01. Ans: (d)
Sol:

<table>
<thead>
<tr>
<th>Road</th>
<th>Length (km)</th>
<th>Number of with population</th>
<th>Utility</th>
<th>Utility/km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 2000</td>
<td>2000 – 5000</td>
<td>&gt; 5000</td>
</tr>
<tr>
<td>P</td>
<td>20</td>
<td>8</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Q</td>
<td>28</td>
<td>19</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>R</td>
<td>12</td>
<td>7</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

Weightage factor

0.5 1 2

:\ RQP

02. Ans: (a)
Sol:

<table>
<thead>
<tr>
<th>Road Lane</th>
<th>Length (cm)</th>
<th>Number of villages with population ranges</th>
<th>Industrial Product</th>
<th>Utility</th>
<th>Utility/km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1000-2000</td>
<td>2000-5000</td>
<td>5000-10000</td>
<td>&gt;10000</td>
</tr>
<tr>
<td>P</td>
<td>300</td>
<td>100</td>
<td>80</td>
<td>6</td>
<td>200</td>
</tr>
<tr>
<td>Q</td>
<td>400</td>
<td>200</td>
<td>90</td>
<td>00</td>
<td>8</td>
</tr>
<tr>
<td>R</td>
<td>500</td>
<td>240</td>
<td>110</td>
<td>70</td>
<td>10</td>
</tr>
<tr>
<td>S</td>
<td>550</td>
<td>248</td>
<td>112</td>
<td>73</td>
<td>12</td>
</tr>
</tbody>
</table>

Weightage factor

1 2 3 4

\: RSPQ

03. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 2nd Question -pg: 968)
04. Highway Geometric Design - Gradients

*Common data for Questions 01 & 02*

01. Ans: (b)
Sol: Height of crown \( = \frac{W}{2n} = \frac{3.5 \times 1000}{2 \times 60} = 29.2 \text{ mm} \)

02. Ans: (d)
Sol: Height of crown \( = \frac{W}{2n} = \frac{3.5 \times 1000}{2 \times 40} = 43.75 \text{ mm} \)

04. Ans: (a)
Sol: \( G.C = \frac{30 + R}{R} \)
\( G.C = \frac{30 + 50}{50} = 1.6 \)
Max \( G.C = \frac{75}{50} = 1.5 \) \( \Rightarrow GC = 1.5 \)
The compensated gradient = 6% – 1.5 = 4.5%

05. Ans: (a)
Sol: Height of crown \( = \frac{W}{2n} = 7.5 \text{ cm} \)
\( \Rightarrow \frac{W}{2n} = 7.5 \)
\( 2n = \frac{9 \times 100}{7.5} \)
\( n = 60 \Rightarrow 1 \text{ in } 60 \)

Conventional Practice Solutions

01.
Sol: (a) For WBM district road with heavy rainfall
Height of crown with respect to edges
\( = \frac{eW}{2} \)
= \( \frac{1}{33} \text{ W} = 3.5 \text{ m} \)
Height of crown w.r.to edges = \( \frac{1}{33} \times \frac{3.5}{2} = 0.053 \text{ m} \)
(b) For state highway of concrete pavement
Height of crown w.r.to edges = \( \frac{eW}{2} \)
= \( \frac{1}{50} \text{ W} = 7 \text{ m} \)
Height of crown w.r.to edges = \( \frac{1}{50} \times \frac{7}{2} = 0.07 \text{ m} \)

05. Highway Geometric Design - Sight Distances

01. Ans: (c)
Sol: B.D = 16 m,
\( f = 0.4 \)
\( \frac{V^2}{254f} = 16 \Rightarrow \frac{V^2}{254 \times 0.4} = 16 \)
\( V = 40.3 \text{ kmph} \approx 40 \text{ kmph} \)
02. Ans: (c)
Sol: \( V = 30 \text{ kmph, } f = 0.4 \)
\[
\frac{V^2}{254(f - 0.01n)} = 2 \times \frac{V^2}{254(f + 0.01n)}
\]
\[
f + 0.01n = 2f - 0.02n
\]
\[
0.03n = 0.4
\]
\[
n = 13.33\%
\]

03. Ans: (b)
Sol: \( V = 72 \text{ kmph, } n = 2\%, \)
\( f = 0.15, \)
\( t = 1.5 \text{ sec} \)
\[
\text{SSD} = 0.278Vt + \frac{V^2}{254(f + 0.01n)}
\]
\[
= 150 \text{ m}
\]

04. Ans: (b)
Sol: \( V = 60 \text{ kmph} \)
\( t = 2.5 \text{ sec, } f = 0.36 \)
\[
0.278Vt = \frac{6}{5}
\]
\[
0.278 \times 60 \times 2.5 = \frac{6}{5} \left[ \frac{60^2}{254(0.36 + 0.01n)} \right]
\]
\[
n = 4.78 \approx 4.8
\]

05. Ans: (c)
Sol: \( V = 60 \text{ kmph, } t = 2.5 \text{ sec, } f = 0.35 \)
\[
\text{SSD} = 0.278Vt + \frac{V^2}{254f}
\]
\[
= 0.278 \times 60 \times 2.5 + \frac{60^2}{254 \times 0.35} = 82.1 \text{ m}
\]

SSD for single two way traffic = \( 2 \times \text{SSD} = 2 \times 82.1 = 164.2 \text{ m} \)

06. Ans: (c)
Sol: \( \text{ISD} = 2 \times 80 = 160 \text{ m} \)

07. Ans: (83 kmph)
Sol: There are 3 phases in the problem
1. Driver lifts foot from accelerator and moves it to brake pedal – the velocity is uniform.
2. Deceleration increases from zero to maximum
3. Braking system locks the wheels and deceleration assumed to be constant until vehicle strikes the stationary vehicle

\[ A = fg = 0.75 \times 9.81 = 7.35 \text{ m/s}^2 \]

During 1st phase, assume driver reaction time 0.5 sec
\[ v_o = v_1 + \frac{a}{2}(t_1 - t_o) \]

During 3rd phase, deceleration assumed to be uniform
\[ v_1 = \sqrt{v_2^2 + 2aS} = \sqrt{11.18^2 + 2 \times 7.35 \times 27.45} \]
\[ = 22.98 \text{ m/s} = 82.76 \text{ kmph} \]
\[ v_o = 82.76 + \frac{7.35}{2} (0.8 - 0.5) \]
\[ = 83 \text{ kmph} \]

08. Ans: (13.6 m)
Sol: \[ \frac{dv}{dt} = 3 - 0.04v \]
\[ A = 3, \beta = 0.04, t = 5 - 0.75 = 4.25 \]
Width of intersection = 7.5 m
Equation for distance as a function of time
\[ x = \frac{\alpha t}{\beta} - \frac{\alpha}{\beta^2} (1 - e^{-\beta t}) + \frac{v_o}{\beta} (1 - e^{-\beta t}) \]
\[ v_o = \text{initial speed} = 0 \]
\[ = \frac{3(4.25)}{0.04} - \frac{3}{(0.04)^2} (1 - e^{-0.04 \times 4.25}) + 0 \]
\[ x = 25.62 \text{ m} \]
Intersection + length of car
7.5 + 6.1 = 13.6 m
\[ \therefore \text{He can clear the intersection} \]

09. Ans: \( T = 7.13 \text{ sec, } V = 138 \text{ kmph} \)
Sol:

In question they give it will take 3 sec to red sign
So
\[ \text{Speed of } \frac{20}{40} \text{ vision driver} = \frac{115}{3} \text{ m/sec} \]
\[ = 138 \text{ kmph} \]
For speed of \( \frac{20}{40} \text{ vision driver} \) is 58kmph
\[ \text{i.e. } 58 \times \frac{5}{18} = 16.11 \text{ m/sec} \]
\[ \text{Velocity} = \frac{D}{T} \]
\[ T = \frac{115}{16.11} \]
\[ T = 7.13 \text{ sec} \]

10. Ans: 142
Sol: For normal driver with 6/6 vision the position of sign post is shown below.
\[ S_2 = 174 - 48 = 126 \text{ m} \]
\[ S_2 = \text{The distance from sign post to the start of zone-y} \]
\[ S_1 = \text{Distance traveled by the vehicle during perception – reaction time for 6/6 vision driver} \]
\[ S = \text{total distance required to reduce the speed to 30 kmph from design speed.} \]
For a driver with 6/9 vision (with defective sight), the distance of sign post should be nearer as compared to driver with normal sight.

\[ \therefore \text{Modified } S_1 = \frac{6}{9} \times 48 = 32 \text{ m} \]

The position of sign post is as shown below

\[ A \quad S_1 = 32 \text{ m} \quad S_2 = X = \text{?} \quad \text{Start of zone-y} \quad B \]

\[ S = 174 \text{ m} \]

The distance from modified position of sign post to the start of zone-y (i.e. C'B)

\[ = 174 - 32 = 142 \text{ m.} \]

11. Ans: 900.79

Sol: Refer previous GATE solutions Book
(Cha-2, Two marks 9th Question -pg: 821)

12. Ans: (d)

Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-5, 5th Question -pg: 977)

13. Ans: (c)

Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-5, 9th Question -pg: 978)

**Conventional Practice Solutions**

01.

**Sol:** (a) Two way Traffic on a two lane Road:

\[ S.S.D = 0.278 V_t + \frac{V^2}{254f} \]

\[ = (0.278 \times 100 \times 2.4) + \frac{100^2}{254 \times 0.35} \]

\[ = 66.72 + 112.49 \]

\[ = 179.2 \text{ m} \]

(b) Two way traffic on a single lane Road

\[ S.S.D = 2 \times \left(0.278V_t + \frac{V^2}{254f}\right) \]

\[ = 2 \times 179.2 \]

\[ = 358.4 \text{ m} \]

02.

**Sol:** Minimum distance Required = SSD$_1$ + SSD$_2$

\[ = \left(0.278V_t + \frac{V_i^2}{254f} \right) + \left(0.278V_t + \frac{V_2^2}{255f} \right) \]

\[ = \left[(0.278 \times 100 \times 2.5) + \frac{100^2}{254 \times 0.33 \times 0.5} \right] + \]

\[ [0.278 \times 80 \times 25] + \frac{80^2}{254 \times 0.33 \times 0.5} \]

\[ = 69.5 + 238.6 + 55.6 + 152.7 = 516.4 \text{ m} \]
03.

Sol: $SSD_1 = 0.278Vt + \frac{V^2}{254(f+x)}$ ----- (i)

$SSD_2 = 0.278Vt + \frac{V^2}{254(f-x)}$ ----- (ii)

Subtracting 2 equations

$10 = \frac{V^2}{254(f-x)} - \frac{V^2}{254(f+x)}$

$10 = \frac{V^2}{254} \left[ \frac{1}{f-x} - \frac{1}{f+x} \right]$

$10 \times \frac{254}{V^2} = \frac{(f+x)-(f-x)}{(f^2-x^2)}$

$0.706 = \frac{2x}{0.16-x^2}$

$x = 0.054$

or

$x = 5.54\%$

04.

Sol: (a) $v^2 - u^2 = 2gfs$

$0 - \left( \frac{60 \times 5}{18} \right)^2 = -2 \times 9.8 \times f \times 5.8$

$277.78 = 113.796 f$

$f = 2.44$

(b) $V = \mu + at$

$\mu = -a t$

$\left( \frac{60 \times 5}{18} \right) = +g f t$

$16.67 = 9.81 \times f \times 2$

$f = 0.85$

(c) $S = ut + \frac{1}{2}at^2$

$7 = \left( 60 \times \frac{5}{18} \right) \times 1.5 + \frac{1}{2} \times 9.81(-f) \times 1.5^2$

$7 = 25 - 11.04 f$

$f = \frac{18}{11.04} = 1.63$

05.

Sol: $v^2 - u^2 = 2as$

$0 - \left( \frac{65 \times 5}{18} \right)^2 = 2 \times a \times 25.5$

$-326 = 51 a$

$a = -6.392$

$a = -g f \eta$

$-9.81 \times 0.7 \times \eta = -6.392$

$\eta = 0.93$

06. Highway Geometric Design – Overtaking Sight Distance

Common data for Questions 01, 02 & 03

01. Ans: (c)

Sol: $V = 80 \text{ kmph} = 2.5 \text{ kmph/sec}$

$V_b = 50 \text{ kmph}$

$S = 16 \text{ m}$

$t = 2 \text{ sec}$

$T = \sqrt{\frac{14.4s}{A}} = \sqrt{92.16 \text{ sec}}$

$= 9.6 \text{ sec}$

$OSD = d_1 + d_2$

$= 0.278 V_b t + (0.278 V_b T + 2s)$

$= 193.24 \text{ m}$
02. Ans: (d)  
Sol: \[ \text{OSD} = d_1 + d_2 + d_3 \]
\[ = 0.278V_{b}T + (0.278V_{b}T + 2s) + 0.278VT \]
\[ = 406.74 \text{ m} \]

03. Ans: (c)  
Sol: Since division is there  
\[ \text{OSD} = d_1 + d_2 = 193.24 \text{ m} \]

**Common data for Questions 04 & 05**  
04. Ans: (c)  
Sol: \[ V = u + at \]
\[ u = 100 \text{ kmph} \]
\[ = 27.7 \text{ m/s} \]
\[ = 27.7 + 0.8 \times 5 \]
\[ V = 31.72 \text{ m/s} \]
\[ V^2 - u^2 = 2 \times as \]
\[ (31.7)^2 - (27.7)^2 = 2 \times 0.8 \times S \]
\[ S = 148.5 \text{ m} \]
Distance traveled in next 2 sec  
\[ = 323 - 148.5 \]
\[ S = 174.5 \text{ m} \]
Now, \[ u = 31.7 \text{ m/s} \]
\[ S = ut + \frac{1}{2}at^2 \]
\[ 174.5 = (31.7 \times 5) + \left( \frac{1}{2} \times a \times 5^2 \right) \]
\[ a = 1.2 \text{ m/sec}^2 \]

05. Ans: (d)  
Sol: Distance traveled in overtaking process (d_2)  
\[ d_2 = (V_bT + 2s) \quad S_1 = 25 \text{ m} \]
\[ = (V_bT + S_1 + S_2) \quad S_2 = 20 \text{ m} \]
\[ T = \frac{\sqrt{4s}}{a} = 10.6 \text{ sec} \]
\[ d_2 = (0.278 \times 100 \times 10) + (25 + 20) \]
\[ = 323 \text{ mm} \]

**Common data for Questions 06 & 07**  
06. Ans: (c)  
Sol: \[ \text{OSD} = d_1 + d_2 \]
\[ V = 22.22 \text{ m/s} \]
\[ V_b = 16.67 \text{ m/s} \]
\[ a = 0.7 \text{ m/s}^2 \]
\[ S = (0.7V_b + l) = 17.67 \text{ m} \]
\[ T = \frac{\sqrt{4s}}{a} = 10.05 \text{ sec} \]
\[ t = 2 \text{ sec} \]
\[ \text{OSD} = d_1 + d_2 + d_3 \]
\[ = V_b t + (V_bT + 2s) + VT \]
\[ = 236.21 + (22.22 \times 10.05) \]
\[ = 459.521 \text{ m} \]
\[ \approx 460 \text{ m} \]

07. Ans: (d)  
Sol: Desirable length of OZ = 5 OSD  
\[ = 5 (d_1 + d_2 + d_3) \]
\[ = 5 \times 460 \]
\[ \approx 2300 \text{ m} \]
01. **Ans:** (a)

**Sol:**

\[ d_1 = V_b t \]
\[ = 0.278 \times 80 \times 2 = 44.48 \text{ m} \]

(ii) \[ d_2 \]

\[ T = \sqrt{\frac{4S}{a}} \]
\[ S = (0.2 V_b + l) = (0.2 \times 80 + 6) = 22 \text{ m} \]
\[ T = \sqrt{\frac{4 \times 22}{0.92}} = 9.78 \text{ sec} \]
\[ d_2 = (V_b T + 2S) = (80 \times 9.78 \times 0.278) + 44 = 261.5 \text{ m} \]

(iii) \[ d_3 = (V_a \times T) \]
\[ = 0.278 \times 100 \times 9.78 = 271.9 \text{ m} \]
\[ OSD = d_1 + d_2 + d_3 = 577.88 \text{ m} \]

Desirable length of overtaking zone
\[ = 5 \times OSD = 2889.4 \text{ m} \]
Common data for Questions 04 to 06

04. Ans: (b)
Sol: $e + f = \frac{V^2}{127R}$

\[
e + 0.15 = \frac{100^2}{127 \times 500}
\Rightarrow e = 0.00748 = 0.74\%
\]

05. Ans: (b)
Sol: $f = \frac{V^2}{127R} = \frac{100^2}{127 \times 500} = 0.157 \approx 0.16$

06. Ans: (c)
Sol: $f = 0$; $e + 0 = \frac{100^2}{127 \times 500}$

\[
\Rightarrow e = 15.75\%
\]

07. Ans: (a)
Sol: $e = \frac{V^2}{225R} = \frac{60^2}{225 \times 500} = 0.032 = 3.2\%
\]

08. Ans: (b)
Sol: $R_{\text{Ruling}} = \frac{V^2}{127(f + e)}$

\[
= \frac{100^2}{127(0.07 + 0.13)}
= 393.7 \text{ m} \approx 395 \text{ m}
\]

09. Ans: (a)
Sol: $b = 2.4 \text{ m}$
$h = 4.2 \text{ m}$

10. Ans: (d)
Sol: $\frac{b}{2h} = \frac{2.4}{2 \times 4.2} = 0.286 > f$
\[
\Rightarrow \frac{b}{2h} > f
\]

\[
\therefore \text{Lateral skidding occur first}
\]

11. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 9th Question -pg: 984)

12. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 10th Question -pg: 984)

Conventional Practice Solutions

01.
Sol: (a) $e = \frac{V^2}{225R}$

\[
e = \frac{120^2}{225 \times 450}
= 0.142
\]

but $e > 0.07$
So use $e = 0.07$

(b) $e + f = \frac{V^2}{127R}$

\[
V = \sqrt{(e + f) \times 127R}
= \sqrt{(0.07 + 0.15)127 \times 450}
= 112.1 \text{ kmph}$
02. Sol:

To avoid overturning

\[ W \times \frac{b}{2} > P \times h \]
\[ \frac{b}{2h} > \frac{P}{W} \]

(i) Minimum speed to avoid shading

\[ f > \frac{P}{W} \left[ \frac{P}{W} = \frac{V^2}{gR} \right] \]
\[ f > \frac{V^2}{gR} \]
\[ V = \sqrt{f \cdot g \cdot R} \]
\[ = \sqrt{0.15 \times 9.81 \times 200} \]
\[ V < 17.16 \text{ m/sec} \]

(ii) Minimum speed to avoid overturning

\[ \frac{b}{2g} > \frac{V^2}{gR} \]
\[ V < \sqrt{\frac{bgR}{2h}} = \sqrt{\frac{3.5 \times 9.81 \times 200}{2 \times 1.4}} \]
\[ = 49.52 \text{ m/sec} \]

So maximum speed = 17.16 m/sec

08. Horizontal Curves (Extra Widening)

Common data for Questions 01 & 02

01. Ans: (d)

Sol: \( e + f = \frac{V^2}{127R} \)

\( R_{\text{Ruling}} = \frac{76^2}{127\left(\frac{1}{15} + 0.15\right)} \)
\[ = 209.9 \text{ m} \]

02. Ans: (d)

Sol: \( W_e = \frac{n \ell^2}{2R} + \frac{V}{9.5\sqrt{R}} \)

\[ = \frac{2 \times 7^2}{2 \times 209} + \frac{76}{9.5 \sqrt{209}} \]
\[ = 0.787 \text{ m} \]

\[ \therefore \text{ Total width} = 7 + 0.787 \]
\[ = 7.78 \text{ m} \]

03. Ans: (c)

Sol: \( W_e = \frac{n \ell^2}{2R} + \frac{V}{9.5\sqrt{R}} \)

\[ = \frac{2 \times 8^2}{2 \times 300} + \frac{100}{9.5 \sqrt{300}} \]
\[ = 0.821 \text{ m} \]
04. Ans: (c)

Sol: Given

\[ W_m = 0.096 \]

\[ \frac{\ell^2}{2R} = 0.096 \Rightarrow R = 226.87 \text{ m} \]

\[ W_e = W_m + W_{ps} = \frac{n \ell^2}{2R} + \frac{V}{9.5 \sqrt{R}} \]

\[ = \frac{2 \times 6.6^2}{2 \times 226.87} + \frac{80}{9.5 \sqrt{226.87}} \]

\[ = 0.75 \text{ m} \]

Conventional Practice Solutions

01.

Sol: (1) Ruling minimum radius \( e + f = \frac{V^2}{127R} \)

\[ R = \frac{V^2}{127(e + f)} \]

\[ = \frac{120^2}{127(0.07 + 0.15)} \]

\[ R = 515 \text{ m} \]

(2) Extra widening

\[ W_e = \frac{n \ell^2}{2R} + \frac{V}{9.5 \sqrt{R}} \]

\[ = \frac{4 \times 6.1^2}{2 \times 515} + \frac{120}{9.5 \sqrt{515}} \]

\[ = 0.145 + 0.555 \]

\[ W_e = 0.7 \text{ m} \]

02.

Sol:

By property of circle,

\[ (AD) \cdot (DB) = (CD) \cdot (DE) \]

\[ \frac{L}{2} \cdot \frac{L}{2} = (W - 10) \left[ 2R - (W - 10) \right] \]

\[ \frac{L^2}{4(W - 10)} = 2R - (W - 10) \]

\[ 2R = \frac{L^2}{4(W - 10)} + W - 10 \]

\[ R = \frac{L^2}{8(W - 10)} + \left( \frac{W - 10}{2} \right) \]
09. Set Back Distance and Curve Resistance

01. Ans: (a)
Sol: Set back or the clearance is the distance required from the centre line of horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance at a horizontal curve.

02. Ans: (c)
Sol: \[ m = \frac{S^2}{8R} \Rightarrow R = \frac{80^2}{8 \times 10} = 80 \text{ m} \]

Common data for Questions 03 & 04

03. Ans: (c)
Sol: \[ L = 180 \text{ m} \quad S = 80 \text{ m} \]
\[ L > S \]
\[ m = \frac{S^2}{8R} = \frac{80^2}{8 \times 360} = 2.22 \text{ m} \]
Width of pavement is not indicated
\[ m = R - R \cos \left( \frac{\alpha}{2} \right) \]
\[ \frac{\alpha}{2} = \frac{180S}{2 \pi R} = \frac{180 \times 80}{2 \pi \times 360} = 6.36 \]
\[ m = 360 - 360 \cos (6.36) = 2.2 \text{ m} \]

04. Ans: (c)
Sol: \[ L = 180 \text{ m} \quad S = 250 \text{ m} \]
\[ L < S \]
\[ m = R - R \cos \left( \frac{\alpha}{2} \right) + \frac{S - L}{2} \sin \left( \frac{\alpha}{2} \right) \]

\[ \alpha = \frac{180L}{2} \quad \Rightarrow \quad \frac{180 \times 180}{2 \pi R} = \frac{180 \times 180}{2 \pi \times 360} = 14.32 \]
\[ m = 360 - 360 \cos (14.32) + \frac{250 - 180}{2} \sin (14.32) = 19.85 \text{ m} \]

Common data for Questions 05 & 06

05. Ans: (c)
Sol: \[ SSD = 0.278Vt + \frac{V^2}{254f} \]
\[ \Rightarrow \quad (0.278 \times 80 \times 2.4) + \frac{80^2}{254 \times 0.355} = 124.35 \text{ m} \approx 125 \text{ m} \]

06. Ans: (d)
Sol: \[ S = 125 \text{ m} \]
\[ d = \frac{W}{4} = \frac{7}{4} = 1.75 \text{ m} \]
\[ \alpha = \frac{180S}{2 \pi (R - d)} = \frac{180 \times 125}{2 \pi (200 - 1.75)} = 18.06 \]
\[ m = R - (R - d) \cos \left( \frac{\alpha}{2} \right) \]
\[ = 11.52 \text{ m} \]
\[ m^1 = m - d = 11.52 - 1.75 = 9.77 \text{ m} \]
(or)
In approximately
\[ m = \frac{S^2}{8R} = 9.76 \text{ m} \]
Problems on Curve Resistance

01.
Sol: Let ‘T’ is the original Tractive force
loss of tractive force = T(1– cosθ)
= T(1–cos45°)
Ratio of loss of Tractive force to original is
= 0.243

02.
Sol: Curve resistance = T(1 – cosθ)
= T(1 – cos30°)
= 0.134 T

03.
Sol: Curve resistance = T(1–cosθ)
= T(1–cos90°)
= 0

Common data for Questions 01 & 02

01. Ans: (d)
Sol: \[ L = \frac{0.0215 V^3}{C R} \]
\[ = \frac{0.0215 \times 60^3}{0.6 \times 200} = 38.7 \text{ m} \]
Considering N value
\[ L = eN (W + W_e) = 0.07 \times 100 (7 + 0.2) \]
\[ = 50.4 \text{ m} \]
\[ L = \frac{2.7 V^2}{R} = \frac{2.7 \times 60^2}{200} = 48.6 \text{ m} \]
\[ \therefore \text{The length of T.C} = 50.4 \text{ m} \]
(from the 3 values maximum value)
02. Ans: (d)
Sol: \[ S = \frac{L^2}{24R} = \frac{(50.4)^2}{24 \times 200} = 0.53 \text{ m} \]

Common data for Questions 03 & 04

03. Ans: (c)
Sol: \[ C = \frac{80}{75 + V} = \frac{80}{75 + 80} \]
\[ = 0.516 \text{ m/sec}^3 \]

04. Ans: (a)
Sol: Considering ‘C’ value
\[ L = \frac{0.0215V^3}{CR} = \frac{0.0215 \times 80^3}{0.516 \times 900} \]
\[ = 23.7 \text{ m} \]

Considering ‘N’ value
\[ e = \frac{V^2}{225R} = \frac{80^2}{225 \times 900} = 0.0316 \]

(for mixed traffic)
\[ L = \frac{eN}{2}(W + W_e) \]
\[ = \frac{0.0316 \times 150}{2} \times 7 = 16.59 \text{ m} \]

Considering terrain
\[ L = \frac{2.7V^2}{R} = \frac{2.7 \times 80^2}{900} = 19.2 \text{ m} \]
\[ \therefore \text{Length of T.C} = 23.7 \text{ m} \]

05. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-9, 9th Question -pg: 992)

06. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-9, 10th Question -pg: 992)

07. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-9, 11th Question -pg: 992)

Conventional Practice Solutions

01. Sol: (i) Minimum sight distance
\[ = 0.278vt + \frac{V^2}{254f} \]
\[ [\text{Assume } t = 2.5 \text{ sec, } & f = 0.4] \]
\[ = \left(0.278 \times 100 \times 2.5\right) + \frac{100^2}{254 \times 0.4} \]
\[ = 167.9 \text{ m} \]

(ii) Design super elevation
\[ e = \frac{V^2}{225R} = \frac{100^2}{225 \times 900} \]
\[ = 0.148 \]
\[ \text{But } e \geq 0.07 \]

So limit e to 0.07
Check \[ e + f = \frac{V^2}{127R} \]
0.07 + f = \frac{100^2}{127 \times 300}

f = 0.192 > 0.15

So since reduce the speed or increase the radius of the curve.

11. Highway Geometric Design – Vertical Curves

**01. Ans: (b)**
Sol: Length of summit parabolic curve,
Assume L > S
\[
L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2} = \frac{0.09 \times 120^2}{(\sqrt{2 \times 1.5} + \sqrt{2 \times 0.15})^2} = 249 \text{ m}
\]

**02. Ans: (d)**
Sol: N = 4 – (−2) = 6%
6% → 150 nm
4% → \(\frac{4}{6}\) \times 150 = 100 m

**03. Ans: (c)**
Sol: N = \(\frac{1}{50} - \left(\frac{1}{100}\right)\) = 0.03 = 3%
1 % → 100 m
3 % → \(\frac{3}{1}\) \times 100 = 300 m

**Common data for Q 04 & 05**

**04. Ans: (c)**
Sol: N = \(\frac{1}{25} - \left(\frac{1}{50}\right)\) = 0.06 = 6%
S = 180 m
Take L > SSD
\[
L = \frac{NS^2}{4.40} = \frac{0.06 \times 180^2}{4.4} = 441.8 \text{ m} 
\]

**05. Ans: (b)**
Sol: 6 % → 442 m
4 % → \(\frac{4}{6}\) \times 442 = 294.66 m = 294.66

**06. Ans: (a)**
Sol: Refer previous GATE solutions Book
(Cha-2.8, Two marks 5th Question -pg: 859)

**07. Ans: (b)**
Sol: N = \(\frac{1}{100} - \left(\frac{1}{120}\right)\) = 0.0183
Assume L > OSD
\[
L = \frac{NS^2}{9.6} = \frac{0.0183 \times 470^2}{9.6} = 421.09 \text{ m}
\]

421.09 < 470
Take L < OSD
\[
L = 2S - \frac{9.6}{N} = 2 \times 470 - \frac{9.6}{0.0183} = 406.66 \text{ m}
\]
08. Ans: (c)
Sol: Take \( L \geq \text{OSD} \)
\[
L = \frac{\text{NS}^2}{9.6} = \frac{0.018 \times 500^2}{9.6}
\]
\[= 468.75 \text{ m} < 500 \text{ m} \]
Take \( L < \text{OSD} \)
\[
L = 2S - \frac{9.6}{N} = 2 \times 500 - \frac{9.6}{0.018}
\]
\[= 466.67 \text{ m} < 500 \text{ m} \]
\[
\therefore \text{Length of summit curve,} \quad L \approx 467 \text{ m}
\]

09. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-10, 4th Question -pg: 997)

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Conventional Practice Solutions

01.
Sol: Length of summit curve
Assume \( L > \text{SSD} \)
\[
L = \frac{\text{NS}^2}{4.4}
\]
\[
N = \frac{1}{50} - \left( - \frac{1}{30} \right) = \frac{80}{1500} = \frac{8}{150}
\]
\[
L = \frac{8 \times 180^2}{150} \times \frac{4.4}{4.4}
\]
\[= 392.7 \text{ m} \approx 400 \text{ m} \]
Assumption was correct as \( L > \text{SSD} \)
(ii) Summit point is at a distance of

---

\[
x = \frac{NL}{N} \quad \text{from start}
\]
\[
= \frac{0.02 \times 400}{0.0533} = 150.09 \text{ from start}
\]
Equation of parabola
\[
\frac{N}{2L} = \frac{0.053x^2}{2 \times 400}
\]
\[= 0.00006625 \text{ m}^2 \]
R.L of summit
\[
= 10 + 150.09 \times 0.02 - (0.00006625 \times 180.09^2)
\]
\[= 11.511 \text{ m} \]
Vertical distance between point of intersection and curve
\[
= \frac{NL}{8} \times \frac{0.053 \times 400}{8} = 2.650 \text{ m}
\]

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</tr>
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<td>7</td>
<td>120</td>
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</tr>
<tr>
<td>8</td>
<td>140</td>
<td>11.5015</td>
</tr>
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<td>9</td>
<td>160</td>
<td>11.504</td>
</tr>
<tr>
<td>10</td>
<td>180</td>
<td>11.4535</td>
</tr>
<tr>
<td>11</td>
<td>200</td>
<td>11.352</td>
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<td>19</td>
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<td>380</td>
<td>8.0335</td>
</tr>
<tr>
<td>21</td>
<td>400</td>
<td>7.408</td>
</tr>
</tbody>
</table>
12. Highway Geometric Design – Valley Curves

Common data for Questions 01 to 03

01. Ans: (c)
Sol: \( n_1 = \frac{1}{25} \) \( V = 100 \text{ kmph} \)
\[ n_2 = \frac{1}{20} \quad C = 0.6 \text{ m/s}^3 \]
SNF 180 m
\[ N = |n_1 - n_2| = n_1 + n_2 \]
\[ = \frac{1}{25} + \frac{1}{20} = 0.09 \]
(a) \( L = 0.38 (NV^3)^{1/2} \)
\[ = 0.38 \left(0.09 	imes 100 \right)^{1/2} = 114 \]
L > SSD
(b) \( L = \frac{NS^2}{1.5 + (0.035S)} \)
\[ = \frac{0.09 	imes 180^2}{1.5 + 0.035 \times 180} = 137.1 \text{ m} \]
Assume L < SSD
\[ L = 2S \frac{1.5 + 0.035S}{N} \]
\[ = 2 	imes 180 - \frac{1.5 + 0.035 \times 180}{0.033} = 123.6 \text{ m} \]
Provide a length of 125 m

02. Ans: (b)
Sol: \[ I = \frac{1.6NV^2}{L} \]
\[ = \frac{1.6 	imes 0.09 	imes 100^2}{374} = 3.85 \]

03. Ans: (a)
Sol: For 9\% \Rightarrow 373.86
For 4\% \Rightarrow ?
\[ = \frac{4 	imes 374.0}{9} = 166.22 \text{ m} \approx 166 \]

Conventional Practice Solutions

01.
Sol: \( N_1 = 0 \)
\( N_2 = -0.033 \)
\( N = N_1 - N_2 = 0.033 \)
Assume L > SSD
\[ L = \frac{NS^2}{1.5 + 0.035S} \]
\[ = \frac{0.033 	imes 180 	imes 180}{1.5 + 0.035 	imes 180} = 137.1 \text{ m} \]
Assume L < SSD
\[ L = 2S \frac{1.5 + 0.035S}{N} \]
\[ = 2 	imes 180 - \frac{1.5 + 0.035 \times 180}{0.033} = 123.6 \text{ m} \]
Provide a length of 125 m

<table>
<thead>
<tr>
<th>Station</th>
<th>x</th>
<th>y</th>
<th>RL</th>
</tr>
</thead>
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<td>0</td>
<td>10.000</td>
</tr>
<tr>
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<td>25</td>
<td>0.083</td>
<td>10.083</td>
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<tr>
<td>3</td>
<td>50</td>
<td>0.330</td>
<td>10.330</td>
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<tr>
<td>4</td>
<td>75</td>
<td>0.743</td>
<td>10.743</td>
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<tr>
<td>5</td>
<td>100</td>
<td>1.320</td>
<td>11.320</td>
</tr>
<tr>
<td>6</td>
<td>125</td>
<td>2.063</td>
<td>12.063</td>
</tr>
</tbody>
</table>
13. Highway Materials and Testing

01. Ans: (a)
Sol: \( k_1 d_1 = k_2 d_2 \)
\[ (200) \times (30) = (k_2) (75) \]
\[ k_2 = k_{ef \text{soil}} = 80 \text{ N/cm}^3 \]

03. Ans: (a)
Sol: \( E = \frac{1.18 \times 800 \times (75/2)}{2.5 \times 10^{-4}} \)
\[ = 141600 \text{ N/cm}^2 \]
\[ = 141.6 \text{ kN/cm}^2 \]

04.
Sol: Total weight = 825 + 1200 + 325 + 150 + 100
\[ = 2600 \text{ gm} \]
% wt of material ;
\[ A_1 \to \frac{825}{2600} \times 100 = 31.7\% \]
\[ A_2 \to \frac{1200}{2600} \times 100 = 46.15\% \]
\[ A_3 \to \frac{325}{2600} \times 100 = 12.5\% \]
\[ A_4 \to \frac{150}{2600} \times 100 = 5.7\% \]

Bitumen \( \to \frac{100}{2600} \times 100 = 3.8\% \)

\[ G_1 = \frac{100}{(w_1 / G_1 + w_2 / G_2 + w_3 / G_3 + w_4 / G_4 + w_5 / G_5)} \]
\[ = \frac{100}{\left[ \frac{31.7}{2.63} + \frac{46.15}{2.51} + \frac{12.5}{2.46} + \frac{5.7}{2.43} + \frac{3.8}{1.05} \right]} \]
\[ = 2.41 \]

(a) \( V_a = \frac{G_t - G_m}{G_t} \times 100 = \frac{2.41 - 2.31}{2.41} \times 100 \)
\[ = 4.15\% \]

(b) \( V_b = \frac{w_b \times G_m}{G_b} \times \frac{3.80}{1.05} \times 2.31 = 8.36 \)

(c) \( VMA = V_a + V_b = 4.15\% + 8.36 \)
\[ = 12.51\% \]

\[ VFB = \frac{V_b}{VMA} \times 100 \]
\[ = \frac{8.36}{12.51} \times 100 \]
\[ = 67\% \]
05. Ans: \( G_t = 2.48, G_m = 2.30 \)

\[ G_t = \frac{100}{\frac{w_1}{G_1} + \frac{w_2}{G_2} + \frac{w_3}{G_3}} \]

\[ = \frac{100}{\frac{60}{2.72} + \frac{35}{2.66} + \frac{5}{1.0}} = 2.48 \]

\( V_a = 7\% \)

\[ V_a = \frac{G_t - G_m}{G_t} \times 100 \]

\[ \Rightarrow 7 = \frac{2.48 - 2.30}{2.48} \times 100 \]

\[ G_m = 2.30 \]

06. Ans: (c)

\[ \text{Sol: } CBR(\%) = \frac{P_{2.5}}{P_{st 2.5}} \times 100 \]

\[ = \frac{60.5}{1370} \times 100 = 4.4\% \]

\[ \text{CBR}(\%) = \frac{P_{5}}{P_{st 5}} \times 100 \]

\[ = \frac{80.5}{2055} \times 100 = 3.92\% \]

Adopt higher one.

\[ \therefore \text{CBR}(\%) = 4.4 \]

07. Ans: (b)

\[ \text{Sol: Refer previous ESE-Obj-(Vol-2) solutions} \]

Book (Cha-12, 4th Question - pg: 1002)

08. Ans: (a)

\[ \text{Sol: Refer previous ESE-Obj-(Vol-2) solutions} \]

Book (Cha-12, 5th Question - pg: 1002)

09. Ans: (c)

\[ \text{Sol: Refer previous ESE-Obj-(Vol-2) solutions} \]

Book (Cha-12, 10th Question - pg: 1003)

10. Ans: (a)

\[ \text{Sol: Refer previous ESE-Obj-(Vol-2) solutions} \]

Book (Cha-12, 21st Question - pg: 1005)

11. Ans: (d)

\[ \text{Sol: Refer previous ESE-Obj-(Vol-2) solutions} \]

Book (Cha-12, 30th Question - pg: 1006)

12. Ans: (d)

\[ \text{Sol: Refer previous ESE-Obj-(Vol-2) solutions} \]

Book (Cha-12, 56th Question - pg: 1011)

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14. Highway Construction and Pavement Maintenance

32. Ans: (c)

\[ \text{Sol: Refer previous GATE-(Cha-4, 2nd Question} \]

- 1 mark - pg: 888)

35. Ans: (c)

\[ \text{Sol: Refer previous GATE-(Cha-4, 6th Question} \]

- 1 mark - pg: 888)
36. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 1st Question -pg: 1021)

38. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 3rd Question -pg: 1021)

41. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 4th Question -pg: 1021)

44. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 8th Question -pg: 1022)

02. Ans: (c)
Sol: \[ N = \frac{365[(1 + r)^n - 1] \times A \times D \times F}{r} \]
Assume F = 0.75
\[ N = \frac{365[(1 + 0.1)^{15} - 1] \times 1610.51 \times 3 \times 0.75}{0.1} = 42.02 \text{ msa} \]

A = P(1+r)^n
\[ A = 1000(1+0.1)^5 = 1610.51 \]

03. Ans: (b)
Sol: \[ N = N_1 + N_2 \]
\[ N = \frac{365[(1 + r)^n - 1] \times A \times D \times F}{r} \]
\[ N = \frac{365[(1 + 0.075)^{10} - 1] \times [2000 \times 5 + 200 \times 6]}{0.075} = 57.8 \text{ msa} \]

15. Pavement Design

01. Ans: 34.22 msa
Sol: Assume lane distribution factor, F = 1
\[ A = 1000 \left(1 + \frac{7.5}{100}\right)^5 = 1435.6 \text{ CVPD} \]
\[ N = \frac{365[(1 + 0.075)^{10} - 1] \times 1435.6 \times 2.5 \times 1}{0.075} = 34.22 \text{ msa} \]
**4. Ans:** \( F = 3.74, \quad N = 25.86 \text{ msa} \)

**Sol:**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Wheel load</th>
<th>% Total Traffic (Ni)</th>
<th>EF [Fi]</th>
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<tbody>
<tr>
<td>1</td>
<td>2268</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2722</td>
<td>12</td>
<td>2.07</td>
</tr>
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<td>3</td>
<td>3175</td>
<td>9</td>
<td>3.84</td>
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<td>6</td>
<td>6.55</td>
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<td>4082</td>
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<td>6</td>
<td>4536</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>4490</td>
<td>1</td>
<td>23.43</td>
</tr>
</tbody>
</table>

\[ \sum N_i = 59\% \]

\[ \Sigma EF = \left( \frac{\text{Actual load}}{\text{Standard load}} \right)^4 \]

\[ (1) \rightarrow EF_1 = \left( \frac{2268}{2268} \right)^4 = 1 \]

\[ (2) \rightarrow EF_2 = \left( \frac{2722}{2268} \right)^4 = 2.07 \ldots \]

\[ VDF = \frac{\Sigma N_i f_i}{\Sigma N_i} = \frac{25 \times 1 + 12 \times 2.07 + 9 \times 3.84 + 6 \times 6.55 + 4 \times 10.49 + 2 \times 16 + 1 \times 23.23}{59} \]

\[ VDF = 3.74 \]

Given \( \text{LDF} = 0.4 \)

Total Traffic = 1860 cv/day

\[ \therefore \text{Total commercial traffic (A)} = 1860 \times \frac{59}{100} = 1094.4 \text{ cv/day} \]

\[ N = \frac{365 \left( (1 + 0.075)^{20} - 1 \right)}{0.075} \times 10^4 \times 0.4 \times 3.74 \]

\[ N = 25.94 \times 10^6 \text{ csa} = 25.87 \text{ msa} \]
05. Ans: 1.26
Sol:
Equivalent axle load and vehicle damage factor (VDF)

<table>
<thead>
<tr>
<th>Axle load</th>
<th>Number of load repetition</th>
<th>Equivalent factor</th>
<th>Equivalent axle load</th>
</tr>
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<tbody>
<tr>
<td>80</td>
<td>1000</td>
<td>((80/80)^4 = 1)</td>
<td>1000</td>
</tr>
<tr>
<td>160</td>
<td>100</td>
<td>((160/80)^4 = 16)</td>
<td>1600</td>
</tr>
<tr>
<td>40</td>
<td>1000</td>
<td>((40/80)^4 = 0.0625)</td>
<td>62.5</td>
</tr>
</tbody>
</table>

\[ \text{The equivalent axle load} = 2662.5 \text{ kN} \]
\[ \text{VDF} = \frac{(1000 \times 1) + (100 \times 16) + (1000 \times 0.0625)}{1000 + 100 + 1000} = 1.26 \]

06. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 2nd Question - pg: 1021)

07. And: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 6th Question - pg: 1021)

08. And: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 11th Question - pg: 1022)

09. And: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 15th Question - pg: 1023)

10. And: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-13, 30th Question - pg: 1026)
Deflection after subgrade correction = \( K \times 1.544 \)

\[ = 1.6 \times 1.544 = 2.47 \text{ mm} \]

Thickness of granular overlay = 550

\[ \log_{10} \left( \frac{D_c}{D_D} \right) = 550 \log_{10} \left( \frac{2.47}{1} \right) \]

\[ = 216.02 \text{ mm} \quad \text{i.e} \quad 21.6 \text{ cm} \]

02.

**Sol:**

No of Repetitions in an year = 365 \( \times \) \( \sum \left( \frac{\text{Mean weight}}{80} \right)^4 \times \text{No.of axles} \)

\[ = 365 \left[ \left( \frac{1.5}{80} \right)^4 \times 14 + \left( \frac{2.5}{80} \right)^4 \times 76 + \left( \frac{3.5}{80} \right)^4 \times 77 \right. \]

\[ + \left. \left( \frac{4.5}{80} \right)^4 \times 70 + \left( \frac{5.5}{80} \right)^4 \times 28 + \left( \frac{6.5}{80} \right)^4 \times 18 \right] \]

\[ + \left( \frac{8.5}{80} \right)^4 \times 11 + \left( \frac{9.5}{80} \right)^4 \times 11 + \left( \frac{10.5}{80} \right)^4 \times 11 \]

\[ + \left( \frac{11.5}{80} \right)^4 \times 12 + \left( \frac{12.5}{80} \right)^4 \times 15 + \left( \frac{13.5}{80} \right)^4 \times 7 \]

\[ + \left( \frac{14.5}{80} \right)^4 \times 3 + \left( \frac{15.5}{80} \right)^4 \times 1 \]

\[ = 365 \times 0.0344 \]

\[ = 12.579 \text{ axle} \]

03.

**Sol:**

After correcting for initial concavity loads at 2.5 mm & 5 mm penetration = 55 & 78 kg respectively.

Area of plunger of 5 cm diameter = 19.6 cm²

Pressure at 2.5 mm penetration

\[ = \frac{55}{19.6} \text{ kg/cm}^2 \]

Pressure at 5 mm penetration = \( \frac{78}{19.6} \text{ kg/cm}^2 \)

CBR value at 2.5 mm

\[ \text{Pressure at plunger at 2.5mm penetration for stone} \]

\[ \text{Pressure as above for standard stone} \]

\[ = \frac{55 \times 100}{19.6 \times 70} = 4.0 \text{ percent} \]

CBR at 5 mm = \( \frac{78 \times 100}{19.6 \times 105} = 3.8 \text{ percent} \)

Adopt CBR = 4%

04.

**Sol:**

Present traffic = 1000 cv/day

Traffic after completion of strengthening

\[ = 1000 \times (1 + 0.1)^5 \]

\[ = 1611 \text{ cv/day} \]

No. of commercial vehicles per day in design lane

\[ = 1611 \times 0.75 \]

Cumulative standard axles

\[ = 365 \times 1611 \times 0.75 \times 3 [(1 + 0.1)^{15} - 1] \]

\[ = 42.03 \text{ msa} \]
So we can design for 50 msa traffic data

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDBC</td>
<td>50 mm</td>
</tr>
<tr>
<td>DBM</td>
<td>50 mm</td>
</tr>
<tr>
<td>Aggregate Layer</td>
<td>100 mm</td>
</tr>
<tr>
<td>CT Base</td>
<td>190 mm</td>
</tr>
<tr>
<td>GSB</td>
<td>250 mm</td>
</tr>
</tbody>
</table>

05.
Sol: Area of steel per metre length of longitudinal joint

\[
A_s = \frac{b \times f \times h \times w}{100 S_s}
\]

\[
= \frac{3.75 \times 1.5 \times 20 \times 2400}{100 \times 1400}
\]

\[
= 1.93 \text{ cm}^2 \text{ per m length}
\]

For 15 m length

\[
A_{st} = 15 A_s
\]

\[
= 28.93 \text{ cm}^2
\]

06.
Sol: \( A_s = \frac{b \times f \times h \times w}{100 S_s} \)

\[
= \frac{7 \times 1.3 \times 24 \times 2400}{100 \times 1400}
\]

\[
= 3.744 \text{ cm}^2
\]

Assume 1 cm diameter of bar

No. of tie bar Required = \( \frac{3.744}{0.785} \)

\[
= 4.77 \approx 5
\]

Spacing of tie bar = \( \frac{100}{5} = 20 \text{ cm} \)

07.
Sol: \( \delta' = \frac{2.5}{2} \)

\[
= 1.25 \text{ cm}
\]

\( T_2 - T_1 = 54 - 10 = 44^\circ \text{ C} \)

\( \delta' = L \alpha \Delta T \)

\[
L = \frac{\delta'}{\alpha \Delta T}
\]

\[
= \frac{1.25}{100 \times 10 \times 10^{-6} \times 44}
\]

\[
L = 28.5 \text{ m}
\]

16. Rigid Pavements

01. Ans: (a)
Sol: \( L = \frac{\delta'}{\alpha(t_2 - t_1)} = \frac{2.5}{10 \times 10^{-6} (45 - 10)} \)

\[
= 3571.42 \text{ cm}
\]

\[
= 35.71 \text{ m}
\]

(\( \delta' = 50\% \text{ of gap expansion joint} \))

Common data for Questions 02 & 03

02. Ans: (a)
Sol: \( \sigma_{w(e)} = \frac{C_s E \alpha t}{2} \)

\[
= \frac{0.92 \times 3 \times 10^5 \times 10 \times 10^{-6} \times 16.2}{2}
\]

\[
= 22.35 \text{ kg/cm}^2
\]
03. Ans: (d)

Sol: \[ I = \left[ \frac{Eh^3}{2k(l - \mu^2)} \right]^{\frac{1}{4}} \]
\[ = \left[ \frac{3 \times 10^5 \times 20^3}{12 \times 8(1 - 0.15^2)} \right]^{\frac{1}{4}} = 71.1 \text{ cm} \]

\[ \sigma_{w(c)} = \frac{E \alpha t}{3(l - \mu)} \sqrt{\frac{a}{l}} \]
\[ = \frac{3 \times 10^5 \times 10 \times 10^{-6} \times 16.2}{3(1 - 0.15)} \times \sqrt{\frac{15}{71.1}} \]
\[ = 8.75 \text{ kg/cm}^2 \]

Common data for Questions 06 & 07

06. Ans: (c)

Sol: \[ L = \frac{2\sigma_c}{\gamma_c f} = \frac{2 \times 0.8 \times 10^4}{2400 \times 1.5} = 4.4 \text{ m/c} \]

07. Ans: (c)

Sol: \[ L = \frac{200\sigma_c A_s}{B h \gamma_c f} \]
\[ = \frac{200 \times 1200 \times \pi \times (10 \times 10^{-1})^2}{3.75 \times 20 \times 2400 \times 1.5} \times \text{no. of bars} \]
\[ = 8.72 \text{ c/c} \]

No. of bars \[ \text{width} \times \text{length} \]
\[ = \frac{0.3}{0.3} \]
\[ = 12.5 \approx 13 \]

No’s

08. Ans: (a)

Sol: \[ \sigma_f = \frac{\gamma_c f L}{2 \times 10^4} = \frac{2400 \times 4 \times 1.2}{2 \times 10^4} \]
\[ = 0.576 \text{ kg/cm}^2 \]

09. Ans: (b)

Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-14, 1st Question -pg: 1032)

10. Ans: (c)

Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-14, 5th Question -pg: 1032)
11. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-14, 8th Question -pg: 1033)

12. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-14, 12th Question -pg: 1033)

13. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-14, 24th Question -pg: 1035)

### 17. Traffic Engineering

01. Ans: (a)
Sol: Time mean speed
\[ V_t = \frac{50 + 40 + 60 + 54 + 45}{5} \]
\[ (V_t) = 49.8 \text{ kmph} \]

02. Ans: (a)
Sol:

<table>
<thead>
<tr>
<th>Speed Range (m/s)</th>
<th>Frequency PCU/hr (q)</th>
<th>Mid-pt speed (v)</th>
<th>qv</th>
<th>q/v</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>1</td>
<td>2.5</td>
<td>2.5</td>
<td>0.4</td>
</tr>
<tr>
<td>7.5</td>
<td>4</td>
<td>7.5</td>
<td>30</td>
<td>0.533</td>
</tr>
<tr>
<td>11.5</td>
<td>0</td>
<td>11.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15.5</td>
<td>7</td>
<td>15.5</td>
<td>108.5</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Σq=12</td>
<td>Σqv= 142.0</td>
<td>Σ q / v = 1.38</td>
<td></td>
</tr>
</tbody>
</table>

\[ V_t = \frac{\Sigma q v}{\Sigma q} = \frac{141}{12} = 11.75 \text{ m/s} \]
\[ V_s = \frac{\Sigma q}{\Sigma (q / v)} = \frac{12}{1.38} = 8.69 \text{ m/s} \]

Always the time mean speed is more than space mean speed i.e., \( V_t > V_s \)

03. Ans: 40.91
Sol: Speed of vehicle-A = \( \frac{1}{1.2/60} = 50 \text{ kmph} \)

Speed of vehicle-B = \( \frac{1}{1.5/60} = 40 \text{ kmph} \)

Speed of vehicle-C = \( \frac{1}{1.7/60} = 35.3 \text{ kmph} \)

Average travel speed
\[ (V_t) = \frac{50 + 40 + 35.3}{3} = 41.8 \text{ kmph} \]
Space mean speed \((V_s) = \frac{n}{\sum \frac{1}{v_i}}\)

\[= \frac{3}{\frac{1}{50} + \frac{1}{40} + \frac{1}{35.3}}\]
\[= 40.91 \text{ kmph}\]

04. **Ans: 4000 veh/hr**

**Sol:** Design flow rate \(= \frac{q}{pHF}\)

\[PHF = \frac{q}{4(q_{15})}\]

Volume during peak 15 min \((q_{15}) = 1000\)

Peak hour volume \((q)\)

\[= 700 + 812 + 1000 + 635\]
\[= 3147\]

\[\therefore \text{Design flow rate} \approx 4000 \text{ v/hhr}\]

05.

**Sol:** Total frequency = 100

\[\% \text{ frequency} = \frac{10}{1000} \times 100 = 1\]

(i) 85th percentile speed is considered as a safe speed from graph \(V_{85} = 65 \text{ kmph}\)

(ii) 98th percentile speed is considered as a design speed from graph \(V_{98} = 85 \text{ kmph}\)

(iii) 15th percentile speed is considered as a minimum speed on the highway from graph \(V_{15}=35 \text{ kmph}\)

06. **Ans: (c)**

**Sol:** \[SSD = 0.278Vt + \frac{V^2}{254f}\]

\[= 0.278 \times 65 \times 2.5 + \frac{65^2}{254 \times 0.4}\]
\[= 86.7 \text{ m}\]

\[S = SSD + L = 86.7 + 5 = 91.7 \text{ m}\]

\[C = \frac{1000V}{S} = \frac{1000 \times 65}{91.7}\]
\[\approx 709 \text{ v/hhr/lan}\]

07. **Ans: (b)**

**Sol:** \(t = 0.7\) Assume

\[SSD = 0.278Vt = 7.78 \text{ m}\]

\[S = SSD + L = 12.78 \text{ m}\]

\[C = \frac{1000V}{S} = \frac{1000 \times 65}{12.78}\]
\[\approx 3130 \text{ v/hr}\]
08. Ans: (b)
Sol:  
\[ S = SSD + L = 20 + 6 = 26 \text{ m} \]
\[ C = \frac{1000V}{S} = \frac{1000 \times 40}{26} = 1538 \text{ veh/hr/lane} \]

09. Ans: (c)
Sol:
Given standard deviation (SD) = 8.8kmph
mean speed \( \bar{x} = 33 \text{ kmph} \)
Coefficient of variation \( \frac{SD}{\bar{x}} = \frac{8.8}{33} = 0.2666 \)

10. Ans: (b)
Sol:  
\[ q = uk \]
\[ U = U_{sf} \left[ 1 - \frac{k}{k_j} \right] \]
\[ \therefore q = U_{sf} \left[ 1 - \frac{k}{k_j} \right] k = U_{sf} \left[ k - \frac{k^2}{k_j} \right] \]
For max traffic flow;  
\[ \frac{d}{dk} = 0 \]
\[ \frac{d}{dk} = U_{sf} \left[ 1 - \frac{2k}{k_j} \right] = 0 \]
\[ 1 - \frac{2k}{k_j} = 0 \]
\[ \frac{k_j}{2} = k \]
\[ k_j = 2k \]
\[ U_{sf} = 70 \text{ km/hr} \]
\[ k_j = \frac{1000}{s} = \frac{1000}{7} \]
\[ k = \frac{k_j}{2} \]

11. Ans: (d)
Sol:  
\[ V_{sf} = 80 \text{ kmph} \]
\[ k_j = 100 \text{ veh/km} \]
\[ q_{max} = \frac{V_{sf} \times k_j}{4} = \frac{80 \times 100}{4} = 2000 \text{ veh/hr} \]
\[ V_s = \frac{V_{sf}}{2} \text{ (the speed corresponding to } q_{max} \text{ is } V_s \text{ max)} = \frac{80}{40} = 40 \text{ kmph} \]

12. Ans: 33 veh/km & 149 veh/km
Sol:  
\[ q_m = 1700 \text{ veh/hr} \]
\[ k_m = \frac{1000}{s} = \frac{1000}{5.5} = 181.81 \]
\[ q_m = \left( \frac{V_m}{2} \right) \left( \frac{k_m}{2} \right) \]
\[ 1700 = \left( \frac{V_m}{2} \right) \left( \frac{181.81}{2} \right) \]
\[ V_m = 37.40 \text{ kmph} \]
For \( q = 1000 \text{ veh/hr} \)
\[ V_{sf} = \frac{37.4}{181.81} \]
\[ k \]
\[ k_j \]
\[
\tan \theta = \frac{V_m}{k_m} \\
v = \frac{37.4}{181.81} \times (181.81 - k)
\]

For normal condition
\[
q = v \cdot k \\
1000 = \frac{37.4}{181.81} \times (181.81 - k) \times k \\
4861.23 = (181.81 - k)k \\
4861.23 = 181.81 k - k^2
\]
\[
k = 149 \text{ veh/km and } k = 32.6 \text{ veh/km} \approx 33 \text{ veh/km}
\]

13. Ans: 35.7 kmph
Sol: \( V_{sf} = 50 \text{ kmph} \)
\[
t_j = 70 \text{ veh/km} \\
q_{max} = \frac{V_{sf} \times K_j}{4} = \frac{50 \times 70}{4} = 875 \text{ veh/hr} \\
K = 20 \text{ veh/km} \\
\frac{K_j}{V_{sf}} = \frac{K_j - K}{V - 0} \\
70 = \frac{70 - 20}{V} \Rightarrow V = 35.7 \text{ kmph}
\]

14. Ans: 1268 veh/hr
Sol:
\[
V_{max} = 30 \text{ kmph} \\
K_{max} = \frac{30}{130 - 30} \\
K_{max} = 130 \text{ veh/km} \\
V_{max} = \frac{30}{130 - 30} \times 130 \\
= 39 \text{ kmph} \\
K_{max} = \left( \frac{V_{max}}{2} \right) \left( \frac{K_{max}}{2} \right) \\
= \frac{39 \times 130}{2} \approx 1268 \text{ veh/hr}
\]

15. Ans: (b)
Sol: \( Q_p = \frac{280}{1 + \frac{e}{w} \left( 1 - \frac{p}{3} \right)} \)
\[
w = 14 \text{ m} \quad e = 8.4 \text{ m} \\
L = 35 \text{ m} \\
p = \text{Total traffic} = 1000 \\
\frac{280 \times 14 \left( 1 + \frac{8.4}{14} \left( 1 - \frac{0.5}{3} \right) \right)}{1 + 14 \times 35} \\
= 3733.33 \text{ PCU/hr}
\]

16. Ans: 2064.10 veh/hr
Sol: \( w = 6 \text{ m} \quad p = 0.5 \)
\[
L = 20 \text{ m} \quad e = 5.5 \text{ m} \\
280 \times 6 \left[ 1 + \frac{5.5}{6} \left( 1 - \frac{0.5}{3} \right) \right] \\
= \frac{1 + \frac{6}{20}}{1 + 6 \times 35} \\
Q_p = 2064.10 \text{ veh/hr}
\]
17. Ans: 0.8%
Sol: Weaving ratio = \( \frac{\text{weaving traffic}}{\text{total traffic}} \)
\[ = \frac{V_{13} + V_{24} + V_{43}}{V_{13} + V_{23} + V_{24} + V_{14} + V_{43} + V_{21}} \]
\[ = \frac{450 + 1090 + 600 + 310}{450 + 200 + 1090 + 412 + 600 + 310} \]
Weaving ratio = 0.80%

18. Ans: (b)
Sol:
\[ y_N = \frac{1000}{2500} \]
\[ y_S = \frac{700}{2500} \]
\[ y_E = \frac{900}{3000} \]
\[ y_w = \frac{550}{3000} \]
\[ y = y_{NS} + y_{EW} = 0.4 + 0.3 = 0.7 \]
L = 12 sec
\[ C_o = \frac{1.5L + 5}{1 - y} = \frac{1.5 \times 12 + 5}{1 - 0.7} \]
\[ = 76.7 \text{ sec} \approx 77 \text{ sec} \]

19. Ans: (d)
Sol: \( y = 0.5 = y_a + y_b \)
L = 10 sec
\[ C_o = \frac{1.5L + 5}{1 - y} = \frac{1.5 \times 10 + 5}{1 - 0.5} = 40 \text{ sec} \]

20. Ans: 14.23 /veh, 1540 veh/hr
Sol: \[ C = S \times \frac{g}{C_o} \]
S → Saturation flow
g → effective green time
\( C_o \) → Cycle time/Optimum signal cycle length
\[ \frac{g}{C_o} \rightarrow \text{Green Ratio} \]
\[ C = 2800 \times 0.55 \]
\[ = 1540 \text{ veh/hr} \]
\[ \frac{C_o}{2} \left( 1 - \frac{g}{C_o} \right)^2 \]
\[ d_i = \frac{1 - \frac{V}{s}}{1} \]
\[ \frac{90}{2} (1 - 0.55)^2 \]
\[ = 14.2 \text{ /veh} \]

21. Ans: (a)
Sol: Average delay at red signal is \( = \frac{\text{red time}}{2} \)
\[ = \frac{30}{2} \]
\[ = 15 \text{ sec} \]
Alternative Solution:

From fig:
The average delay = The area between cumulative arrival and cumulative departure
/Total no of vehicles (or) The hatched area
in above figure/total number of vehicles
∴ The average delay

\[
= \frac{1}{2} (50)(40) - \frac{1}{2} (20)(40)
\]

\[
= \frac{1}{2} (50) - \frac{1}{2} (20) = 25 - 10 = 15 \text{ sec}
\]

22. Ans: (a)
Sol:
Critical lane volume on major road is increased to 440 veh/hr/lane those for green
time should be increased for major road and it remains same for minor road.

23. Ans: (a)
Sol: Green Time = 27 sec
Yellow Time = 4 sec
Total lost time, \( t_L \) = Start up lost time
+ Clearance lost time
= 2 + 1 = 3 sec
Effective green time ; \( g = G + y - t_L \)
= 27 + 4 - 3 = 28 sec
Saturation flow rate; \( S = \frac{3600}{h} = \frac{3600}{2.4} \)
= 1500 veh/hr

h \to Time headway

Capacity of lane, \( C = S \times \left( \frac{g}{C_o} \right) \)
= 1500 \times \left( \frac{28}{60} \right)
= 700 veh/hr/lane

24. Ans: (d)
Sol: Distance travelled by bicycle = 5 km
Time of travel, \( t = 40 - 15 = 25 \) min
Stop time = 15 min
Speed of bicycle = \( V_b = \frac{5}{25} \) km/min
Let speed of stream is \( V \) km/min
Assume traffic density is the constant on the road (\( K = \) Constant).

but \( K = \frac{q}{V} \)
During journey relative speed of stream = \( V - V_b \)

\[
K = \frac{\left( V - \frac{5}{25} \right)V_{\text{vehicles/min}}}{15V} \quad \text{.....(1)}
\]

During stop \( (V_b = 0) \)

\[
K = \frac{\left( \frac{45}{15} \right)V_{\text{vehicles/min}}}{V} = \frac{45}{15V} \quad \text{.....(2)}
\]

Equating (1) & (2)

\[
K = \frac{\left( \frac{60}{25} \right)}{\left( \frac{V - \frac{5}{25}}{V} \right)} = \frac{45}{15V}
\]

\[
0.8 = \left( 1 - \frac{5}{25V} \right)
\]

\[
0.2 = \frac{5}{25V}
\]

\[
\Rightarrow V = \frac{5}{25 \times 0.2} = \frac{5}{5} = 1 \text{ km/min}
\]

\[
\Rightarrow V = 60 \text{ km/hr}
\]

25. Ans: 2133.33 veh/hr

Sol: \( V = 80 - 0.75K \)

\[
V_{\text{max}} \text{ occur, when } K = 0
\]

\[
V_{\text{max}} = 80 \text{ kmph}
\]

\[
K_{\text{max}} \text{ occur when } V = 0
\]

\[
K_{\text{max}} = \frac{80}{0.75} = 106.67 \text{ veh/km}
\]

Capacity of road, \( q = \left[ \frac{K_{\text{max}} \times V_{\text{max}}}{4} \right] \)

\[
q = \frac{106.67 \times 80}{4} = 2133.33 \text{ veh/hr}
\]

26. Ans: (c)

Sol: In R: 2,5 combination is possible 1,3 and 4,6 are not possible

27. Ans:

Sol:

Given:

Speed of the vehicle = 60 kmph

Amber duration = 4 sec

Comfortable deceleration = 3m/sec²

Car length = 4.0 m

Intersection width = 14

Longitudinal friction factor = 0.35

Perception reaction time = 1.5 sec

When the vehicle reaches section A, he sees the amber right. Here, two situation are possible.

There are two possibilities
(i) Driver decides to cross intersection:

Total distance to be covered

\[ = SSD + 14 + 4.0 \]

\[ SSD = (vt) + \frac{v^2}{2gf} \]

\[ = (16.67 \times 1.5) + \frac{(16.67)^2}{2 \times 9.81 \times 0.35} \]

\[ = 65.47 \text{ m} \]

Total distance to be covered

\[ = 65.47 + 14 + 4 = 83.47 \text{ m} \]

Time required

\[ = \frac{\text{distance}}{\text{speed of vehicle}} \]

\[ = \frac{83.47}{16.67} = 5.0 \text{ sec} > 4 \text{ sec} \]

(ii) He decides to stop the vehicle time taken to stop the vehicle after sighting the amber light.

\[ = \text{Reaction time} + \text{time taken to stop the vehicle after application of brakes} \]

\[ = 1.5 + \left( \frac{60 \times 5}{18} - 0 \right) = 1.5 + 5.55 \]

\[ = 7.05 \text{ sec} > 4 \text{ sec} \]

Therefore, in both the situation, the required duration is greater than the provided amber duration hence the driver’s claim is correct.

28. Ans: 0.1353

Sol: Probability that the gap is greater than 8 sec

\[ P (h \geq t) = e^{-\lambda t} \]

\[ \lambda = \text{rate of arrival per second} \]

\[ = \frac{900}{3600} = 0.25 \]

\[ t = 8 \text{ sec} \]

\[ P (h \geq 8) = e^{-0.25 \times 8} \]

\[ P (h \geq 8) = 0.1353 \]

29. Ans: (a)

Sol: Refer previous ESE-Obj-(Vol-2) solutions

Book (Cha-15, 4th Question -pg: 1040)

30. Ans: (c)

Sol: Refer previous ESE-Obj-(Vol-2) solutions

Book (Cha-15, 24th Question -pg: 1044)

Conventional Practice Solutions

01. Sol: Time mean speed

\[ = \frac{V_1 + V_2 + V_3 + V_4}{4} \]

\[ = \frac{20 + 35 + 40 + 45}{4} \]

\[ = 35 \text{ kmph} \]
Space mean speed = \[\frac{\sum n_i}{\sum \frac{n_i}{v_i}}\]

\[= \frac{4}{\frac{20}{35} + \frac{1}{40} + \frac{1}{45}} = 31.8 \text{ kmph}\]

02.

Sol:

<table>
<thead>
<tr>
<th>Speed range kmph</th>
<th>Mid speed kmph</th>
<th>Frequency f</th>
<th>Frequency %</th>
<th>Commulative Frequency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column-1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>0 – 10</td>
<td>5</td>
<td>12</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td>10 – 20</td>
<td>15</td>
<td>18</td>
<td>2.12</td>
<td>3.53</td>
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<tr>
<td>20 – 30</td>
<td>25</td>
<td>68</td>
<td>8.00</td>
<td>11.53</td>
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<td>30 – 40</td>
<td>35</td>
<td>89</td>
<td>10.47</td>
<td>22.00</td>
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<td>40 – 50</td>
<td>45</td>
<td>204</td>
<td>24.00</td>
<td>46.00</td>
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<tr>
<td>50 – 60</td>
<td>55</td>
<td>255</td>
<td>30.00</td>
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<td>60 – 70</td>
<td>65</td>
<td>119</td>
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<td>90.00</td>
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<td>70 – 80</td>
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<td>90 – 100</td>
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<td>1.06</td>
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</tbody>
</table>

(1) Upper speed limit for regulation = \(85^{th}\) percentile speed
\[= 60 \text{ kmph}\]

(2) Lower speed limit for regulation = \(15^{th}\) percentile speed
\[= 30 \text{ kmph}\]

(3) Speed to check design elements – \(98^{th}\) percentile speed
\[= 84 \text{ kmph}\]

03.

Sol: (a) \[k_j = \frac{1000}{L}\]
\[V_{sf} = 60 \text{ kmph}\]

Theoretical capacity = \[\frac{V_{sf} k_j}{4}\]
\[= \frac{1000 \times 60}{6.1 \times 4} = 2459 \text{ veh/hr}\]

(b) Maximum Theoretical capacity
\[= \frac{3600}{\text{Time headway}} = \frac{3600}{5}\]
\[= 720 \text{ veh/hr}\]
04. 
Sol: \( q = k \, u \)
\[ q = k \left( 42.76 - 0.22t \right) \]
for \( q \) to be maximum

\[ \frac{dq}{dk} = 0 \]

\[ 42.76 - 0.44 \, k = 0 \]

\[ k = 97.18 \, \text{veh/km} \]

\[ u = 42.76 - 0.22 \times 97.18 \]

\[ u = 21.38 \, \text{km/hr} \]

\[ q = ku \]

\[ = 21.38 \times 97.18 \]

\[ = 2077 \, \text{veh/hr} \]

Comment: \( q \) is maximum when

\[ V = \frac{V_{sf}}{2} \, \text{&} \, q = \frac{dV}{dt} \]

05. 
Sol: 
\[ y_a = \frac{q_a}{S_a} = \frac{400}{1250} = 0.32 \]

\[ y_b = \frac{q_b}{S_b} = \frac{250}{1000} = 0.25 \]

\[ Y = y_a + y_b = 0.57 \]

06. 
Sol: 
Saturation flow is 160 PCU/0.3 m with of approach

For road A: Saturation flow

\[ S_A = \frac{160}{0.3} \times \frac{19}{2} = 5066.673 \, \text{PCU/hr} \]

For road B: Saturation flow

\[ S_B = \frac{160}{0.3} \times \frac{7.5}{2} = 2000 \, \text{PCU/hr} \]

Maximum flow road A = \( q_A = 1360 \, \text{veh/hr} \)
Maximum flow for road B = \( q_B = 310 \) veh/hr
Flow ratio for road
\[
A = y_A = \frac{q_A}{S_A} = \frac{1360}{5066.67} = 0.268
\]
Flow ratio for road
\[
B = y_B = \frac{q_B}{S_B} = \frac{310}{2000} = 0.155
\]
Flow ratio for road
\[
B = y_B = \frac{q_B}{S_B} = \frac{310}{2000} = 0.155
\]
Lost time = \( 2n + R = 2(2) + 6 + 6 = 16 \) sec
Cycle time =
\[
\frac{1.5L + 5}{1 - y} = \frac{1.5(16) + 5}{1 - (0.268 + 0.155)} = 50.26 \text{ sec}
\]
Green time for road A = \( \frac{y_a}{4}(C_o - L) \)
\[
= \frac{0.268}{0.269 + 0.155}(50.5 - 16)
\]
Say 21.9 sec
Green time for road B = \( \frac{y_b}{4}(G - C) \)
\[
= \frac{0.155}{0.268 + 0.155}(50.5 - 16)
\]
= 12.64 sec  Say 12.6 sec

07.
Sol: Given:
- Speed of the vehicle = 50 km/hr
- Amber duration = 4.5 sec
- Comfortable deceleration = 3 m/sec^2
- Car length = 4.6 m
- Intersection width = 15 m

Perception reaction time = 1.5 sec
When the vehicle reaches section A, he sees the amber light. Here, two situations are possible.

(i) He decides to cross the intersection:
Total distance to be covered
\[
= SSD + 15 + 4.6
\]
SSD = Lag distance + Brake distance
\[
= v \times t + \frac{v^2}{2 \times a} = \left(50 \times \frac{5}{18}\right) \times 1.5 + \frac{\left(50 \times \frac{5}{18}\right)^2}{2 \times 3}
\]
= 0.83 + 32.15 = 32.98 m
Total distance to be covered
\[
= 52.98 + 15 + 4.6 = 72.58 \text{ m}
\]
Time required = $\frac{72.58}{50 \times \frac{5}{18}}$

= 5.23 sec > 4.5 sec

(ii) **He decides to stop the vehicle**

Time taken to stop the vehicle after sighting
the amber light.

= Reaction time + Time taken to stop the
vehicle after application of brakes

\[
= 1.5 + \frac{50 \times \frac{5}{18}}{3} = 1.5 + 4.63
\]

= 6.13 sec > 4.5 sec

Therefore, in both the situation, the
required duration is greater than the
provided amber duration hence the driver’s
claim is correct.

08.

Sol:

(i) Since it is urban area, as per IRC, design
speed = 30 kmph

(ii) Radius of curve at entry = $\frac{V^2}{127f}$

\[
f = 0.47
\]

\[
\therefore R_{entry} = \frac{40}{127 \times 30}
\]

= 26.8 m say 27 m

(iii) Radius of curve at exist = (1.5 to 2) $R_{entry}$

\[
= 2 \times 27 = 54 m
\]

(iv) Radius of central traffic island

\[
= 1.33 \times R_{entry}
\]

\[
= 1.33 \times 27 = 35.91 m \text{ say 36 m}
\]

(v) Let width of carriageway at entrance $e_1$

\[
= 8 m
\]

(vi) Width of weaving section

\[
= \frac{e_1 + e_2}{2} + 3.5
\]

\[
w = \frac{8 + 8}{2} + 3.5
\]

\[
= 11.5 m
\]

(vii) Length of weaving section = 4w

\[
= 4 \times 11.5 = 46 m
\]

(viii) Proportion of weaving traffic

\[
= \frac{\text{Weaving traffic}}{\text{Total traffic}}
\]

\[
P_{NE} = \frac{300 + 650 + 500 + 225}{300 + 650 + 500 + 225 + 415 + 300}
\]

= 0.7

\[
P_{ES} = \frac{500 + 600 + 650 + 300}{500 + 600 + 650 + 300 + 300 + 300}
\]

= 0.773
\[
P_{SW} = \frac{400 + 225 + 550 + 300}{400 + 225 + 550 + 300 + 350 + 250} = 0.7108
\]
\[
P_{WN} = \frac{500 + 300 + 400 + 250}{500 + 300 + 400 + 250 + 225 + 400}
\]

Maximum proportioning ratio gives minimum capacity
\[
\therefore P_{\text{min}} = P_{\text{WN}} = 0.698
\]

Capacity of the rotary
\[
280\left(1 + \frac{e}{w}\right)\left(1 - \frac{p}{3}\right) \left(1 + \frac{W}{L}\right)
\]
\[
= 280 \times 11.5 \left(1 + \frac{8}{11.5}\right) \left(1 - \frac{0.698}{3}\right) \left(1 + \frac{11.5}{46}\right)
\]
\[
= 3351.71 \text{ veh/hr}
\]

09. 
**Sol: Correction for elevation**

Basic length is increased by 7% per 300 m above M.S.L

Correction for elevation
\[
= \frac{7}{100} \times 600 \times 1800 = 252 \text{ m}
\]
Length of runway after elevation down
\[
= 1800 + 252 = 2052 \text{ m}
\]

**Temperature correction:**

Temperature at R.L = 600 m
\[
= 15 - 6.5 \times \frac{600}{1000} = 11.1^\circ \text{C}
\]

Difference between airport reference and standard atmospheric temperature
21.6 – 11.1 = 10.5^\circ \text{C}

Apply correction of 1% per 1^\circ \text{C}

Correction for temperature
\[
= 2052 \times \frac{1}{100} \times 10.5 \approx 215.46 \text{ m}
\]
Corrected runway length = 2052 + 215.46 = 2267.46 m

**Correction for Gradient**

20% for 1% effective gradient
\[
= \frac{20}{100} \times 2267.46 \times 0.6 = 272.1 \text{ m}
\]
Actual length of runway = 272.1 + 2267.46 = 2539.55 m

**Check:**

Total correction for elevation and temperature
According to ICAO, this should not be more than 35%.

10. Sol:

(1) Turning radius:

\[ R = \frac{V^2}{125f} \]

\[ = \frac{50^2}{125 \times 0.13} \]

\[ = 153.85 \text{ m} \]

(2) Horon jeff = n

\[ R = \frac{0.388W^2}{\frac{T}{2} - S} \]

\( W = \text{Wheel bar of aircraft} = 35 \text{ m} \)

\( T = \text{widen of taxiway pavement} = 27 \text{ M} \)

\( S = \text{distance between point midway of the main gears and edge of taxiway pavement} \)

\[ = 6 + \frac{7.5}{2} = 9.75 \text{ m} \]

\[ R = \frac{0.388 \times 35^2}{\frac{27}{2} - 9.75} = 126.75 \text{ m} \]

(3) Absolute minimum turning radius for supersonic aircraft irrespective of any speed = 180 m.

So, adopt turning radius = maximum value of above 3 i.e. 180 m.

11. Sol: End to end of runway

<table>
<thead>
<tr>
<th>Chains</th>
<th>Metres</th>
<th>Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5</td>
<td>0 – 120</td>
<td>+ 1</td>
</tr>
<tr>
<td>5 – 15</td>
<td>120 – 360</td>
<td>- 1</td>
</tr>
<tr>
<td>15 – 30</td>
<td>360 – 720</td>
<td>+ 0.8</td>
</tr>
<tr>
<td>30 – 40</td>
<td>720 – 960</td>
<td>- 0.8</td>
</tr>
</tbody>
</table>

Maximum difference in elevation = (101.68 – 98.8) = 2.88 m

Total runway length = 960 m

Effective gradient = \[ \frac{2.88 \times 100}{960} \]

= 0.3%
18. Railway Engineering

18.1 GEOMETRIC DESIGN OF RAILWAY TRACK

01. Ans: (b)
Sol: Grade compensations on curves:
   For BG: 0.04% per degree of curve
   For MG: 0.03% per degree of curve
   For NG: 0.02% per degree of curve
   Therefore, in the present case, for 4° curve, the grade compensation is
   = 0.04 × 4 = 0.16%

03. Ans: (b)
Sol: Ruling gradient in % = \( \frac{1}{250} \times 100 = 0.4\% \)
   Grade compensation at 0.04% per degree of curve
   Curve = 0.04 × 3 = 0.12%
   Compensated gradient = 0.4 − 0.12
   = 0.28%
   = \( \frac{0.28}{100} = \frac{1}{357} \)

06. Ans: (c)
Sol:
   From circle property,
   \( \frac{\ell \ell}{2} = h(2r - h) \)
   \( \frac{\ell^2}{4} = 2rh - h^2 \)
   \( h^2 \) is neglected (being very small)
   \( \therefore h = \frac{\ell^2}{8r} \)

07. Ans: (a)
Sol: Grade compensation = 2 × 0.04 % = 0.08%
   Stipulated ruling gradient = 0.5%
   Steepest gradient = 0.5% − 0.08% = 0.42% = \( \frac{1}{238} \)

08. Ans: (c)
Sol:
   Curve resistance = 0.04% × D°
   = 0.04 × 4 = 0.16%
   Ruling gradient = \( \frac{1}{150} \)
   = \( \frac{1}{150} \times 100 = 0.67\% \)
   Compensated gradient
   = 0.67 − 0.16
   = 0.51%
   = \( \frac{0.51}{100} = \frac{1}{196} \)
10. Ans: 91.26 kmph

Sol: Given, \( D^\circ = 2^\circ \)

\[
R = \frac{1720}{D^\circ} = \frac{1720}{2}
\]

\( R = 860 \text{ mm} \)

The “weighted average” of different trains at different speeds is calculated from the equation

\[
\text{Weighted average} = \frac{n_1V_1 + n_2V_2 + n_3V_3 + n_4V_4}{n_1 + n_2 + n_3 + n_4}
\]

\[
V = \frac{15 \times 50 + 10 \times 60 + 5 \times 70 + 2 \times 80}{15 + 10 + 5 + 2}
\]

\( V = 58.125 \text{ kmph} \)

\[
e = \frac{GV^2}{127R} = \frac{1.676 \times 58.125^2}{127 \times 860}
\]

\( e = 0.0518 \text{ m} = 5.18 \text{ cm} \)

Theoretical cant = Equilibrium cant + cant deficiency

\( = 5.18 + 7.60 \)

\( = 12.78 \text{ cm} \)

\[
e = \frac{GV^2}{127R} = \frac{1.676 \times V^2}{127 \times 860}
\]

\( \frac{12.78}{100} = \frac{1.676 \times V^2}{127 \times 860} \)

\( V = 91.26 \text{ kmph} \)

According to railway boards Speed formula

\( V = 4.35\sqrt{R - 67} \)

\( V = 4.35\sqrt{860 - 67} \)

\( V = 122.5 \text{ kmph} \)

Hence maximum permissible speed (i.e lower of the two value) is 91.26 kmph

11. Ans: 86.4 m

Sol: \( e = 12 \text{ cm} \)

\( V_{\text{max}} = 85 \text{ kmph} \)

\( D = 7.6 \text{ cm (BG)} \)

Length of transition curves maximum of following:

(a) Based on arbitrary gradient of 1 in 720

\( L = 7.20 \times e \)

\( L = 7.20 \times 12 = 86.4 \text{ cm} \)

(b) Based on rate of change of cant deficiency

\( L = 0.073DV_{\text{max}} \)

\( L = 0.073 \times 7.6 \times 85 \)

\( L = 47.158 \text{ cm} \)

(c) Based on rate of change of super elevation

\( L = 0.073eV_{\text{max}} \)

\( L = 0.073 \times 12 \times 85 \)

\( L = 74.46 \text{ cm} \)

\( \therefore \text{Take maximum } L = 86.4 \text{ cm} \)

18. 2 TRACTIVE RESISTANCES AND HAULING CAPACITY

01. Ans: (b)

Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 2nd Question -pg: 1061)
02. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-1, 3rd Question -pg: 1061)

03. Ans: (e)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-1, 4th Question -pg: 1061)

18. 3 POINTS & CROSSING

01. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-3, 1st Question -pg: 1070)

02. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-3, 2nd Question -pg: 1070)

03. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-3, 3rd Question -pg: 1070)

04. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-3, 5th Question -pg: 1070)

05. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-3, 6th Question -pg: 1070)

06. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-3, 7th Question -pg: 1070)

18.4 TRACK JUNCTION

01. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-3, 4th Question -pg: 1070)

03. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-3, 10th Question -pg: 1071)

18.5 PERMANENT WAY

03. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
   Book (Cha-4, 3rd Question -pg: 1074)
18.6 STRESSES IN RAILWAY TRACK
01. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-4, 5th Question -pg: 1074)

18.8 CREEP OF RAILS
01. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-5, 10th Question -pg: 1078)
02. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-5, 11th Question -pg: 1078)

18.9 SLEEPER
01. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-5, 7th Question -pg: 1077)
02. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-5, 8th Question -pg: 1078)
03. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-5, 9th Question -pg: 1078)

18.11 BALLAST
01. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-4, 6th Question -pg: 1074)

18.12 MATERIAL REQUIRED FOR RAILWAY TRACK
01. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-4, 2nd Question -pg: 1074)

18.15 STATION AND YARDS
01. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 3rd Question -pg: 1082)
02. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 9th Question -pg: 1084)

18.16 EQUIPMENT IN STATION YARD
01. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 7th Question -pg: 1083)

18.17 SIGNALLING AND CONTROL SYSTEM
01. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-7, 2nd Question -pg: 1087)
02. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-7, 3rd Question -pg: 1087)
03. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-7, 4th Question -pg: 1087)

04. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-7, 5th Question -pg: 1087)

05. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-7, 6th Question -pg: 1087)

06. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-7, 7th Question -pg: 1088)

18.19 TRACK MODERNISATION

01. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 2nd Question -pg: 1082)

02. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 6th Question -pg: 1083)

03. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 5th Question -pg: 1083)

04. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 8th Question -pg: 1083)

05. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (Cha-6, 10th Question -pg: 1084)
(c) \( L = 0.073 \cdot V_{\text{max}} \)
\[ = 0.073 \times 22.58 \times 97.9 \]
\[ = 161.37 \text{ m} \]
Hence provide \( L = 162.576 \approx 165 \text{ m} \)

(iv) Offsets at every 10 m interval are calculated from cubic parabola equation as follows
\[
Y = \frac{x^3}{6RL} = \frac{x^3 \times 100}{6 \times 573 \times 165} \text{ cm} = \frac{x^3}{5673.0} \text{ cm}
\]

<table>
<thead>
<tr>
<th>( x \text{(m)} )</th>
<th>( y \text{ (cm)} )</th>
</tr>
</thead>
<tbody>
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<td>10</td>
<td>0.176</td>
</tr>
<tr>
<td>20</td>
<td>1.408</td>
</tr>
<tr>
<td>30</td>
<td>4.752</td>
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<tr>
<td>40</td>
<td>11.264</td>
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<td>50</td>
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<tr>
<td>160</td>
<td>720.87</td>
</tr>
<tr>
<td>165</td>
<td>790.61</td>
</tr>
</tbody>
</table>

02.

Sol: (i) S.E of Branch track = \( \frac{0.8V^2}{R} \)
\[
= \frac{0.8 \times 30^2}{1719/6}
= 2.51 \text{ cm}
\]

-ve super elevation = \((2.51 - 5) = -2.49 \text{ cm}\)

Maximum S.E on main line = 2.49 cm
Theoretical S.E = 2.49 + 5 = 7.49 cm

\[
7.49 = \frac{V^2}{1719/3} \times 0.8
\]

\[V = 73.24 \text{ kmph} \quad \text{------ (1)}\]

Maximum permissible speed
\[V = 4.4\sqrt{R - 70}\]
\[= 4.4\sqrt{\frac{1719}{3} - 70}\]
\[= 98.68 \text{ kmph} \quad \text{----- (2)}\]

So adopt lower value of (1) & (2)
\[V = 73.24 \text{ kmph}\]

(ii) \( e_{\text{th}} = \frac{0.8V^2}{R} \)
\[
= \frac{0.8 \times 70^2}{1719/3} = 6.84 \text{ cm}
\]
\[e_{\text{th}} = e_{\text{act}} + CD\]
\[6.84 = e_{\text{act}} + 5\]
\[e_{\text{act}} = 1.84 \text{ cm}\]

For branch track:
\[e_{\text{act}} = -1.84 \text{ cm}\]
\[e_{\text{th}} = e_{\text{act}} + CD\]
\[= -1.84 + 5 = 3.16 \text{ cm}\]
\[ e_{th} = \frac{0.8V^2}{R} \]
\[ 3.16 = \frac{0.8 \times V^2}{(1719/6)} \]
\[ V = 33.64 \text{ kmph} \]

Check:
\[ V_{\text{max}} = 4.4\sqrt{R - 70} = 4.4\sqrt{\frac{1719}{6} - 70} \]
\[ = 64.74 \text{ kmph} \]
Hence \( V = 33.64 \text{ kmph} \) is ok

04.

Sol: Deviation angle \( N = 0.03 - (0.04) = 0.07 \)

Length of valley curve
\[ = \frac{\text{Deviation angle}}{\text{Rate of change of gradient}} \]
\[ = \frac{7}{0.25} = 28 \text{ chains} \]

Assume chain length = 20 m

Length of valley curve = 560 m

Intersection of gradients is

At mid point of curve (C)
So changing of A
\[ = 3200 - \frac{560}{2} = 2920 \text{ m} \]

Change of B
\[ = 3200 + \frac{560}{2} = 3480 \text{ m} \]

Chainage of valley point
\[ = \frac{n_2}{(n_1 + n_2)}L = \frac{4}{7} \times 560 = 320 \text{ m from B} \]

From A

RL of C = RL of A – \( N_1 \times L \) + \( \frac{N_2^2}{2L} \)

\[ 350 = \text{R.L of A} - 0.03 \times 280 + \]

\[ 0.07 \times 280^2 \]

\[ 2 \times 560 \]

\[ 350 = \text{R.L of A} - 8.4 + 4.9 \]

R.L of A = 353.5 m

RL of B = RL of A – \( N_1 \times L \) + \( \frac{N_2^2}{2L} \)

\[ = 353.5 - 0.03 \times 560 + \frac{0.07 \times 560^2}{2 \times 560} \]

\[ = 353.5 - 7.2 + 3.6 \]

RL of B = 356.6 m

RL of valley point = RL of A – \( n_1 \times L \) + \( \frac{N_2^2}{2L} \)

\[ = 353.5 - 3.6 + 3.6 \]

\[ = 349.9 \text{ m} \]
05.
Sol: Having capacity of loco motive
\[ = \frac{1}{6} \times 3 \times 21 \]
\[ = 10.5 \text{ tonne} \]
(a) On a straight track, train resistance
= Resistance due to friction wave action + resistance due to speed
\[ 10 = \frac{0.0025 \times W + 0.0000015 \times W \times V^2}{10.5} \]
\[ W = 826.44 \text{ tonne} \]
(b) Total Train resistance
\[ = \frac{0.0025 \times W + 0.0000015 \times W \times V^2 + W \times \frac{1}{\text{rate of grade}}}{10.5} \]
\[ V = 58.9 \text{ kmph} \]
(c) Total Train Resistance
\[ 10.5 = \frac{0.0025 \times W + 0.0000015 \times W \times V^2 + 0.0004 \times 3 \times W}{10.5} \]
\[ W = 826.44 \text{ tonne} \]
\[ 10.5 = 2.0661 + 0.992 + (1.24 \times 10^{-3}) \times V^2 \]
\[ V = 77.47 \text{ kmph} \]
(d) Total train Resistance
\[ = \frac{0.0025 \times W + 0.0000015 \times W \times V^2 + 0.0004 \times 3 \times W \times \frac{1}{\text{rate of grade}}}{10.5} \]
\[ 10.5 = 2.0661 + (1.24 \times 10^{-3}) \times V^2 + 0.992 + 4.1322 \]
\[ V = 51.66 \text{ kmph} \]

06.
Sol: (a) Curve is starting from toe of switch and end at theoretical nose of crossing
\[ \therefore \text{Using Coles method:} \]
Crossing number \( N = 12 \)
Curve lead = \( CL = 2G \)
\[ = \frac{2 \times 1.676 \times 12}{10} = 40.224 \text{ m} \]
Radius of outer curve \( R_o = 1.5G + 2GN^2 \)
\[ = (1.5 \times 1.676) + (2 \times 1.676 \times 12^2) = 485.202 \text{ m} \]
Radius of centre line = \( R_o - \frac{G}{2} = 484.364 \text{ m} \)
Switch lead = \( \sqrt{2R_o d} = \sqrt{2 \times 485.202 \times 0.12} = 10.79 \text{ m} \)
\[ \text{Lead} = LL - SL = 40.224 - 10.79 = 0 \]
(b) Curve is starting from heel of switch and ends at TNC
Crossing number \( N = 16 = \cot \alpha \)
\[ A = 3^\circ 34' 34.8'' \]
Angle of switch \( P = 1^\circ 30'00'' \)
Radius of outer curve = \( \frac{G - d}{\cos \beta - \cos \alpha} \)
\[ = \frac{1.676 - 0.12}{\cos(1^\circ30'00'') - \cos(3^\circ34'34.8'')} = 969.62 \text{ m} \]
Radius of centre line = \( R_o - \frac{G}{2} = 968.78 \text{ m} \)
\[ \text{Lead} = (G - d) \cot \left(\frac{\alpha + \beta}{2}\right) \]
\[(1.676 - 0.12)\cot\left(\frac{1^\circ 30' + 3^\circ 34' 34.8^s}{2}\right)\]
\[= 35.1 \text{ m}\]

Switch lead = \(\sqrt{2R_o d} = \sqrt{2 \times 969.62 \times 0.12}\)
\[= 15.25 \text{ m}\]

Curve lead = \(L + SL\)
\[= 35.1 + 15.25 = 50.35 \text{ m}\]

(c) Straight portion before TNC = \(x = 1.3 \text{ m}\)

Curve is provided between heel of switch and starting point of straight portion

\(N = 12; \beta = 1^\circ 30'\)

\(\Rightarrow \cot \alpha = 12\)

\(\Rightarrow \alpha = 4^\circ 45' 49.11''\)

Lead = \(x \cos \alpha + (G - d - x \sin \alpha)\)

\[\left(\cot\left(\frac{\alpha + \beta}{2}\right)\right)\]
\[= 1.3 \cos (4^\circ 45' 49.11'') + \left[ (1.676 - 0.12 - 1.3 \sin (4^\circ 45' 49.11'') \right] \cot\left(\frac{1^\circ 30' + 4^\circ 45' 49.11''}{2}\right)\]
\[= 1.2955 + (1.448 \times 18.276)\]
\[= 27.76 \text{ m}\]

Radius of outer curve = \(\frac{(G - d - x \sin \alpha)}{\cos \beta - \cos \alpha}\)

\(R_o = 1.676 - 0.12 - 1.3 \sin (4^\circ 45' 49.11'')\)
\[= 465.36 \text{ m}\]

Radius of centre line = \(R_o - \frac{G}{2}\)
\[= 465.36 - \frac{1.676}{2} = 464.522 \text{ m}\]

07. Sol: (i)

(ii) Since the intermediate portion is straight the crossing angle with be same. Let the crossing number = 12

Length of cross over = \(2G + \text{horizontal projection of straight portion} + 2GN\)
\[= 4GN + ST\]
\[= 4 \times 1.676 \times 12 + (12 - 1.676) \times 12 - 1.676 \sqrt{1 + 12^2}\]
\[= 184.154 \text{ m}\]
10. 
Sol: Let, Angle of crossing = $\alpha$
Number of crossing $N = 4$
$G = 1.676m$ for B.G tack
Diamond crossing

From $\Delta$CDF,

\[ \sin \alpha = \frac{FD}{CD} \]

Where, $FD = G$
\[ \sin \alpha = \frac{G}{CD} \]
$CD = G \cdot \csc \alpha$

From figure,
$AB = BC = CD = DA = G \cdot \csc \alpha$
$AB = BC = CD = DA = 1.676 \csc \alpha$

We know that, $N = \cot \alpha$
$4 = \cot \alpha$
$\alpha = 14^\circ 2'10.48''$

(i) $AB = BC = CD = DA$
\[ = 1.676 \csc(14^\circ 2'10.48'') \]
\[ = 6.91 m \]

(ii) $AE = CF = G \cdot \cot \alpha = 1.676 \times 4$
\[ = 6.704 m \]

(iii) $AC = 2 \cdot AB \sin \frac{\alpha}{2}$
\[ = 2 \times 6.91 \sin \left( \frac{14^\circ 2'10.48''}{2} \right) \]
\[ = 1.688 m \]

(iv) $BD = G \cdot \csc \frac{\alpha}{2}$
\[ = 1.676 \times \csc \left( \frac{14^\circ 2'10.48''}{2} \right) \]
$BD = 13.72 m$

19. Airport Engineering

19.2 Runway

01. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (23rd Question -pg: 1096)

02. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (2nd Question -pg: 1093)

03. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (19th Question -pg: 1096)
**04. Ans: (c)**

**Sol:** Refer previous ESE-Obj-(Vol-2) solutions
Book (30th Question -pg: 1098)

**05. Ans: (a)**

**Sol:** Refer previous ESE-Obj-(Vol-2) solutions
Book (6th Question -pg: 1093)

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### 19.3 GEOMETRIC DESIGN OF RUNWAY

**01. Ans: (a)**

**Sol:** Length of runway under standard condition
= 2100 m

We have to increase 7% for every 300 m elevation above ground so length of runway = 2100 + \( \frac{7}{100} \times 2100 = 2247 \text{ m} \)

**02. Ans: (c)**

**Sol:** Runway elevation = 1000 m (above msl)

Airport reference temperature (ART) = 16°C

Airport standard temperature (AST) = standard temperature at msl – 6.5°C for 1 km height above msl

AST = 15 – 6.5 = 8.5°C

Rise in temperature as per ICAO = 16 – 8.5 = 7.5°C

---

**03. Ans: 4 km**

**Sol:** Runway length = 2460 m

Correction for elevation (ICAO)

300 m \( \rightarrow \) 7%

486 \( \rightarrow \) x

x = 11.34 %

Corrected length after elevation correction = \( \frac{11.34}{100} \times 2460 + 2460 = 2738.964 \text{ m} \)

Correction for temperature

\[
ART = T_1 + \frac{T_2 - T_1}{3}
\]

= 30.2 + \((46.3 - 30.2)\) \(\frac{3}{3}\)

ART = 35.57°

Temperature gradient 1000 – 6.5

486 – x

x = 3.159°

Temperature @ airport @ 486 m elevation

= 15 – 3.159 = 11.841°

1% increase in length for 1° above standard temperature. \((3.507^\circ - 11.841^\circ) = 23.729^\circ\)

1% \( \rightarrow \) 1° change

x \( \rightarrow \) \((35.57^\circ - 11.84%)\)

x = 23.729%

Correction = \( \frac{23.729}{100} \times 2738.964 + 2738.964 = 3388.89 \text{ m} \)
Correction for effective gradient

20% ↑ → 1% effective gradient

x → 0.75%

x = 15%

Total runway length = 1.15 \times 3388.89

= 3897.22 m

≈ 4000 m = 4 km

04. Ans: (d)

Sol: The runway length after being corrected for elevation and temperature should further be increased at the rate of 20% for every 1% of the effective gradient for 0.5%, 10% should be increased.

So runway length after correction of temperature and elevation

= 2845 + 10\left(\frac{2845}{100}\right) = 3129.5 ≈ 3130 m

05. Ans: (d)

Sol: Given \( T_m = 40°C \)

\( T_a = 25°C \)

\( ART = \frac{2T_a + T_m}{3} \)

\begin{align*}
&= \frac{2 \times 25 + 40}{3} \\
&= 30°C
\end{align*}

06. Ans: 2102.17 m

Sol: Length of runway = 1640 m

Elevation = 280 m

Reference temperature = 33.5°C

Effective gradient = 0.2%

Correction for Elevation (ICAO)

For 300 m – 7%

280 → x

x = 6.53%

correction = \frac{6.53 \times 1640}{100} = 1747.15 m

Correction for temperature (ICAO)

ART = 33.5°C m

Temperature gradient

1000 m → 6.5°

280 m → x

x = 1.82°

Temp @ airport @ 280 m elevation

= 15 – 1.82

= 13.18°

1% increase in length for 1° above standard temperature = 33.5° – 13.18°

= 20.32°

1° ↑→ 1% ↑
20.32° → x

x = 20.32%

Correction = \( \frac{20.32}{100} \times 1747.15 + 1747.15 \)

= 2102.17 m

07. Ans: 0.36%

Sol:

<table>
<thead>
<tr>
<th>Chainage</th>
<th>Gradient</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>–</td>
<td>280 m</td>
</tr>
<tr>
<td>300</td>
<td>+1%</td>
<td>(280 +0.01×300) = 283</td>
</tr>
<tr>
<td>900</td>
<td>–0.5%</td>
<td>283 – ( \frac{0.5}{100} \times 600 ) = 280</td>
</tr>
<tr>
<td>1500</td>
<td>+0.5</td>
<td>280 + ( \frac{0.5}{100} \times 690 ) = 283</td>
</tr>
<tr>
<td>1800</td>
<td>+1</td>
<td>283 + 0.01×300 = 286</td>
</tr>
<tr>
<td>2100</td>
<td>–0.5</td>
<td>286 – ( \frac{0.5}{100} \times 300 ) = 284.5</td>
</tr>
<tr>
<td>2700</td>
<td>0.4</td>
<td>284.5 – ( \frac{0.4}{100} \times 600 ) = 282.1</td>
</tr>
<tr>
<td>3000</td>
<td>–0.1</td>
<td>282.1 – ( \frac{0.1}{100} \times 300 ) = 281.8</td>
</tr>
</tbody>
</table>

Effective gradient = \( \left( \frac{286 - 280}{1640} \right) \times 100 = 0.36\% \)

20% → 1%

x → 0.36%

x = 7.2%↑

Total length of runway = 1.072 × 2102.17

= 2253.5 m

08. Ans: (d)

Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (3rd Question -pg: 1093)

09. Ans: (a)

Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (16th Question -pg: 1095)

10. Ans: (a)

Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (20th Question -pg: 1096)

11. Ans: (c)

Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (25th Question -pg: 1097)

12. Ans: (a)

Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (26th Question -pg: 1097)

13. Ans: (d)

Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (28th Question -pg: 1097)

14. Ans: (b)

Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (29th Question -pg: 1098)

15. Ans: (b)

Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (33rd Question -pg: 1098)
16. Ans: (b)

Sol:

Speed of airplane = 800 km/hr = 222.22 m/sec

Air temperature = 0°C

Mach number = \( \frac{\text{Speed of airplane}}{\text{Speed of sound}} \)

Speed of sound at 0°C = 331.5 m/sec

\( \text{as } V \approx 20.05 \sqrt{T} \text{ (T in Kelvin)} \)

\( = 20.05 \sqrt{273} = 331.28 \text{ m/sec} \)

\( \therefore \) Mach number = \( \frac{222.22}{331.25} = 0.67 \)

Corrected length, \( L' = L + 130.67 \)

\( = 2000 + 130.67 \)

\( = 2130.67 \text{ m} \)

**Correction for temperature:**

Airport reference temperature,

\( T_R = T_1 + \frac{T_2 - T_1}{3} \)

Where

\( T_1 = \) mean of average daily temperature

\( = 35°C \)

\( T_2 = \) Mean of maximum daily temperature

\( = 42°C \)

\( T_R = 35 + \frac{42 - 35}{3} \)

\( T_R = 37.33 \text{ °C} \)

We know that,

Standard atmospheric temperature at mean sea level = 15°C

Taking the temperature gradient as equal to 6.5°C per 1000 m rise in Elevation, the standard temperature at the airport site will be,

Temperature at given elevation

\( = 15 - \left[ 6.5 \times \frac{280}{1000} \right] = 13.18°C \)

Rise in temperature from standard temperature

\( = T_R - T_S \)

\( = 37 - 13.18 \)

\( = 23.82°C \)
ICAO recommends,
Correction for temperature shall be 1% for every 1°C rise in temperature.

\[
\text{Correction} = \frac{1}{100} \times (\text{rise in temperature}) \times L'
\]

\[
= \frac{1}{100} \times 23.82 \times 2130.67 = 507.52 \text{ m}
\]

Corrected length, \( L'' = 2130.67 + 507.52 \)
\( L'' = 2638.19 \text{ m} \)

Check:
As per ICAO, total correction for sum of elevation and temperature shall not exceed 35% of basic runway.

Length total correction for elevation and temperature.
\( = 130.67 + 507.52 \)
\( = 638.19 \text{ m} \)

Total correction in percentage
\( = \frac{638.19}{2000} \times 100 \)
\( = 31.9 \% < 35 \% \)
Hence Accepted.

Correction for gradient:
(Recommendation of FAA),
Runway length shall be further increased at the rate of 20% for energy 1% of effective gradient after being corrected for elevation and temperature.

\[
\text{Correction for gradient} = \frac{20}{100} \times 0.12 \times 2638.19
\]
\( = 63.32 \text{ m} \)

Final runway length = \( L'' + 63.32 \)
\( = 2638.19 + 63.32 \)
\( = 2701.51 \text{ m} \)

19.4 TAxIwAy deSign

01. Ans: 400 m
Sol:
(i) Horonjeff’s equation:
\[
R = \frac{0.388 w^2}{0.5 T - S} = \frac{0.388 \times 17.7^2}{0.5(23) - \left(6 + \frac{6.62}{2}\right)} = 55.50 \text{ m}
\]

(ii) Turning radius
\[
R = \frac{V^2}{125 f} = \frac{80^2}{125 \times 0.13} = 393.85 \text{ m}
\]

(iii) The minimum radius of sub sonic aircraft is 135 m
\( \therefore \) Turning radius = Maximum of three conditions
\( = 393.85 \text{ m} \)
\( R \approx 400 \text{ m} \)

02. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (12th Question - pg: 1094)
01. **Sol:** Given:

- Turning speed, \( V = 60 \) kmph
- Wheel base, \( W = 35 \) m
- Tread of main landing gear, \( T' = 4 \) m
- Co-efficient of friction, \( f = 0.13 \)
- Width of taxiway , \( T = 22.5 \) m

The following three values of \( R \) shall be worked out, and maximum of three will be final radius of taxiway.

(i) \[ R = \frac{V^2}{125f} = \frac{60^2}{125 \times (0.13)} = 221.54 \text{ m} \]

(ii) Horonjeff’s equation

\[ R = \frac{0.388W^2}{T - S} \]

Where \( S \) is distance between point midway of main gears and the edge of taxiway pavement.

\[ S = \text{edge distance } + \frac{T'}{2} \]

(Assume edge distance as 6 m)

\[ S = 6 + \frac{4}{2} = 8 \text{ m} \quad \ldots \quad (1) \]

Substituting equation (1) in Horonjeff’s equation

\[ R = \frac{0.388 \times (35)^2}{0.5(22.5) - 8} = 146.25 \text{ m} \]

(iii) The absolute minimum turning radius for supersonic aircraft irrespective of any speed = 180 m.

The maximum value among the above three is 221.54 m. Hence the radius is approximately 221.54 m.

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**19.5 PLANNING AND DESIGN OF TERMINAL AREA & VISUAL AIDS**

01. **Ans:** (c)

**Sol:** Refer previous ESE-Obj-(Vol-2) solutions Book (1st Question -pg: 1093)

02. **Ans:** (d)

**Sol:** Refer previous ESE-Obj-(Vol-2) solutions Book (4th Question -pg: 1093)

03. **Ans:** (a)

**Sol:** Refer previous ESE-Obj-(Vol-2) solutions Book (5th Question -pg: 1093)

04. **Ans:** (a)

**Sol:** Refer previous ESE-Obj-(Vol-2) solutions Book (8th Question -pg: 1094)

05. **Ans:** (d)

**Sol:** Refer previous ESE-Obj-(Vol-2) solutions Book (11th Question -pg: 1094)
06. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (13th Question -pg: 1095)

07. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (14th Question -pg: 1095)

08. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (15th Question -pg: 1095)

09. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (17th Question -pg: 1095)

10. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (21st Question -pg: 1096)

11. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (22nd Question -pg: 1096)

12. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (27th Question -pg: 1097)

13. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (31st Question -pg: 1098)

14. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (32nd Question -pg: 1098)

15. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (34th Question -pg: 1099)

16. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (35th Question -pg: 1099)

17. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (36th Question -pg: 1099)

19. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (42nd Question -pg: 1099)

20. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (39th Question -pg: 1099)

20. Harbour Engineering

01. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (2nd Question -pg: 1105)
02. Ans: (a)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (4th Question -pg: 1105)

03. Ans: (d)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (5th Question -pg: 1106)

04. Ans: (b)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (7th Question -pg: 1106)

05. Ans: (c)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (8th Question -pg: 1106)

06. Ans: (a)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (9th Question -pg: 1106)

07. Ans: (c)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (10th Question -pg: 1106)

08. Ans: (a)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (8th Question -pg: 1106)

09. Ans: (b)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (12th Question -pg: 1107)

10. Ans: (c)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (13th Question -pg: 1107)

11. Ans: (c)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (14th Question -pg: 1107)

12. Ans: (b)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (15th Question -pg: 1107)

13. Ans: (d)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (16th Question -pg: 1107)

14. Ans: (d)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (17th Question -pg: 1107)

15. Ans: (d)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (18th Question -pg: 1108)

16. Ans: (a)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (19th Question -pg: 1108)

17. Ans: (b)  
Sol: Refer previous ESE-Obj-(Vol-2) solutions  
Book (20th Question -pg: 1108)
18. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (21st Question -pg: 1108)

19. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (22nd Question -pg: 1108)

20. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (23rd Question -pg: 1108)

21. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (25th Question -pg: 1109)

22. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (26th Question -pg: 1109)

23. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (27th Question -pg: 1110)

24. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (28th Question -pg: 1110)

25. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (29th Question -pg: 1110)

26. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (30th Question -pg: 1110)

29. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (31st Question -pg: 1110)

31. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (33rd Question -pg: 1110)

32. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (34th Question -pg: 1110)

21. Tunnel Engineering

01. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (4th Question -pg: 1115)

02. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (5th Question -pg: 1115)

03. Ans: (a)
Sol: Refer previous ESE-Obj-(Vol-2) solutions
Book (6th Question -pg: 1116)
04. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (7th Question -pg: 1116)

05. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (8th Question -pg: 1116)

06. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (9th Question -pg: 1116)

07. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (10th Question -pg: 1116)

08. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (11th Question -pg: 1117)

09. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (12th Question -pg: 1117)

10. Ans: (b)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (13th Question -pg: 1117)

11. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (15th Question -pg: 1118)

12. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (16th Question -pg: 1118)

14. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (17th Question -pg: 1118)

15. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (18th Question -pg: 1118)

16. Ans: (d)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (19th Question -pg: 1118)

17. Ans: (c)
Sol: Refer previous ESE-Obj-(Vol-2) solutions Book (20th Question -pg: 1118)