CHAPTER 2 - HYDRAULICS

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Solutions to Practice Problems

1. $P = 0.43 \times h$ (Equation 2-2b)
   $P = 0.43 \times 50$ ft = 22 psi at the bottom of the reservoir
   $P = 0.43 \times (50 - 30) = 0.43 \times 20$ ft = 8.6 psi above the bottom

2. $h = 0.1 \times P = 0.1 \times 50 = 5$ m (Equation 2-3a)

3. Depth of water above the valve: $h = (78 \text{ m} - 50 \text{ m}) + 2 \text{ m} = 30$ m
   $P = 9.8 \times h = 9.8 \times 30 = 294$ kPa $\approx$ 290 kPa (Equation 2-2a)

4. $h = 2.3 \times P = 2.3 \times 50 = 115$ ft, in the water main
   $h = 115 - 40 = 75$ ft
   $P = 0.43 \times 75 = 32$ psi, 40 ft above the main (Equation 2-2b)

5. Gage pressure $P = 30 + 9.8 \times 1 = 39.8$ kPa $\approx$ 40 kPa
   Pressure head (in tube) = 0.1×40 kPa = 4 m

6. $Q = A \times V$ (Eq. 2-4), therefore $V = Q/A$
   $A = \pi D^2/4 = \pi (0.3)^2/4 = 0.0707 \text{ m}^2$
   $100 \text{L/s} \times 1 \text{ m}^3/1000\text{L} = 0.1 \text{ m}^3/\text{s}$
   $V = 0.1 \text{ m}^3/\text{s}\ 0.707\text{m}^2 = 1.4$ m/s

7. $Q = (500 \text{ gal/min}) \times (1 \text{ min}/60 \text{ sec}) \times (1 \text{ ft}^3/7.5 \text{ gal}) = 1.11$ cfs
   $A = Q/V$ (from Eq. 2-4)
   $A = 1.11 \text{ ft}^3/\text{sec} / 1.4 \text{ ft/sec} = 0.794 \text{ ft}^2$
   $A = \pi D^2/4$, therefore $D = \sqrt{4A/\pi} = \sqrt{(4)(0.794)/\pi} = 1$ ft = 12 in.

8. $Q = A1 \times V1 = A2 \times V2$ (Eq.2-5)
   Since $A = \pi D^2/4$, we can write

   $D_1^2 \times V_1 = D_2^2 \times V_2$ and $V_2 = V_1 \times (D_1^2/D_2^2)$
   In the constriction, $V_2 = (2 \text{ m/s}) \times (4) = 8$ m/s

9. Area of pipe A = $\pi(0.3)^2/4 = 0.0707$ m^2

Area of pipe B = $\pi(0.1)^2/4 = 0.00785$ m^2

Area of pipe C= $\pi(0.2)^2/4 = 0.03142$ m^2

$Q_A = Q_B + Q_C = 0.00785$ m^2 x 2 m/s + 0.03142 m^2 x 1 m/s

= 0.04712 m^3/s (from continuity of flow: $Q_{IN} = Q_{OUT}$)

$V_A = Q_A/A_A = 0.4712/0.0707 \approx 0.67$ m/s (from Eq. 2-4)

10. $p_1/w + V_1^2/2g = p_2/W + V_2^2/2g$ (Eq.2-8)

$A_1 = \pi(1.33)^2/4 = 1.4$ ft^2 $A_2 = \pi(0.67)^2/4 = 0.349$ ft^2

$V_1 = 6/1.4 = 4.29$ ft/sec $V_2 = 6/0.349 = 17.2$ ft/sec

w = 62.4 lb/ft^3 and g = 32.2 ft/sec^2

From Eq. 2-8, and multiplying *psi* x 144 in^2/ft^2 to get lb/ft^2

$50(144)/62.4 + 4.29^2/2(32.2) = p_2(144)/62.4 + 17.2^2/2(32.2)$

$115.38 + 0.28578 = 2.3076p_2 + 4.5937$

$p_2 = 111.07/2.307 \approx 48$ psi

11. $p_1/w + v_1^2/2g = p_2/w + v_2^2/2g$ (Eq.2-8)

$A_1 = \pi(0.300)^2 / 4 = 0.0707$ m^2 $A_2 = \pi(0.1\ 00)^2/4 = 0.00785$ m^2

Q= 50 L/s x 1 m^3/1000 L = 0.05 m^3/s

$V_1 = 0.05/0.0707 = 0.70721$ m/sec $V_2 = 0.05/0.00785 = 6.369$ m/sec

w = 9.81 kN/m^3 and g = 9.81 m/s^2; From Eq. 2-8,

$700/2(9.81) + 0.70721^2/2(9.81) = p_2/2(9.81) + 6.369^2/2(9.81)$

$35.67789 + 0.02549 = 0.05097p_2 + 2.06775$ and $p_2 = 660$ kPa

12. From Figure 2.15, with Q = 200 L/s and D = 600 mm, read S = 0.0013. Therefore h_L= S x L = 0.0013 x 1000 m = 1.3 m

Pressure drop p = 9.8 x 1.3 ≈ 12.7 ≈ 13 kPa per km

13. h_L= 2.3 x 20 = 46 ft and S = 46/5280 = 0.0087 (where 1 mi = 5280 ft)

From Figure 2.15, with Q = 1000 gpm and S = 0.0087, read D = 10.3 in.

Use a 12 in. standard diameter pipe

14. S = 10/1000 = 0.01

From the nomograph (Figure 2.15) read Q ≈ 100 L/s = 0.1 m^3/s

Check with Eq. 2-9: $Q = 0.28 \times 100 \times 0.3^{2.63} \times 0.01^{0.54} \approx 0.1$ m^3/s OK

15. Use (Eq. 2-10): $Q = C \times A_2 \times \{(2g(p_1 - p_2)/w)/(1 - (A_2/A_1)^2\}^{1/2}$

where $A_1 = \pi(6)^2/4 = 28.27$ in^2 and $A_2 = \pi(3)^2/4 = 7.07$ in^2

g = 32.2 ft/s^2 = 386.4 in/s^2

w = 62.4 lb/ft^3 x 1 ft^3/12^3 in^3 = 0.0361 lb/in^3

$Q = 0.98 \times 7.07 \times \{(2(386.4)(10)/0.0361)1(1 - (7.07/28.27)^2)\}^{1/2}$

$Q = 0.98 \times 7.07 \times \sqrt{228{,}354} = 3311\ in^3/s = 1.9\ cfs \approx 2\ cfs$

16. Use (Eq. 2-10): $Q = C \times A_2 \times \{(2g(p_1 - p_2)/w)/(1 - (A_2/A_1)^2)\}^{1/2}$

$A_1 = \pi(0.15)^2/4 = 0.01767\ m^2$ and $A_2 = \pi(0.075)^2/4 = 0.00442\ m^2$

$g = 9.81\ m/s^2$ $w = 9.81\ kN/m^3$

$1 - (A_2/A_1)^2 = 1 - (0.00442/0.01767)^2 = 0.93743$

$Q = 0.98 \times 0.00442 \times \{(2(9.81)(100)/9.81)/0.93743)\}^{1/2} = 0.063\ m^3/s$

(or, $Q = 0.063\ m^3/s \times 1000\ L/m^3 = 63\ L/s$)

17. Use Manning's nomograph (Figure 2.21): With D = 800 mm = 80 cm, n=0.013 and S = 0.2% = 0.002, read Q= 0.56 m^3/s = 560 L/s and V = 1.17 m/s

18. S = 1.5/1000 = 0.015; from Fig. 2.21, Q ≈ 1800 gpm and V ≈ 2.3 ft/s

19. Q= 200 L/s = 0.2 m^3/s; from Fig. 2.21, D ≈ 42 cm; Use 450 mm pipe

20. Q = 7 mgd = 7,000,000 gal/day x 1 day/1440 min ≈ 4900 gpm

From Fig. 2.21, with n=0.013, D=36 in and Q=4900 gpm: S = 0.00027, V = 1.54 ft/s Since 1.54 ft/s is less than the minimum self-cleansing velocity of 2 ft/s, it is necessary to increase the slope of the 36 in pipe.

From Fig. 2.21, with 36 in and 2 ft/s: S = 0.00047 = 0.047% = 0.05%

21. For full-flow conditions, with D = 300 mm and S = 0.02, read from

Fig. 2.21: Q = 0.135 m^3/s = 135 L/s and V = 2m/s

q/Q = 50/135 = 0.37 From Fig. 2.22, d/D = 0.42 and v/V = 0.92

Depth at partial flow d = 0.42 x 300 = 126 mm ≈ 130 mm

Velocity at partial flow v = 0.92 x 2 ≈ 1.8 m/s

22. For full-flow conditions, from Fig. 2.21 read Q = 1800 gpm. From Fig. 2.22, the maximum value of q/Q = 1.08 when d/D = 0.93. Therefore, the highest discharge capacity for the 18" in pipe, q_{max} = 1800 x 1.08 ≈ 1900 gpm,
would occur at a depth of d = 18 x 0.93 ≈ 17 in.

23. For full-flow conditions, from Fig. 2.21 read Q = 0.55 m^3/s = 550 L/s. From Fig.2.22, the maximum value of v/V = 1.15 when d/D = 0.82. Therefore, the highest flow velocity for the 900 mm pipe, v_{max} = 0.9 x 1.15 ≈ 1 m/s, would occur at a depth of d = 900 x 0.82 ≈ 740 mm. When the flow occurs at that depth, q/Q = 1.05 and the discharge q = 580 L/s

24. S = 0.5/100 = 0.005

For full-flow conditions, Q = 0.44 m^3/s = 440 L/s and V = 1.6 m/s

Since d/D = 200/600 = 0.33, from Fig. 2.22 q/Q = 0.23 and v/V = 0.8 Therefore, q = 440 x 0.23 ≈ 100 L/s and v = 1.6 x 0.8 ≈ 1.3 m/s

25. $Q = A \times V = 2 \times 0.75 \times 25/75 = 0.5\ m^3/s = 500\ L/s$

26. From Eq. 2-12, $Q = 2.5 \times (4/12)^{2.5} = 0.16$ cfs

27. 150 mm x 1 in/25.4 mm x 1 ft/12 in = 0.492 ft
From Eq. 2-12, $Q = 2.5 \times (0.492)^{2.5} = 0.425$ cfs x 28.32 L/ft^3 ≈ 12 L/s

28. From Eq. 2-13, $Q = 3.4 \times (20/12) \times (10/12)^{1.5} = 4.3$ cfs ≈ 120 L/s