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CHAPTER 2 - HYDRAULICS

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Solutions to Practice Problems

- $P = 0.43 \times h$ (Equation 2-2b)
 $P = 0.43 \times 50 \text{ ft} = 22 \text{ psi}$ at the bottom of the reservoir
 $P = 0.43 \times (50 - 30) = 0.43 \times 20 \text{ ft} = 8.6 \text{ psi}$ above the bottom
- $h = 0.1 \times P = 0.1 \times 50 = 5 \text{ m}$ (Equation 2-3a)
- Depth of water above the valve: $h = (78 \text{ m} - 50 \text{ m}) + 2 \text{ m} = 30 \text{ m}$
 $P = 9.8 \times h = 9.8 \times 30 = 294 \text{ kPa} \approx 290 \text{ kPa}$ (Equation 2-2a)
- $h = 2.3 \times P = 2.3 \times 50 = 115 \text{ ft}$, in the water main
 $h = 115 - 40 = 75 \text{ ft}$
 $P = 0.43 \times 75 = 32 \text{ psi}$, 40 ft above the main (Equation 2-2b)
- Gage pressure $P = 30 + 9.8 \times 1 = 39.8 \text{ kPa} \approx 40 \text{ kPa}$
Pressure head (in tube) = $0.1 \times 40 \text{ kPa} = 4 \text{ m}$
- $Q = A \times V$ (Eq. 2-4), therefore $V = Q/A$

$$A = \pi D^2/4 = \pi (0.3)^2/4 = 0.0707$$

$$m \quad 100L/s \times 1 m /1000L=0.1 m /s$$

$$V = 0.1 m /s \cdot 0.0707m = 1.4 m/s$$

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)

$$A = 1.11 \text{ ft}^3/\text{sec} / 1.4 \text{ ft/sec} = 0.794 \text{ ft}^2$$

$$A = \pi D^2/4, \text{ therefore } D = \sqrt{4A/\pi} = \sqrt{(4)(0.794)/\pi} = 1 \text{ ft} = 12 \text{ in.}$$

8. $Q=A_1 \times V_1 = A_2 \times V_2$ (Eq.2-5)

Since $A = \pi D^2/4$, we can write

$$D_1^2 \times V_1 = D_2^2 \times V_2 \text{ and } V_2 = V_1 \times (D_1^2/D_2^2)$$

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

9. Area of pipe A = $\pi(0.3)^2/4 = 0.0707 \text{ m}^2$
 Area of pipe B = $\pi(0.1)^2/4 = 0.00785 \text{ m}^2$

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

$Q_A = Q_B + Q_C = 0.00785 \text{ m}^2 \times 2 \text{ m/s} + 0.03142 \text{ m}^2 \times 1 \text{ m/s}$
 $= 0.04712 \text{ m}^3/\text{s}$ (from continuity of flow: $Q_{IN} = Q_{OUT}$)

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

10. $p_1/w + V_1^2/2g = p_2/w + V_2^2/2g$ (Eq.2-8)
 $A_1 = \pi(1.33)^2/4 = 1.4 \text{ ft}^2$ $A_2 = \pi(0.67)^2/4 = 0.349 \text{ ft}^2$

$V_1 = 6/1.4 = 4.29 \text{ ft/sec}$ $V_2 = 6/0.349 = 17.2 \text{ ft/sec}$
 $w = 62.4 \text{ lb/ft}^3$ and $g = 32.2 \text{ ft/sec}^2$

$$115.38 + 0.28578 = 2.3076p_2 + 4.5937$$

 $p_2 = 111.07 / 2.307 \approx 48 \text{ psi}$

11. $p_1/w + v_1^2/2g = p_2/w + v_2^2/2g$ (Eq.2-8)
 $A_1 = \pi(0.300)^2 / 4 = 0.0707 \text{ m}^2$ $A_2 = \pi(0.100)^2/4 = 0.00785 \text{ m}^2$

$Q = 50 \text{ L/s} \times 1 \text{ m}^3/1000 \text{ L} = 0.05 \text{ m}^3/\text{s}$

$V_1 = 0.05/0.0707 = 0.70721 \text{ m/sec}$ $V_2 = 0.05/0.00785 = 6.369 \text{ m/sec}$

$w = 9.81 \text{ kN/m}^3$ and $g = 9.81 \text{ m/s}^2$; From Eq. 2-8, $700/2(9.81)$

$$0.02549 = 0.05097p_2 + 2.06775$$
 and $p_2 = 660 \text{ kPa}$

12. From Figure 2.15, with $Q = 200 \text{ L/s}$ and $D = 600 \text{ mm}$, read $S = 0.0013$. Therefore $h_L = S \times L$
 $= 0.0013 \times 1000 \text{ m} = 1.3 \text{ m}$
 Pressure drop $p = 9.8 \times 1.3 \approx 12.7 \approx 13 \text{ kPa per km}$

13. $h_L = 2.3 \times 20 = 46 \text{ ft}$ and $S = 46/5280 = 0.0087$ (where $1 \text{ mi} = 5280 \text{ ft}$)
 From Figure 2.15, with $Q = 1000 \text{ gpm}$ and $S = 0.0087$, read $D = 10.3 \text{ in.}$
 Use a 12 in. standard diameter pipe

14. $S = 10/1000 = 0.01$
 From the nomograph (Figure 2.15) read $Q \approx 100 \text{ L/s} = 0.1 \text{ m}^3/\text{s}$
 Check with Eq. 2-9: $Q = 0.28 \times 100 \times 0.3^{2.63} \times 0.01^{0.54} \approx 0.1 \text{ m}^3/\text{s}$ OK

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

$$g = 32.2 \text{ ft/s}^2 = 386.4 \text{ in/s}^2$$

 $w = 62.4 \text{ lb/ft}^3 \times 1 \text{ ft}^3/12^3 \text{ in}^3 = 0.0361 \text{ lb/in}^3$

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

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

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

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

$$g = 9.81 \text{ m/s}^2 \quad w = 9.81 \text{ kN/m}^3$$

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

$$Q = 0.98 \times 0.00442 \times \{(2(9.81)(100)/9.81)/0.93743\}^{1/2} = 0.063 \text{ m}^3/\text{s} \text{ (or, } Q = 0.063 \text{ m}^3/\text{s} \times 1000 \text{ L/m}^3 = 63 \text{ L/s)}$$

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

18. $S = 1.5/1000 = 0.015$; from Fig. 2.21, $Q \approx 1800 \text{ gpm}$ and $V \approx 2.3 \text{ ft/s}$

19. $Q = 200 \text{ L/s} = 0.2 \text{ m}^3/\text{s}$; from Fig. 2.21, $D \approx 42 \text{ cm}$; Use 450 mm pipe

20. $Q = 7 \text{ mgd} = 7,000,000 \text{ gal/day} \times 1 \text{ day}/1440 \text{ min} \approx 4900 \text{ gpm}$

From Fig. 2.21, with $n=0.013$, $D=36 \text{ in}$ and $Q=4900 \text{ gpm}$: $S = 0.00027$, $V = 1.54 \text{ ft/s}$ 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 $D = 300 \text{ mm}$ and $S = 0.02$, read from

Fig. 2.21: $Q = 0.135 \text{ m}^3/\text{s} = 135 \text{ L/s}$ and $V = 2 \text{ m/s}$

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

Depth at partial flow $d = 0.42 \times 300 = 126 \text{ mm} \approx 130 \text{ mm}$

Velocity at partial flow $v = 0.92 \times 2 \approx 1.8 \text{ m/s}$

22. For full-flow conditions, from Fig. 2.21 read $Q = 1800 \text{ gpm}$. 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, $q_{\text{max}} = 1800 \times 1.08 \approx 1900 \text{ gpm}$, would occur at a depth of $d = 18 \times 0.93 \approx 17 \text{ in}$.

23. For full-flow conditions, from Fig. 2.21 read $Q = 0.55 \text{ m}^3/\text{s} = 550 \text{ L/s}$. 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, $v_{\text{max}} = 0.9 \times 1.15 \approx 1 \text{ m/s}$, would occur at a depth of $d = 900 \times 0.82 \approx 740 \text{ mm}$. When the flow occurs at that depth, $q/Q = 1.05$ and the discharge $q = 580 \text{ L/s}$

24. $S = 0.5/100 = 0.005$

For full-flow conditions, $Q = 0.44 \text{ m}^3/\text{s} = 440 \text{ L/s}$ and $V = 1.6 \text{ m/s}$

Since $d/D = 200/600 = 0.33$, from Fig. 2.22 $q/Q = 0.23$ and $v/V = 0.8$ Therefore, $q = 440 \times 0.23 \approx 100 \text{ L/s}$ and $v = 1.6 \times 0.8 \approx 1.3 \text{ m/s}$

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

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

27. $150 \text{ mm} \times 1 \text{ in}/25.4 \text{ mm} \times 1 \text{ ft}/12 \text{ in} = 0.492 \text{ ft}$

From Eq. 2-12, $Q = 2.5 \times (0.492)^{2.5} = 0.425 \text{ cfs} \times 28.32 \text{ L/ft}^3 \approx 12 \text{ L/s}$

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