

HYDRAULICS IN CIVIL AND ENVIRONMENTAL ENGINEERING

Fourth edition

SOLUTIONS MANUAL

Andrew Chadwick, John Morfett and Martin Borthwick



This solutions manual is made available free of charge. Details of the accompanying textbook *Hydraulics in Civil and Environmental Engineering* are on the website of the publisher www.sponpress.com and can be ordered from Book.orders@tandf.co.uk or phone: +44 (0) 1264 343071

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Preface

This manual has been prepared for use in conjunction with the textbook *Hydraulics in Civil and Environmental Engineering* (4th edition). The Problems for solution in the book cover the material found in Chapters 1-11.

The *Solutions Manual* is particularly intended for use by course tutors. It provides detailed methods of solution for all of the problems in the 4th edition, so that they can be integrated into the tutorial scheme for a hydraulics lecture programme.

Chapter 1

Problem 1

Apply hydrostatic equation for head of oil: $h = \frac{p}{\rho g} = \frac{200000}{850 \times 9.81} = 24 \text{ m}$

Apply hydrostatic equation for head of water: $h = \frac{p}{\rho g} = \frac{200000}{1000 \times 9.81} = 20.4 \text{ m}$

Problem 2

From the hydrostatic equation $p = \rho gh$

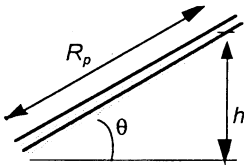
$$400 = 1800 \times 9.81 \times h$$

therefore:

$$h = 0.0226 \text{ m}$$

$$\frac{h}{R_p} = \frac{0.0226}{0.15} = 0.151 = \sin \theta$$

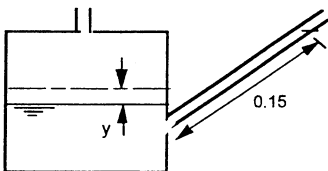
$$\theta = 8.69^\circ$$



Problem 3

Volume of fluid in manometer tube $= A_{\text{TUBE}} \times 0.15$

Volume of fluid in reservoir tank $= A_{\text{TANK}} \times y$



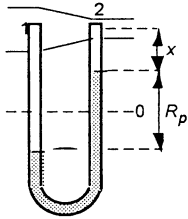
$$A_{\text{TUBE}} \times 0.15 = A_{\text{TANK}} \times y$$

$$y = \frac{A_{\text{TUBE}} \times 0.15}{A_{\text{TANK}}} = \frac{0.15}{40} = 0.00375 = 3.75 \text{ mm}$$

$$\text{Error in } R_p = \frac{y}{\sin \theta} = \frac{3.75}{0.151} = 24.8 \text{ mm}$$

$$\text{Percentage error} = \frac{24.8}{151} \times 100 = 16.5\%$$

Problem 4



On left side of manometer

$$38000 + 9.81 \times 1000 (x + R_p)$$

On right side of manometer

$$- 50000 + 9.81 \times 1000 (x) + 9.81 \times 13600 (R_p)$$

Therefore:

$$38000 - (- 5000) = 9.81 R_p (13600 - 1000)$$

$$\text{Therefore: } R_p = 0.712 \text{ m} \quad 712 \text{ mm}$$

Problem 5

$$101500 = 9.81 \times 13600 \times H_m \quad H_m = 760.7 \text{ mm}$$

Problem 6

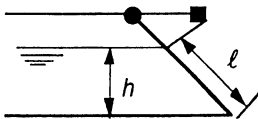
$$\text{Gauge pressure} = 103000 - 101500 = 1500 \text{ N/m}^2$$

$$h = \frac{p}{\rho g} = \frac{1500}{1000 \times 9.81} = 0.153 \text{ m} = 153 \text{ mm Water}$$

At highest point:	Atmospheric pressure	= 101500 - 1.21 \times 9.81 \times 150
		= 99719 N/m²
	Gas pressure	= 103000 - 0.56 \times 9.81 \times 150
		= 102176 N/m²
	Gauge pressure	= 102176 - 99719
		= 2457 N/m²

$$h = \frac{p}{\rho g} = \frac{2457}{1000 \times 9.81} = 0.250 \text{ m} = 250 \text{ mm Water}$$

Problem 7



Moment holding gate shut

$$= 100 \times 9.81 \times 0.5 + 250 \times 9.81 \times 0.5$$

$$= 1717 \text{ N-m}$$

$$l = \frac{h}{\sin 45^\circ}$$

$$\begin{aligned}\text{Force on immersed surface} &= \rho g A \bar{y} = 1000 \times 9.81 \times \left(1 \times \frac{h}{\sin 45^\circ}\right) \times \frac{h}{2} \\ &= 6937 h^2\end{aligned}$$

Centre of pressure or "point of action" is at $\frac{I}{A \bar{y}}$ below water surface
i.e

$$\bar{\ell} = \frac{1 \times \left(\frac{h}{\sin 45^\circ}\right)^3 \times 2}{12 \times \left[\left(\frac{h}{\sin 45^\circ}\right) \times 1\right] \times \frac{h}{\sin 45^\circ}} = 0.2357$$

$$\text{Distance from hinge to point of action} = \left(\frac{1-h}{\sin 45^\circ}\right) + 0.2357h = 1.414 - 1.179h$$

$$\text{Moment of force} = (1.414 - 1.179h) 6937 h^2 = 1717 \text{ N-m}$$

Therefore $h = 0.58 \text{ m}$ when gate is on point of opening

Problem 8

There are two ways of tackling the problem. One (as below) is to calculate vertical and horizontal components separately. The other is to apply 1st and 2nd moments directly to the two parts (vertical and sloping) of the upstream dam face.

Forces on dam:

Horizontal

$$\begin{aligned}F_H &= \text{force on vertical projected area} \\ &= \rho g A \bar{y} = 1000 \times 9.81 \times 25 \times 200 \times 12.5 \\ &= 613.13 \times 10^6 \text{ N}\end{aligned}$$

F_H acts at centre of pressure, which is $(2/3 \times 25) \text{ m}$ i.e 16.67 m below water level.

Vertical

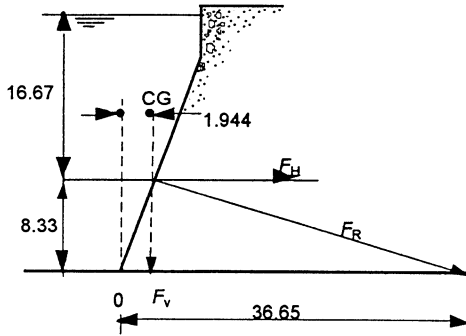
$$\begin{aligned}\text{Volume of water above dam foot, } v &= \left[\left(\frac{20 \times 5}{2}\right) + (5 \times 5)\right] \times 20 \\ &= 15000 \text{ m}^3\end{aligned}$$

$$F_v = \text{weight} = \rho g v = 1000 \times 9.81 \times 15000 = 147.15 \times 10^6 \text{ N}$$

Force acts through centre of gravity. To find centre of gravity take moments:

$$\left[\left(\frac{20 \times 5}{2}\right) \times \frac{5}{3} + (5 \times 5)\right] \times \frac{5}{2} = 148.53 \text{ m}^3$$

$$\bar{x} = \frac{145.83}{\left[\left(\frac{20 \times 5}{2}\right) + (5 \times 5)\right]} = 1.944 \text{ to right of vertical through } O$$



Resultant force on dam F_R

$$F_R = (613.13^2 + 147.15^2)^{\frac{1}{2}} \\ = 630.5 \text{ MN}$$

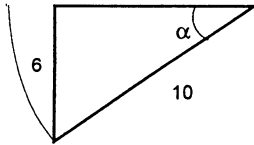
Angle of F_R to horizontal

$$= \tan^{-1} \frac{147.15}{613.13} = 13.5^\circ$$

$$\text{Distance} = 8.33 \times \frac{613.13}{147.15} = 34.7$$

$$34.7 + 1.944 = 36.65 \text{ m}$$

Problem 9



$$\alpha = \sin^{-1} \frac{6}{10} = 36.9^\circ$$

$$\text{Area of sector} = \frac{36.9}{360} \times \pi \times 10^2 = 32.2 \text{ m}^2$$

$$\text{Area of triangle} = \frac{1}{2} \times 6 \times 10 = 30 \text{ m}^2$$

Therefore:

$$\text{Area of segment} = 32.2 - 30 = 2.2 \text{ m}^2$$

$$\text{Volume of water displaced} = 2.2 \times 10 = 22 \text{ m}^3$$

$$\text{So vertical (weight) force} = 22 \times 9.81 \times 1000 = 215820 \text{ N}$$

$$\text{Horizontal force} = \text{Force on vertical projected area}$$

$$= \rho g A \bar{y} = 1000 \times 9.81 \times (6 \times 10) \times 3$$

$$= 1765800 \text{ N}$$

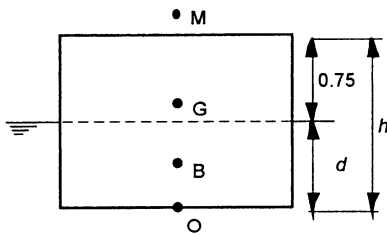
$$\text{Resultant force} = \sqrt{215820^2 + 1765800^2}$$

$$= 1778940 \text{ N}$$

$$\text{Therefore load on each bearing} = \frac{1778940}{2} = 889470 \text{ N} = 0.889 \text{ MN}$$

Force is perpendicular to radial surface and so must pass through bearings.

Problem 10



$$\text{Displacement} = 300000/1000 = 300 \text{ m}^3$$

$$\text{Draft, } d = \frac{\text{Vol}}{bL} = \frac{300}{6L}$$

therefore centre of buoyancy

$$CB = \frac{300}{12L} \text{ above O}$$

$$\overline{MB} = \frac{I}{V} = \frac{L \times 6^3}{12 \times 300} = 0.06L$$

$$h = d + 0.75 = \frac{300}{6L + 0.75} \text{ therefore } \overline{OG} = \frac{h}{2} + 0.3$$

$$\overline{MG}(\text{metacentric height}) = 1.5 = \overline{MB} + \overline{BO} - \overline{OG}$$

Therefore

$$1.5 = 0.06L + \frac{300}{12L} - \left(\frac{300}{12L} + 0.375 + 0.3 \right)$$

$$= 0.06L - 0.675$$

$$L = 36.25 \text{ m}$$

$$h = \frac{300}{6 \times 36.25} + 0.75 = 2.13 \text{ m}$$

Chapter 2

Problem 1

Apply energy equation entry to (1) to (2)

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} = \frac{p_0}{\rho g} + \frac{V_2^2}{2g} = \frac{p_{\text{entry}}}{\rho g} + \frac{V_{\text{entry}}^2}{2g} + 4$$

$$\frac{p_{\text{entry}}}{\rho g} = 2m \quad V_{\text{entry}} = 0 \quad \frac{p_0}{\rho g} = 0$$

$$\therefore \frac{V_2^2}{2g} = 2 + 4$$

$$V_2 = \sqrt{12g} = \underline{10.85 \text{ m/s}}$$

To find p_1 , first find V_1

$$V_1 A_1 = V_2 A_2$$

$$V_1 = V_2 \frac{A_2}{A_1} = 10.85 \times \frac{300^2}{200^2}$$

$$V_1 = 24.41 \text{ m/s}$$

hence
$$\frac{p_1}{\rho g} + \frac{24.41^2}{2g} = 6$$

$$\frac{p_1}{\rho g} = 6 - 30.37$$

$$p_1 = -239 \text{ kN/m}^2 \quad !$$

The solution is physically impossible as p_1 cannot be less than negative atmospheric pressure. Either frictional losses would reduce the velocities and/or cavitation would occur.