ESE | GATE | PSUs

CIVIL ENGINEERING
IRRIGATION ENGINEERING

Text Book & Work Book:
Theory with worked out Examples and Practice Questions
01. Basics of water resources Engineering

Objective Practice Solutions

02. Ans: (a)
Sol: 
\[ Q = 50 \text{ lit/sec} \Rightarrow 5 \times 10^{-3} \text{ m}^3/\text{s} \]
\[ f = 5 \text{ cm/hr} \Rightarrow \frac{5 \times 10^{-2}}{3600} \text{ m}^2/\text{s} \]
\[ A_{max} = \frac{Q}{f} = \frac{5 \times 10^{-3} \times 3600}{5 \times 10^{-2}} = 3600 \text{ m}^2 \]
1 ha = 10000 m
1 ha = 10^4 m
In hectares = 3600 \times 10^{-4} hectares = 0.36 ha

Conventional Practice Solutions

01. Ans: (b)
Sol: Time required to irrigate
\[ A = 0.04 \text{ ha} = 400 \text{ m}^2 \]
\[ f = 5 \text{ cm/hr} = \frac{5 \times 10^{-2}}{3600} \text{ m/s} \]
\[ y = 10 \text{ cm} = 10^{-1} \text{ m} \]
\[ Q = 0.02 \text{ cumec} = 2 \times 10^{-2} \text{ m}^3/\text{s} \]
\[ t = \frac{y}{f} \log_e \left( \frac{Q}{Q - fA} \right) \]

02. Soil, water and plant

Objective Practice Solutions

01. Ans: (b)
Sol:
Evapo-transpiration (E.T) = \( c_u \leftrightarrow d_w \)
\[ f = \frac{d_w}{c_u} \]
\[ d_w = c_u \]
\[ d_w = S_d [FC - OMC] \]
\[ = 1.3 \times 70 [0.28 - 0.16] \]
\[ = 10.92 \text{ cm} \]

Note
In this problem time frequency is taken as 1 day \( f = 1 \)

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02. Ans: (b)
Sol: Leaching is not separately mentioned in this case
\[ \Rightarrow CIR = NIR \]
\[ \text{GIR} = \frac{\text{NIR}}{\eta_i} = \frac{\text{NIR}}{\eta_a \cdot \eta_c} = \frac{14.9}{(0.8)(0.7)} = 26.6 \text{cm} \]

03. Ans: (c)
Sol: Available Moisture (A.M) \[ y \text{ in depth} \]
\[ S = \frac{12.75}{9.81} \Rightarrow \frac{\gamma_{\text{soil}}}{\gamma_w} (\text{Soil}) \]
\[ = 1.3 \]
\[ y = \frac{s}{d} [\text{FC} – \text{PWP}] \]
\[ = 1.3 \times 80 \times [35–0.2] \]
\[ y = 15.6 \text{ cm} \]
19. Ans: (d)
Sol: The annual intensity of irrigation for this state
\[
= \left( \frac{4.5}{5} \times 90 \right) + \left( \frac{2.5}{5} \times 80 \right) = 121\%
\]

Objective Practice Solutions

02. Ans: (c)
Sol:
\[
\frac{50}{100} = \text{Area to be irrigated} = \frac{8000 - 8000 \times \frac{30}{100}}{0.05 \times 5600} = \text{Area to be irrigated}
\]
Area to be irrigated = 2800 hect

03. Ans: (c)
Sol: Base period = 90 days
\[
D = 8.64 \frac{B}{\Delta} = 8.64 \times \frac{90}{(105-15)} = 8.64 \times 1 \text{ ha/cm}^3
\]
\[
= 864 \text{ ha/m}^3
\]

04. Ans: (d)
Sol: \( \eta_a = 0.8, \eta_c = 0.7 \)
Net irrigation requirement, NIR = 14.9
\[
\text{FIR} = \frac{\text{NIR}}{\eta_a} = \frac{14.9}{0.8} = 18.625 \text{ cm}
\]
\[
\therefore \text{GIR} = \frac{\text{FIR}}{\eta_c} = \frac{18.625}{0.7} = 26.607 \text{ cm}
\]

Conventional Practice Solutions

01.
Sol: Watering interval
\[ \text{i.e frequency of irrigation = ?} \]
FC = 30\%, PWP = 11\%, \( \rho_{\text{soil}} = 1300 \text{ kg/m}^3 \)
d = 700 mm, \( C_u = 12 \text{ mm/day} \)
\[
s = \frac{1300}{1000} = 1.3
\]
RAM = 75\% AM, because mc should not fall below 25\% of water holding capacity
\[ d_w = 0.75 y \]
\[ = 0.75 \times (\text{FC – PWP}) \]
\[ = 0.75 \times 1.3 \times 700 \left[\frac{30 – 11}{100}\right] \]
\[ = 10.8 \text{ days} \]

03.
Sol: Depth and frequency of irrigation = ?
d = 90 cm
FC = 22\%, PWP = 12\%, s = 1.5
\[ d_w = 50\% y, C_u = 6 \text{ mm/day} \]
\[ d_w = 50\% y = 0.5 y = 0.5 \text{ sd } \left(\text{FC – PWP}\right) \]
\[ = 0.5 \times 1.5 \times (90) \left[\frac{22 – 12}{100}\right] \]
\[ = 6.75 \text{ cm} = 67.5 \text{ mm} \]
\[ f = \frac{d_w}{C_u} = \frac{67.5}{6} = 11.25 \text{ days} \]
04.

Sol: FC = 23%, PWP = 10%

\[ d = 65 \text{ cm}, \text{ OMC} = 10\%, \eta_a = 0.7 \]

\[ \gamma_d = 1.5\text{ gm/cc} \]

\[ s = \frac{\gamma_d}{\gamma_w} = 1.5 \]

Storage capacity of soil,

\[ y = sd [FC – PWP] = 1.5 \times 65 \left( \frac{23 - 10}{100} \right) = 12.7 \text{ cm} \]

\[ y_{\text{field}} = \frac{y_{\text{plant}}}{\eta_a} = \frac{sd[FC – OMC]}{\eta_a} = \frac{1.5(65)(23 - 10)}{0.7 \times 100} = 18.1 \text{ cm} \]

05.

Sol: \( Q_c = 150 \text{ lps} \)

\( Q_f = 110 \text{ lps} \)

\( A = 2.2 \text{ ha} \)

Runoff loss in field = 445 m³

\[ y_f = 1.5 \text{ m (entry)}, y_p = 1.1 \text{ m (exit)} \]

\[ d = 1.5 \text{ m} \]

\[ y = 200 \text{ mm per meter depth} = 200 \times 1.5 = 300 \text{ mm} \]

Irrigation was started at a moisture extraction level of 50%

\[ d_w = 0.5 y = 0.5 (300) = 150 \text{ mm} \]

\[ \eta_c = \frac{Q_f}{Q_c} \times 100 = \frac{110}{150} \times 100 = 73.33\% \]

\[ \forall f = Q_f t = 110 \times 10^{-3} \times 8 \times 3600 = 3168 \text{ m}^3 \]

Runoff loss = 445 m³

\[ \forall_{\text{plant}} = \forall_f – \text{ losses} = 3168 – 445 = 2723 \]

\[ \eta_a = \frac{\forall_{\text{plant}}}{\forall_{\text{field}}} \times 100 \]

\[ = \frac{2723 \times 100}{3168} = 85.95\% = 86\% \]

For \( \eta_d \):

\[ \gamma_m = \frac{y_1 + y_2}{2} = \frac{1.5 + 1.1}{2} = 1.3 \text{ m} \]

\[ y_d = \frac{0.2 + 0.2}{2} = 0.2 \text{ m} \]

\[ \eta_d = \left( 1 - \frac{y_d}{\gamma_m} \right) \times 100 \]

\[ = \left( 1 - \frac{0.2}{1.3} \right) \times 100 \]

\[ = \frac{1.1}{1.3} \times 100 \]

\[ = 84.6\% \]

06.

Sol: CCA = 2600 ha

Sugarcane I = 20%

\[ \Rightarrow A = \frac{20}{100} (2600) = 520 \text{ ha} \]

Rice I = 40%

\[ \Rightarrow A = \frac{40}{100} (2600) = 1040 \text{ ha} \]

Duties:
750 ha/cumec for Sugarcane
1800 ha/cumec for Rice

\[ Q_{\text{average}} = Q_{\text{sc}} + Q_{\text{rice}} \]

\[ = \frac{A_1}{D_1} + \frac{A_2}{D_2} \]

\[ = \frac{520}{750} + \frac{1040}{1800} \]

\[ = 0.693 + 0.58 \]

\[ = 1.273 \]

\[ Q_{\text{Required}} = 1.2 \times (Q_{\text{av}}) \]

\[ = 1.2 \times 1.273 \]

\[ = 1.525 \text{ cumec} \]

07.

**Sol:** The canal with higher duty is more efficient

**Left canal:**

\[ D = \frac{A}{Q} = \frac{80\% (20,000)}{20} = 800 \text{ ha/cumec} \]

**Right canal:**

\[ D = \frac{A}{Q} = \frac{50 (12000)}{8} \]

\[ = 750 \text{ ha/cumec} \]

\[ \therefore \text{ Left canal is more efficient} \]

08.

**Sol:** GCA = 1000 ha

\[ C_u = kf \]

\[ = \frac{KP(1.8t + 32)}{40} \]

\[ C_u \text{ for Nov} = \frac{0.75(7.91)(1.8(19) + 32)}{40} \]

\[ = 8.924 \text{ cm} \]

\[ C_u \text{ for Dec} = \frac{0.75(7.15)(1.8(16) + 32)}{40} \]

\[ = 8.151 \text{ cm} \]

\[ C_u \text{ for Jan} = \frac{0.75(7.30)(1.8(12.5) + 32)}{40} \]

\[ = 7.460 \text{ cm} \]

\[ C_u \text{ for Feb} = \frac{0.75(7.03)(1.8(13) + 32)}{40} \]

\[ = 7.302 \text{ cm} \]

\[ C_u \text{ for season} = \Sigma C_u \]

\[ \Delta = 8.64 \text{ B/D} \]

\[ = 864 \text{ B/D} \Rightarrow D = \frac{864B}{\Delta} \]

\[ D_{\text{field}} = \frac{864(15)}{38} = 341 \text{ ha/cumec} \]

\[ \eta_c = 0.8 \]

\[ \frac{D_{\text{canal}}}{D_{\text{field}}} = \eta_c \]

\[ D_{\text{canal}} = 0.8 (341) = 273 \text{ ha/cumec} \]

\[ Q = \frac{A}{D_{\text{canal}}} = \frac{700}{273} = 2.564 \text{ cumec} \]
= 31.837 cm
Rainfall of season = 1.2 + 0.8 = 2 cm
CIR = \( C_u - P_e \)
\[= 31.837 - 2 = 29.837 \text{ cm}\]
\(\eta_a = 0.7\)
FIR = \( \frac{\text{CIR}}{\eta_a} \)
\[= \frac{29.837}{0.7} = 42.624 \text{ cm}\]

10.

Sol: y values
2.0 , 1.9 , 1.8 , 1.6 , 1.5 m
\[y_m = \frac{\Sigma y_i}{n} = \frac{8.8}{5} = 1.76 \text{ m}\]
\[= |2 - 1.76| + |1.9 - 1.76| + |1.8 - 1.76| + |1.6 - 1.76| + |1.5 - 1.76| \]
\[y_d = \Sigma y_i = \frac{0.24 + 0.14 + 0.04 + 0.16 + 0.26}{5} \]
\[= \frac{0.84}{5} = 0.168 \text{ m}\]
\(\eta_d = \left[1 - \frac{y_d}{y_m}\right] 100 = \left[1 - \frac{0.168}{1.76}\right] 100 = 90.45 \%\)

12.

Sol: FC = 38%, \( C_u = 15 \text{ mm/day} \)
PWP = 10%, \(\eta_i = 0.6,\)
n = 45%
\[\Rightarrow e = \frac{0.45}{0.55} = 0.8\]
d = 1 m
d\(_w\) = 0.5y (given)
\[= 0.5 \, sd \, [FC - PWP]\]
f = \[\frac{d\(_w\)}{C_u} = \frac{0.5sd[FC - PWP]}{C_u}\]

To calculate specific gravity(s):
\[e \times D_s = FC \times G_s \quad \& \quad \gamma_d = \frac{G_s \gamma_w}{1 + e}\]
Where e = void ratio

\(D_s = \text{Degree of saturation}\)

\(FC = \text{Field capacity}\)

\(G_s = \text{Specific gravity for saturated soil}\)

\[S = \frac{\gamma_d}{\gamma_w} = \frac{G_s}{1 + e} \]
\[= \frac{eD_s}{(FC)(1 + e)} = \frac{0.8(1)}{0.38(18)} \]
\[= 1.17\]

\[f = \frac{d\(_w\)}{C_u} = \frac{0.5sd[FC - PWP]}{C_u}\]
\[= \frac{0.5(1.17)(100)(0.38 - 0.1)}{1.5}\]
\[= 10.92 \text{ days}\]
\[= 11 \text{ days}\]
04. Quality of irrigation water

Conceptual Solutions

05. Ans: (c)
Sol:  
\[ \begin{align*} 
Na^+ &= 345 \text{ppm} \\
Ca^{++} &= 60 \text{ ppm} \\
Mg^{++} &= 16 \text{ ppm} 
\end{align*} \]

Converting them into milli equivalent / litre

\[ \text{Milli equivalent / wire} = \frac{\text{concentration in ppm}}{\text{equivalent weight of element}} \]

\[ \begin{align*} 
Na^+ &= \frac{345}{23} = 15 \\
Ca^{++} &= \frac{60}{30} = 2 \\
Mg^{++} &= \frac{18}{12} = \frac{3}{2} = 1.5 
\end{align*} \]

Sodium absorption ratio (SAR)

\[ \text{SAR} = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} = \frac{15}{\sqrt{\frac{2 + 1.5}{2}}} = 11.33 \]

10. Ans: (a)
Sol:  
If electro conductivity < 4000 ⇒ black alkali soil

If electro conductivity > 4000 ⇒ white alkali soil

05. Design of Lined Canals

Conceptual Solutions

03. Ans: (a)
Sol:  
Given channel is triangular lined channel

\[ \Rightarrow \text{Area} = y^2(\theta + \cot \theta) \]

Here \( \tan \theta = \frac{1}{1.5} \Rightarrow \theta = \tan^{-1} \left( \frac{1}{1.5} \right) = 33.69 \)

\( \theta = 33.69 \times \frac{\pi}{180} = 0.588 \)

\( \cot \theta = 1.5 \)

Area = \((2.5)^2 (0.58 + 1.5) \)

Area = 13

We know \( Q = AV \)

26 = 13 \times V

\( V = 2 \text{m/s} \)

Considering F.O.S as 1.1

\[ \Rightarrow V = 2 \times 1.1 = 2.2 \]

Objective Practice Solutions

01. Ans: (c)
Sol:  
\( y = 4 \text{ m} \)

\[ \begin{align*} 
R &= ? \\
A &= y^2 (\theta + \cot \theta) \\
P &= 2y (\theta + \cot \theta) \\
R &= \frac{A}{P} = \frac{y^2 (\theta + \cot \theta)}{2y(\theta + \cot \theta)} \\
y &= 4 \text{ m} \]
02. Ans: (c)
Sol:
\[ R = \frac{4}{2} = 2 \text{m} \]
\[ \theta = \cot^{-1}(1.5) = \tan^{-1}\left(\frac{2}{3}\right) = 0.588 \]
\[ \theta + \cot \theta = 2.088 \]
\[ A = y^2 (\theta + \cot \theta) = 2.088 y^2 \]
\[ P = 2y (\theta + \cot \theta) = 2(2.088)y \]
\[ R = \frac{A}{P} = \frac{y}{2} \]
\[ Q = AV = A \frac{1}{N} R^{2/3} S^{1/2} \]
\[ 30 = \left(2.088y^2\right) \frac{1}{0.012} \left(\frac{y}{2}\right)^{2/3} \left(\frac{22.5}{10^5}\right)^{1/2} \]
\[ y^{8/3} = \frac{30(0.012)(2^{2/3})}{2.088 \times 225^{1/2}} \left(10^6\right)^{1/2} \]
\[ \Rightarrow y = 2.9712 \text{ m} \]
\[ y = 3 \text{ m} \]

04. Sol: \[ S = \frac{1}{2000} \]
\[ Q = 30 \text{ m}^3/\text{s} \Rightarrow \text{(Triangular section with rounded bottom)} \]
\[ N = 0.012 \]
\[ \cot \theta = \frac{2H}{1V} = 2 \]
\[ Q = 30 \text{ cumec} \]
\[ \theta = \cot^{-1}(2) = 0.464 \]
\[ \theta + \cot \theta = 2.464 \]
\[ A = y^2 (\theta + \cot \theta) = 2.464 y^2 \]
\[ P = 2y (\theta + \cot \theta) = 2y (2.464) \]
R = \frac{A}{P} = \frac{y}{2}

Q = AV = A \frac{1}{N} R^{2/3} S^{1/2}

30 = 2.464 y^2 \left( \frac{y}{2} \right)^{2/3} \left( \frac{1}{2000} \right)^{1/2}

y^{8/3} = \frac{30 \left( 0.012 \right)^{2/3} \left( 2000 \right)^{1/2}}{2.464}

\Rightarrow y = 2.404 \text{ m}

y = 2.4 \text{ m}

06.
Sol: Q = 20 m$^3$/s
Trapezoidal lined canal
\[ \cot \theta = \frac{1.5 H}{1V} = \frac{3}{2} \]
\[ \theta = \cot^{-1} \left( \frac{3}{2} \right) = 0.588 \]
\[ \theta + \cot \theta = 2.088 \]

N = 0.015
V = 1 m/s
For minimum amount of lining, wetted perimeter should be minimum

\[ A = By + y^2 (\theta + \cot \theta) = \frac{\theta}{V} = 20 \]
\[ 20 = By + 2.088 y^2 \]
\[ B = \frac{20 - 2.088 y^2}{y} \]
\[ P = B + 2y (\theta + \cot \theta) \]

07.
Sol: Trapezoidal cross section
\[ Q = 250 \text{ m}^3/\text{s}, S = \frac{1}{6000} \]
\[ \cot \theta = \frac{1.5}{1}, \quad \theta = \cot^{-1} (1.5) = 0.588 \]
\[ \theta + \cot \theta = 2.088 \]
\[ y = 3 \text{ m} \]
N = 0.015
\[ A = By + y^2 (\theta + \cot \theta) = 3B + 9(2.088) \]
\[ = 3B + 18.792 \]
\[ P = B + 2y (\theta + \cot \theta) = B + 6(2.088) \]
\[ = B + 12.528 \]
\[
R = \frac{A}{P} = \frac{3B + 18.792}{B + 12.528} \\
Q = AV \\
= A \frac{1}{N} R^{2/3} S^{1/2} \\
250 = (2B + 18.792) \frac{1}{0.015} \left( \frac{3B + 18.792}{B + 12.528} \right)^{2/3} \left( \frac{1}{6000} \right)^{1/2} \\
\Rightarrow B = 44 \text{ m} \\
y = 3 \text{ m} \\
\]

08. Refer solution of question 1

06. Design of unlined canals in alluvial soils

Conceptual Solutions

02. Ans: (b) 
Sol: \[ V = mV_0 \]
\[ = 0.55 \times 0.90 \times 1 = 0.495 \]

03. Ans: (c) 
Sol: \[ \tau_c = \tau_c \left( \frac{1 - \sin^2 \theta}{\sin^2 \phi} \right) \]
\[ \cot \theta = 1.5 = \frac{3}{2} \]
\[ \sin \theta = \frac{2}{\sqrt{13}} \]
\[ \phi = 37^\circ \]
\[ \sin \phi = \frac{3}{5} \]
\[ \tau_c = 0.059 \text{ wd} \]

04. Ans: (c) 
Sol: \[ P = 4.75 \sqrt{Q} \]
\[ P \propto \sqrt{Q} \]
\[ P_1 = \sqrt{Q} \]
\[ P_2 = \sqrt{1.96Q} \]
\[ \% \text{ increase in wetted perimeter} = \frac{\sqrt{1.96Q} - \sqrt{Q}}{\sqrt{Q}} \times 100 = 40\% \]

05. Ans: (b) 
Sol: Lacey’s require sour depth = \[ R_L = \frac{1.35 (\frac{q^2}{f})^{1/3}}{3} \]
\[ = 1.35 \left( \frac{3^2}{1.2} \right)^{1/3} \]
\[ = 1.35 \left( \frac{90}{12} \right)^{1/3} = 2.64 \]

06. Ans: (b) 
Sol: \[ D_{50} = 0.4 \text{ mm} \]
\[ f = 1.76 \sqrt{D_{50}} = 1.76 \sqrt{0.4} = 1.11 \]
\[ Q = 40 \text{ m}^3/\text{s} \]
\[ S = \frac{f^{5/3}}{3340Q^{1/6}} = \frac{1}{5190} \]
07. **Ans:** (b)  
**Sol:**  
\[ \text{Perimeter} = b + d\sqrt{5} \]
\[ = 22 + 2.5\sqrt{5} = 27.59 \]

We know \[ P = 4.75\sqrt{Q} \]
\[ 27.59 = 4.75\sqrt{Q} \]
\[ \sqrt{Q} = 5.80 \]
\[ Q = 33.64 \]

08. **Ans:** (b)  
**Sol:**  
\[ D \times 9.57 = BD + 2.236D^2 \]
\[ BD + 0.5D^2 = 5.74 \]
\[ BD + 2.236D^2 = 9.57D \]
\[ 1.736 = 9.570 – D \]
\[ D = 1.36 \text{ m} \]

09. **Ans:** (c)  
**Sol:**  
Average grain size, \( m = 0.16 \text{ mm} \)
Lacey’s silt factor, \( f = ? \)
\[ D_{50} = 0.16 \]
\[ f = 1.76\sqrt{D_{50}} \]
\[ = 1.76\sqrt{0.16} = 0.704 \]

**Objective Practice Solutions**

05. **Ans:** (a)  
**Sol:**  
\( Q = 4 \text{ m}^3/\text{s} \)
\( f = 2 \)
\[ V = \left( \frac{Qr^2}{140} \right)^{\frac{1}{6}} \]
\[ = \left( \frac{4 \times 2^2}{140} \right)^{\frac{1}{6}} \]
\[ = 0.6966 \text{ m/s} \]
\[ A = \frac{Q}{V} = \frac{4}{0.6966} = 5.742 \]
\[ R = 2.5 \frac{V^2}{f} = 2.5 \times \frac{0.6966^2}{2} = 0.60 \]
\[ P = \frac{A}{R} = 9.57 \]
\[ A = BD + \frac{D^2}{2} \]
\[ 5.742 = BD + 0.5D^2 \]
\[ P = B + 2.236D \]

06. **Ans:** (c)  
**Sol:**  
\( f = 1 \)
\( Q = 30 \text{ m}^3/\text{s} \)
\( S = ? \)
\[ S = \frac{f^{5/3}}{3340Q^{1/6}} = \frac{1}{5887} \]

07. **Ans:** (a)  
**Sol:**  
\( V_o = ? \)
\( D = 1.5 \text{ m} \)
\( m = 1.1 \)
\( N = 0.018 \)
\[ V_o = 0.55D^{0.64} \]
\[ = 0.55(1.5)^{0.64} \]
\[ = 0.713 \text{ m/s} \]

08. **Ans:** (b)  
**Sol:**  
\( \text{Perimeter} = b + d\sqrt{5} \)
\[ = 2 + 8\sqrt{5} = 19.88 \]

We know \[ P = 4.75\sqrt{Q} \]
\[ 19.88 = 4.75\sqrt{Q} \]
\[ Q = 17.51 \]
02. Sol: The sediment concentration at a distance ‘y’ from the bed

\[ C = \left( \frac{a(D - y)}{y(D - a)} \right)^{0.4} \]

\[ w_0 = 0.4 \]

\[ C = \frac{2.5(2.8 - 0.1)}{0.1(0.3)}^{0.4} \]

\[ C = 6109 \text{ ppm} \]

a, y measured above the bed

03. Sol: Lacey’s Design

\[ Q_{Rabi} = \frac{A}{D} \times \frac{A \Delta}{8.64B} = \frac{3600(13.5)}{100} \times \frac{8.64(28)}{8.64(2)} = 2.008 \text{ cumec} \]

\[ Q_{khariff} = \frac{A}{D} \times \frac{A \Delta}{8.64B} = \frac{1400(19)}{100} \times \frac{8.64(2.5)(7)}{8.64(2.5)(7)} = 1.8 \text{ cumec} \]

\[ Q_{design} = 2 \text{ m}^3/\text{s} \]

\[ f = 0.85 \]

\[ V = \left( \frac{Qf^2}{140} \right)^{1/6} = \left( \frac{2(0.85)^2}{140} \right)^{1/6} = 0.47 \text{ m/s} \]

\[ Q = AV \Rightarrow A = \frac{25}{0.775} = 32.25 \text{ m}^2 \]

\[ R = 2.5 \frac{V^2}{f} = \frac{2.5(0.775)^2}{1.1} = 1.365 \text{ m} \]

04. Sol: Q = 25 m³/s

\[ f = 1.1 \]

Design of unlined canal by Lacey’s theory

\[ V = \left( \frac{Qf^2}{140} \right)^{1/6} = 0.775 \text{ ms}^{-1} \]

\[ Q = AV \Rightarrow A = \frac{25}{0.775} = 32.25 \text{ m}^2 \]

\[ R = 2.5 \frac{V^2}{f} = \frac{2.5(0.775)^2}{1.1} = 1.365 \text{ m} \]

\[ R = \frac{A}{P} \Rightarrow P = \frac{A}{R} = \frac{32.25}{1.365} = 23.63 \text{ m} \]
\[ A = BD + \frac{D^2}{2} = 32.25 \]

\[ P = B + 2.236D = 23.63 \]

\[ S = \frac{f^{5/3}}{3340Q^{1/6}} = \frac{1.1^{5/3}}{3340 \times 25^{1/6}} = \frac{1}{4872} \]

\[ B = 23.63 - 2.236D \]

\[ 23.63D - 2.236D^2 + 0.5D^2 = 32.25 \]

\[ 1.736D^2 - 23.63D + 32.25 = 0 \]

\[ D = \frac{23.63\sqrt{23.63^2 - 4(1.736)(32.25)}}{2(1.736)} \]

\[ = 23.63 - 18.29 \]

\[ = \frac{5.34}{2(1.736)} = 1.54 \text{ m} \]

\[ B = 23.63 - 2.236D \]

\[ = 23.63 - 2.236(1.54) \]

\[ = 20.18 \text{ m} \]

\[ \Rightarrow B = 20.18 \text{ m} \]

\[ D = 1.54 \text{ m} \]

\[ S = \frac{1}{4872} \]

### Costs

\[ C = C_1 + C_2 \]

\[ C_1 = \text{Cost due to annual principle amount required for lining} \]

\[ C_2 = \text{Cost due to interest paid on that annual principle amount} \]

Consider 1 km length of canal

Area of wetted perimeter

For LC = 20 \times 1000 = 20,000 \text{ m}^2

For ULC = 25 \times 1000 = 25,000 \text{ m}^2

Seepage loss in LC = \frac{0.02}{10^6} \times 20000 = 4 \times 10^{-4} \text{ m}^3/\text{s}

Seepage loss in ULC

\[ = \frac{2.5}{10^6} \times 25000 = 0.0625 \text{ m}^3/\text{s} \]

Saving in Q = (625 - 4) \times 10^{-4} = 621 \times 10^{-4} \text{ m}^3/\text{s}

1 m\(^3\)/s water saved = 25 lakhs rupees

\[ \therefore \text{Annual seepage saved} = 621 \times 10^{-4} \times 25 \times 10^5 \]

\[ B_1 = 155250 \text{ rupees} \]

\[ B_2 = \text{AMC of ULC} = 1 \times 25000 = 25,000 \text{ Rs} \]

\[ \text{Saving in AMC} = \frac{40}{100} \times 25000 = 10,000 \text{ Rs} \]

\[ B_2 = 10000 \text{ Rs} \]

\[ B = 155250 + 10000 = 165250 \text{ Rs} \]

Cost \[ C_1 \Rightarrow \text{Per m}^3 \text{ cost Rs 100/-} \]

\[ = 2 \times 10^6 \text{ Rs} \]

Per 50 years
06. Sol: Tactive force approach:

Given data: \( Q = 45 \) cumec

\[ S = \frac{1}{4800}, \quad N = 0.0225 \]

Permissible tactive stress

\[ \tau_c = 0.0035 \text{ kPa} \]

As it is unlined canal, side slope is fixed at \( \frac{1}{2} H : 1V \)

Tactive stress \( \tau_c = wRS \)

\[ 0.0035 \times 10^3 = 1000 \times 9.81 \times R \times \frac{1}{4800} \]

\[ R = 1.712 \text{ m} \]

\[ Q = AV = A \frac{1}{N} R^{2/3} S^{1/2} \]

\[ 45 = A \frac{1}{0.0225} (1.712)^{2/3} \left( \frac{1}{4800} \right)^{1/2} \]

\[ A = 49.02 \text{ m}^2 \]

\[ R = \frac{A}{P} \Rightarrow P = \frac{A}{R} = \frac{49.02}{1.712} = 28.63 \text{ m} \]

\[ A = BD + \frac{D^2}{2} = 49.02 \]

\[ P = B + 2.236D = 28.63 \]

Solving, \( B = 24.3 \text{ m} \)

\( D = 1.95 \text{ m} \)

07. Sol: Design of regime channel

\( Q = 40 \text{ m}^3/\text{s} \)

Side slope 1 : 1

Shape is trapezoidal

\( D_{50} = 0.8 \text{ mm} \)

\[ A = (B + B + 2D) \frac{D}{2} = BD + D^2 \]

\[ P = B + 2\sqrt{2D} = B + 2.828D \]

\[ f = 1.76\sqrt{D_{50}} = 1.574 \]

\[ V = \left( \frac{Qf^2}{140} \right)^{1/6} = \left( \frac{40(1.574)^2}{140} \right)^{1/6} = 0.944 \text{ m} \]

\[ Q = AV \Rightarrow 40 = A (0.944) \]

\[ A = 42.37 \text{ m}^2 \]

\[ R = 2.5 V^2/f = 1.415 \text{ m} \]
R = \frac{A}{P} \Rightarrow P = \frac{A}{R} = \frac{42.37}{1.415} = 30 \text{ m}

BD + D^2 = 42.4

B + 2.828 D = 30

B = 25.6 m

D = 1.6 m

S = \frac{f^{5/3}}{3340Q^{1/6}} = \frac{1.574^{5/3}}{3340 \times 40^{1/6}} = \frac{1}{2900}

\therefore B = 25.6 m

D = 1.6 m

S = \frac{1}{2900}

\textbf{08.}

**Sol:** Design of irrigation channel by Kennedy’s theory:

\[ Q = 50 \text{ m}^3/\text{s} \]

\[ \frac{B}{D} = 2.5 \]

\[ m = 1.1 \]

\[ N = 0.025 \]

\[ Z = \frac{1}{2} H : 1V \Rightarrow A = BD + \frac{D^2}{2} \]

\[ P = B + 2.236 D \]

\[ A = BD + \frac{D^2}{2} = 2.5D^2 + 0.5D^2 = 3D^2 \rightarrow (1) \]

\[ V = 0.55 \text{ m} D^{0.64} \]

\[ = 0.55 (1.1) D^{0.64} = 0.605 D^{0.64} \rightarrow (2) \]

\[ Q = AV \]

\[ 50 = 3D^2 (0.605) D^{0.64} \]

\[ D^{2.64} = \frac{50}{3(0.605)} \Rightarrow D = 3.5 \text{ m} \]

\[ B = 8.75 \text{ m} = 2.5 D \]

\[ V = 0.55 \text{ m} D^{0.64} \]

\[ = 0.55 \times 1.1 \times 3.5^{0.64} = 1.35 \text{ m/s} \]

Applying Kutter’s formula

\[ R = \frac{A}{P} = \frac{BD + \frac{D^2}{2}}{B + 2.236D} = \frac{36.75}{16.326} = 2.251 \text{ m} \]

\[ V = C\sqrt{RS} \]

Where

\[ C = \frac{23 + \frac{0.00155}{N}}{S} \]

\[ = \left[ \frac{1}{0.025} + 23 + \frac{0.00155}{S} \right] \frac{N}{\sqrt{R}} \]

\[ = \left[ 1 + \left( \frac{23 + 0.00155}{S} \right) \frac{0.025}{\sqrt{2.251}} \right] \frac{1}{S} \]

Solving by Trial & error method

\[ S = \frac{1}{2590} \]

\[ \therefore B = 8.75 \text{ m} \]

\[ D = 3.5 \text{ m} \]

\[ S = \frac{1}{2590} \]
07. Water Logging and Drainage

Conceptual Solutions

03. Ans: (a)
Sol: \( P_H > 7 \Rightarrow \text{alkaline} \)
\( P_H < 7 \Rightarrow \text{acidic} \)
Gives \( P_H = 9.5 \Rightarrow \) the soil is alkaline.

Conventional Practice Solutions

02. \( b = 10 - 1.5 = 8.5 \, \text{m} \)
\( a = 10 - 2.0 = 8.0 \, \text{m} \)
\( L = ? \)
\( K = 6 \times 10^{-6} \, \text{m/s} \)
\( \bar{P} = 96 \, \text{cm} = 96 \times 10^{-2} \, \text{m} \)
\( D_c = \frac{\bar{P}}{100 \, 86400} = \frac{4K(b^2 - a^2)}{L} \)
\( \Rightarrow L^2 = \frac{4(864)10^4K(b^2 - a^2)}{\bar{P}} \)
\( L = \sqrt{\frac{4(864)10^4K(b^2 - a^2)}{\bar{P}}} \)
\( = \sqrt{\frac{4(864)10^4(6 \times 10^{-6})(8.5^2 - 8^2)}{96 \times 10^{-2}}} \)
\( = 42.2 \, \text{m} \)
Spacing of tile drains = 42.2 m

03. Sol:
\( h = \text{capillarity height} = \frac{4t \cos \theta}{\rho gd} \)
\( = \frac{4(0.054) \cos 0^\circ}{1000(9.81)(8 \times 10^{-5})} = 0.275 \, \text{m} \)
RZD + Capillary height = 1.8 + 0.275 = 2.075 m
GWT is at 2 m
\( \therefore \) Roots will reach the capillary saturated zone by 7.5 cm
\( \therefore \) Field is slightly water logged
(b) \( q = D_c \frac{4k(b^2 - a^2)}{L} = D_c \)
\( b = 7 - 1.725 = 5.275 \, \text{m} \)
a = ?
\( 4 \times 10^{-6}(5.275^2 - a^2) = 0.116 \times 10^{-6} \times 15 \times 1 \)
\( \Rightarrow a^2 = 21.3 \)
Irrigation Engineering

Centre of tile drain is at 4.61 m above impervious stratum.

04.

Sol: Two water logged areas

\[
\begin{align*}
K_A &= 2 & L_A &= 2 \left( \frac{b^2 - a^2}{b} \right)_A = \frac{5}{6} \\
K_B &= 1 & L_B &= 3 \left( \frac{b^2 - a^2}{b} \right)_B = \frac{5}{6} \\
\end{align*}
\]

(i) \( q = \frac{4K(b^2 - a^2)}{L} \)

\[
q_A = K_A \left( \frac{b^2 - a^2}{b} \right)_A L_B / K_B \left( \frac{b^2 - a^2}{b} \right)_B L_A = \frac{2 \times 5}{1 \times 6} = \frac{5}{3} = 2.5
\]

(ii) \( q = \frac{P}{100} \text{ l/day} \)

\[
q_A = \frac{P_A}{P_B} \frac{L_A}{L_B}
\]

\[
\frac{5}{2} = \frac{P_A}{P_B} \frac{2}{3}
\]

\[
\Rightarrow \frac{P_A}{P_B} = \frac{15}{4} = 3.75
\]

08. Cross Regulatory Works, Canal outlets & Cross Drainage Works

Conceptual Solutions

12. Ans: (c)

Sol: \( S_e = \frac{m}{n} = \frac{1}{2} \times \frac{3}{5} = \frac{3}{10} = 0.3 \)

22. Ans: (c)

Sol: \( S = \frac{q \times 100}{dq} \)

Objective Practice Solutions

02. Ans: (b)

Sol:

\[
y - 0.4y = 0.6y
\]

\[
S_e = \frac{H}{D} = \frac{0.6y}{y} \\
\Rightarrow S_e = 0.6
\]

06. Ans: (c)

Sol: (Canal) \( Q_c > Q_d \) (drainage)

Type II Siphon (or) canal siphon
Conventional Practice Solutions

03. Sol: Submerged pipe outlet diameter (d)

\[ Q = C_d A \sqrt{2gH} \]

\[ H = \text{FSL of minor distributory} - \text{FSL of field channel} \]
\[ = 100 - 99.9 = 0.1 \text{ m} \]

\[ Q = 0.04 \text{ m}^3/\text{s} \]

\[ C_d = 0.7 \]

\[ Q = C_d A \sqrt{2gH} \]

\[ 0.04 = 0.7 \times A \sqrt{2(9.81)(0.1)} \]

\[ A = 0.0408 \text{ m}^2 \]

\[ \frac{\pi d^2}{4} = 0.0408 \]

\[ d = 0.2279 \text{ m} \]
\[ = 22.8 \text{ cm} \]

09. Diversion Head Works

Conceptual Solutions

06. Ans: (b)

Sol:

\[ K = \text{m} \]
\[ C = \text{m} \]

\[ L = (6 + 6) + \frac{36}{3} + (10 + 10) \]

\[ L = 44 \text{ m} \]

\[ H = 4 \text{ m} \]

\[ C_L = \frac{L}{H} = \frac{44}{4} = 11 \text{ m} \]

16. Ans: (b)

Sol: \( P_e = \frac{P}{\gamma} + Z + h \)

\[ 10 = 2 + 3 + h \]
\[ 10 = 5 + h \]

\[ h = 5 \text{ m} \]

\[ t_{\text{min bottom}} = \frac{h}{s_c} \]
\[ = \frac{5}{2.5} = 2 \text{ m} \]

17. Ans: (b)

Sol: Floor thickness with suitable F.O.S (2.4) is

\[ \frac{4}{3} \times \frac{h}{s - 1} \]
\[ = \frac{4 \times 2.8}{3 \times 2.4 - 1} = 2.66 \approx 2.67 \]
02. Ans: (a)
Sol:
\[
\lambda = \frac{1 + \sqrt{1 + \alpha^2}}{2} \quad \alpha = \frac{b}{d} = \frac{54}{6} = 9
\]
\[
G_E = \frac{H}{d\pi\sqrt{\lambda}}
\]
\[
G_E = \frac{1}{6\pi\sqrt{5.02}} = \frac{1}{\pi\times5.02}
\]

03.
Sol:
\[
\lambda = \frac{1 + \sqrt{1 + \alpha^2}}{2} \quad \alpha = \frac{b}{d} = \frac{10}{1.5} = 6.66
\]
\[
G_E = \frac{H}{d\pi\sqrt{\lambda}}
\]

05.
Sol:
By Bligh’s Theory
\[
L = 6(2) + 22 + 2(8) = 50 \text{ m}
\]
\[
H = 4 \text{ m}
\]
\[
C = \frac{L}{H} = \frac{50}{4} = 12.5
\]
Average hydraulic gradient
\[
i = \frac{1}{C} = \frac{4}{50} = 0.08
\]
(b) At 6 m from U/S end
\[
l = 12 + 6 = 18 \text{ m}
\]
\[
h' = \frac{\ell}{C} = \frac{18}{12.5} = 1.44 \text{ m}
\]
\[
h = H - h' = 4 - 1.44 = 2.56 \text{ m}
\]
\[
t_{\text{min}} = \frac{4}{3S_c - 1} \frac{h}{3(22.4 - 1)} = \frac{4}{3(2.24 - 1)}
\]
\[
= 2.76 \text{ m}
\]
At 12 m from U/S end

\[ l = 12 + 12 = 24 \text{ m} \]

\[ h' = \frac{\ell}{C} = \frac{24}{12.5} = 1.92 \text{ m} \]

\[ h = H - h' = 4 - 1.92 = 2.08 \text{ m} \]

\[ t_{\text{min}} = \frac{4}{3} \frac{h}{S_c - 1} = \frac{4}{3} \frac{2.08}{2.24 - 1} = 2.236 \text{ m} \]

At 18 m from U/S end

\[ L = 12 + 18 = 30 \text{ m} \]

\[ h' = \frac{\ell}{C} = \frac{30}{12.5} = 2.4 \text{ m} \]

\[ h = H - h' = 4 - 2.4 = 1.6 \text{ m} \]

\[ t_{\text{min}} = \frac{4}{3} \frac{h}{S_c - 1} = \frac{4}{3} \frac{1.6}{2.24 - 1} = 1.72 \text{ m} \]

10. River Training Works

02. Ans: (b)

Sol: \( Q = 1600 \text{ m}^3/\text{s} \)

Meander belt = \( 153.75 \sqrt{Q} \)

\[ = 153.75 \sqrt{1600} = 6150 \text{ m} \]

i.e., the order of 6 km

03. Ans: (b)

Sol: \( Q = 6000 \text{ m}^3/\text{s} \)

\[ M_w = 153.75 \sqrt{Q} \]

\[ M_L = 53.75 \sqrt{Q} \quad M_R = \frac{M_w}{m_L} = 2.97 \approx 3 \]

04. Ans: (d)

Sol: Meander belt = \( 153.75 \sqrt{Q} = 3000 \text{ m} \)

\[ \sqrt{Q} = \frac{3000}{153.75} \]

\[ Q = 380.72 \text{ cumec} \]

\( Q_{\text{peak}} = 2Q = 760 \text{ cumec} \)

i.e., the order of 700cumec

06. Ans: (a)

Sol: \( Q = 1600 \text{ cumec} \)

\[ P = 4.75 \sqrt{Q} \]

\[ = 4.75 \sqrt{1600} = 190 \text{ m} \]

11. Dams General Principles

06 Ans: (a)

Sol: Rate of silt deposition per year = 0.1 Mm³/year

Capacity of reservoir = 30 Mm³

Silt storage capacity = 20% capacity

\[ = \frac{20}{100} \times 30 = 6 \text{ Mm}^3 \]

Life of reservoir = \( \frac{6}{0.1} = 60 \) years
12. Gravity Dams

08. Ans: (a)
Sol: \( \mu = 0.75 \)
\[
\begin{align*}
\sum PV &= 6000 \text{ t} \\
\sum P_H &= 5000 \text{ t} \\
b &= 70 \text{ m} \\
q &= 140 \text{ t/m}^2 \\
\end{align*}
\]
F.O.S against sliding \( \mu \sum PV \frac{\sum P_H}{\sum P_H} = 0.75 \times 6000 \frac{5000}{5000} = 0.9 \)
(b)
Sol: SFF = \( \frac{\mu \sum P_V + b q}{\sum P_H} \)
\[
\begin{align*}
\text{SFF} &= \frac{0.75 \times 6000 + 70 \times 140}{5000} = 2.86 \\
\end{align*}
\]

11. Ans: (d)
Sol: For \( F > 32 \text{ km} \), the wave is given by equation given below
\[
\begin{align*}
\text{wave height} \quad h_w &= 0.032 \sqrt{F} \quad \text{m} \\
&= 0.032 \times \sqrt{160 \times 4} = 2.56 \text{ m} \\
\end{align*}
\]
Force caused by waves \( P_w \) is given by equation
\[
\begin{align*}
P_w &= 19.62 \ h_w ^2 \text{ kN/m run of dam} \\
&= 19.62 \times (2.56)^2 \text{ kN} = 128.6 \text{ kN} \\
&\approx 130 \text{ kN} \\
\end{align*}
\]

13. Ans: (c)
Sol: Wave height
\[
\left( h_w \right) = 0.032 \sqrt{V.F} + 0.763 - 0.271(F)^{1/4} \text{ for} \ F < 32 \text{ km} \\
\]
\[
\begin{align*}
h_w &= 0.032 \sqrt{100 \times 20} + 0.763 - 0.271(20)^{1/4} \\
&= 1.62 \text{ m} \\
\end{align*}
\]
Free board generally provided equal to \( 1.5 h_w = 1.5 \times 1.62 = 2.45 \text{ m} \approx 2.5 \text{ m} \)

16. Ans: (d)
Sol: \( B = \frac{H}{\sqrt{S-C}} = \frac{60}{\sqrt{2.4-1}} = \frac{60}{\sqrt{1.4}} \)
\[
\begin{align*}
&= 50.7 \text{ m} \\
\text{(with full uplift pressure} \ C = 1 \text{) } \rightarrow (1)} \\
B &= \frac{H}{\mu(S-C)} = \frac{60}{0.7(1.4)} = 61.22 \text{ m} \approx 61 \text{ m} \rightarrow (2) \\
\end{align*}
\]
From (1) and (2) which is greater i.e. 61 m

04. Ans: (c)
Sol: Limiting height (or) critical height of a dam
\[
\begin{align*}
H_c &= \frac{f}{\gamma_w(G+1)} = \frac{2500}{10(2.4+1)} = 73.52 \text{ m} \\
\end{align*}
\]

05. Ans: (d)
Sol: Limiting height at low dam with our considering uplift \( H_v = \frac{f}{w(s-G+1)} \)
\[
\begin{align*}
\frac{f}{w(2.5 - 1 + 1)} &= \frac{f}{w(2.5)} \\
\text{Limiting height at low dam with our considering uplift } \frac{H_s}{H_v} &= \frac{f}{w(s - G + 1)} \\
\frac{H_s}{H_v} &= \frac{w(2.5)}{w(2.5)} = \frac{3.5}{2.5} = 1.4 \\
\text{Ratio of } \frac{H_s}{H_v} &= \frac{w(2.5)}{w(3.5)} = \frac{3.5}{2.5} = 1.4
\end{align*}
\]

06. Ans: (d) 
Sol:

![Diagram](image1)

1. With drainage gallery

\[
U_1 = \frac{B}{10(2)} \left[ \text{CWH} + \frac{1}{3} \text{CWH} \right] + \frac{9B}{10(2)} \cdot \frac{\text{CWH}}{3} = \frac{B}{20} \left( \frac{4}{3} \text{CWH} \right) + \frac{9B \text{ CWH}}{20 \cdot 3}
\]

2. Without drainage gallery

\[
U_2 = \frac{1}{2} \text{BCWH}
\]

![Diagram](image2)

Reduction in uplift force in case of DG

\[
\text{Reduction} = \frac{17}{60} \text{CW} \times 100 = 56.67\%
\]

07. Ans: (A) 
Sol: 
\[
\text{SFF} = \frac{M \sum V + bq}{\sum H} \quad \sum H = 70
\]

Factor of safety against sliding = \( \frac{\mu \sum V}{\sum H} \)

\[
1.05 = \frac{\mu \sum V}{70} \quad \mu \sum V = 72.8 \\
q = 1.4 \text{ MPa} \\
b = 70 \text{ m} \\
\text{SFF} = \frac{72.8 + 70 \times 1.4}{70} \\
\text{SFF} = 2.44
\]

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03. Conventional Practice Solutions

Sol:

Ice force, wind force, seismic force need not be considered.

No Tail water therefore \( P_2 = 0 \)

Only \( W, P, \& U \) are to be considered.

\( W : W = W_1 + W_2 + W_3 \) as shown in figure

consider 1 m length of dam

\[
W_1 = \frac{1}{2} \times 1.8 \times (18) \times (26.4) = 427.68 \text{ kN}
\]

\[
W_2 = 4 \times (28) \times (26.4) = 2956.8 \text{ kN}
\]

\[
W_3 = \frac{1}{2} \times \frac{44}{3} \times (22) \times (26.4) = 4259.2 \text{ kN}
\]

\[
P = \frac{wH^2}{2} = \frac{10 \times (26)^2}{2} = 3380 \text{ kN}
\]

\( W_w = \) Weight of water on u/s side

\[
= \left(\frac{26 + 8}{2}\right) \times 1.8 \times (10) = 306 \text{ kN}
\]

\[
\Sigma V = W - U + W_w = 6070 \text{ kN}
\]

\[
\Sigma H = P = 3380 \text{ kN}
\]

04. Sol:

For safety against sliding \( FSS > 1.0 \)

\[
\Sigma H = \frac{wH^2}{2} = \frac{1 \times (97)^2}{2} = 4704.5
\]
05.

Sol:

$FSS = \frac{\mu \Sigma V}{\Sigma H} = \frac{0.75(3760)}{4704.5}$

$= 0.6 < 1$ Not safe

$W_1 = \frac{1}{2}(1)(10)(22.4) = 112$ kN

$x_1 = 7.25 + \frac{1}{3}$

$= 7.58$ m from toe

$W_2 = 10(1) 22.4 = 224$ kN

$x_2 = 6.25 + \frac{1}{2}$

$= 6.75$ m from toe

$W_3 = \frac{1}{2}(6.25)(10)(22.4) = 700$ kN

$x_3 = \frac{2}{3}(6.25)$

$= 4.16$ m from toe

$W = W_1 + W_2 + W_3$

$= 112 + 224 + 700 = 1036$ kN

$M_w = W_1x_1 + W_2x_2 + W_3x_3 = 5272.96$ kN-m

$P = \frac{wH^2}{2} = \frac{10(10)^2}{2} = 500$ kN

At $\frac{10}{3} = 3.33$ m from toe

$W_w = \frac{1}{2}1(10)(10) = 50$ kN

Acting at $7.25 + \frac{2}{3}(1) = 7.91$ m from toe

$\Sigma H = P = 500$ kN

$\Sigma V = W + W_w = 1036 + 50 = 1086$ kN

$FSS = \frac{\mu \Sigma V}{\Sigma H} = \frac{0.75(1086)}{500} = 1.63 > 1$ (Safe)

$SFF = \frac{\mu \Sigma V + bq}{\Sigma H} = FSS + \frac{bq}{\Sigma H}$

$= 1.63 + \frac{8.25(14)}{500} \times 9.81 \times 10^{-3} \times 10^4$

Safe = 24.3 > 2

$FSOT = \frac{\Sigma M_R}{\Sigma M_o} = \frac{5272.96 + 50(7.91)}{500(3.33)}$

$= 3.4$ (Safe)

13. Spillways

Conceptual Solutions

06. Ans: (b)

Sol: If initial head is $H$

Increased head by 125% $\Rightarrow H + 1.25H$

$= 2.25 H$
Q for ogee spill way = \( C \times L_e \times H_e^{3/2} \)
\( Q \propto H_e^{3/2} \)
\( Q_1 = (H_1)^{3/2} \)
\( Q_2 = (2.25H_2)^{3/2} = 3.375H^{3/2} \)
\% increased in discharge = \( \frac{Q_2 - Q_1}{Q_1} \times 100 \)
= \( \frac{3.375H^{3/2} - H^{3/2}}{H^{3/2}} \times 100 = 237.5\% \)

12. **Ans: (9.96)**
   **Sol:**
   \[ L_e = L - 2H_d \left[ K_A + (n - 1)K_p \right] \]
   \( n = \) no. of spans
   \( = 10 - 2(0.6) [0.1 + 2(0.1)] \)
   \( n - 1 = \) no. of piers
   \( = 10 - 0.36 = 99.64 \text{ cms} \)
   \( = 9.96 \text{ mts} \)

**Conventional Practice Solutions**

01. **Sol:**
   \( q = 1 \text{ m}^2/\text{s}, C_d = 0.7 \)
   \[ q = \frac{2}{3} C_d \sqrt{2gH^{3/2}} \Rightarrow h = 0.62 \text{ m} \]
   Height of crest above floor level = 10 m
   Total height = \( 10 + \frac{0.62}{2} = 10.31 \text{ m} \)
   Theoretical velocity at foot of spillway
   \[ = \sqrt{2gH} = \sqrt{29.81 \times 10.31} = 14.22 \text{ m/s} \]

03. **Sol:**
   **Given data**
   \( H = 20 \text{ m} \)
   Slope of U/S face = \( 1 : 1.5 \text{ (H : V)} \)
   \( K = 1.939, n = 1.81 \)
   Ogee spillway downstream profile

Assume \( C_v = 0.9 \)
\( V_1 = 0.9 \times 14.22 = 12.80 \text{ m/s} \)
At the foot of spillway, \( y_1 = \frac{q}{V_1} = \frac{1}{12.80} = 0 \)
\[ F_{y1} = \frac{V_1}{\sqrt{gy_1}} = \frac{12.80}{\sqrt{9.81 \times 0.078}} = 14.62 > 1 \]
Flow will be supercritical
Depth of flow on d/s, \( y_2 = 1 \text{ m} \)
\[ V_2 = \frac{q}{y_2} = \frac{1}{1} = 1 \text{ m/s} \]
\[ F_{y2} = \frac{V_2}{\sqrt{gy_2}} = \frac{1}{\sqrt{9.81 \times 1}} = 0.32 < 1 \]
Subcritical
\[ \therefore \text{Hydraulic jump will be formed} \]
\[ y_2 = \frac{y}{2} \left[ 1 + \sqrt{1 + 8F_{y2}^2} \right] = 1.574 \]
But depth available in the stream at d/s = 1.0 m
\[ \therefore \text{The stilling basin has to be depressed by} \]
\( 1.574 - 1.0 = 0.574 \text{ m} \)
Length of stilling basin
\( = 5(y_2 - y_1) = 5(1.574 - 0.078) \]
\( = 7.5 \text{ m} \)
\[ x^n = kH^{n-1}y \]

\[ H_c = H_d + H_a \]

\( H_a \): Due to velocity of approach (negligible)

\( O \): Origin at highest point C of crest

\( n = 1.81 \)

\( k = 1.939 \)

\[ x^{1.81} = 1.939 \times 20^{1.81-1}y \]

\[ \Rightarrow x^{1.81} = 21.95y \]

Profile of ogee spillway upstream profile can extend upto

\[ x = -0.27H_d \]

\[ = -0.27(20) = -5.4 \text{ m} \]

<table>
<thead>
<tr>
<th>( x )</th>
<th>( y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.042 m</td>
</tr>
<tr>
<td>2</td>
<td>0.16 m</td>
</tr>
<tr>
<td>3</td>
<td>0.33 m</td>
</tr>
<tr>
<td>4</td>
<td>0.56 m</td>
</tr>
<tr>
<td>5</td>
<td>0.84 m</td>
</tr>
<tr>
<td>6</td>
<td>1.17 m</td>
</tr>
<tr>
<td>7</td>
<td>1.54 m</td>
</tr>
<tr>
<td>8</td>
<td>1.96 m</td>
</tr>
<tr>
<td>9</td>
<td>2.43 m</td>
</tr>
<tr>
<td>10</td>
<td>2.94 m</td>
</tr>
</tbody>
</table>

\[ y_2 = -\frac{y_1}{2} + \sqrt{\frac{y_1^2}{4} + \frac{2q}{g'}} \]

\[ = -0.8 + \sqrt{\frac{0.8^2}{4} + \frac{2(100)}{9.81 \times 0.8}} = 4.664 \text{ m} \]

With 7\% margin for sweep out caused by jumping water on tail water

\[ y_2 = 1.07 \times 4.664 = 4.99 \text{ m} \]

\[ \therefore \text{ Tail water depth = 6 m, is more than } 4.99 \text{ m} \]

\[ \therefore \text{ The jump to be formed will get drowned out by tail water and proper energy dissipation will not occur.} \]

\[ \therefore \text{ Point of jump formation will have to be raised by providing a sloping glacier apron.} \]
14. Earth Dams

Conventional Practice Solutions

02.
Sol:

F is focus and origin (0, 0)
The curve shown of phreatic line is a parabola. Any point on parabola is equidistant from focus & directrix
Distance of directrix from focus = S
Any point P on the parabola (x, y)

\[ x + s \sqrt{x^2 + y^2} \]

\[ x^2 + s^2 + 2xs = x^2 + y^2 \]

\[ y = \sqrt{s^2 + 2xs} \]

Point A lies on curve with x
\[ = 47.4375 + 165 - 158.125 + 8 + 150 - 120 \]
\[ = 92.3125 \]

y- coordinate = 57.5 m

\[ s = \sqrt{x^2 + y^2} - x \]

\[ = \sqrt{92.3125^2 + 57.5^2} - 92.3125 \]

As per Darcy’s law:
\[ i = \frac{dy}{dx} \Rightarrow y = \sqrt{s^2 + 2xs} \]

\[ \frac{dy}{dx} = \frac{2s}{2\sqrt{s^2 + 2xs}} \]

\[ = \frac{s}{\sqrt{s^2 + 2xs}} \]

\[ q = k \frac{dy}{dx} y = \sqrt{k_x k_y \frac{s}{\sqrt{s^2 + 2xs}}} \]

\[ = \sqrt{4 \times 10^{-7} \times 10^{-7} (16.44)} \]

\[ = 3.3 \times 10^{-6} \text{ m}^2/\text{s} \]