HYDRAULICS IN CIVIL AND ENVIRONMENTAL ENGINEERING
Fourth edition

SOLUTIONS MANUAL

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Spon Press
Taylor & Francis Group
LONDON AND NEW YORK

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

First published 2004 by Spon Press, an imprint of Taylor & Francis, 11 New Fetter Lane, London EC4P 4EE

Simultaneously published in the USA and Canada by Spon Press 29 West 35th Street, New York, NY 10001

Publisher's note
This book has been produced from camera ready copy provided by the authors

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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

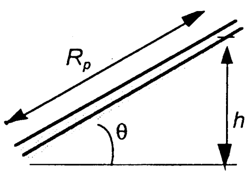
Apply hydrostatic equation for head of oil: $h = \frac{p}{\rho g} = \frac{200000}{850 \times 9.81} = 24 \text{ m}$

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 $p = \rho g h$

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



therefore:

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

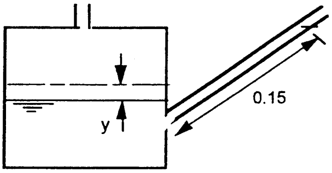
$$\frac{h}{R_p} = \frac{0.0226}{0.15} = 0.151 = sin\theta$$

$$\theta = 8.69^\circ$$

Problem 3

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

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



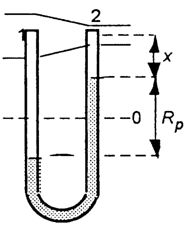
$$A_{TUBE} \times 0.15 = A_{TANK} \times y$$

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

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

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:

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

Therefore: $R_p = 0.712$ m   712 mm

Problem 5

$101500 = 9.81 \times 13600 \times H_m$ $H_m = 760.7$ mm

Problem 6

Gauge pressure = 103000 - 101500 = 1500 N/m²

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

At highest point: Atmospheric pressure $= 101500 - 1.21 \times 9.81 \times 150$

$= 99719$ N/m²

Gas pressure $= 103000 - 0.56 \times 9.81 \times 150$

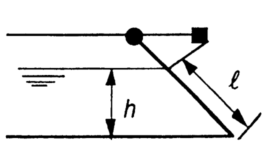
$= 102176$ N/m²

Gauge pressure $= 102176 - 99719$

$= 2457$ N/m²

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

Problem 7



Moment holding gate shut

= 100 x 9.81 x 0.5 +250 x 9.81 x 0.5

= 1717 N-m

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

Force on immersed surface = $\rho g A\bar{y} = 1000 \times 9.81 \times \left(1 \times \frac{h}{\sin 45°}\right) \times \frac{h}{2}$

$= 6937\ h^2$

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

i.e

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

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

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

Therefore h = 0.58 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

F_H = force on vertical projected area

$= \rho g A\bar{y} = 1000 \times 9.81 \times 25 \times 200 \times 12.5$

$= 613.13 \times 10^6 N$

F_H acts at centre of pressure, which is ($^2/_3$ x 25) m i.e 16.67 m below water level.

Vertical

Volume of water above dam foot, $v = \left[\left(\frac{20 \times 5}{2}\right) + (5 \times 5)\right] \times 20$

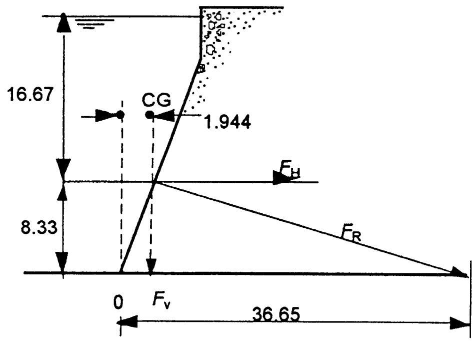
$= 15000\ m^3$

F_v = weight = $\rho g v$ = 1000 × 9.81 × 15000 = 147.15 x 10^6 N

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

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

$$\bar{x} = \frac{145.83}{\left[\left(\frac{20\times5}{2}\right)+(5\times5)\right]} = 1.944 \text{ to right of vertical through } O$$



Resultant force on dam F_R

$$F_R = \left(613.13^2 + 147.15^2\right)^{\frac{1}{2}}$$

$$= 630.5 \text{ MN}$$

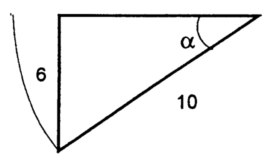
Angle of F_R to horizontal

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

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

34.7 + 1.944 = 36.65 m

Problem 9



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

$$\text{Area of sector} = \frac{36.9}{360}\times\pi\times10^2 = 32.2 \text{ m}^2$$

$$\text{Area of triangle} = \frac{1}{2}\times6\times10 = 30 \text{ m}^2$$

Therefore:

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

Volume of water displaced = 2.2 × 10 = 22 m³

So vertical (weight) force = 22 × 9.81 × 1000 = 215820 N

Horizontal force = Force on vertical projected area

$$= \rho g A\bar{y} = 1000\times9.81\times(6\times10)\times3$$

$$= 1765800 \; N$$

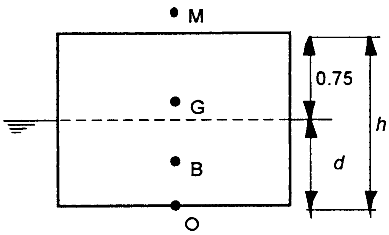
Resultant force $= \sqrt{215820^2 + 1765800^2}$

$$= 1778940 \text{ N}$$

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

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

Problem 10



Displacement = 300000/1000 = 300 m³

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

therefore centre of buoyancy

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

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

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

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

Therefore

$$\begin{aligned}
1.5 \quad &= 0.06L + \frac{300}{12L} - \left(\frac{300}{12L} + 0.375 + 0.3\right) \\
&= 0.06L - 0.675 \\
L \quad &= 36.25 \text{ m} \\
h \quad &= \frac{300}{6 \times 36.25} + 0.75 = 2.13 \text{ m}
\end{aligned}$$

Chapter 2

Problem 1

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

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

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

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

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

To find p_1, first find V_1

$$V_1A_1=V_2A_2$$

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

$$V_1=24.41\ m/s$$

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

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

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

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.