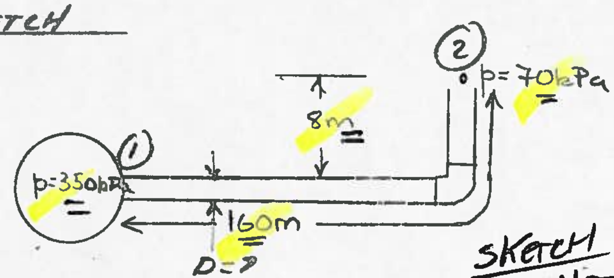
CE 3305 Fluid Mechanics
Exam 3
Spring 2014

1. The pressure at a water main is 350 kPa gage. What diameter of galvanized-steel pipe is required to carry water from the main at a rate of 0.025 m^3/s to a customer that is 160 meters from the main. Assume the required pressure at the meter (the customer's location) is 70 kPa gage at a point 8 meters above the main connection.[1]

SKETCH



$Q = 0.025 m^3/s$

$k_s = 0.15 mm$ (TABLE 10.4)

2 pts

SKETCH 4PTS

EQUATIONS

ENERGY + MOODY CHART

SOLUTION

$$\frac{p_1}{\gamma} + \cancel{\frac{V_1^2}{2g}} + z_1 = \frac{p_2}{\gamma} + \cancel{\frac{V_2^2}{2g}} + z_2 + h_f \quad 2 \text{ pts}$$

1 pts $\rightarrow V_1 = V_2$

OK TO NEGLECT MINOR LOSS

$$\frac{350\,000 \text{ Pa}}{9800 N/m^3} = \frac{70{,}000 \text{ Pa}}{9800 N/m^3} + 8 + f\frac{L}{D}\frac{Q^2}{A^2}\frac{1}{2g} + K_b\frac{Q^2}{A^2}\cdot\frac{1}{2g} \quad 2 \text{ pts}$$

$$20.54 = \left(f\frac{L}{D}\frac{1}{2g} + \frac{K_b}{2g}\right)\frac{16Q^2}{\pi^2 D^4} \Rightarrow \text{BUILD A TABLE}$$

1 pts

1st NEED CONSTANTS

$L = 160 m$

$K_b = 0.9$ (TABLE 10.5)

$g = 9.8 m/s^2$

$Q = 0.025$

[1] Chapter 10, Chapter 14

Problem 1 (Continued)

$$20.54 = f\frac{L}{D}\frac{1}{2g}\frac{4Q^2}{\pi^2 D^4} + \frac{K_b}{2g}\frac{4Q^2}{\pi^2 D^4}$$

$$\frac{4Q^2}{\pi^2} = 0.0002533$$

$$= \frac{f(8.1633)(0.0002533)}{D^5}$$

$$\frac{K_b}{2g} = \frac{0.9}{2(9.8)} = 0.0459$$

$$+\frac{(0.0459)(0.0002533)}{D^4}$$

$$\frac{L}{2g} = \frac{160}{2(9.8)} = 8.1633$$

		A	B		
D(m)	f_{guess}	$\frac{f(8.1633)(0.0002533)}{D^5}$	$\frac{(0.0459)(0.0002533)}{D^4}$	A+B	GOAL(20.54)
0.101	0.02	4.13	0.11	4.25	20.54 D↓
0.01	0.02	413555	1163	414718	20.54 D↑
0.05	0.02	132	1.86	134	20.54 D↑
0.06	0.02	53	0.89	53.89	20.54 D↑
0.07	0.02	24.6	0.48	25.09	20.54 D↑
0.073	~~0.02~~ 0.024	19.9	0.4	~~20.35~~ 24.34	≈close 20.54 ✓ MAKE D↑
	NOW CHECK Re TO REVISE f				
0.0755	0.024	20.22	0.357	20.58	20.54
					GOOD

$\nu = 1.31 \cdot 10^{-6}\ m^2/s$ 2pts

$Re_d = \frac{V \cdot D}{\nu} = 332855$ $3.3 \cdot 10^5$

$k_s/D = \frac{0.00015}{0.073} = 0.002$ $f \approx 0.024$

D = 0.0755

D = 75mm 2pts # + UNIB

(7–10 cm ACCEPTABLE)

REVISION A

16 pts TOTAL

OK IF USE f EQUATION

16

2. A water supply system draws from a river at an elevation of 800-feet and delivers the water to a storage reservoir at elevation 820-feet. The supply pipeline is a 1000-foot long, 10-inch diameter, cast iron pipe. A single pump with the pump characteristic curve in Figure 1 is used to fill the reservoir.[2]

   Determine:

   a) The system loss in the 1000-foot force main for a discharge of 1200, 1600, 2000, 2400, and 2800 gallons-per-minute.

   b) The operating discharge for the system using the supplied pump curve. $Q = 2000\,gpm$ @ 41' head

   c) The electric power supplied to the pump to lift the water at the operating point.[3] 24.4hp

   Show your work on the attached Moody chart (Figure 2) as well as your selection of minor loss coefficients.

   Neglect minor loss ok

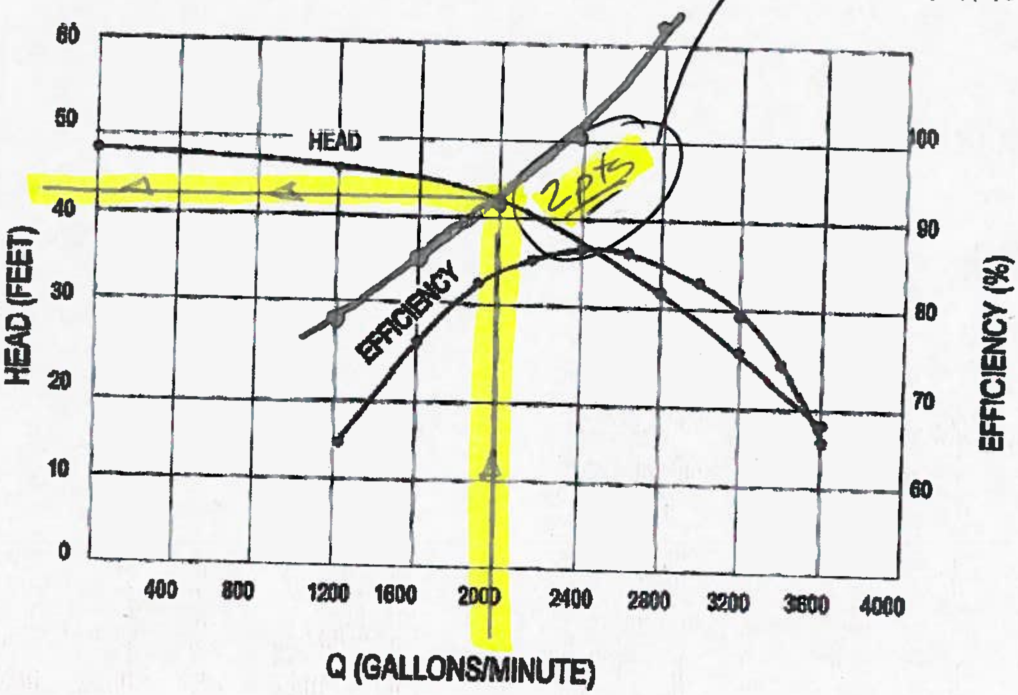


Figure 1: Pump characteristic curve

[2]Chapter 10

[3]Assume the efficiency on the pump curve is representative of the wire-to-water efficiency

Name:__________________________

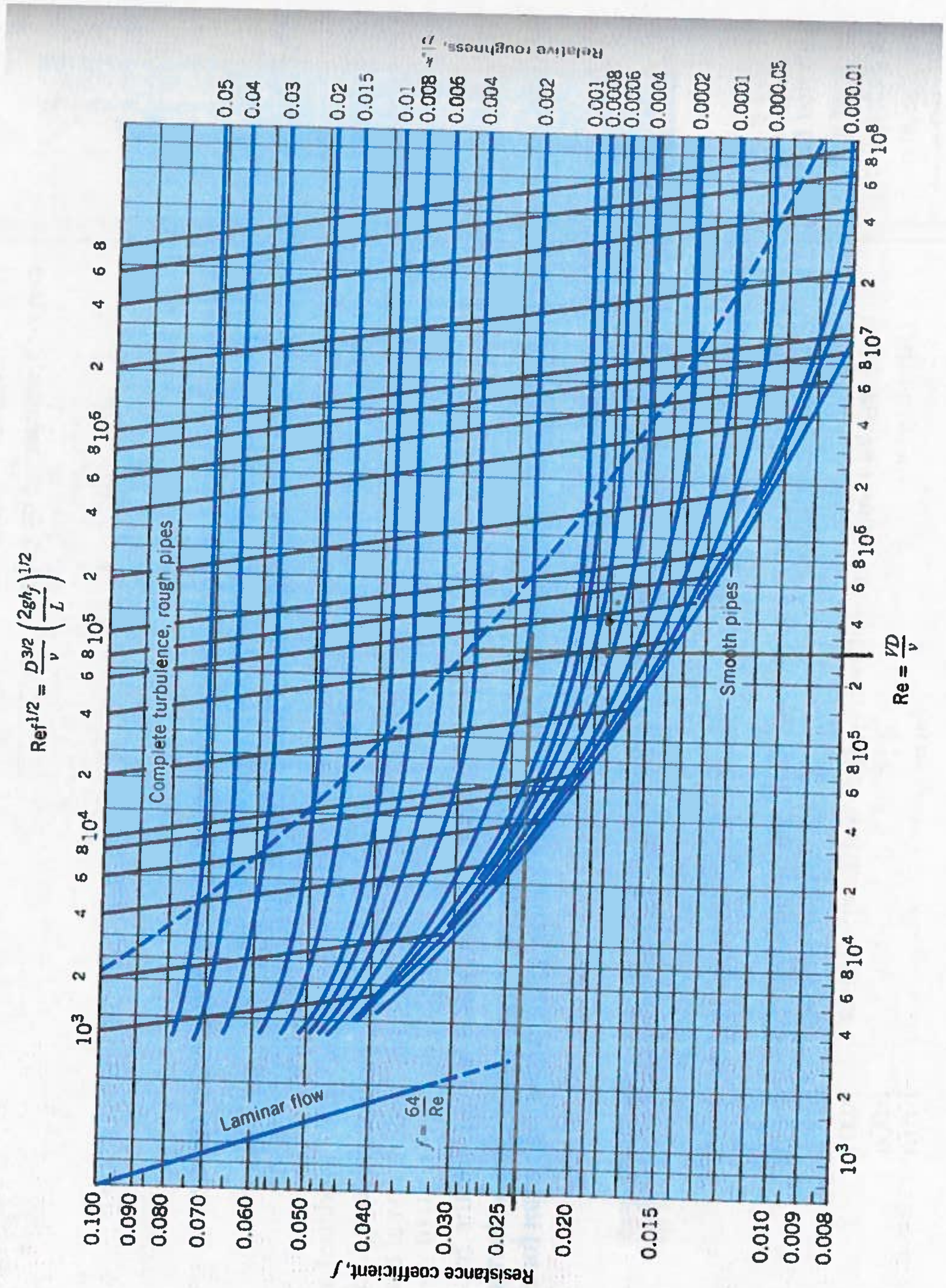
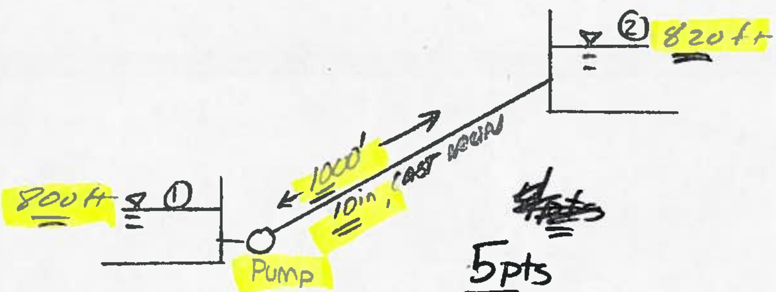


Figure 2: Moody-Stanton Chart

Problem 2 (Continued)

SKETCH



~~4pts~~ 5pts

$$\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_f$$ 1pts

$p_1 = p_2$

$V_1 = V_2$

$h_p = (z_2 - z_1) + h_f$

$h_p = 20\,ft + h_f$

$\frac{k_s}{D} = \frac{0.005\,in}{10\,in} = 0.0005$ 1pts

$h_f = f \frac{L}{D} \frac{V^2}{2g}$

Q(gpm)	Q(cfs)	V(ft/s)	Re	f	h_F	h_p
1200	2.67	4.9	$2.9\cdot10^5$	0.018	8.06	28
1600	3.56	6.53	$3.8\cdot10^5$	0.018	14.33	34
2000	4.45	8.17	$4.8\cdot10^5$	0.017	21.14	41
2400	5.34	9.8	$5.8\cdot10^5$	0.017	30.45	50
2800	6.23	11.43	$6.8\cdot10^5$	0.017	41.44	61

~~2pts~~ 5pts

$X \frac{gal}{min} \cdot \frac{1\,min}{60\,sec} \cdot \frac{1\,ft^3}{7.48\,gal} = Y\,c$

$\nu_{50F} = 1.4\cdot10^{-5}$ (TABLE A.5) 1pts

$V = \frac{Q}{A} = \frac{4Q}{\pi\left(\frac{10}{12}\right)^2}$

$$P = \frac{Q\gamma h}{\eta} = \frac{(4.45\,ft^3/s)(62.4\,lbf/ft^3)(41)}{0.85} = 13393.9\,\frac{lbf\cdot ft}{s}$$

1pts 2pts 2pts

$$\frac{13394}{550\,\frac{lbf\cdot ft}{hp}} = 24.4\,hp$$

18 pts THIS PROBLEM

18

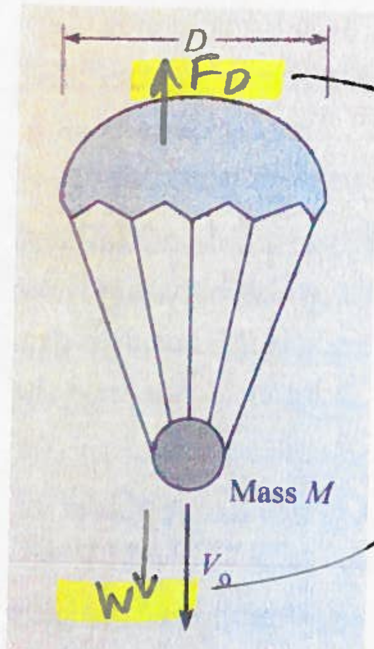
3. A 35-cm-diameter emergency medicine parachute (Figure 3) supports a mass of 20 grams. It is deployed and falls in air at 20°C. Estimate the terminal velocity of the system, using the projected area based on the parachute diameter.[4]

$W = mg$ 2pts

$\Sigma F_y = 0 = F_D - W$

$\therefore F_D = W = mg$

2pts



2pts

Figure 3: Medical parachute system

$F_D = C_D A \frac{\rho V^2}{2} = C_D \left(\frac{\pi D^2}{4}\right)\left(\frac{\rho V^2}{2}\right)$ SOLVE FOR V

2pts

$mg = C_D \left(\frac{\pi D^2}{4}\right)\left(\frac{\rho}{2}\right) V^2$, 2pts

$V = \sqrt{\frac{8mg}{C_D \pi D^2 \rho}} = \sqrt{\frac{8(0.02\,kg)(9.81\,m/s^2)}{(2.2)\pi(0.35\,m)^2(1.2\,kg/m^3)}}$

2pts

$= 1.24\ m/s$ 2pts #, UNITS

[4]Chapter 11

REVISION A

~~12pts~~ 14pts

~~pts~~ THIS PROBLEM

14

Problem 3 (Continued)

4. High-speed rail (HSR) passenger trains are streamlined to reduce shear force. The cross section of a HSR car is shown in Figure 4. For a 81 meter long train, estimate [5]
   a) The shear force on the car skin at 81.1 km/hr
   b) The shear force on the car skin at 204 km/hr
   c) The power required just to overcome the shear force in a).
   d) The power required just to overcome the shear force in b).

2pts → $\nu = 1.41\cdot10^{-5}\ m^2/s$ (TABLE A.3)

2pts → $\rho = 1.25\ kg/m^3$

!! ASSUME LAYER TRIPS ON LEAD EDGE !!

$81.1\ km/hr \cdot \frac{1000\,m}{1\,km} \cdot \frac{1\,hr}{3600\,s} = 22.5\ m/s$ 2pts

$204\ km/hr \cdot \frac{1000\,m}{1\,km} \cdot \frac{1\,hr}{3600\,s} = 56.7\ m/s$ 2pts

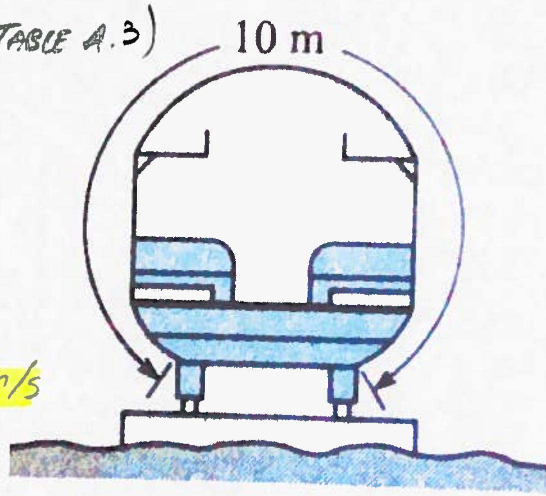
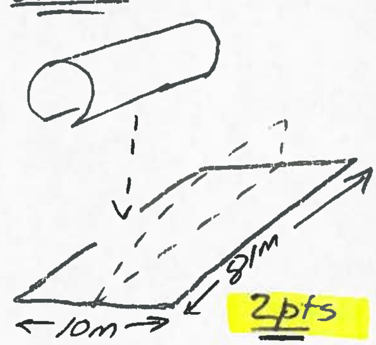


Figure 4: Schematic of HSR car.

UNWRAP



2pts

$Re_L = \frac{UL}{\nu}$ 2pts

$= \frac{(22.5\,m/s)(81\,m)}{1.41\cdot10^{-5}} = 1.29\cdot10^{8}$ 1pts

$= \frac{(56.7\,m/s)(81\,m)}{1.41\cdot10^{-5}} = 3.26\cdot10^{8}$ 1pts

Greater than 10^7

Use $c_f = \frac{0.523}{\ln^2(0.06Re)}$ 1pts

$C_{f_{81.1}} = 0.00208$ 1pts

$C_{f_{204}} = 0.00186$ 1pts

14

[5] Chapter 9

Problem 4 (Continued)

$$F_{s_{81}} = C_f A \frac{\rho V^2}{2}$$ 1pts

$$= (0.00208)(10)(81)\left(\frac{1.25 kg/m^3 \; (22.5 m/s)^2}{2}\right) = 534 N$$ 2pts

$$F_{s_{204}} = (0.00186)(10)(81)\left(\frac{1.25 kg/m^3 \; (56.7 m/s)^2}{2}\right) = 3020 N$$ 2pts

ALTERNATE OK to use this instead

$$C_f = \frac{0.032}{Re_L^{1/7}}$$

$C_{f_{81}} = 0.00222$

$C_{f_{204}} = 0.0014$ ← SUBSTANTIAL DIFFERENCE

$\Rightarrow F = 2277 N$

$$P = F \cdot V$$ 1pts

$$P_{81} = 534 N (22.5 m/s) = 12015 \frac{N \cdot m}{s} = 12 kW$$ 3pts

$$P_{204} = 3020 N (56.7 m/s) = 171234 \frac{N \cdot m}{s} = 171 kW$$ 3pts

29 pts this problem

29

5. Figure 5 is a sketch of an engineered channel looking downstream. The right side of the channel has a "bench" area (like a bicycle path). The longitudinal slope of the stream is 0.001. Manning's roughness coefficient is n=0.025. Use the sketch and these properties to answer the following questions and complete the table.[6]

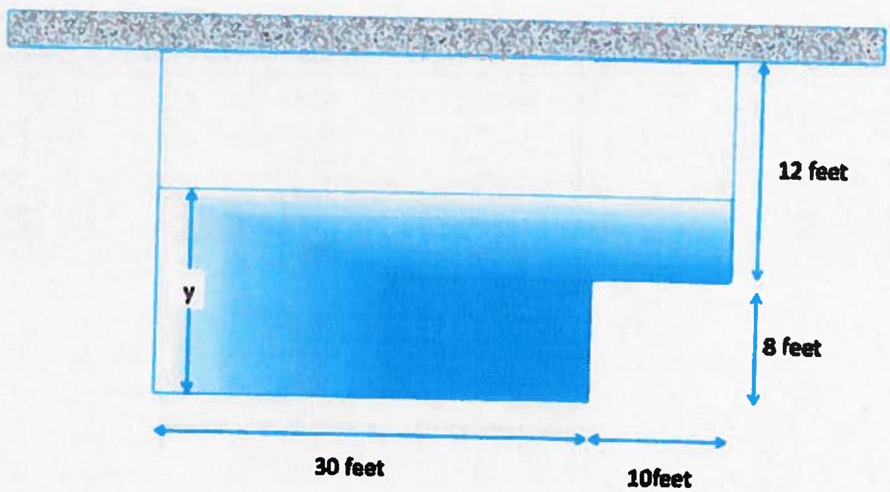


Figure 5: Channel at Bridge

a) What is the wetted perimeter in the channel when the flow depth is 3 feet?

3 3 30 = 36 ft ~~2pts~~ 1pts

b) What is the flow area in the channel when the flow depth is 3 feet?

3 30 $= 3 \times 30 = 90\ ft^2$ ~~2pts~~ 1pts

c) What is the hydraulic radius in the channel when the flow depth is 3 feet?

$R_h = A/p = \frac{90\ ft^2}{36\ ft} = 2.5\ ft$ ~~2pts~~ 1pts

[6] Chapter 15

3

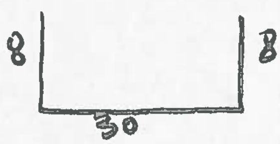
d) What is the discharge in the channel when the flow depth is 3 feet?

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

$$= \frac{1.49}{0.025} \cdot 90\,ft^2 \,(2.5\,ft)^{2/3} (0.001)^{1/2} = 312 \text{ cfs}$$

~~1pts~~ 1 1pts

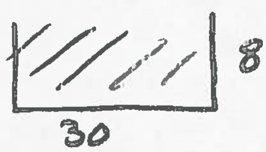
e) What is the wetted perimeter in the channel when the flow depth is 8 feet?



$P_w = 8 + 8 + 30 = 46\,ft$

~~2pts~~ 1pts

f) What is the flow area in the channel when the flow depth is 8 feet?



$A = 240\,ft^2$

~~2pts~~ 1pts

g) What is the hydraulic radius in the channel when the flow depth is 8 feet?

$$R_h = A/P = \frac{240\,ft^2}{46\,ft} = 5.21\,ft$$

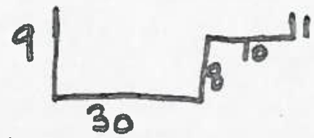
~~2pts~~ 1pts

h) What is the discharge in the channel when the flow depth is 8 feet?

$$Q = \frac{1.49}{0.025} 240\,ft^2 (5.21\,ft)^{2/3} (0.001)^{1/2} = 1360 \text{ cfs}$$

~~2pts~~ 1pts

i) What is the wetted perimeter in the channel when the flow depth is 9 feet?



$$P_w = 9 + 30 + 8 + 10 + 1$$
$$= 58\ \text{ft}$$

~~2pts~~ 1pts

j) What is the flow area in the channel when the flow depth is 9 feet?

A =

$$A = 9 \cdot 30 + 10 \cdot 1$$
$$= 280\ \text{ft}^2$$

1pts ~~2pts~~

k) What is the hydraulic radius in the channel when the flow depth is 9 feet?

$$R_h = A/p = \frac{280\ \text{ft}^2}{58\ \text{ft}} = 4.827\ \text{ft}$$

1pts ~~2pts~~

l) What is the discharge in the channel when the flow depth is 9 feet?

$$Q = \frac{1.49}{0.025}(280\ \text{ft}^2)(4.827)^{2/3}(0.001)^{1/2}$$

1pts

$$= 1507\ \text{cfs}$$

~~2pts~~

2²

4

m) What is normal flow depth in the channel when the discharge is 900 ft^3/s ?

$312 \le 900 \le 1360 \therefore 3 < y_n < 8$ ft BETWEEN 3 & 8 1pts

GUESS 5

$P = 5+5+30 = 40$

$A = 5(30) = 150$

$R_h = \frac{150}{40} = 3.75$

$Q_5 = \frac{1.49}{0.025}(150 ft^2)(3.75)^{2/3}(0.001)^{1/2} = 682$

682 < 900 MAKE DEEPER

GUESS 6 1 pts

$P = 6+6+30 = 42$

$A = 6(30) = 180$

$R_h = \frac{180}{42} = 4.28$

$Q_6 = \frac{1.49}{0.025}(180 ft^2)(4.28)^{2/3}(0.001)^{1/2} = 895$

895 ≈ 90

CLOSE ENOUGH

$y_n = 6$ ft

n) What is critical flow depth when the discharge is 900 ft^3/s?

$y_c = \left(\frac{Q^2}{B^2 g}\right)^{1/3}$ (PG 571 & 570) 1 pts

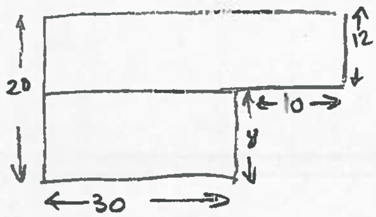
$= \left(\frac{900^2}{(30)^2(32.2)}\right)^{1/3} = \underline{\underline{3.03 ft}}$ 1pts

$\therefore y_n > y_c$ (SUBCRIT)

20

4

o) What is the discharge in the channel when the flow depth is nearly 20 feet (just touching the bottom side of the bridge)?



$P_w = 20 + 30 + 8 + 10 + 12$
$= 50 + 8 + 22$
$= 80$ ft   2pts

$A = (30)(8) + (12)(40) = 720 \text{ ft}^2$
2pts

$R_h = A/P = \frac{720}{80} = 9$

$Q = \frac{1.49}{(0.025)}(720 \text{ ft}^2)(9)^{2/3}(0.001)^{1/2} = 5871$ cfs   2pts

p) Complete the table below where y is the flow depth, A is the cross sectional flow area, P is the wetted perimeter, R_h is the hydraulic radius, and Q is the discharge.

Table 1: Hydraulic Values for Channel with Bicycle Path

y (ft)	A (ft^2)	P (ft)	R_h (ft)	Q (ft^3/s)
0.0	0	0	0	0
3.0	90	36	2.5	312
6	180	42	4.28	900.0
8.0	240	46	5.21	1360
~~9.0~~	280	58	4.83	1507
20.0	720	80	.9	5871

4 pts

23 pts this problem   14

7

6. Water flows uniformily at depth $y_1 = 32$ cm in the 8 meter wide concrete channel in Figure 6. Estimate the height of the hydraulic jump that will form when a sill is installed to force the jump. Manning's n for the channel is $n = 0.012$.[7]

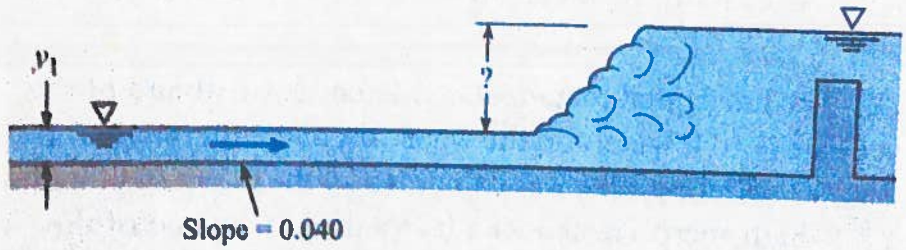


Figure 6: Hydraulic jump elevation view

JUMP OVER SHORT DISTANCE, NEGLECT FRICTION

$$y_2 = \frac{y_1}{2}\left(\sqrt{1+8Fr_1^2} - 1\right)$$ 2 pts

$$Fr_1^2 = \frac{V}{\sqrt{gy_1}}$$ 2 pts NEED V

ASSUME MANNING'S OK

$$V_1 = \frac{1}{n} R^{2/3} S^{1/2}$$

$$= \left(\frac{1}{0.012}\right)(0.29)^{2/3}(0.04)^{1/2}$$

$$= 7.4 \text{ m/s}$$ 2 pts

$A = (0.32)(8) = 2.56 \text{ m}^2$

$P_w = 8 + 2(0.32) = 8.64$ m

$R_h = A/P = \frac{2.56}{8.64} = 0.29$ m

$$= \frac{7.4 \text{ m/s}}{\sqrt{(9.8 \text{ m/s}^2)(0.32 \text{ m})}}$$

$$= 4.17$$ 2 pts

$$y_2 = \frac{0.32}{2}\left(\sqrt{1+8(4.17)^2} - 1\right) = \cancel{0.77}\ 1.734 \text{ m}$$ 2 pts

10

[7]Chapter 15

Problem 6 (Continued)

16
18
14
29
3
5
4
4
7
10
110

16
18
14
29
23
10
110