ^oC) flows uniformly in a channel at a depth of 0.009 m. Assuming a critical Reynolds number of 500, what is the largest slope on which *laminar flow* can be maintained? What mean velocity will occur on this slope?

6. (10-33) What uniform flowrate occurs in a 1.5 *m* circular brick conduit laid on a slope of 0.001 when the depth of flow is 1.05 *m*? What is the mean velocity of this flow?



7. (10-36) A channel flow cross section has an area of 18 m^2. Calculate its best dimensions if (*a*) rectangular, and (*b*) trapezoidal with 1 (vert.) on 2 (horiz.) side slopes.

8. (10-42) What is the minimum slope at which 5.67 m^3/s may be carried uniformly in a rectangular channel (having a value of *n* of 0.014) at a mean velocity of 0.9 m^3/s.

9. (10-45) This flood channel has a Manning *n* of 0.017 and a slope of 0.0009. Estimate the depth of uniform flow for a flowrate of 1,200 *cfs*.