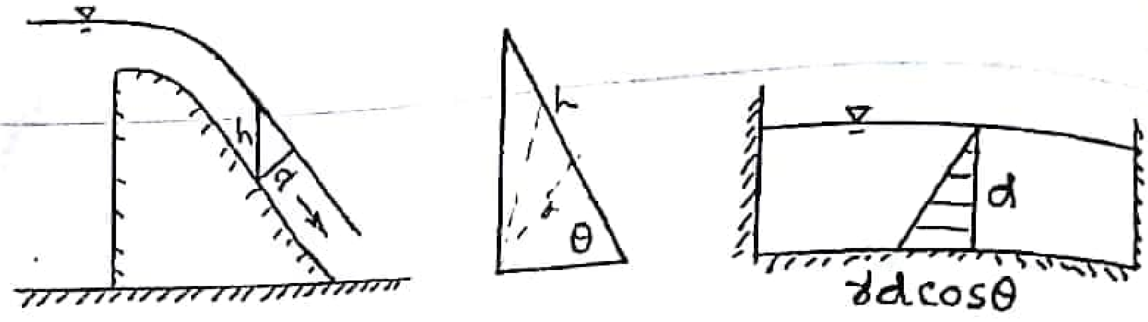
Thus, for channels of large slope, the pressure ... depth multiplied by a correction factor $\cos^2\theta$. For a small slope channel, $\theta$ ... and $S_0 < 0.1$, the use of Eq. (1.22) instead of Eq. (1.27) involves an error less than about 1% and can safely be ignored.

**Example 1.7**

Prove that the shear force and the overturning moment on the side walls of a steep rectangular channel are $(1/2)\gamma h^2 \cos^3\theta$ and $(1/6)\gamma h^3 \cos^4\theta$, respectively, where h is the depth of flow and $\theta$ is the bottom slope of the channel.




**Solution** $\quad p/\gamma = d\cos\theta$

$$\text{Shear force, } F = \frac{1}{2}\times \gamma d\cos\theta \times d \qquad (\text{per unit width})$$

$$= \frac{1}{2}\gamma d^2\cos\theta = \frac{1}{2}\gamma h^2\cos^3\theta \quad (\because d = h\cos\theta)$$

$$\text{Overturning moment} = F\times arm = F\times d/3$$

$$= \frac{1}{2}\gamma d^2\cos\theta\times\frac{d}{3} = \frac{1}{6}\gamma d^3\cos\theta = \frac{1}{6}\gamma h^3\cos^4\theta$$

## PROBLEMS

(Take ν for water = $10^{-6}$ m²/s and g = 9.81 m/s²)

1.1 (a) The depth and mean velocity upstream and downstream of a vertical sluice gate in a horizontal rectangular channel are 4 m and 1 m and 2 m/s and 8 m/s, respectively. The width of the channel is 6 m. Determine the state of flow both upstream and downstream of the gate.

(b) Consider the following data for the Padma (Ganges) river at the Baruria station in Faridpur on the 2nd July, 1989: A = 33,500 m², Q = 56,200 m³/s and B = 3820 m. Compute the state of flow. Assume that the river is wide.

1.2 Water flows in an open channel at a depth of 1 m and a mean velocity of 3 m/s. Compute the discharge and determine the state of flow if the channel is

i) wide

ii) rectangular with b = 6 m,

iii) trapezoidal with b = 6 m and s = 2,

iv) triangular with s = 2,

v) parabolic with B = 4 m, and

vi) circular whose diameter is 2.5 m.

If elementary waves are created in these channels, determine the speeds of the wave fronts upstream and/or downstream.

1.3(a) The average depth of water in a wide river connected to sea is 5 m. Determine the time taken by a tidal wave to travel from the river mouth to 30 km upstream (i) when there is no flow in the river, and (ii) when the average flow velocity in the river is 1 m/s?

(b) Waves of small amplitude are created at the center of a circular-shaped pond of radius 50 m. The waves are found to reach the edge of the pond in 10 s. Estimate the approximate volume of water in the pond assuming that the depth of water in the pond is same everywhere.

1.4(a) In a wide river the velocity varies linearly along a vertical from 0.10 m/s at the bottom to 2.10 m/s at the surface. (i) Compute the discharge per unit width, and (ii) determine the state of flow, if the depth of flow is 4 m.

(b) In a wide river the velocity varies along a vertical as $u = 1 + 2z/h$, where h is the total depth and u is the velocity at a distance z from the channel bottom. The river is 5 m deep. (i) Compute the discharge per unit width, and (ii) determine the state of flow.

1.5(a) The velocity of flow is zero over one-third of the cross-section of a channel and uniform over the rest of the cross-section. Compute the numerical values of the velocity distribution coefficients α and β.

(b) The velocity is zero along the lower 20% of a vertical in a wide channel and uniform along the rest of the vertical. Compute the numerical values of the velocity distribution coefficients α and β.

1.6(a) For laminar flow the velocity distribution along a vertical can be approximated by

$$u = u_o \sin \frac{\pi z}{2h}$$

where u is the velocity at a distance z from the channel bottom, h is the depth of flow and $u_o$ is the velocity at the free surface. Compute the velocity distribution coefficients α and β and the ratio (α-1)/(β-1).

(b) For turbulent flow the velocity distribution along a vertical can be approximated by $u \propto z^n$, when n = 1/7 (Prandtl's one-seventh power law). Determine the velocity distribution coefficients α and β and the ratio (α-1)/(β-1) in terms of n and for n = 1/7. Compare the numerical values of α and β with those obtained for laminar flow in Problem 1.6(a).

1.7 Compute the values of the velocity distribution coefficients α and β and the ratio (α-1)/(β-1) for the following velocity distributions along a vertical in a wide channel when the depth of flow in the channel is (a) 5 m, and (b) 10 m.

i) $u = 2z/h$
ii) $u = 2 + 2z/h$
iii) $u = 4(z/h)^{1/2}$
iv) $u = 1 + 2(z/h)^{1/2}$

1.8(a) Solve Example 1.5 using the Simpson's rules of numerical integration.

(b) Figure 1.14 shows the velocity distribution downstream of a sluice gate under submerged condition. Using the trapezoidal rule of numerical integration, compute the discharge per unit width, the mean velocity of flow and the numerical values of α and β.

1.9(a) A steep rectangular chute has a slope of 1H:3V. Compute the pressure at the bed of the chute if the vertical depth of water flowing over the chute is 1 m. Also, compute the force and the overturning moment on its side walls.

(b) While computing the shear force and the overturning moment on the side walls of a steep spillway chute, an engineer assumed that the water pressure varies linearly from zero at the free surface to ρgh at the bed of the chute, where h is the depth measured vertically. Are the computed results correct? If not, compute (i) the correct values of the shear force and the overturning moment, and (ii) the % error. The chute has an inclination of 1H:3V and h = 1 m.

(c) A high-head overflow spillway is shown in Fig.1.15. The flip bucket at the toe of the spillway acts to change the direction of flow from the slope of the spillway face to the horizontal and to discharge the flow into the air. If $r_1 = r_2 = 20$ m, $h_1 = h_2 = h_3 = h_4 = 1$ m and the discharge over the spillway is 6.5 $m^3/s/m$, determine the intensities of pressure at points 1, 2, 3 and 4.

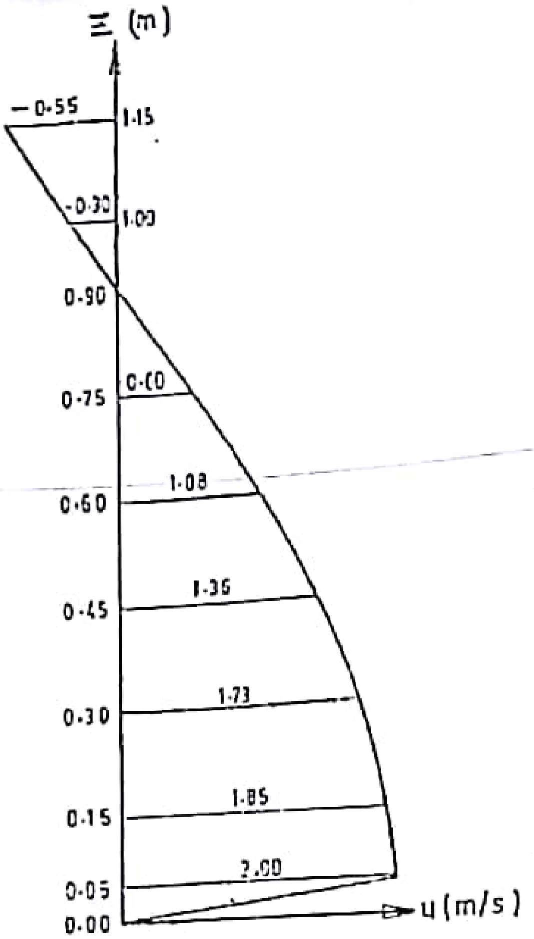



Fig. 1.14

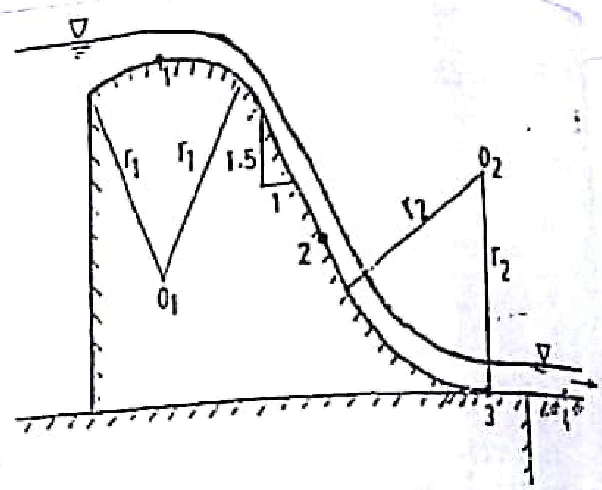



Fig. 1.15

## Answers to the Problems

1.1(a) Upstream: subcritical turbulent, Downstream: supercritical turbulent (b) Subcritical turbulent

1.2 (i) 3 $m^2/s$, subcritical turbulent, 0.13 m/s upstream, 6.13 m/s downstream
(ii) 18 $m^3/s$, subcritical turbulent, 0.13 m/s upstream, 6.13 m/s downstream
(iii) 24 $m^3/s$, supercritical turbulent, 0.20 m/s downstrtem, 5.80 m/s downstrem
(iv) 6 $m^3/s$, supercritical turbulent, 0.79 m/s downstream, 5.21 m/s downstream
(v) 8 $m^3/s$, supercritical turbulent, 0.44 m/s downstream, 5.56 m/s downstream
(vi) 5.50 $m^3/s$, supercritical turbulent, 0.29 m/s downstream, 5.71 m/s downstream

1.3(a) (i) 4286 s (ii) 5000 s (b) 20,015 $m^3$

1.4(a) (i) 4.4 $m^2/s$ (ii) Subcritical turbulent (b) (i) 10 $m^2/s$ (ii) Subcritical turbulent

1.5(a) $\alpha = 2.25$, $\beta = 1.50$ (b) $\alpha = 1.56$, $\beta = 1.25$

1.6(a) $\alpha = \pi^2/6 = 1.645$, $\beta = \pi^2/8 = 1.234$, Ratio = 2.76
(b) $\alpha = (n+1)^3/(3n+1) = 1.045$, $\beta = (n+1)^2/(2n+1) = 1.016$, Ratio = 2.828

1.7 (i) $\alpha = 2.000$, $\beta = 1.330$, Ratio = 3.00 (ii) $\alpha = 1.111$, $\beta = 1.037$, Ratio = 3.00
(iii) $\alpha = 1.350$, $\beta = 1.125$, Ratio = 2.80 (iv) $\alpha = 1.118$, $\beta = 1.041$, Ratio = 2.89

1.8(a) $q = 20.597\ m^2/s$, $\bar{U} = 3.433$ m/s, $\alpha = 1.181$, $\beta = 1.078$
(b) $q = 1.018\ m^2/s$, $\bar{U} = 0.885$ m/s, $\alpha = 3.450$, $\beta = 1.906$

1.9(a) $p = 980.83\ N/m^2$, F = 155.07 N, O.M. = 16.35 m-N (b) Not correct, (i) F = 155.07 N, O.M. = 16.35 m-N (ii) Error for F = +3,063%, Error for O.M. = +9,906%
(c) $p_1 = 7{,}697.50\ N/m^2$, $p_2 = 3{,}018.46\ N/m^2$, $p_3 = 11{,}922.50\ N/m^2$, $p_4 = 9{,}810\ N/m^2$

$$2g \quad 2g \quad \ldots \quad 2\times 9.81$$

$$= 0.50 - 0.16 = 0.34\ m\ of\ water$$

Applying the momentum equation between sections 1 and 2 and assuming unit width, we obtain

$$\rho q(U_2 - U_1) = \frac{1}{2}\gamma h_1^2 - \frac{1}{2}\gamma h_2^2 - F$$

$$\therefore F = \frac{1}{2}\gamma(h_1^2 - h_2^2) - \rho q(U_2 - U_1)$$

$$= \frac{1}{2}\times 1000\times 9.81\times(2^2 - 1.5^2) - 1000\times 4\times(2.67 - 2.0)$$

$$= 8583.75 - 2666.67 = 5917.08\ N = 5.92\ kN$$

The force on the weir plate is equal and opposite to F.

(2)

## PROBLEMS

2.1 When a Pitot tube is placed in an open channel (Fig. 2.8), the water rises in the tube to a height H. Applying the Bernoulli equation between points 1 and 2, show that the velocity of stream upstream of the tube is

$$u = \sqrt{2gH}$$

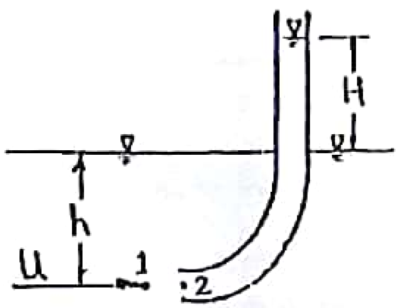



Fig. 2.8

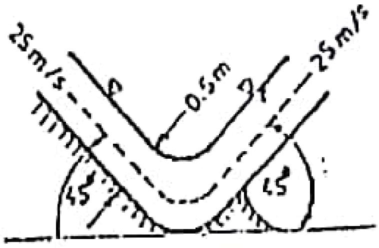



Fig. 2.9

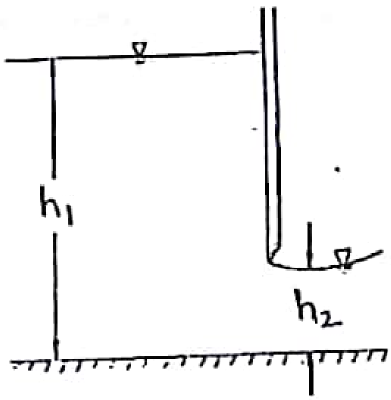



Fig. 2.10

2.2 The inlet and exit angles of a ski-jump spillway (Fig.2.9) are 45° and the flow over it has a velocity of 25 m/s and a depth of 0.5 m. Neglecting all losses, estimate the maximum elevation of the outflow trajectory. Also compute the horizontal and vertical forces on the spillway as a result of the change in the flow direction. Assume unit width.

2.3(a) Show that the force on a vertical sluice gate in a horizontal rectangular channel (Fig.2.10) is given by

$$F = \frac{1}{2}\gamma\frac{(h_1 - h_2)^3}{h_1 + h_2}$$

where $\gamma$ is the specific weight of water.

(b) The depths of flow a short distance upstream and at the vena contracta downstream of a vertical sluice gate in a horizontal rectangular channel are 4 m and 1 m, respectively. The width of the channel is 6 m.

i) Neglecting energy losses and taking $\alpha_1 = \alpha_2 = 1$, compute the discharge under the gate.

ii) Compute the force on the sluice gate and compare it with that obtained by assuming hydrostatic pressure distribution. Assume that the coefficient of contraction, $C_c = 0.61$.

2.4 A bridge across a river has its piers placed symmetrically at the rate of 30 m center to center. Upstream of the bridge the water depth is 10 m and the velocity is 4 m/s. When the flow has gone far enough downstream to even out again after the disturbance caused by the piers, the depth is 9 m. Compute the thrust on each pier. Neglect the bed slope and the bed friction.

*******

**Answers**

2.2 15.93 m, $F_x = 0$, $F_z = 441{,}941$ N

2.3 (b) i) $Q = 47.54\ m^3/s$ ii) $F_{actual} = 159.06$ kN, $F_{hydrostatic} = 163.91$ kN

2.4 Thrust on each pier = 2,268 kN

## PROBLEMS

3.1 A rectangular channel has a bottom width of 6 m. (i) Construct the specific energy curve for $Q = 15\ m^3/s$ and determine the critical depth and the minimum value of the specific energy. (ii) Construct the discharge-depth curve for $E = 3$ m and determine the critical depth and the maximum value of the discharge.

3.2 Compute the numerical values of the hydraulic exponent for critical flow computation M for $h = 1$ m in a (i) trapezoidal channel with $b = 6$m, $s = 2$ and $Q = 20\ m^3/s$, and (ii) circular channel with $d_0 = 3$ m.

3.3 Prove the following equations when the flow is critical in a rectangular channel:

$$i)\ h_c = \sqrt[3]{\frac{\alpha Q^2}{g b^2}} = \sqrt[3]{\frac{\alpha q^2}{g}} \qquad ii)\ U_c = \sqrt{\frac{g h_c}{\alpha}} = \sqrt[3]{\frac{gQ}{\alpha b}}$$

$$iii)\ E_c = 1.5 h_c \qquad iv)\ Q = \sqrt{g}\, b\, h_c^{1.5} = 3.132 b h_c^{1.5} = 0.544 \sqrt{g}\, b E_c^{1.5}$$

3.4 Compute the critical depth and velocity in a (i) wide rectangular channel with $q = 4\ m^2/s$, (ii) rectangular channel with $b = 6$ m and $Q = 35\ m^3/s$, (iii) triangular channel with $s = 1$ and $Q = 5\ m^3/s$, and (iv) parabolic channel whose profile is given by $y^2 = 5z$ with $Q = 25\ m^3/s$. In all cases assume $\alpha = 1.12$.

3.5 (a) Compute the critical depth and velocity in a trapezoidal channel with $b = 6$m, $s = 2$ and $Q = 30\ m^3/s$ by (i) the trial-and-error, (ii) the bisection, and (iii) the Newton-Raphson methods, if $\alpha = 1.12$.

(b) Compute the critical depth and velocity in a circular channel with $d_0 = 3$ m and $Q = 5\ m^3/s$ by the trial-and-error method, if (i) $\alpha = 1$, and (ii) $\alpha = 1.12$.

3.6 (a) Prove that the section of a channel at which the flow is critical at all depths can be expressed by

$$B^2 G^3 = Q^2 / 8g$$

where B is the top width, G is the vertical distance between the energy line and the water surface, Q is the discharge and g is the acceleration due to gravity.

(b) A rectangular channel section is to take a certain discharge Q at the critical state and at the same time the wetted perimeter is to be a minimum. Show that the width of the channel must be equal to 4/3 times the depth.

3.7(a) Show that the relation between the alternate depths $h_1$ and $h_2$ for a rectangular channel is given by

$$\frac{2h_1^2 h_2^2}{h_1 + h_2} = h_c^3$$

where $h_c$ is the critical depth.

(b) The alternate depths in a rectangular channel 6 m wide are 2 m and 1 m. Compute the discharge, the specific energy and the critical depth.

3.8 Compute the maximum discharge that may be carried by a channel for a specific energy of 2.0 m when the channel is (i) rectangular with $b = 6$ m, (ii) triangular with $s = 1$, (iii) parabolic whose profile is given by $y^2 = 4z$, (iv) trapezoidal with $b = 6$ m and $s = 2$, and (v) circular with $d_0 = 3$ m.

3.9 The depth upstream of a vertical sluice gate in a rectangular channel is 2 m and the discharge under the gate is $30.67\ m^3/s$. The channel is 6 m wide. Compute the downstream depth.

3.10 Prove that the minimum height of a hump that will produce critical flow in a rectangular channel is given by

$$\Delta z_c = h_1(1 + 0.50Fr_1^{\,2} - 1.50Fr_1^{\,0.67})$$

where $h_1$ is the upstream depth and $Fr_1$ is the Froude number corresponding to $h_1$.

3.11 Water is flowing at a velocity of 2 m/s and a depth of 2.5 m in a long rectangular channel 6 m wide. Compute (a) the height of a smooth upward step in the channel bed to produce critical flow, and (b) the depth and the change in water level produced by (i) a smooth upward step of 0.40 m, (ii) a smooth upward step of 0.80 m, and (iii) a smooth downward step of 0.40 m. In all cases, neglect energy losses and take $\alpha = 1$.

3.12 Water is flowing at a velocity of 2 m/s and a depth of 2.5 m in a long rectangular channel 6 m wide. Compute (a) the contraction in width of the channel for producing critical flow, and (b) the depth and the change in water level produced by (i) a smooth contraction in width to 5 m, (ii) a smooth contraction in width to 3 m, and (iii) a smooth expansion in width to 8 m. In all cases neglect energy losses and take $\alpha = 1$.

3.13 The upstream conditions are as in Prob. 3.11 and there is a smooth upward step of 0.80 m in the channel bed. What expansion or contraction in width must simultaneously take place to produce critical flow in the channel?

3.14 The upstream conditions are as in Prob. 3.11 and the width of the channel is reduced to 5 m. How much the channel bottom is to be raised or lowered to produce critical flow in the channel?

3.15 A bridge is to be constructed across a 10 km wide river carrying a discharge of 1,00,000 $m^3/s$ at a depth of 10 m. If it is intended to provide the minimum length of the bridge by reducing the river width, what would be the minimum river width without affecting the upstream flow? Neglect energy losses and assume $\alpha = 1$.

3.16(a) A broad-crested weir is built in a rectangular channel of width 1 m. The height of the weir crest above the channel bed is 0.60 m and the head over the weir is 0.40 m. Calculate the discharge.

(b) Compute the discharge through a Venturi flume having a throat width of 0.30 m when the upstream depth is 0.50 m.

***********

**Answers**

3.1 (i) $h_c = 0.85$ m, $E_{min} = E_c = 1.30$ m (ii) $h_c = 2$ m, $Q_{max} = 53.20\ m^3/s$

3.2 (i) M = 3.25 (ii) M = 3.74

3.4 (i) $h_c = 1.222$ m, $U_c = 3.372$ m/s (ii) $h_c = 1.083$ m, $U_c = 3.079$ m/s

(iii) $h_c = 1.417$ m, $U_c = 2.490$ m/s (iv) $h_c = 1.863$ m, $U_c = 3.298$ m/s

3.5(a) $h_c = 1.23$ m, $U_c = 2.883$ m/s (by all methods)

(b) (i) $h_c = 0.950$ m, $U_c = 2.600$ m/s (ii) $h_c = 0.977$ m, $U_c = 2.501$ m/s

3.7(b) $Q = 30.688\ m^3/s$, $E = 2.333$ m, $h_c = 1.387$ m

3.8 (i) 28.933 $m^3/s$ (ii) 7.172 $m^3/s$ (iii) 15.344 $m^3/s$ (iv) 42.270 $m^3/s$ (v) 11.13 $m^3/s$

3.9 1 m

3.11 (a) $\Delta z_c = 0.655$ m

(b) (i) $h_2 = 1.98$ m, Drop in water level = 0.12 m

(ii) $h_1' = 2.67$ m, Drop in water level = 0.51 m

(iii) $h_2 = 2.96$ m, Rise in water level = 0.06 m

3.12 (a) $b_c = 3.96$ m

(b) (i) $h_2 = 2.38$ m, Drop in water level = 0.12 m

(ii) $h_1' = 3.12$ m, Drop in water level = 0.95 m

(iii) $h_2 = 2.60$ m, Rise in water level = 0.10 m

3.13 Expansion in width = 0.70 m 3.14 Bottom is to be raised by 0.39 m

3.15 Minimum river width = 1840 m 3.16(a) 0.448 $m^3/s$ (b) 0.181 $m^3/s$

## PROBLEMS

4.1 Assuming that the velocity distribution along a vertical in an open channel is logarithmic, compute the position of the mean velocity below the free surface. Also show that (i) the velocity at 0.6 depth, and (ii) the average of the velocities at 0.2 and 0.8 depths are approximately equal to the mean velocity in a vertical.

4.2(a) A trapezoidal channel has a bottom width of 6.0 m, side slopes of 1.5H:1V, a depth of flow of 2.0 m, $n = 0.025$ and $S_0 = 0.0001$. Assuming that the flow is uniform, (i) compute Q, (ii) compute C, f, $\tau_0$ and $u^*$, and (iii) compute $k_s$, determine whether the channel boundary is smooth or rough and state if the Manning formula is applicable for computing flow in this channel. Assume that the velocity distribution is logarithmic.

(b) Consider the following data for the Padma (Ganges) river at the Baruria station in Faridpur on the 2nd July, 1989: $A = 33{,}500\ m^2$, $Q = 56{,}200\ m^3/s$ and $B = 3820$ m. Assuming that the flow is uniform, (i) compute n, C, f, $u^*$ and $\tau_0$, and (ii) determine whether the channel boundary is smooth or rough taking the velocity distribution as logarithmic. Assume that the river is wide. Longitudinal slope of the river is 4 cm/km.

4.3(a) Show that for a wide rough channel with logarithmic velocity distribution in the vertical, the Manning's roughness coefficient n may be expressed by

$$n = \frac{(r-1)h^{1/6}}{5.57(r+0.95)}$$

where r $(= u_{0.2}/u_{0.8})$ is the ratio between the measured velocities at two-tenths and eight-tenths of depth.

(b) The velocities at 0.2 and 0.8 of the depth along a vertical in a wide river are 1.25 m/s and 1 m/s, respectively. (i) Compute the numerical value of Manning's n, and (ii) determine the variation of velocity in the vertical, if the river is 10 m deep.

4.4(a) Using the Manning formula and taking h = 1 m, compute the hydraulic exponent for uniform flow computation N for a

i. rectangular channel with b = 6 m,
ii. trapezoidal channel with b = 6 m and s = 2,
iii. parabolic channel whose profile is given by $y^2 = 4z$, and
iv. circular channel whose diameter is 2 m.

(b) Solve Problem 4.4(a) using the Chezy formula.

4.5(a) A wide channel with $n = 0.025$ and $S_0 = 0.0025$ carries a discharge of $3\ m^2/s$. Compute the normal depth and velocity.

(b) A wide channel with $S_0 = 0.006$ and $C = 50\ m^{1/2}/s$ carries a discharge of $4\ m^2/s$. Compute the normal depth and velocity.

4.6(a) A triangular channel with side slopes 1:1 is laid on a slope of 0.001. If $n = 0.015$ and $h_n = 1$ m, compute the discharge.

(b) A triangular channel with s = 1, n = 0.025 and $S_0$ = 0.0025 carries a discharge of 5 $m^3/s$. Compute the normal depth and velocity.

4.7 Water flows at a velocity of 1 m/s in an open channel under uniform flow condition. The longitudinal slope of the channel is 0.0016 and n = 0.020. Compute the depth of flow when the channel is

i) rectangular with b = 6 m,
ii) trapezoidal with b = 6 m and s = 2,
iii) triangular with s = 1,
iv) parabolic whose profile is given by $y^2 = 4z$, and
v) circular whose diameter is 2 m.

4.8 Uniform flow occurs in an open channel with $h_n$ = 1 m, $S_0$ = 0.0001 and n = 0.015. Compute the discharge if the channel is

i) rectangular with b = 6 m,
ii) trapezoidal with b = 6 m and s = 1,
iii) triangular with s = 1.5,
iv) parabolic whose profile is given by $y^2 = 4z$, and
v) circular whose diameter is 1.5 m.

4.9(a) A rectangular channel having n = 0.025 and $S_0$ = 0.0001 carries a discharge of 6 $m^3/s$ at a normal depth of 1.5 m. Compute the bottom width.

(b) A trapezoidal channel having side slopes of 1.5H:1V, n = 0.020 and $S_0$ = 0.0002 carries a discharge of 25 $m^3/s$ at a normal depth of 2 m. Compute the bottom width.

4.10 Compute the normal depth and velocity in a

i. rectangular channel with b = 8 m and Q = 22 $m^3/s$,
ii. trapezoidal channel with b = 6 m, s = 2 and Q = 30 $m^3/s$,
iii. parabolic channel whose profile is given by $y^2 = 5z$ and Q = 15 $m^3/s$, and
iv. circular channel whose diameter is 2 m and Q = 3 $m^3/s$.

In all cases, take n = 0.025 and $S_0$ = 0.0025.

4.11(a) A trapezoidal channel has a bottom width of 6 m, side slopes of 1.5:1, $\alpha$ = 1 and n = 0.025. (i) Determine the normal slope at a normal depth of 1 m when the discharge is 20 $m^3/s$. (ii) Determine the critical slope when the discharge is 20 $m^3/s$. (iii) Determine the critical slope when the normal depth is 1 m.

(b) Solve Problem 4.11(a) when $\alpha$ = 1.12.

4.12 When the Manning formula is used, show the critical slope at a given normal depth $h_n$ may be expressed by

$$S_c = \frac{gn^2 D_n}{R_n^{4/3}}$$

and that this slope for a wide channel is

$$S_c = \frac{gn^2}{h_n^{1/3}} = \frac{n^2 g^{10/9}}{q^{2/9}}$$

where q is the discharge per unit width.

4.13 A channel consists of a main section and two side sections as shown in Fig.4.4. Compute the total discharge, the mean velocity of flow and the Manning's n for the entire section when n = 0.025 for the main channel, n = 0.045 for the side channels and $S_0$ = 0.0002. Also, compute the numerical values α and β for the entire section assuming that α = β = 1.00 for the main and the side sections.

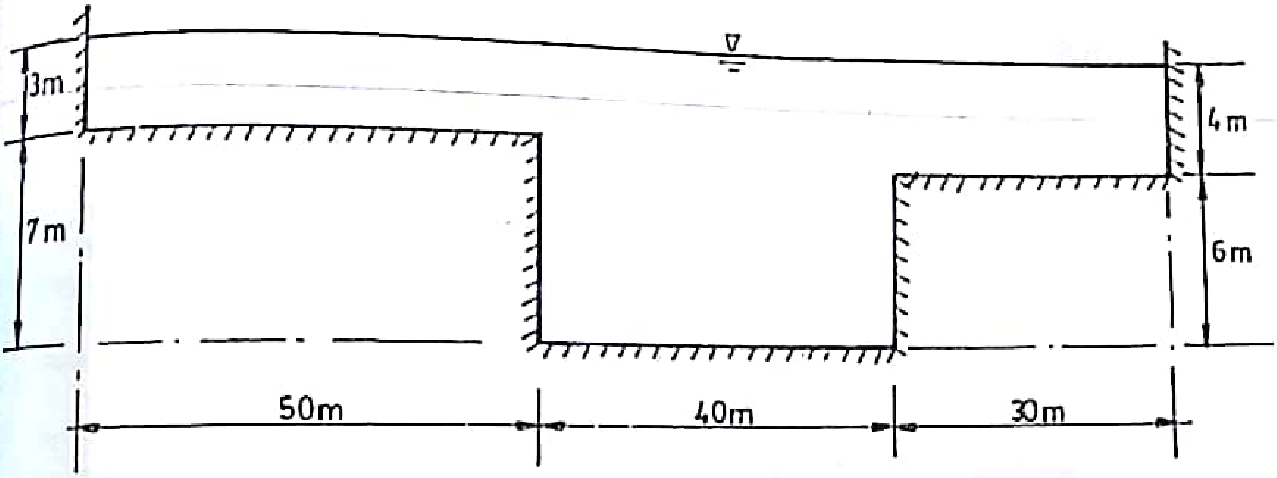



Fig. 4.4 for Problem 4.13

4.14 An unlined irrigation canal (n = 0.025) is trapezoidal and has a bottom width of 6 m, side slopes of 1:1 and a depth of flow of 2 m. The longitudinal slope of the canal is 0.0005. Compute the discharge carried by the canal under uniform flow condition. It is proposed to line the canal with concrete having n = 0.013. Compute the discharge that would be carried by the canal when (i) only the sides are lined, (ii) only the bottom is lined, and (iii) both the bottom and the sides are lined.

4.15 A rectangular testing channel is 0.60 m wide and is laid on a slope of 0.1%. When the channel bed and walls were made smooth by neat cement, the measured normal depth of flow was 0.40 m for a discharge of 0.23 $m^3/s$. The same channel was then roughened by cemented sand grains and the measured normal depth was 0.35 m for a discharge of 0.12 $m^3/s$. Determine the discharge for a normal depth of 0.45 m if the bed is roughened and the walls are made smooth.

4.16 Compute the flood discharge through a river reach 1000 m long having a fall in water surface of 0.85 m. Neglect the eddy loss. Use the following data:

| Section | A ($m^2$) | P (m) | n | α |
|---|---|---|---|---|
| Upstream | 12,000 | 2,150 | 0.030 | 1.15 |
| Downstream | 10,500 | 2,050 | 0.030 | 1.18 |

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...gn of alluvial channels. ... Hence, it is customary to assume a ... fine sediments,

*Example 5.7*

Design a stable alluvial channel using the Lacey's theory. The channel is to carry 10 m³/s through 1 mm sand.

*Solution* $Q = 10\ m^3/s \quad d = 1\ mm$

$$f_s = 1.76\sqrt{d} = 1.76\sqrt{1} = 1.76$$

$$S_0 = \frac{f_s^{5/3}}{3340Q^{1/6}} = \frac{1.76^{5/3}}{3340\times 10^{1/6}} = 5.233\times 10^{-4}$$

$$R = 0.47(Q/f_s)^{1/3} = 0.47\times(10/1.76)^{1/3} = 0.8387\ m$$

$$P = 4.75\sqrt{Q} = 4.75\sqrt{10} = 15.02\ m$$

so that

$$A = PR = 15.02\times 0.8387 = 12.60\ m^2$$

Assuming that the side slope is 1/2H:1V so that $s = 0.5$, we obtain

$$P = 15.02 = b + 2\sqrt{1+0.5^2}\times h = b + 2.236h$$

$$A = 12.60 = (b+0.5h)h = bh + 0.50h^2$$

Eliminating b between the above two equations, we get the quadratic equation

$$h^2 - 8.652h + 7.258 = 0$$

which gives $h = 0.941$ m and $7.711$ m. Using these two values of h, we get $b = 15.02 - 2.236h =$ 12.916 m and $-2.222$ m. Since b cannot be negative, we accept

$h = 0.941$ m and $b = 12.916$ m.

## PROBLEMS

5.1 (a) Show that the best hydraulic circular section is a semi-circle.

(b) Show that the best hydraulic triangular section is one-half of a square.

(c) Show that for the best hydraulic parabolic section the top width is equal to $2\sqrt{2}$ times the depth of flow.

5.2 (a) The cross-sectional area of a channel is $40\ m^2$. Calculate the wetted perimeter and the hydraulic radius of the best hydraulic section if the channel is (i) rectangular, (ii) triangular, (iii) trapezoidal, (iv) circular, and (v) parabolic. Which section has the minimum wetted perimeter?

(b) Show that for a given area A, the best hydraulic rectangular and triangular sections have the same wetted perimeter.

5.3 Compute the wetted perimeter of the best hydraulic section for a lined channel to carry a discharge of 15 m³/s with $n = 0.013$ and $S_0 = 0.001$ if the section is (i) rectangular, (ii) triangular, (iii) trapezoidal, (iv) circular, and (v) parabolic. Which section has the minimum wetted perimeter?

5.4 (a) Design the best hydraulic trapezoidal section to carry a discharge of 20 $m^3/s$ on a slope of 1 in 2500 if s = 1 and n = 0.012.

(b) Determine the bottom width of the best hydraulic trapezoidal section to carry a discharge of 10 $m^3/s$ if s = 2 and n = 0.015 in which the depth of flow is to be restricted to 1 m. Also, determine the bottom slope of the channel.

5.5 A lined channel (n = 0.015) is to be laid on a slope of 1 in 2000. The side slope of the channel is to be maintained at 1.5:1. (i) Determine the depth of flow of a triangular section with rounded corner to carry a discharge of 40 $m^3/s$. (ii) Determine the dimensions of a trapezoidal section with rounded corners to carry a discharge of 80 $m^3/s$ when the maximum permissible velocity is 2 m/s.

5.6 An irrigation canal has to carry a discharge of 30 $m^3/s$ through a coarse non-cohesive material having $d_{50}$ = 2.5 cm, $d_{75}$ = 3 cm and n = 0.025. The angle of repose of the perimeter material is $32^0$. The canal is to be trapezoidal in shape having s = 2 and laid on a slope of 1 in 1000. Compute the bottom width and the depth of flow (i) using the method of Lane, and (ii) using the modified Yalin-Karahan diagram.

5.7 Using the Lacey method, design a stable alluvial channel when d = 1.5 mm and Q = 25 $m^3/s$.

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Answers

5.2(a)(i) P = 17.889 m, R = 2.236 m (ii) P = 17.889 m, R = 2.236 m
(iii) P = 16.647 m, R = 2.403 m (iv) P = 15.853 m, R = 2.523 m
(v) P = 17.369 m, R = 2.303 m Circular section has the minimum wetted perimeter
5.3(a)(i) P = 7.256 m (ii) P = 7.256 m (iii) P = 6.632 m (iv) P = 6.239 m
(v) P = 6.994 m Circular section has the minimum wetted perimeter
5.4(a) h = 2.408 m, b = 1.994 m (b) b = 0.472 m, $S_0 = 9.278 \times 10^{-3}$
5.5(i) h = 3.098 m (ii) h = 1.824 m, b = 18.124 m
5.6 (i) b = 9.67 m, h = 1.61 m (ii) b = 14.76 m, h = 1.30 m
5.7 b = 21.150 m, h = 1.163 m

**Example 6.7**

Determine the depth of flow 100 m upstream of the dam of Example 6.5 using the Euler and the modified Euler methods.

**Solution** Trapezoidal channel, $b = 6$ m, $s = 2$, $S_0 = 0.0025$, $Q = 30$ m$^3$/s, $\alpha = 1.12$, $n = 0.025$

**Euler mothod** $h_1 = 2.50$ m, $A_1 = 27.50$ m$^2$, $P_1 = 17.18$ m, $R_1 = 1.601$ m, $R_1^{2/3} = 1.368$, $S_{f1} =$ 0.000397, $B_1 = 16$ m and $\Delta x = 100$ m

$$\left(\frac{dh}{dx}\right)_1 = \frac{S_0 - S_{f1}}{1 - \dfrac{\alpha Q^2 B_1}{g A_1^3}} = \frac{0.0025 - 0.000379}{1 - \dfrac{1.12 \times 30^2 \times 16}{9.81 \times 27.50^3}} = 2.283 \times 10^{-3}$$

$$h_2 = h_1 + \Delta x \left(\frac{dh}{dx}\right)_1 = 2.50 + (-100) \times 2.283 \times 10^{-3} = 2.2717\,m$$

**Modified Euler Method** As in the Euler method, $(dh/dx)_1 = 2.283 \times 10^{-3}$.

$$\therefore h_{1\frac{1}{2}} = h_1 + \frac{\Delta x}{2}\left(\frac{dh}{dx}\right)_1 = 2.50 + 0.5 \times (-100) \times 2.283 \times 10^{-3} = 2.3853\ m$$

For this depth, we obtain $A = 25.701$ m$^2$, $P = 16.67$ m, $R = 1.54$ m, $R^{2/3} = 1.3345$, $S_f = 0.000478$ and $B = 15.543$ m.

$$\therefore \left(\frac{dh}{dx}\right)_{1\frac{1}{2}} = \frac{S_0 - S_f}{1 - \dfrac{\alpha Q^2 B}{g A^3}} = \frac{0.0025 - 0.000478}{1 - \dfrac{1.12 \times 30^2 \times 15.543}{9.81 \times 25.701^3}} = 2.232 \times 10^{-3}$$

$$\therefore h_2 = h_1 + \Delta x \left(\frac{dh}{dx}\right)_{1\frac{1}{2}} = 2.50 + (-100) \times 2.232 \times 10^{-3} = 2.2768\ m$$

## PROBLEMS

6.1 Show that the gradually varied flow equation for flow in a rectangular channel of variable width b may be expressed as

$$\frac{dh}{dx} = \frac{S_0 - S_f + (\alpha Q^2 h / g A^3)(db/dx)}{1 - \alpha Q^2 b / g A^3}$$

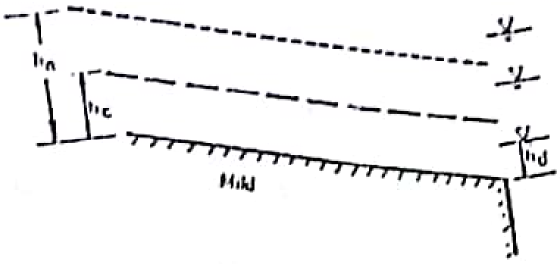
6.2 Prove that the specific energy of the M1, S1, S2 and C1 profiles increases and of the M2, M3, S3, C3, H2, H3, A2 and A3 profiles decreases in the downstream direction.

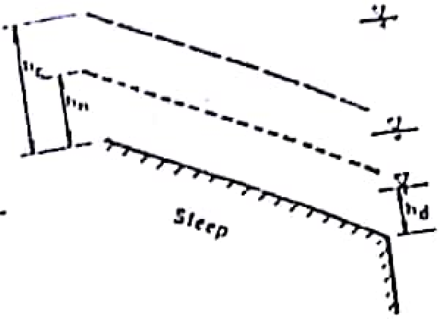
6.3 Sketch the possible flow profiles produced on the upstream and downstream of a sluice gate in a (i) mild, (ii) critical, (iii) steep, (iv) horizontal and (v) adverse slope channels.

6.4 (a) Draw the possible flow profiles when there is a free overfall at the end of a (i) mild, (ii) critical, (iii) steep, (iv) horizontal and (v) adverse slope channels.

(b) There is a free overfall at the end of mild slope channel. Draw all the possible flow profiles for different water levels downstream of the channel.

(c) Same as Prob. 6.4(b), but now the channel is steep.




Problem 6.4(b) Problem 6.4(c)

6.5 Sketch the possible flow profiles in the following combination of slopes:

a) mild-horizontal
b) horizontal-mild
c) steep-horizontal
d) critical-horizontal
e) horizontal-adverse
f) mild-critical
g) adverse-mild
h) critical-steep
i) mild-steeper mild
j) horizontal-critical
k) steep-critical
l) adverse-steep

6.6 Sketch the possible flow profiles in the following serial arrangement of channels. The flow is from left to right.

a) mild-milder-steep
b) critical-steep-mild
c) steep-mild-milder
d) horizontal-mild-critical
e) steep-critical-mild
f) critical-horizontal-steep
g) mild-horizontal-critical-free overfall
h) mild-steep-milder steep-free overfall
i) critical-adverse-horizontal
j) horizontal-adverse-steep-free overfall
k) mild-adverse-horizontal-free overfall
l) mild-critical-steep

6.7 Sketch the possible flow profiles in the channels shown in Fig. 6.9.

6.8(a) Determine the flow profile developed as a result of an increase in surface roughness in a (i) mild slope, and (ii) steep slope channel.

(b) Determine the flow profile developed as a result of a decrease in surface roughness in a (i) mild slope, and (ii) steep slope channel.

6.9 A rectangular channel with $b = 6.0$ m and $n = 0.020$ carries a discharge of 24 $m^3/s$. Identify the flow profiles produced in the channel for the following changes in the bottom slope:

i) $S_0 = 0.0040$ to $S_0 = 0.0090$
ii) $S_0 = 0.0030$ to $S_0 = 0.0050$
iii) $S_0 = 0.0085$ to $S_0 = 0.0000$
iv) $S_0 = 0.0095$ to $S_0 = 0.0075$
v) $S_0 = 0.0000$ to $S_0 = 0.0045$

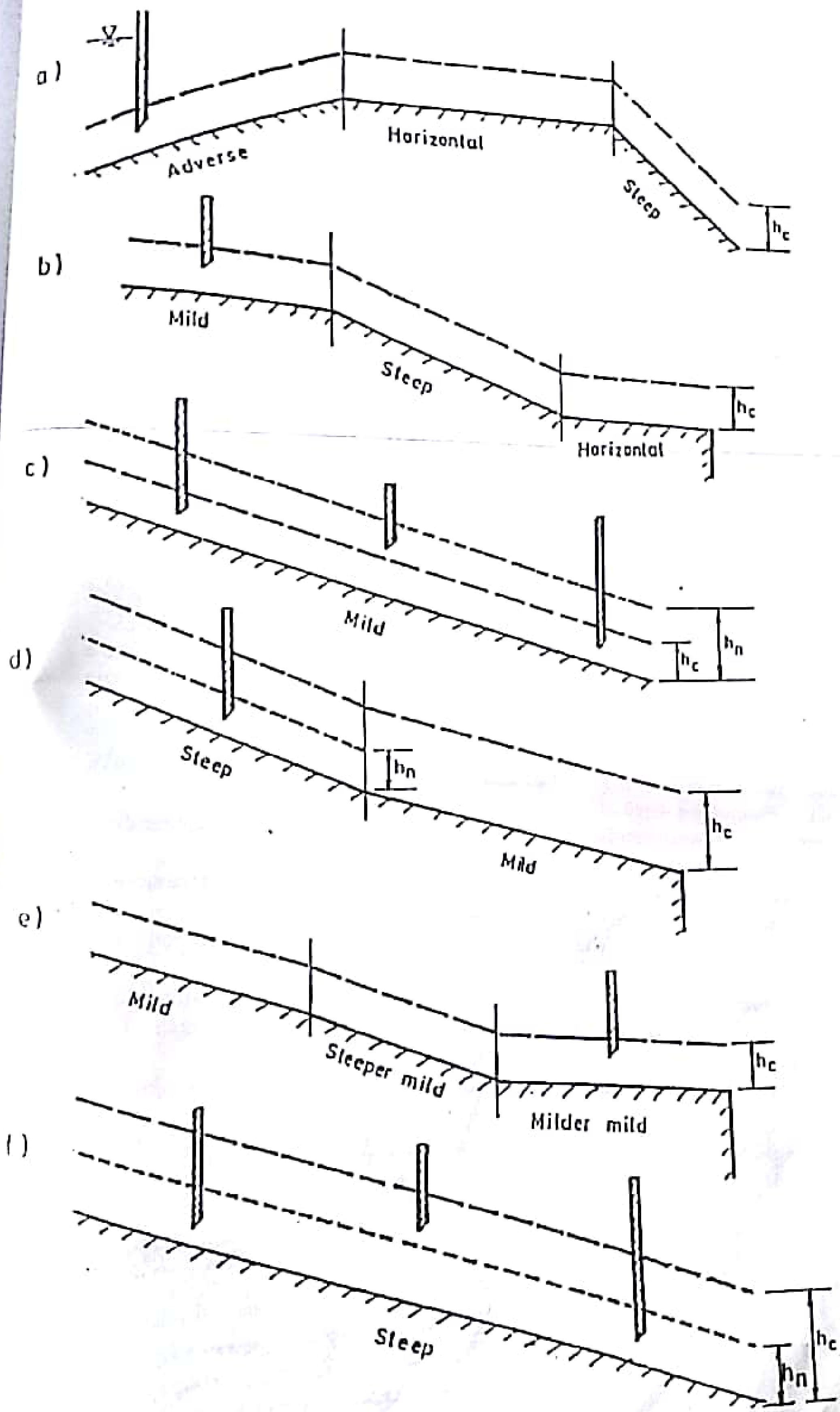



Fig. 6.9 for Problem 6.7

6.10(a) A rectangular channel 6 m wide and having n = 0.025 has three reaches arranged serially. The bottom slopes of the three reaches are 0.0016, 0.0150 and 0.0064, respectively. For a discharge of 20 $m^3$/s through this channel, sketch the resulting flow profiles.

(b) Same as Problem 6.10(a) except that n = 0.015 for the middle reach.

(c) Same as Problem 6.10(a) except that the Manning roughness coefficient values for the three reaches are 0.020, 0.015 and 0.025, respectively.

6.11(a) A wide rectangular channel with C = 45 $m^{1/2}$/s and $S_0$ = 0.0001 carries a discharge of 1.8 $m^2$/s. A weir causes the water level to be raised by 0.50 m above the normal depth. Compute the length of the resulting flow profile between the weir site and the location where the depth is 2.80 m by the Bresse method.

(b) A wide river has an average depth of 5 m, an average slope of 1 in 10,000 and n = 0.025. A dam increases the water depth by 1.0 m. Find out the length of the flow profile created by the dam assuming that the upstream end of the profile is at a depth 10% higher than the average depth. Use the Bresse method.

6.12(a) An overflow spillway discharges 4.25 $m^2$/s into a horizontal floor. Compute the length of the flow profile between the sections where the depths are 0.35 m and 0.65 m.. Take n = 0.015.

(b) A vertical sluice gate having $C_c$ = 0.61 and gate opening = 0.60 m discharges 27 $m^3$/s into a horizontal rectangular channel 6 m wide. Compute the length of the flow profile between the vena contracta and the location where the depth is 0.50 m. Take n = 0.013.

6.13 A rectangular channel with b = 6 m, n = 0.025 and $S_0$ = 0.0025 carries a discharge of 40 $m^3$/s. At a section A of this channel the depth of flow is 2 m.

(a) How far upstream or downstream from this section will the depth be 2.25 m? Use the direct step method.

(b) What will be the depth at a distance of 50 m upstream of section A? Assume that the elevation of the channel bed at section A is 100.00 m. Use the standard step method.

(c) Solve Problem 6.13(b) by (i) the Euler method, and (ii) the modified Euler method.

6.14 A trapezoidal channel having b = 5 m, s = 2, n = 0.020 and $S_0$ = 0.002 carries a discharge of 48.67 $m^3$/s. A dam constructed across the channel raises the water level to a depth of 5 m immediately upstream of it.

a) How far upstream or downstream from the dam will the depth be 4.90 m? Use the direct step method.

b) What will be the depth at a distance of 50 m upstream of the dam? Assume that the elevation of the channel bed at the dam site is 100.00 m. Use the standard step method.

*******

**Example 7.5**

Proportion a USBR stilling basin II for an overflow spillway with the following data:

| | |
|---|---|
| Design discharge | $= 15{,}870\ m^3/s$ |
| TW level | $= 17.26$ m |
| Basin width | $= 227.1$ m |
| Elevation of ground | $= 0.00$ m |
| Velocity at the foot of the spillway | $= 24.70$ m/s |

**Solution** $Q = 15870\ m^3/s$, $h_t = 17.26$ m, $B = 227.1$ m, $U_1 = 24.70$ m/s

$$h_1 = \frac{Q}{BU_1} = \frac{15870}{227.1 \times 24.70} = 2.83\ m$$

$$Fr_1 = \frac{U_1}{\sqrt{gh_1}} = \frac{24.70}{\sqrt{9.81 \times 2.83}} = 4.69 > 4.50$$

$$\frac{h_2}{h_1} = \frac{1}{2}(\sqrt{1+8Fr_1^2} - 1) = \frac{1}{2}(\sqrt{1+8 \times 4.69^2} - 1) = 6.15$$

$$\therefore h_2 = 6.15 \times 2.83 = 17.40\ m \quad and\ h_t = 17.26 m$$

$$\therefore h_2 > h_t$$

So, when the basin floor is set at 0.00 m, the jump moves downstream and more basin length need to be provided. Hence, the floor must lowered. With 5% safety margin

$$h_t = 1.05 h_2 = 1.05 \times 17.40 = 18.27\ m$$

Hence, the floor must be set at elevation (17.26 – 18.27) m = - 1.01 m

From Fig. 7.9(c), for $Fr_1 = 4.69$, $L/h_2 = 3.70$. Hence, the length of the basin

$$L = 3.70 \times 17.40 = 64.40\ m$$

The height, width and spacing of the chute blocks = $h_1 = 2.83$ m

The height of the dentated sill = $0.2h_2 = 0.2 \times 17.40 = 3.48$ m and the width and spacing of the dentates = $0.15h_2 = 0.15 \times 17.40 = 2.61$ m

## PROBLEMS

7.1 Verify Eqs. (7.10), (7.11), (7.15), (7.18), (7.20), (7.21) and (7.26).

7.2 (a) Compute the sequent depth ratio $h_2/h_1$, the relative energy loss $h_L/E_1$ and the relative height of jump $h_j/E_1$ for $Fr_1$ = 1, 1.7, 2.5, 4.5, 9 and 15 for jumps in horizontal rectangular channels.

(b) Show that for jumps in horizontal rectangular channels, the maximum relative height $h_j/E_1$ is 0.51 and it occurs at $Fr_1 = 2.77$.

7.3(a) Water flows at a velocity of 6.1 m/s and a depth of 1 m in a horizontal rectangular channel 6.1 m wide. Find (i) the downstream depth necessary to form a hydraulic jump, (ii) the type of jump, (iii) the height of the jump, (iv) the length of the jump, (v) the horsepower dissipation in the jump, and (vi) the efficiency.

(b) The depth and velocity at the foot of an overflow spillway are 0.50 m and 15.50 m, respectively. What tailwater depth is needed to form a hydraulic jump? If a jump is formed, determine the type of jump, the height of jump, the length of jump and the energy loss in the jump as a percentage of the initial energy.

7.4 The values of two variables in connection with a hydraulic jump in a horizontal rectangular channel are given in the following table. Compute the values of other variables in this table.

| | $h_1$ (m) | $U_1$ (m/s) | $h_2$ (m) | $U_2$ (m/s) | $q$ ($m^2$/s) | $Fr_1$ | $Fr_2$ | $h_L$ (m) |
|---|---|---|---|---|---|---|---|---|
| a) | 0.25 | 12.75 | | | | | | |
| b) | 0.25 | | 2.76 | | | | | |
| c) | | | 2.76 | 1.16 | | | | |
| d) | | 12.75 | | 1.16 | | | | |
| e) | | | | | | 8.14 | | 5.71 |
| f) | | | | | | | 0.22 | 5.71 |
| g) | | | | | 3.19 | | | 5.71 |

7.5 Water flows at a depth of 1 m in a horizontal trapezoidal channel having a base width 5 m and side slope 1:1 and $Q = 30$ $m^3$/s. If a hydraulic jump occurs in this channel, compute the sequent depth and the energy lost in the jump.

7.6 A horizontal triangular channel having $s = 2$ carries a discharge of 20 $m^3$/s at a depth of 1 m. Compute the downstream depth that will form a hydraulic jump.

7.7 A horizontal parabolic channel contains a discharge of 10 $m^3$/s at a depth of 0.50 m. The profile of the channel is given by the equation $y^2 = 4z$. If a hydraulic jump occurs in this channel, compute the sequent depth.

7.8(a) A rectangular channel is 1.2 m wide and inclined at an angle of 3° with the horizontal. The channel carries a discharge of 0.14 $m^3$/s at a vertical depth of 0.02 m. If a hydraulic jump occurs in this channel, compute the sequent depth.

(b) A rectangular channel 6.0 m wide is inclined at an angle of 3.5° with the horizontal. Determine the jump type if $Q = 0.75$ $m^3$/s, $h_1 = 0.02$ m and $h_t = 0.45$ m.

7.9 A rectangular channel 6 m wide and inclined at an angle of 5° with the horizontal carries a discharge of 20 $m^3$/s. Determine the jump type if the upstream depth (normal to the direction of flow) is (i) 0.20 m, (ii) 0.30 m, and (iii) 0.40 m, when the tailwater depth is 3.20 m.

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Answers

7.2(b) $Fr_1 = 1$, $h_2/h_1 = 1$, $h_L/E_1 = 0$, $h_j/E_1 = 0$ $Fr_1 = 1.7$, $h_2/h_1 = 1.96$, $h_L/E_1 = 0.05$, $h_j/E_1 = 0.39$
$Fr_1 = 2.5$, $h_2/h_1 = 3.07$, $h_L/E_1 = 0.18$, $h_j/E_1 = 0.50$ $Fr_1 = 4.5$, $h_2/h_1 = 5.88$, $h_L/E_1 = 0.44$, $h_j/E_1 = 0.44$
$Fr_1 = 9$, $h_2/h_1 = 12.24$, $h_L/E_1 = 0.70$, $h_j/E_1 = 0.27$ $Fr_1 = 15$, $h_2/h_1 = 20.71$, $h_L/E_1 = 0.82$, $h_j/E_1 = 0.17$
7.3(a)(i) 2.30 m (ii) weak jump (iii) 1.30 m (iv) $L_j = 9.66$ m using Fig. 7.3 and $L_j = 9.28$ m by Silvester formula (v) 116.2 (vi) 91.78%
(b) 4.71 m, steady jump, 4.21 m, $L_j = 28.7$ m using Fig. 7.3, 62.1%
7.4 For the two given variables, values of other variables in the table are obtained.
7.5 1.88 m, 0.12 m 7.6 3.05 m 7.7 2.45 m 7.8(a) 0.438 m (b) Jump type B
7.9(i) Jump type A (ii) Jump type B (iii) Jump type D

(c) ... under submerged

$$Q = A_2\sqrt{2g(h_1 - h_2)}/\sqrt{1-r^2} = 0.1125\times\sqrt{2\times 9.81\times(0.50-0.45)}/\sqrt{1-0.375^2} = 0.103\ m^3/s$$

**Example 8.8**

Determine the discharge through a 4-ft Parshall flume if the gage reading $h_1$ is 1.25 m under free-flow condition.

**Solution** B = 4 ft $h_1 = 1.25\ m = 1.25\times 3.28 = 4.10\ ft$

$$\therefore Q = 4Bh_1^{1.522B^{0.026}} = 4\times 4\times 4.10^{1.522\times 4^{0.026}} = 148.254\ ft^3/\sec = 4.202 m^3/s$$

## PROBLEMS

8.1 Find the discharge through a vertical sluice gate in a horizontal rectangular channel 6 m wide and having a gate opening of 1 m under an upstream head of 4 m (i) for free flow condition, and (ii) for submerged condition when the tailwater depth is 3.25 m. (iii) Also compute the depth of submergence by Eq.(8.9).

8.2(a) A horizontal rectangular channel carries a discharge of 1.30 $m^2/s$. There is a vertical sluice gate in the channel. What would be the height of the gate opening to pass the stated flow when the upstream head is 4 m and the gate operates under free flow condition?

(b) Assuming that the flow though the sluice gate in Prob. 8.3(a) occurs under submerged condition and the tailwater depth is 3.2 m, what would be the upstream depth $h_1$ and the submergence depth $h_3$ if the discharge in the channel remains the same?

(c) Compute the force on the sluice gate in Problems 8.3(a) and 8.3(b).

8.3 Derive Eqs.(8.11) to (8.13).

8.4 A horizontal channel ends in a free overfall. The brink depth is measured and found to be 0.50 m. Compute the discharge if the channel is

i) rectangular with b = 6 m,
ii) triangular with s = 2,
iii) parabolic with perimeter equation $y^2 = 4z$,
iv) circular with $d_0 = 2$ m, and
v) trapezoidal with b = 6 m and s = 2.

8.5. An open channel having a slope of 0.0025 ends in a free overfall. The brink depth is measured and found to be 0.50 m. Compute the discharge if the channel is

i) rectangular with b = 6 m,
ii) triangular with s = 2,
iii) trapezoid with b = 6 m and s = 2.

8.6 A broad-crested weir with vertical faces is 1 m high, has a crest length of 2 m and spans the entire width of the channel. If the head over the weir is 0.80 m, compute the discharge per unit width. What would be the discharge per unit width if the depth downstream of the weir is (i) 0.60 m, and (ii) 0.75 m?

8.7 A broad-crested weir with sharp square corner and vertical faces at the upstream and spanning the full width of a rectangular channel has a crest length of 2.50 m. The height of the weir is 1.50 m and the channel is 6 m wide. Calculate the depth of flow upstream of the weir when the discharge is (i) 6 $m^3/s$, and (ii) 10 $m^3/s$, assuming free flow.

8.8 A rectangular channel 10 m wide is to carry a discharge of 15 $m^3/s$. It is desired to place a broad-crested weir across the channel. Compute the height of the weir and its crest length.

8.9 Compute the discharge over a suppressed sharp-crested weir of height 0.50 m and constructed in 2 m wide rectangular channel. The head over the weir is 0.50 m.

8.10 Compute the discharge over a contracted sharp-crested weir 2 m wide and 0.50 m high constructed in a 2.5 m wide rectangular channel. The head over the weir is 0.50 m.

8.11 The depth and discharge in a rectangular channel 2 m wide are 0.75 m and 0.50 $m^3/s$, respectively. Find the height of a supressed sharp-crested weir that will pass the channel discharge.

8.12 In Problem 8.10, if a contracted sharp-crested weir of width 1.6 m is used, what would be the height of the weir?

8.13 Estimate the discharge over a suppressed sharp-crested weir spanning the full width of a rectangular channel 2 m wide when the depths upstream and downstream of the weir above the weir crest are 1.6 m and 1.3 m, respectively, and the height of the weir is 1m.

8.14 Show from Eqs.(8.29) and (8.32) that $C_c = 0.715$ for the completely free overfall ($p = 0$).

8.15 Compute the theoretical discharge through a Venturi flume having a throat width of 0.65 m, (i) when the critical depth measured at the throat is 0.45 m under free-flow condition, and (ii) when the upstream and downstream depths measured are 0.60 m and 0.50 m, respectively, and the channel width is 0.75 m, under submerged condition.

8.16 Determine the discharge through a 5-ft Parshall flume if the gage reading $h_1$ is 1.32 m under free-flow condition.

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