



**GATE | PSUs**

# **CIVIL ENGINEERING**

## **Transportation Engineering**

**(Text Book : Theory with worked out Examples  
and Practice Questions)**



# Transportation Engineering

(Solutions for Text Book Practice Questions)

## 01. Highway Development and Planning

01. Ans: (d)

Sol:

Road	Length (km)	Number of Villages with population			Utility	Utility/km
		< 2000	2000 – 5000	> 5000		
P	20	8	6	1	$8 \times 0.5 + 6 \times 1 + 1 \times 2 = 12$	$12/20 = 0.6$
Q	28	19	8	4	$19 \times 0.5 + 8 \times 1 + 4 \times 2 = 25.5$	$25.5/28 = 0.91$
R	12	7	5	2	$7 \times 0.5 + 5 \times 1 + 2 \times 2 = 12.5$	$12.5/12 = 1.04$
Weightage factor		0.5	1	2		

∴ RQP

02. Ans: (a)

Sol:

Road Lane	Length (cm)	Number of villages with population ranges				Industrial Product	Utility	Utility/km
		1000-2000	2000-5000	5000-10000	>10000			
P	300	100	80	30	6	200	$100 \times 1 + 80 \times 2 + 30 \times 3 + 6 \times 4 + 200 = 574$	$574/300 = 1.91$
Q	400	200	90	00	8	270	$200 \times 1 + 90 \times 2 + 8 \times 4 + 270 = 682$	$682/400 = 1.70$
R	500	240	110	70	10	315	$240 \times 1 + 110 \times 2 + 70 \times 3 + 10 \times 4 + 315 = 1025$	$1025/500 = 2.05$
S	550	248	112	73	12	335	$248 \times 1 + 112 \times 2 + 73 \times 3 + 12 \times 4 + 335 = 1074$	$1074/550 = 1.95$
Weightage factor		1	2	3	4			

∴ RSPQ



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**04. Highway Geometric Design -  
Gradients**

*Common data for Questions 01 & 02*

**01. Ans: (b)**

$$\text{Sol: Height of crown} = \frac{W}{2n} = \frac{3.5 \times 1000}{2 \times 60} = 29.2 \text{ mm}$$

**02. Ans: (d)**

$$\text{Sol: Height of crown} = \frac{W}{2n} = \frac{3.5 \times 1000}{2 \times 40} = 43.75 \text{ mm}$$

**04. Ans: (a)**

$$\text{Sol: G.C} = \frac{30 + R}{R}$$

$$\text{G.C} = \frac{30 + 50}{50} = 1.6$$

$$\text{Max G.C} = \frac{75}{50} = 1.5 \quad \therefore \text{G.C} = 1.5$$

$$\text{The compensated gradient} = 6\% - 1.5 = 4.5\%$$

**05. Ans: (a)**

$$\text{Sol: Height of crown} = \frac{W}{2n} = 7.5 \text{ cm}$$

$$\frac{W}{2n} = 7.5$$

$$2n = \frac{9 \times 100}{7.5}$$

$$n = 60 \Rightarrow 1 \text{ in } 60$$

**05. Highway Geometric Design -  
Sight Distance**

**01. Ans: (c)**

$$\text{Sol: B.D} = 16 \text{ m,}$$

$$f = 0.4$$

$$\frac{V^2}{254f} = 16 \Rightarrow \frac{V^2}{254 \times 0.4} = 16$$

$$V = 40.3 \text{ kmph} \approx 40 \text{ kmph}$$

**02. Ans: (c)**

$$\text{Sol: } V = 30 \text{ kmph,}$$

$$f = 0.4$$

$$BD_{\text{down}} = 2 BD_{\text{up}}$$

$$\frac{V^2}{254(f - 0.01n)} = \frac{2 \times V^2}{254(f + 0.01n)}$$

$$f + 0.01n = 2f - 0.02n$$

$$0.03n = 0.4$$

$$n = 13.33\%$$

**03. Ans: (b)**

$$\text{Sol: } V = 72 \text{ kmph, } n = 2\%,$$

$$f = 0.15,$$

$$t = 1.5 \text{ sec}$$

$$\text{SSD} = 0.278 Vt + \frac{V^2}{254(f + 0.01n)} = 150 \text{ m}$$

**04. Ans: (b)**

**Sol:**  $V = 60 \text{ kmph}$

$$t = 2.5 \text{ sec}, f = 0.36$$

$$\frac{0.278 Vt}{V^2 / 254(f + 0.01n)} = \frac{6}{5}$$

$$0.278 \times 60 \times 2.5 = \frac{6}{5} \left[ \frac{60^2}{254(0.36 + 0.01n)} \right]$$

$$n = 4.78 \approx 4.8$$

**05. Ans: (c)**

**Sol:**  $V = 60 \text{ kmph}, t = 2.5 \text{ sec}, f = 0.35$

$$\text{SSD} = 0.278 Vt + \frac{V^2}{254f}$$

$$= 0.278 \times 60 \times 2.5 + \frac{60^2}{254 \times 0.35} = 82.1 \text{ m}$$

$$\begin{aligned} \text{SSD for single two way traffic} &= 2 \times \text{SSD} \\ &= 2 \times 82.1 = 164.2 \text{ m} \end{aligned}$$

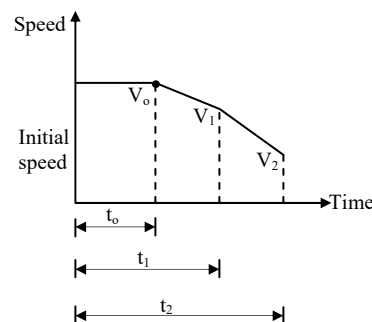
**06. Ans: (c)**

**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 1<sup>st</sup> phase, assume driver reaction time  
0.5 sec

$$v_o = v_1 + \frac{a}{2}(t_1 - t_o)$$

During 3<sup>rd</sup> phase, deceleration assumed to be uniform

$$\begin{aligned} v_1 &= \sqrt{v_2^2 + 2aS} = \sqrt{11.18^2 + 2 \times 7.35 \times 27.45} \\ &= 22.98 \text{ m/s} = 82.76 \text{ kmph} \end{aligned}$$

$$\begin{aligned} v_o &= 82.76 + \frac{7.35}{2}(0.8 - 0.5) \\ &= 83 \text{ kmph} \end{aligned}$$

**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

$$x = \frac{\alpha t}{\beta} - \frac{\alpha}{\beta^2}(1 - e^{-\beta t}) + \frac{v_o}{\beta}(1 - e^{-\beta t})$$

$v_o = \text{initial speed} = 0$

$$= \frac{3(4.25)}{0.04} - \frac{3}{(0.04)^2}(1 - e^{-0.04 \times 4.25}) + 0$$

$$x = 25.62 \text{ m}$$

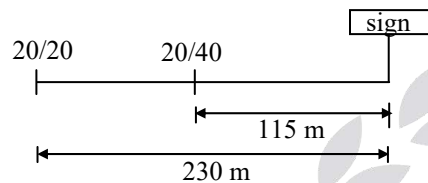
Intersection + length of car

$$7.5 + 6.1 = 13.6 \text{ m}$$

∴ He can clear the intersection

**09. Ans: T = 7.13 sec, V = 138 kmph**

**Sol:**



$$\frac{20}{20} \rightarrow 230 \text{ m}$$

$$\frac{20}{40} \rightarrow x$$

$$x = 115 \text{ m}$$

In question they have given it will take 3 sec to read sign

So

$$\begin{aligned} \text{Speed of } \frac{20}{40} \text{ vision driver} &= \frac{115}{3} \text{ m/sec} \\ &= 138 \text{ kmph} \end{aligned}$$

For speed of  $\frac{20}{40}$  vision driver is 58kmph

$$\text{i.e. } 58 \times \frac{5}{18} = 16.11 \text{ m/sec}$$

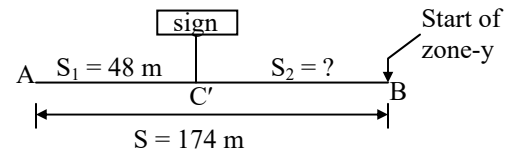
$$\text{Velocity} = \frac{D}{T}$$

$$T = \frac{115}{16.11}$$

$$T = 7.13 \text{ sec}$$

**10. Ans: 142**

**Sol:** For normal driver with 6/6 vision the position of sign post is shown below.



$$S_2 = 174 - 48 = 126 \text{ m}$$

$S_2$  = The distance from sign post to the start of zone-y

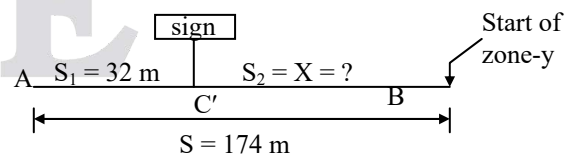
$S_1$  = Distance traveled by the vehicle during perception – reaction time for 6/6 vision driver

$S$  = 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



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

$$= 174 - 32 = 142 \text{ m.}$$

**11. Refer previous GATE solutions Book**

**(Cha-2, Two marks 9<sup>th</sup> Question)**

## 06. Highway Geometric Design - Overtaking Sight Distance

**Common data for Questions 01, 02 & 03**

**01. Ans: (c)**

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

$$V_b = 50 \text{ kmph}, S = 16 \text{ m}$$

$$t = 2 \text{ sec}$$

$$T = \sqrt{\frac{14.4s}{a}} = \sqrt{92.16 \text{ sec}} \\ = 9.6 \text{ sec}$$

$$\text{OSD} = d_1 + d_2 \\ = 0.278 V_b t + (0.278 V_b T + 2s) \\ = 193.24 \text{ m}$$

**02. Ans: (d)**

**Sol:**  $\text{OSD} = d_1 + d_2 + d_3$   
 $= 0.278 V_b t + (0.278 V_b T + 2s) + 0.278 VT$   
 $= 406.74 \text{ m}$

**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:**  $V = u + at$

$$u = 100 \text{ kmph}$$

$$= 27.7 \text{ m/s} = 27.7 + 0.8 \times 5$$

$$V = 31.72 \text{ m/s}$$

$$V^2 - u^2 = 2 \times a s$$

$$(31.7)^2 - (27.7)^2 = 2 \times 0.8 \times S$$

$$S = 148.5 \text{ m}$$

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 ( $d_2$ )

$$d_2 = (V_b T + 2s) \quad S_1 = 25 \text{ m}$$

$$= (V_b T + S_1 + S_2) \quad S_2 = 20 \text{ m}$$

$$T = \sqrt{\frac{4s}{a}} = 10.6 \text{ sec}$$

$$d_2 = (0.278 \times 100 \times 10) + (25 + 20) \\ = 323 \text{ m}$$

**Common data for Questions 06 & 07**

**06. Ans: (c)**

**Sol:**  $\text{OSD} = d_1 + d_2$

$$V = 22.22 \text{ m/s} \quad V_b = 16.67 \text{ m/s}$$

$$a = 0.7 \text{ m/s}^2$$

$$S = (0.7 V_b + I) = 17.67 \text{ m}$$

$$T = \sqrt{\frac{4s}{a}} = 10.05 \text{ sec} \quad t = 2 \text{ sec}$$

$$\text{OSD} = d_1 + d_2 + d_3 \\ = V_b t + (V_b T + 2s) + VT \\ = 236.21 + (22.22 \times 10.05) \\ = 459.521 \text{ m} \approx 460 \text{ m}$$

07. Ans: (d)

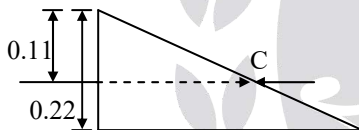
$$\begin{aligned}\text{Sol: Desirable length of OZ} &= 5 \text{ OSD} \\ &= 5 (d_1 + d_2 + d_3) \\ &= 5 \times 460 \\ &\approx 2300 \text{ m}\end{aligned}$$

### 07. Highway Geometric Design - Horizontal Curves

Common data for Questions 01 & 02

01. Ans: (a)

$$\text{Sol: } e = \frac{V^2}{225R} = \frac{65^2}{225 \times 600} = 0.031$$



$$\begin{aligned}E &= e w = 0.031 \times 7 = 0.22 \text{ m} \\ \text{w.r.t centre line} &= 0.11 \text{ m}\end{aligned}$$

02. Ans: (b)

$$\text{Sol: w.r.t inner edge ; } E = 0.22 \text{ m}$$

03. Ans: (c)

$$\text{Sol: } e_{\text{cal}} = \frac{V^2}{225R} = \frac{65^2}{225 \times 125} = 0.15$$

$$e_{\text{cal}} > 0.07$$

∴ V = 65 kmph is not suitable

$$\begin{aligned}0.07 + f &= \frac{V^2}{127R} \rightarrow f = \frac{65^2}{127 \times 125} - 0.07 \\ &= 0.196 > 0.15\end{aligned}$$

$V_a$  should be calculated

$$\begin{aligned}0.07 + 0.15 &= \frac{V_a^2}{127 \times 125} \\ V_a &= 59.1 \text{ kmph}\end{aligned}$$

Common data for Questions 04 to 06

04. Ans: (b)

$$\text{Sol: } e + f = \frac{V^2}{127R}$$

$$\begin{aligned}e + 0.15 &= \frac{100^2}{127 \times 500} \\ \Rightarrow e &= 0.00748 = 0.74\%\end{aligned}$$

05. Ans: (b)

$$\text{Sol: } f = \frac{V^2}{127R} = \frac{100^2}{127 \times 500} = 0.157 \approx 0.16$$

06. Ans: (c)

$$\begin{aligned}\text{Sol: } f &= 0 ; \quad e + 0 = \frac{100^2}{127 \times 500} \\ \Rightarrow e &= 15.75\%\end{aligned}$$

07. Ans: (a)

$$\text{Sol: } e = \frac{V^2}{225R} = \frac{60^2}{225 \times 500} = 0.032 = 3.2\%$$

08. Ans: (b)

$$\begin{aligned}\text{Sol: } R_{\text{Ruling}} &= \frac{V^2}{127(f + e)} \\ &= \frac{100^2}{127(0.07 + 0.13)} \\ &= 393.7 \text{ m} \approx 395 \text{ m}\end{aligned}$$



09. Ans: (a)

Sol:  $b = 2.4 \text{ m}$

$$h = 4.2 \text{ m}$$

$$\frac{b}{2h} = \frac{2.4}{2 \times 4.2} = 0.286 > f$$

$$\frac{b}{2h} > f$$

$\therefore$  Lateral skidding occur first

10. Ans: (a, d)

Sol: Given:  $V = 80 \text{ kmph}$ ;  $H = 2b$

$$\text{Critical case for no overturning: } \frac{V^2}{127R} = \frac{b}{2h}$$

Where:  $b$  = width of vehicle;

$h$  = distance of CG of vehicle from bottom = total height of vehicle ( $H$ )/2

$$\frac{b}{2h} = \frac{b}{H}$$

Critical case for no overturning = 0.5

Speed at which the vehicle overturns

$$= \frac{V^2}{127 \times 250} = 0.5$$

$$V = 126 \text{ kmph}$$

$$= 1.57 \text{ times allowable speed}$$

Super elevation to be provided

$$= \frac{802}{225 \times 250} = 0.113 > 0.07$$

Hence super elevation provided is 7%

## 08. Horizontal Curves (Extra Widening)

Common data for Questions 01 & 02

01. Ans: (d)

$$\text{Sol: } e + f = \frac{V^2}{127R}$$

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

02. Ans: (d)

$$\begin{aligned} \text{Sol: } W_e &= \frac{n \ell^2}{2R} + \frac{V}{9.5\sqrt{R}} \\ &= \frac{2 \times 7^2}{2 \times 209} + \frac{76}{9.5\sqrt{209}} = 0.787 \text{ m} \end{aligned}$$

$$\begin{aligned} \therefore \text{Total width} &= 7 + 0.787 \\ &= 7.78 \text{ m} \end{aligned}$$

03. Ans: (c)

$$\begin{aligned} \text{Sol: } W_e &= \frac{n \ell^2}{2R} + \frac{V}{9.5\sqrt{R}} \\ &= \frac{2 \times 8^2}{2 \times 300} + \frac{100}{9.5\sqrt{300}} = 0.821 \text{ m} \end{aligned}$$

04. Ans: (c)

Sol: Given

$$W_m = 0.096$$

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



$$\begin{aligned}
 W_e &= W_m + W_{ps} = \frac{n \ell^2}{2R} + \frac{V}{9.5\sqrt{R}} \\
 &= \frac{2 \times 6.6^2}{2 \times 226.87} + \frac{80}{9.5\sqrt{226.87}} \\
 &= 0.75 \text{ m}
 \end{aligned}$$

### 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

$$m = R - R \cos(\alpha/2)$$

$$\frac{\alpha}{2} = \frac{180S}{2\pi R} = \frac{180 \times 80}{2\pi \times 360} = 6.36$$

$$\begin{aligned}
 m &= 360 - 360 \cos(6.36) \\
 &= 2.2 \text{ m}
 \end{aligned}$$

**04. Ans: (c)**

**Sol:**  $L = 180 \text{ m} \quad S = 250 \text{ m}$

$$L < S$$

$$m = R - R \cos\left(\frac{\alpha}{2}\right) + \frac{S-L}{2} \sin\left(\frac{\alpha}{2}\right)$$

$$\frac{\alpha}{2} = \frac{180L}{2\pi R} = \frac{180 \times 180}{2\pi \times 360} = 14.32$$

$$m = 360 - 360 \cos(14.32)$$

$$+ \frac{250-180}{2} \sin(14.32) = 19.85 \text{ m}$$

*Common data for Questions 05 & 06*

**05. Ans: (c)**

**Sol:**  $SSD = 0.278 V t + \frac{V^2}{254 f}$

$$\begin{aligned}
 &= (0.278 \times 80 \times 2.4) + \frac{80^2}{254 \times 0.355} \\
 &= 124.35 \text{ m} \approx 125 \text{ m}
 \end{aligned}$$

**06. Ans: (d)**

**Sol:**  $S = 125 \text{ m}$

$$d = \frac{W}{4} = \frac{7}{4} = 1.75 \text{ m}$$

$$\frac{\alpha}{2} = \frac{180S}{2\pi(R-d)} = \frac{180 \times 125}{2\pi(200-1.75)} = 18.06$$

$$m = R - (R-d) \cos\left(\frac{\alpha}{2}\right) = 11.52 \text{ m}$$

$$\begin{aligned}
 m^1 &= m - d \\
 &= 11.52 - 1.75 = 9.77 \text{ m}
 \end{aligned}$$

(or)

In approximately

$$m = \frac{S^2}{8R} = 9.76 \text{ m}$$

**Problems on Curve Resistance**
**07. Ans: 0.293**
**Sol:** Let 'T' is the original Tractive force

 loss of tractive force =  $T(1 - \cos\theta)$ 

$$= T(1 - \cos 45^\circ)$$

Ratio of loss of Tractive force to original is

$$= 0.293$$

**08. Ans: (a)**
**Sol:** Curve resistance =  $T(1 - \cos\theta)$ 

$$= T(1 - \cos 30^\circ)$$

$$= 0.134 T$$

**10. Highway Geometric Design -  
Transition Curves**
**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

$$L = eN (W + W_e) = 0.07 \times 100 (7 + 0.2) = 50.4 \text{ m}$$

$$L = \frac{2.7 V^2}{R} = \frac{2.7 \times 60^2}{200} = 48.6 \text{ m}$$

 $\therefore$  The length of T.C = 50.4 m

(from the 3 values maximum value)

**02. Ans: (d)**

**Sol:** 
$$S = \frac{L^2}{24 R} = \frac{(50.4)^2}{24 \times 200} = 0.53 \text{ m}$$

**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

$$L = \frac{0.0215 V^3}{C R} = \frac{0.0215 \times 80^3}{0.516 \times 900} = 23.7 \text{ m}$$

Considering 'N' value

$$e = \frac{V^2}{225 R} = \frac{80^2}{225 \times 900} = 0.0316$$

(for mixed traffic)

$$L = \frac{eN}{2} (W + W_e) = \frac{0.0316 \times 150}{2} \times 7 = 16.59 \text{ m}$$

Considering terrain

$$L = \frac{2.7 V^2}{R} = \frac{2.7 \times 80^2}{900} = 19.2 \text{ m}$$

 $\therefore$  Length of T.C = 23.7 m

## 11. Highway Geometric Design – Vertical Curves

**01. Ans: (b)**

**Sol:** Length of summit parabolic curve,

Assume  $L > S$

$$L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2}$$

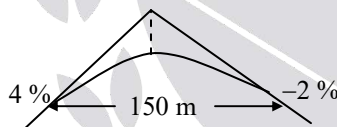
$$= \frac{0.09 \times 120^2}{(\sqrt{2 \times 1.5} + \sqrt{2 \times 0.15})^2} = 249 \text{ m}$$

**02. Ans: (d)**

**Sol:**  $N = 4 - (-2) = 6\%$

$6\% \rightarrow 150 \text{ m}$

$4\% \rightarrow \frac{4}{6} \times 150 = 100 \text{ m}$



**03. Ans: (c)**

**Sol:**  $N = \frac{1}{50} - \left(-\frac{1}{100}\right) = 0.03 = 3\%$

$1\% \rightarrow 100 \text{ m}$

$3\% \rightarrow \frac{3}{1} \times 100 = 300 \text{ m}$

**Common data for Q 04 & 05**

**04. Ans: (c)**

**Sol:**  $N = \frac{1}{25} - \left(-\frac{1}{50}\right) = 0.06 = 6\%$

$S = 180 \text{ m}$

Take  $L > SSD$

$$L = \frac{NS^2}{4.40} = \frac{0.06 \times 180^2}{4.4} = 441.8 \text{ m}$$

$$\approx 442 \text{ m}$$

**05. Ans: (b)**

**Sol:**  $6\% \rightarrow 442 \text{ m}$

$4\% \rightarrow \frac{4}{6} \times 442 = 294.66 \text{ m}$

**06. Ans: (a)**

**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  $L \geq OSD$

$$L = \frac{NS^2}{9.6}$$

$$= \frac{0.018 \times 500^2}{9.6}$$

$$= 468.75 \text{ m} < 500 \text{ m}$$

Take  $L < OSD$

$$L = 2S - \frac{9.6}{N}$$

$$= 2 \times 500 - \frac{9.6}{0.018}$$

$$= 466.67 \text{ m} < 500 \text{ m}$$

$\therefore$  Length of summit curve,

$$L \approx 467 \text{ m}$$

## 12. Highway Geometric Design – Valley Curves

*Common data for Questions 01 to 03*

**01. Ans: (c)**

**Sol:**  $-n_1 = \frac{1}{25}$      $V = 100 \text{ kmph}$

$$n_2 = \frac{1}{20} \quad C = 0.6 \text{ m/s}^3$$

$$SSD = 180 \text{ m}$$

$$N = |(-n_1 - n_2)| = n_1 + n_2$$

$$= \frac{1}{25} + \frac{1}{20} = 0.09$$

$$(a) L = 0.38 (NV^3)^{1/2}$$

$$= 0.38 (0.09 \times 100^3)^{1/2}$$

$$= 114$$

$$L > SSD$$

$$(b) L = \frac{NS^2}{1.5 + (0.035S)} = \frac{0.09 \times 180^2}{1.5 + 0.035(180)}$$

$$= 373.86 \text{ m} \approx 374 \text{ m}$$

**02. Ans: (b)**

**Sol:**  $I = \frac{1.6NV^2}{L}$

$$= \frac{1.6 \times 0.09 \times 100^2}{374} = 3.85$$

**03. Ans: (a)**

**Sol:** For 9%  $\rightarrow 373.86$

For 4 %  $\rightarrow ?$

$$= \frac{4 \times 374.0}{9} = 166.22 \text{ m} \approx 166$$

**04. Ans: (a, b, c, d)**

**Sol:** Length of the valley curve from comfort

$$\text{criteria} = 0.38 \sqrt{NV^3}$$

$$= 0.38 \sqrt{0.075 \times 80^3} = 74.46 \text{ m say } 75 \text{ m}$$

Length of the valley curve from headlight  
sight distance criteria

$$= \frac{NS^2}{1.5 + 0.035S} = \frac{0.075 \times 130^2}{1.5 + 0.035 \times 130} = 209.5 \text{ m say } 210 \text{ m}$$

$$\text{Impact factor} = \frac{1.59NV^2}{L}$$

$$= \frac{1.59 \times 0.075 \times 80^2}{210} = 3.63$$

### 13. Highway Materials and Testing

**01. Ans: (a)**

**Sol:**  $k_1 d_1 = k_2 d_2$

$$(200) \times (30) = (k_2)(75)$$

$$k_2 = k_{\text{of soil}} = 80 \text{ N/cm}^3$$

**03. Ans: (a)**

$$\begin{aligned} \text{Sol: } E &= \frac{1.18 \text{ Pa}}{\delta} = \frac{1.18 \times 800 \times (75/2)}{2.5 \times 10^{-1}} \\ &= 141600 \text{ N/cm}^2 \\ &= 141.6 \text{ kN/cm}^2 \end{aligned}$$

**04.**

$$\begin{aligned} \text{Sol: Total weight} &= 825 + 1200 + 325 + 150 + 100 \\ &= 2600 \text{ gm} \end{aligned}$$

% wt of material ;

$$A_1 \rightarrow \frac{825}{2600} \times 100 = 31.7\%$$

$$A_2 \rightarrow \frac{1200}{2600} \times 100 = 46.15\%$$

$$A_3 \rightarrow \frac{325}{2600} \times 100 = 12.5\%$$

$$A_4 \rightarrow \frac{150}{2600} \times 100 = 5.7\%$$

$$\text{Bitumen} \rightarrow \frac{100}{2600} \times 100 = 3.8\%$$

$$G_t = \frac{100}{\left( \frac{w_1}{G_1} + \frac{w_2}{G_2} + \frac{w_3}{G_3} + \frac{w_4}{G_4} + \frac{w_5}{G_5} \right)}$$

$$= \frac{100}{\left[ \frac{31.7}{2.63} + \frac{46.15}{2.51} + \frac{12.5}{2.46} + \frac{5.7}{2.43} + \frac{3.8}{1.05} \right]}$$

$$= 2.41$$

$$G_m = \frac{1100}{475} = 2.31$$

$$\begin{aligned} \text{(a) } V_a &= \frac{G_t - G_m}{G_t} \times 100 = \frac{2.41 - 2.31}{2.41} \times 100 \\ &= 4.15\% \end{aligned}$$

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

$$\begin{aligned} \text{(c) } VMA &= V_a + V_b = 4.15\% + 8.36 \\ &= 12.51\% \end{aligned}$$

$$\begin{aligned} VFB &= \frac{V_b}{VMA} \times 100 \\ &= \frac{8.36}{12.51} \times 100 = 67\% \end{aligned}$$

**05. Ans:  $G_t = 2.48$ ,  $G_m = 2.30$**

$$\begin{aligned} \text{Sol: } G_t &= \frac{100}{\frac{w_1}{G_1} + \frac{w_2}{G_2} + \frac{w_3}{G_3}} \\ &= \frac{100}{\frac{60}{2.72} + \frac{35}{2.66} + \frac{5}{1.0}} = 2.48 \end{aligned}$$

$$V_a = 7\%$$

$$V_a = \frac{G_t - G_m}{G_t} \times 100$$

$$\Rightarrow 7 = \frac{2.48 - G_m}{2.48} \times 100$$

$$G_m = 2.30$$

**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.

$$\therefore \text{CBR(\%)} = 4.4$$

#### 14. Pavement Design

**01. Ans: 34.22 msa**

**Sol:** Assume lane distribution factor,  $F = 1$

$$A = 1000 \left( 1 + \frac{7.5}{100} \right)^5 = 1435.6 \text{ CVPD}$$

$$N = \frac{365 [(1 + 0.075)^{15} - 1]}{0.075} \times 1435.6 \times 2.5 \times 1$$

$$= 34.22 \text{ msa}$$

**02. Ans: (c)**

$$\text{Sol: } N = \frac{365 [(1 + r)^n - 1]}{r} \times A \times D \times F$$

Assume  $F = 0.75$

$$N = \frac{365 [(1 + 0.1)^{15} - 1]}{0.1} \times 1610.51 \times 3 \times 0.75$$

$$= 42.02 \text{ msa}$$

$$A = P(1+r)^n$$

$$= 1000 (1+0.1)^5 = 1610.51$$

**03. Ans: (b)**

$$\text{Sol: } N = N_1 + N_2$$

$$= \frac{365 [(1 + r)^n - 1]}{r} \times A \times D \times F$$

$$N = \frac{365 [(1 + 0.075)^{10} - 1]}{0.075} [2000 \times 5 + 200 \times 6]$$

$$= 57.8 \text{ msa}$$

**04. Ans:  $F = 3.74$ ,  $N = 25.86 \text{ msa}$**

**Sol:**

S.No	Wheel load	% Total Traffic ( $N_i$ )	EF [ $F_i$ ]
1	2268	25	1
2	2722	12	2.07
3	3175	9	3.84
4	3629	6	6.55
5	4082	4	10.49
6	4536	2	16
7	4490	1	23.43
		$\Sigma N_i = 59\%$	

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

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

$$(2) \rightarrow EF_2 = \left( \frac{2722}{2268} \right)^4 = 2.07 \dots\dots$$

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

$$\text{VDF} = 3.74$$

Given LDF = 0.4

Total Traffic = 1860 cv/day

∴ Total commercial traffic (A)

$$= 1860 \times \frac{59}{100} = 1094.4 \text{ cv/day}$$

$$N = \frac{365((1 + 0.075)^{20} - 1)(1094.4 \times 0.4 \times 3.74)}{0.075}$$

$$N = 25.87 \times 10^6 \text{ csa} = 25.87 \text{ msa}$$

**05. Ans: 266.25 kN, 1.26**

**Sol:** Equivalent axle load and vehicle damage factor (VDF)

Axle load	Number of load repetition	Equivalent factor	Equivalent axle load
80	1000	$(80/80)^4 = 1$	1000
160	100	$(160/80)^4 = 16$	1600
40	1000	$(40/80)^4 = 0.0625$	62.5
			2662.5

∴ The equivalent axle load = 2662.5 kN

$$\text{VDF} = \frac{(1000 \times 1) + (100 \times 16) + (1000 \times 0.0625)}{1000 + 100 + 1000}$$

$$= 1.26$$

## 15. Rigid Pavements

**01. Ans: (a)**

$$\text{Sol: } L = \frac{\delta'}{\alpha(t_2 - t_1)} = \frac{\frac{2.5}{2}}{10 \times 10^{-6}(45 - 10)} = 3571.42 \text{ cm}$$

$$= 35.71 \text{ m}$$

( $\delta' = 50\%$  of gap expansion joint)

**Common data for Questions 02 & 03**

**02. Ans: (a)**

$$\text{Sol: } \sigma_{w(e)} = \frac{C_x E \alpha t}{2}$$

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

$$= 22.35 \text{ kg/cm}^2$$

**03. Ans: (d)**

$$\text{Sol: } l = \left[ \frac{E h^3}{12k(1 - \mu^2)} \right]^{1/4}$$

$$= \left[ \frac{3 \times 10^5 \times 20^3}{12 \times 8(1 - 0.15^2)} \right]^{1/4} = 71.1 \text{ cm}$$

$$\sigma_{w(e)} = \frac{E \alpha t}{3(1 - \mu) \sqrt{l}}$$

$$= \frac{3 \times 10^5 \times 10 \times 10^{-6} \times 16.2}{3(1 - 0.15)} \times \sqrt{\frac{15}{71.1}}$$

$$= 8.75 \text{ kg/cm}^2$$

**Common data for Questions 04 & 05**

**04. Ans: (a)**

$$\text{Sol: } A_s = \frac{B h f r_c}{\sigma_s \times 100} = \frac{\frac{1}{2} \times 7.2 \times 18 \times 1.5 \times 2400}{1700 \times 100}$$

$$= 137.22 \text{ cm}^2/\text{m}$$

$$\text{Spacing} = \frac{100 \times A}{A_s} = \frac{100 \times \left( \frac{\pi}{4} \times 10^2 \right)}{137.22}$$

$$= 57.23 \text{ cm} \approx 550 \text{ mm c/c}$$



**05. Ans: (b)**

$$\text{Sol: } L = \frac{d\sigma_s}{2\sigma_b} = \frac{1 \times 1700}{2 \times 24.6} = 34.55 \text{ cm} \approx 35 \text{ cm}$$

**Common data for Questions 06 & 07**

**06. Ans: (c)**

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

**07. Ans: (c)**

$$\begin{aligned} \text{Sol: } L &= \frac{200\sigma_s A_s}{Bh\gamma_c f} \\ &= \frac{200 \times 1200 \times \frac{\pi}{4} \times (10 \times 10^{-1})^2}{3.75 \times 20 \times 2400 \times 1.5} \times \text{no. of bars} \\ &= 8.72 \text{ c/c} \end{aligned}$$

$$\text{No. of bars} = \frac{\text{width}}{0.3} = \frac{3.75}{0.3} = 12.5 \approx 13 \text{ No's}$$

**08. Ans: (a)**

$$\begin{aligned} \text{Sol: } \sigma_f &= \frac{\gamma_c f L}{2 \times 10^4} = \frac{2400 \times 4 \times 1.2}{2 \times 10^4} \\ &= 0.576 \text{ kg/cm}^2 \end{aligned}$$

## 16. Traffic Engineering

**01. Ans: (a)**

**Sol:** Time mean speed

$$= \frac{50 + 40 + 60 + 54 + 45}{5}$$

$$(V_t) = 49.8 \text{ kmph}$$

$V_s \Rightarrow$  space mean speed

$$\frac{1}{V} = \frac{1}{50} + \frac{1}{40} + \frac{1}{60} + \frac{1}{54} + \frac{1}{45}$$

$$V = 9.76$$

$$V_s = V \times n = 9.76 \times 5 = 48.80 \text{ kmph}$$

**02. Ans: (a)**

**Sol:**

Speed Range (m/s)	Frequency PCU/hr (q)	Mid-pt speed (v)	qv	q/v
2.5	1	2.5	2.5	0.4
7.5	4	7.5	30	0.533
11.5	0	11.5	0	0
15.5	7	15.5	108.5	0.45
	$\Sigma q = 12$		$\Sigma qv = 141.0$	$\Sigma \frac{q}{v} = 1.38$

$$V_t = \frac{\sum qv}{\sum q} = \frac{141}{12} = 11.75 \text{ m/s}$$

$$V_s = \frac{\sum q}{\sum (q/v)} = \frac{12}{1.38} = 8.69 \text{ m/s}$$

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

**03. Ans: 41.8 & 40.91**

$$\text{Sol: Speed of vehicle-A} = \frac{1}{1.2/60} = 50 \text{ kmph}$$

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

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

Average travel speed

$$(V_t) = \frac{50 + 40 + 35.3}{3} \\ = 41.8 \text{ kmph}$$

$$\text{Space mean speed } (V_s) = \frac{n}{\sum \left( \frac{1}{v_i} \right)} \\ = \frac{3}{\frac{1}{50} + \frac{1}{40} + \frac{1}{35.3}} \\ = 40.91 \text{ kmph}$$

04. Ans: 4000 veh/hr

Sol: Design flow rate =  $\frac{q}{\text{PHF}}$

$$\text{PHF} = \frac{q}{4(q_{15})}$$

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

$$\text{Peak hour volume } (q) \\ = 700 + 812 + 1000 + 635 \\ = 3147$$

$$\therefore \text{Design flow rate} = \frac{3147}{\frac{3147}{4000}} \approx 4000 \text{ veh/hr}$$

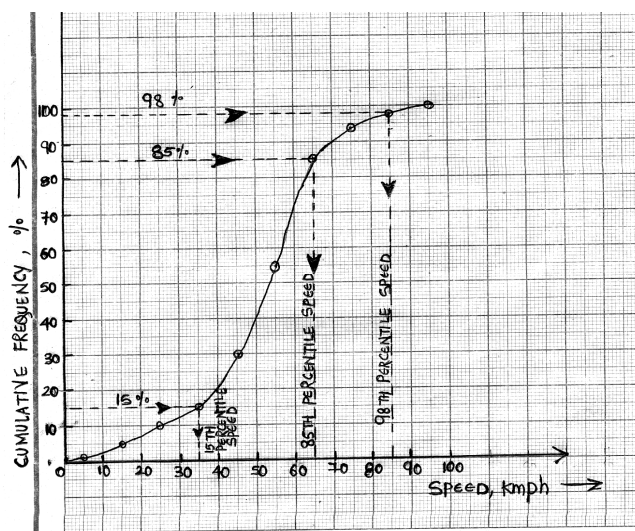
05.

Sol: Total frequency = 100

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

- (i) 85<sup>th</sup> percentile speed is considered as a safe speed from graph  $V_{85} = 65 \text{ kmph}$
- (ii) 98<sup>th</sup> percentile speed is considered as a design speed from graph  $V_{98} = 85 \text{ kmph}$

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



06. Ans: (c)

Sol: 
$$\text{SSD} = 0.278 Vt + \frac{V^2}{254 f}$$

$$= 0.278 \times 65 \times 2.5 + \frac{65^2}{254 \times 0.4}$$

$$= 86.7 \text{ m}$$

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

$$C = \frac{1000 V}{S} = \frac{1000 \times 65}{91.7}$$

$$\approx 709 \text{ veh/hr/lane}$$

07. Ans: (b)

Sol:  $t = 0.7$  Assume

$$\text{SSD} = 0.278 Vt = 7.78 \text{ m}$$

$$S = \text{SSD} + L = 12.78 \text{ m}$$

$$C = \frac{1000 V}{S} = 3129 \approx 3130 \text{ veh/hr}$$

**08. Ans: (b)**

**Sol:**  $S = SSD + L = 20 + 6 = 26 \text{ m}$

$$C = \frac{1000 V}{S} = \frac{1000 \times 40}{26} = 1538 \text{ veh/hr/lane}$$

**09. Ans: (c)**

**Sol:** Given standard deviation (SD) = 8.8 kmph  
mean speed  $\bar{x} = 33 \text{ kmph}$

$$\text{Coefficient of variation} = \frac{SD}{\bar{x}} = \frac{8.8}{33} = 0.2666$$

**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 ;  $\frac{dq}{dk} = 0$

$$\frac{dq}{dk} = U_{sf} \left[ 1 - \frac{2k}{k_j} \right] = 0$$

$$1 - \frac{2k}{k_j} = 0$$

$$k_j = 2k$$

$$U_{sf} = 70 \text{ km/hr}$$

$$k_j = \frac{1000}{s} = \frac{1000}{7}$$

$$k = k_j/2$$

$$q = U_{sf} \left[ k - \frac{k^2}{k_j} \right] = U_{sf} \left[ k - \frac{k}{2} \right]$$

$$= U_{sf} \left[ \frac{k_j}{2} - \frac{k_j}{4} \right]$$

$$= U_{sf} \left[ \frac{k_j}{4} \right]$$

$$q = 70 \times \frac{1000}{7} \times \frac{1}{4} = 2500 \text{ veh/hr}$$

**11. Ans: (d)**

**Sol:**  $V_{sf} = 80 \text{ kmph}$

$$k_j = 100 \text{ veh/km}$$

$$q_{\max} = \frac{V_{sf} \times k_j}{4} = \frac{80 \times 100}{4} = 2000 \text{ veh/hr}$$

$$V_s = \frac{V_{sf}}{2} \text{ (the speed corresponding to } q_{\max} \text{ is } V_{s \max}) = \frac{80}{2} = 40 \text{ kmph}$$

**12. Ans: 33 veh/km & 149 veh/km**

**Sol:**  $q_m = 1700 \text{ veh/hr}$

$$k_m = \frac{1000}{S} = \frac{1000}{5.5} = 181.81$$

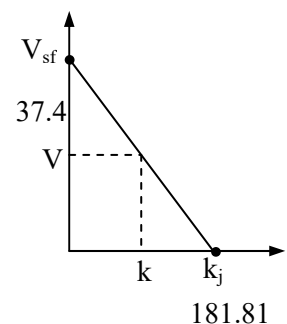
$$q_m = \left( \frac{V_m}{2} \right) \left( \frac{k_m}{2} \right)$$

$$1700 = \left( \frac{V_m}{2} \right) \left( \frac{181.81}{2} \right)$$

$$v_m = 37.40 \text{ kmph}$$

For  $q = 1000 \text{ veh/hr}$

$$\tan \theta = \frac{V_m}{k_m}$$



$$v = \frac{37.4}{181.81} \times (181.81 - k)$$

For normal condition

$$q = v \cdot k$$

$$1000 = \frac{37.4}{181.81} \times (181.81 - k) \times k$$

$$4861.23 = (181.81 - k)k$$

$$4861.23 = 181.81k - k^2$$

$$k = 149 \text{ veh/km and } k = 32.6 \text{ veh/km}$$

$$\approx 33 \text{ veh/km}$$

**13. Ans: 35.7 kmph**

**Sol:**  $V_{sf} = 50 \text{ kmph}$

$$k_j = 70 \text{ veh/km}$$

$$q_{\max} = \frac{V_{sf} \times K_j}{4} = \frac{50 \times 70}{4} = 875 \text{ veh/hr}$$

$$K = 20 \text{ veh/km}$$

$$\frac{K_j}{V_{sf}} = \frac{K_j - K}{V - 0}$$

$$\frac{70}{50} = \frac{70 - 20}{V} \Rightarrow V = 35.7 \text{ kmph}$$

**14. Ans: 1268 veh/hr**

**Sol:**

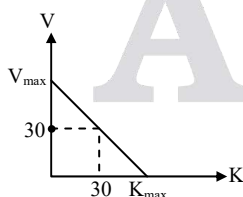
$$\frac{V_{\max}}{K_{\max}} = \frac{30 \text{ kmph}}{(130 - 30)}$$

$$K_{\max} = 130 \text{ veh/km}$$

$$V_{\max} = \frac{30}{130 - 30} \times 130 = 39 \text{ kmph}$$

$$Q_{\max} = \left( \frac{V_{\max}}{2} \right) \left( \frac{K_{\max}}{2} \right)$$

$$= \frac{39}{2} \times \frac{130}{2} \approx 1268 \text{ veh/hr}$$



**15. Ans: (b)**

$$\text{Sol: } Q_p = \frac{280 w \left( 1 + \frac{e}{w} \right) \left( 1 - \frac{p}{3} \right)}{1 + \frac{w}{L}}$$

$$w = 14 \text{ m; } e = 8.4 \text{ m}$$

$$L = 35 \text{ m}$$

$$p = \frac{\text{Crossing traffic}}{\text{Total traffic}}$$

$$= \frac{1000}{2000} = 0.5$$

$$Q_p = \frac{280 \times 14 \left( 1 + \frac{8.4}{14} \right) \left( 1 - \frac{0.5}{3} \right)}{1 + \frac{14}{35}} = 3733.33 \text{ PCU/hr}$$

**16. Ans: 2064.10 veh/hr**

**Sol:**

$$w = 6 \text{ m; } p = 0.5$$

$$L = 20 \text{ m; } e = 5.5 \text{ m}$$

$$= \frac{280 \times 6 \left[ 1 + \frac{5.5}{6} \right] \left[ 1 - \frac{0.5}{3} \right]}{1 + \frac{6}{20}}$$

$$Q_p = 2064.10 \text{ veh/hr}$$

**17. Ans: 0.8%**

$$\text{Sol: Weaving ratio} = \frac{\text{weaving traffic}}{\text{total traffic}}$$

$$= \frac{V_{13} + V_{24} + V_{43}}{V_{13} + V_{23} + V_{24} + V_{14} + V_{43} + V_{21}}$$

$$= \frac{450 + 1090 + 600 + 310}{450 + 200 + 1090 + 412 + 600 + 310}$$

Weaving ratio = 0.80%

**18. Ans: (b)**

**Sol:**

$$\left. \begin{aligned} y_N &= \frac{1000}{2500} \\ y_S &= \frac{700}{2500} \end{aligned} \right\} y_{NS} = 0.4$$

$$\left. \begin{aligned} y_E &= \frac{900}{3000} \\ y_W &= \frac{550}{3000} \end{aligned} \right\} y_{EW} = 0.3$$

$$\begin{aligned} y &= y_{NS} + y_{EW} \\ &= 0.4 + 0.3 = 0.7 \end{aligned}$$

$$L = 12 \text{ sec}$$

$$\begin{aligned} C_o &= \frac{1.5L + 5}{1 - y} = \frac{1.5 \times 12 + 5}{1 - 0.7} \\ &= 76.7 \text{ sec} \approx 77 \text{ sec} \end{aligned}$$

**19. Ans: (d)**

**Sol:**  $y = 0.5 = y_a + y_b$

$$L = 10 \text{ sec}$$

$$C_o = \frac{1.5L + 5}{1 - y} = \frac{1.5 \times 10 + 5}{1 - 0.5} = 40 \text{ sec}$$

**20. Ans: 14.23 /veh , 1540 veh/hr**

**Sol:**  $C = S \times \frac{g}{C_o}$

$S \rightarrow$  Saturation flow

$g_i \rightarrow$  effective green time

$C_o \rightarrow$  Cycle time/Optimum signal cycle length

$\frac{g_i}{C_o} \rightarrow$  Green Ratio

$$C = 2800 \times 0.55 = 1540 \text{ veh/hr}$$

$$\begin{aligned} d_i &= \frac{\frac{C_o}{2} \left( 1 - \frac{g_i}{C_o} \right)^2}{1 - \frac{V_i}{S}} \\ &= \frac{\frac{90}{2} (1 - 0.55)^2}{1 - \frac{1000}{2800}} = 14.23 / \text{veh} \end{aligned}$$

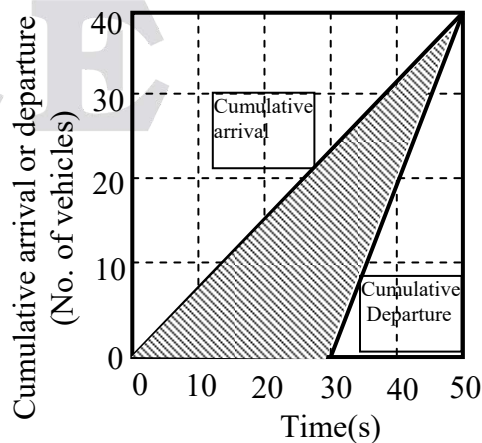
**21. Ans: (a)**

**Sol:** Average delay at red signal is  $= \frac{\text{red time}}{2}$

$$= \frac{30}{2} = 15 \text{ sec}$$

(or)

**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

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

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

**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

$$= 2 + 1 = 3 \text{ sec}$$

Effective green time ;  $g = G + y - t_L$

$$= 27 + 4 - 3 = 28 \text{ sec}$$

$$\text{Saturation flow rate; } S = \frac{3600}{h} = \frac{3600}{2.4}$$

$$= 1500 \text{ veh/hr}$$

$h \rightarrow$  Time headway

$$\text{Capacity of lane, } C = S \times \left( \frac{g_i}{C_0} \right)$$

$$= 1500 \times \left( \frac{28}{60} \right)$$

$$= 700 \text{ veh/hr/lane}$$

**24. Ans: (d)**

**Sol:** Distance travelled by bicycle = 5 km

Time of travel,  $t = 40 - 15 = 25 \text{ min}$

Stop time = 15 min

$$\text{Speed of bicycle} = V_b = \frac{5}{25} \text{ km/min}$$

Let speed of stream is  $V \text{ km/min}$

Assume traffic density is the constant on the road ( $K = \text{Constant}$ ).

$$\text{but } K = \frac{q}{V}$$

During journey relative speed of stream =  $V - V_b$

$$= \left( V - \frac{5}{25} \right)$$

$$K = \frac{\left( \frac{60}{25} \right) \text{ Vehicles/min}}{\left( V - \frac{5}{25} \right)} \dots\dots(1)$$

During stop ( $V_b = 0$ )

$$K = \frac{\left( \frac{45}{15} \right) \text{ Vehicles/min}}{V} = \frac{45}{15V} \dots\dots(2)$$

Equating (1) & (2)

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



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

$$0.2 = \frac{5}{25V}$$

$$\Rightarrow V = \frac{5}{25 \times 0.2}$$

$$\Rightarrow V = 1 \text{ km/min}$$

$$V = 60 \text{ km/hr}$$

**25. Ans: 2133.33 veh/hr**

**Sol:**  $V = 80 - 0.75 K$

$V_{\max}$  occur, when  $K = 0$

$V_{\max} = 80 \text{ kmph}$

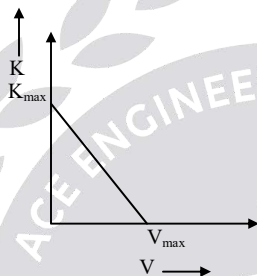
$K_{\max}$  occur when  $V = 0$

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

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

$$q = \frac{106.67 \times 80}{4}$$

$$q = 2133.33 \text{ veh/hr}$$



**26. Ans: (c)**

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

**27. Ans: Drivers Claim was Correct**

**Sol: Given:**

Speed of the vehicle = 60 kmph

Amber duration = 4 sec

Comfortable deceleration =  $3 \text{ m/sec}^2$

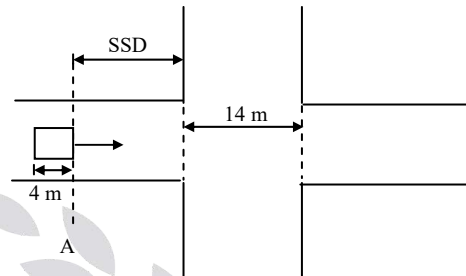
Car length = 4.0 m

Intersection width = 14 m

Longitudinal friction factor = 0.35

Perception reaction time = 1.5 sec

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



**(i) Driver decides to cross intersection:**

Total distance to be covered

$$= \text{SSD} + 14 + 4.0$$

$$\text{SSD} = (vt) + \frac{v^2}{2gf}$$

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

$$= 65.47 \text{ m}$$

Total distance to be covered

$$= 65.47 + 14 + 4 = 83.47 \text{ m}$$

$$\text{Time required} = \frac{\text{distance}}{\text{speed of vehicle}} = \frac{83.47}{16.67} = 5.0 \text{ sec} > 4 \text{ sec}$$

**(ii) He decides to stop the vehicle time taken to stop the vehicle after sighting the amber light.**  
= Reaction time + time taken to stop the vehicle after application of brakes

$$= 1.5 + \left( \frac{60 \times \frac{5}{18} - 0}{3} \right)$$

$$= 1.5 + 5.55$$



$$= 7.05 \text{ sec} > 4 \text{ sec}$$

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

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

$\lambda$  = 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, d)**

**Sol:** In North/south direction.

$$\text{Flow ratio } q_1 = 900/2100 = 0.428$$

In East west direction.

$$\text{Flow ratio } q_2 = 950/2150 = 0.442$$

$$\text{Cycle time} = \frac{1.5L + 5}{1 - y}$$

$$L = \text{lost time} = 2n + R = (2 \times 2) + 10 = 14 \text{ sec}$$

$$y = q_1 + q_2 = 0.428 + 0.442 = 0.87$$

$$\text{Cycle time} = \frac{1.5 \times 14 + 8}{1 - 0.87} = 200$$

$$\text{Effective green time per cycle} = 200 - 14 = 186 \text{ sec}$$

## 17. 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  $4^\circ$  curve, the grade compensation is

$$= 0.04 \times 4 = 0.16\%$$

**03. Ans: (b)**

$$\text{Sol: Ruling gradient in \%} = \frac{1}{250} \times 100 = 0.4\%$$

Grade compensation at 0.04% per degree of

Curve =  $0.04 \times 3 = 0.12\%$

Compensated gradient =  $0.4 - 0.12$

$$= 0.28\%$$

$$= \frac{0.28}{100} = \frac{1}{357}$$

**06. Ans: (c)**

**Sol:**

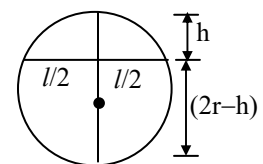
From circle property,

$$\frac{\ell}{2} \cdot \frac{\ell}{2} = h(2r - h)$$

$$\frac{\ell^2}{4} = 2rh - h^2$$

$h^2$  is neglected (being very small)

$$\therefore h = \frac{\ell^2}{8r}$$



**07. Ans: (a)**

**Sol:**

$$\begin{aligned}\text{Grade compensation} &= 2 \times 0.04 \% \\ &= 0.08\%\end{aligned}$$

$$\text{Stipulated ruling gradient} = 0.5\%$$

$$\begin{aligned}\text{Steepest gradient} &= 0.5\% - 0.08\% \\ &= 0.42\% = \frac{1}{238}\end{aligned}$$

**08. Ans: (c)**

**Sol:**

$$\begin{aligned}\text{Curve resistance} &= 0.04\% \times D^\circ \\ &= 0.04 \times 4 = 0.16\%\end{aligned}$$

$$\text{Ruling gradient} = \frac{1}{150} = \frac{1}{150} \times 100 = 0.67\%$$

$$\begin{aligned}\text{Compensated gradient} &= 0.67 - 0.16 \\ &= 0.51\% \\ &= \frac{0.51}{100} = \frac{1}{196}\end{aligned}$$

**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

$$\text{Weighted average} = \frac{n_1 V_1 + n_2 V_2 + n_3 V_3 + n_4 V_4}{n_1 + n_2 + n_3 + n_4}$$

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

$$V = 58.125 \text{ kmph}$$

$$\begin{aligned}e &= \frac{GV^2}{127R} = \frac{1.676 \times 58.125^2}{127 \times 860} \\ &= 0.0518 \text{ m} \\ &= 5.18 \text{ cm}\end{aligned}$$

$$\begin{aligned}\text{Theoretical cant} &= \text{Equilibrium cant} + \text{cant deficiency} \\ &= 5.18 + 7.60 \\ &= 12.78 \text{ cm}\end{aligned}$$

$$\begin{aligned}e &= \frac{GV^2}{127R} \\ \frac{12.78}{100} &= \frac{1.676 \times V^2}{127 \times 860} \\ V &= 91.26 \text{ kmph}\end{aligned}$$

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:**  $e = 12\text{cm}$

$$V_{\max} = 85 \text{ kmph}$$

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

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**

$$L = 0.073 DV_{\max}$$

$$L = 0.073 \times 7.6 \times 85$$

$$L = 47.158\text{cm}$$

**(c) Based on rate of change of super elevation**

$$L = 0.073e V_{\max}$$

$$L = 0.073 \times 12 \times 85$$

$$L = 74.46\text{cm}$$

$\therefore$  Take maximum  $L = 86.4\text{cm}$

**12. (a, b, c, d)**

**Sol:** The permissible speed on a curve in a railway track is minimum

- (i) Maximum sanctioned speed
- (ii) Speed obtained from Martin's formula which depends on Radius of the curve
- (iii) Speed based on Super elevation
- (iv) Speed based on length of the transition curve

**18. Airport Runway and Taxiway Design**

**01. Ans: (a)**

**Sol:** Wind coverage is the time in a year of time during which cross wind component is as minimum as possible.

**02. Ans: (a)**

**Sol:** Length of runway under Standard condition  
 $= 2100\text{ m}$

We have to increase 7% for every 300 m elevation above ground so length of runway

$$= 2100 + \frac{7}{100} \times 2100 = 2247\text{ m}$$

**03. Ans: (c)**

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

Airport reference temperature (ART) =  $16^\circ\text{C}$

Airport standard temperature (AST)

= standard temperature at msl  $-6.5^\circ\text{C}$  for  
 1 km height above msl

$$\text{AST} = 15 - 6.5 = 8.5^\circ\text{C}$$

Rise in temperature as per

$$\text{ICAO} = 16 - 8.5 = 7.5^\circ\text{C}$$

**04. Ans: 3388.89 m**

**Sol:** Runway length = 2460 m

**Correction for elevation (ICAO)**

$$300\text{ m} \rightarrow 7\%$$

$$486 \rightarrow x$$

$$x = 11.34\%$$

**Corrected length after elevation correction**

$$= \frac{11.34}{100} \times 2460 + 2460$$

$$= 2738.964\text{ m}$$

**Correction for temperature**

$$\begin{aligned} \text{ART} &= T_1 + \frac{T_2 - T_1}{3} \\ &= 30.2 + \frac{(46.3 - 30.2)}{3} \end{aligned}$$

$$\text{ART} = 35.57^\circ$$

Standard Temperature at airport

$$= 15 - 0.0065h$$

Temperature @ airport @ 486 m elevation

$$= 15 - 0.0065 \times 486 = 11.841^\circ$$

Runway length corrected for elevation is further corrected at 1% increase in length for 1° rise above standard temperature.

$$\begin{aligned}\text{Rise in temperature} &= (35.57^\circ - 11.841^\circ) \\ &= 23.729^\circ\end{aligned}$$

1% → 1° change

$$x \rightarrow 23.729^\circ$$

$$x = 23.729\%$$

$$\begin{aligned}\text{Correction} &= \frac{23.729}{100} \times 2738.964 + 2738.964 \\ &= 3388.89 \text{ m}\end{aligned}$$

**05. 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

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

**06. Ans: (d)**

**Sol:** Given  $T_m = 40^\circ\text{C}$

$$T_a = 25^\circ\text{C}$$

$$\text{ART} = \frac{2T_a + T_m}{3}$$

$$= \frac{2 \times 25 + 40}{3}$$

$$= 30^\circ\text{C}$$

**07. Ans: 2186.26 m**

**Sol:** Length of runway = 1640 m

$$\text{Elevation} = 280 \text{ m}$$

$$\text{Reference temperature} = 33.5^\circ\text{C}$$

$$\text{Effective gradient} = 0.2\%$$

**Correction for Elevation (ICAO)**

Basic runway length should be increased at the rate of 7% per 300m rise in elevation.

For 300 m – 7 %

$$280 \rightarrow x$$

$$x = 6.53\%$$

$$\begin{aligned}\text{Correction} &= 1640 + \frac{6.53}{100} \times 1640 \\ &= 1747.15 \text{ m}\end{aligned}$$

**Correction for temperature (ICAO)**

Runway length corrected for elevation is further corrected at 1% increase in length for 1° rise above standard temperature.

$$\text{ART} = 33.5^\circ\text{C}$$

Temp @ airport @ 280 m elevation

$$= 15 - 0.0065 \times 280 = 13.18^\circ$$

Raise above standard temperature

$$= 33.5^\circ - 13.18^\circ$$

$$= 20.32^\circ$$

$$1^\circ \uparrow \rightarrow 1\% \uparrow$$

$$20.32^\circ \uparrow \rightarrow x$$

$$x = 20.32\%$$

$$\begin{aligned}\text{Correction} &= \frac{20.32}{100} \times 1747.15 + 1747.15 \\ &= 2102.17 \text{ m}\end{aligned}$$

**Correction for gradient:**

The runway length corrected for elevation and temperature should further be increased by 20% for 1% effective gradient.

For 0.2%, correction = 4%

Runway length corrected to gradient  
 $= 2102.17 + (2102.17 \times 4/100) = 2186.26 \text{ m}$

**08. Ans: 0.2 %**

**Sol:**

Chainage	Gradient	Elevation
0	—	280 m
300	+1%	$(280 + 0.01 \times 300) = 283$
900	-0.5%	$283 - \frac{0.5}{100} \times 600 = 280$
1500	+0.5	$280 + \frac{0.5}{100} \times 600 = 283$
1800	+1	$283 + 0.01 \times 300 = 286$
2100	-0.5	$286 - \frac{0.5}{100} \times 300 = 284.5$
2700	-0.4	$284.5 - \frac{0.4}{100} \times 600 = 282.1$
3000	-0.1	$282.1 - \frac{0.1}{100} \times 300 = 281.8$

Effective gradient = maximum difference in elevation between highest and lowest point of runway divided by total length of runway

$$= \left( \frac{286 - 280}{3000} \right) \times 100 = 0.2\%$$

**09. Ans: 400 m**

**Sol:**

(i) Horonjeff's equation:

$$R = \frac{0.388 w^2}{0.5T - S}$$

$$= \frac{0.388 \times 17.7^2}{0.5(23) - \left( 6 + \frac{6.62}{2} \right)} = 55.50 \text{ m}$$

(ii) Turning radius

$$R = \frac{V^2}{125f}$$

$$= \frac{80^2}{125 \times 0.13} = 393.85 \text{ m}$$

(iii) The minimum radius of sub sonic aircraft is 135 m

∴ Turning radius = Maximum of three conditions

$$= 393.85 \text{ m}$$

$$R \approx 400 \text{ m}$$