th nov,
SUN'
HURSDAY

TRANSPORTATION ENGINEERING

(8-10 marks)

1. Geometric Design (3 to 4 m)
2. Highway material. (1 to 2 m)
3. Pavement Design. (2 to 4 m)
4. Traffic (4 to 5 m)

Carriage way ⇒ LDF = 0.4

01 HIGHWAY DEVELOPMENT AND PLANNING

- Romans are the pioneers in road construction. 29 roads meet in Rome.
- First British Road : GT from Calcutta to Delhi.

→ Chronology of Development.

(i) Treasagat construction T
(ii) Metcalf construction M
(iii) Telford construction T
(iv) Macadam construction. M

→ Highway Development in India

1. Jayakar Committee 1927
2. Central Road Fund - CRF 1929
3. Indian Roads Congress. - IRC 1934
4. Motor Vehicle's Act. 1939
5. Nagpur Road Conference. 1943 - 1963
6. Central Road Research Institute - CRRI. 1950
7. National Highway Act 1956
8. Second Road Development Plan. 1961 - 1981
   (Bombay Road Plan)
9. Highway research board of IRC - 1973
10. Third Twenty Year Plan. 1981 - 2001
    (Lucknow Plan).

11. National Highway Authority of India - NHAI

12. National Highway Development Program - NHDP.

* Projects under NHDP

(i) Golden Quadrilateral.

Delhi - Kolkata - Chennai - Mumbai

(ii) North South Corridor

Srinagar - Kanyakumari

(iii) East West Corridor

Silchar - Porbandar

(iv) Port connectivity & others.

Constructions are based on BOT system (Build Operate Transfer). Contractors will build the roads, operate it and transfer it to government finally.

13. State Highway Research Laboratories.

14. Highway staff Training Institute.

15. National Rural Road Development Agency - NRRDA.

⊙ Longest National Highway - NH 7.

Varanasi - Kanyakumari

For more details : www. nhai.org

→ Concept of Saturation System.

Factors considered are :

(i) Population

(ii) Agricultural and industrial productivity.

)-5

02

Population	1000 – 2000	2000–5000	5000 –10000	>10,000
Weightages (assumed).	1	2	3	4

Priority of road P $= \dfrac{100\times1 + 80\times2 + 30\times3 + 6\times4 + 200}{\text{length of road P}}$

$= \underline{\underline{1.91}}$

Priority of road Q $= \dfrac{200\times1 + 90\times2 + 8\times4 + 270}{400} = \underline{\underline{1.75}}$

Priority of road R $= \dfrac{240\times1 + 110\times2 + 70\times3 + 10\times4 + 315}{500} = \underline{\underline{2.05}}$

Priority of road S $= \dfrac{248\times1 + 112\times2 + 73\times3 + 12\times4 + 335}{550} = \underline{\underline{1.95}}$

Priority order → R – S – P – Q (highest – least).

01. Priority of P $= \dfrac{8\times1 + 6\times2 + 1\times3}{20} = 1.15$

Priority of Q $= \dfrac{19\times1 + 8\times2 + 4\times3}{28} = 1.68$

Priority of R $= \dfrac{7\times1 + 5\times2 + 2\times3}{12} = 1.92$

bination Camber

$\underline{\underline{R > Q > P}}$

02. HIGHWAY ALIGNMENT

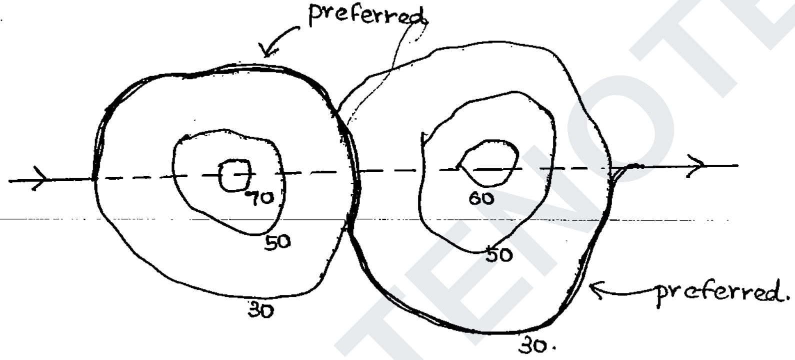
Alignment

- Fixing centre line of a road.
- Alignment should be :-

(i) Short (ii) Easy (iii) Safe (iv) Economy.

Engineering Surveys for Highway Alignment :

(i) Map Study



(ii) Reconaissance.

(iii) Preliminary Survey

(iv) Final location & detailed survey.

Drawings Required :

(i) Keymap

shows proposed and existing roads and important places to be connected.

(ii) Index Map.

shows general topography of the area.

- In submergible area, formation level of road should be 0.6 m above HFL.

03 HIGHWAY GEOMETRIC DESIGN

BASIC ELEMENTS

→ Design Speed

– most important factor controlling geometric design element of highways.

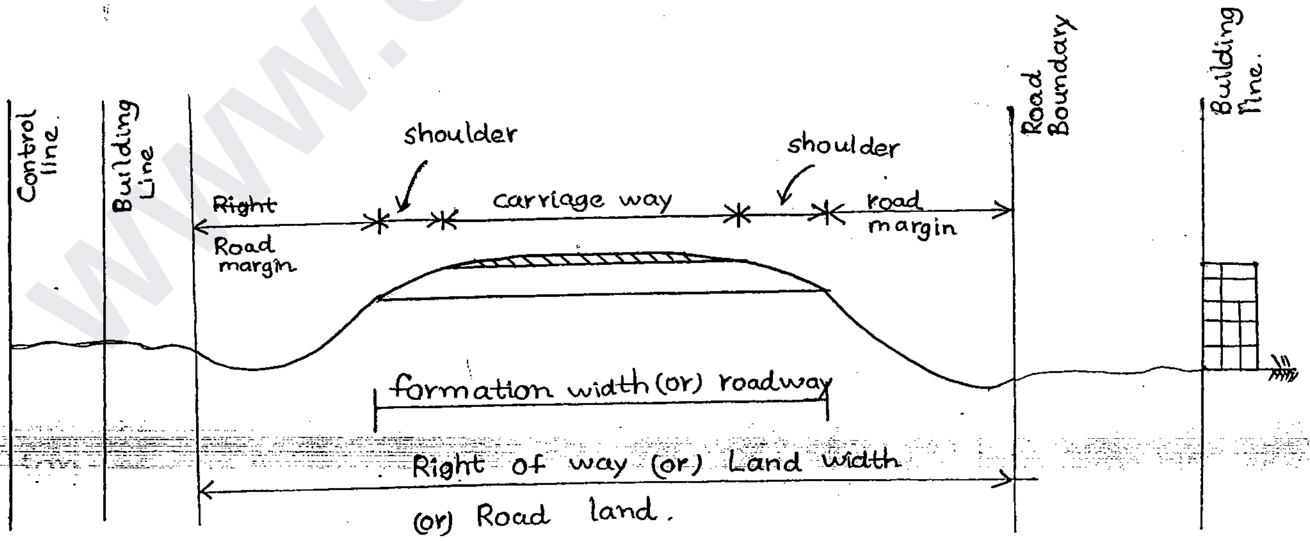
– Factors considered are :

(i) Importance of road.

(ii) Terrain or topography.

	Cross slope (%)
a) Plain	0 - 10
b) Rolling	10-25
c) Mountaneous.	25 - 60
d) Steep.	>60

→ Highway Cross Section Elements.



* Friction (Skid Resistance).

- Longitudinal frictional coeffecient : 0.35 - 0.4

It is recommended by IRC for calculation of SSD.

- For horizontal curve design,

lateral friction coeffecient = 0.15

* Pavement Unevenness

- instruments used roughometer, bump indicator.

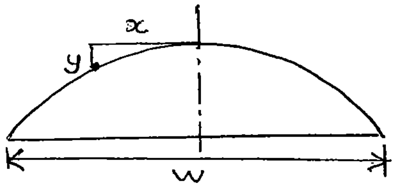
* Camber

- cross slope to drain off rain water from road surface
- Types of cambers :

a) Parabolic Camber

- Flexible pavement (WBM, Gravel, earth, BT).

$$\boxed{y = \frac{2x^2}{NW}}$$; camber slope = 1 in N



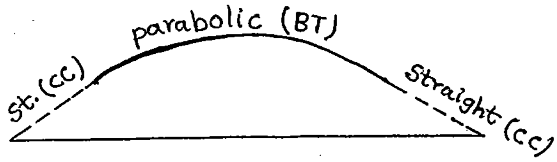
Max. central rise : for $x = \frac{W}{2}$

$$y_{max} = \frac{2\left(\frac{W}{2}\right)^2}{NW} = \frac{W}{2N}.$$

b) Straight line camber

- rigid pavements (RCC, CC)

c) Combination Camber



⊙ Camber should be half of longitudinal gradient (G)

$$\boxed{G = 2C}$$

imp

Type of Road Surface.	Range of camber in rainfall	
	Heavy	Light.
1. Cement concrete & high type bituminous surface.	1 in 50	1 in 60
2. Thin bituminous surface.	1 in 40	1 in 50
3. WBM, Gravel.	1 in 33	1 in 40
4. Earth road.	1 in 25	1 in 33.

RCC > CC >> Thick BT >> Thin BT > WBM > Gravel > Earth.
(Superior the road, flatter the camber)

* Width of Pavement or Carriage way.

– max. width of vehicle as per IRC is 2.44 m

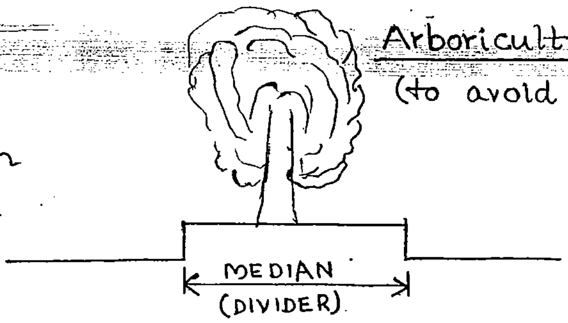
imp

1. Single Lane.	3.75 m
2. Two Lanes without raised kerbs.	7.0 m
3. Two lanes with raised kerbs.	7.5 m
4. Intermediate carriage way.	5.5 m
5. Multilane pavements.	3.5 per lane

* Median.

– min 5m.

– upto 1.2m on long bridges.



Arboriculture
(to avoid night glare).

* Min. shoulder width. = 2.5 m

04. HIGHWAY GEOMETRIC DESIGN

GRADIENTS

→ Gradient

Ground slope along road.

→ Type of Gradients.

1. Ruling Gradient
   - also known as 'Design Gradient'
   - gradient on road during normal course.
   - speed of vehicle should not decrease while moving on gradient.
2. Limiting Gradient
   - maximum gradient steeper than ruling gradient for restricted length.
3. Exceptional Gradient.
   - gradient steeper than limiting gradient.
   - used in short stretches only (<60m in 1 km length).
   - in exceptional situations
4. Minimum Gradient.
   - based of road drainage requirements.

→ Grade Compensation.

– It is the reduction in gradient if gradient + horiz. curve occur on road.

$$\boxed{GC\,(\%) = \frac{30+R}{R} \text{ or } \frac{75}{R}}$$; whichever is less.

R → radius of curve (in m).

⊙ Gradient more than 4% is to be compensated. After grade compensation, the gradient to be provided on the road should not be less than 4%.

P-13

Q.1 $G = \frac{1}{20} = 5\%$; $R = 150$ m.

$$GC = \frac{30+R}{R} = \frac{30+150}{150} = 1.2\%$$

$$= \frac{75}{150} = 0.5\%$$

Grade compensation $= \underline{\underline{0.5\%}}$ (min).

Q.2. $GC = \frac{30+30}{30} = 2\%$

$= \frac{75}{30} = 2.5\%$

} min $= 2\%$

But $5-2 = 3\% \underline{\underline{< 4\%}}$

$G = \frac{1}{20} = 5\%$.

$\Rightarrow GC = 5-4 = \underline{\underline{1\%}}$

Q.8. $G = \frac{1}{20} = 5\%$

$$GC = \frac{30+80}{80} = 1.375\%$$

$$= \frac{75}{80} = 0.9375\%$$

$\therefore GC = 0.9375\%$

Compensated gradient $= 5 - 0.9375 = 4.0625\%$

$$= \frac{1}{100/4.0625} = \underline{\underline{\frac{1}{24.6}}}$$

6. $y = \frac{2x^2}{NW} = \frac{2x^2}{60 \times 3.5} = \underline{\underline{\frac{x^2}{105}}}$

7 $G = 2C = 2 \times \frac{1}{48} = \underline{\underline{\frac{1}{24}}}$

P-15.

1. $W = 3.5$ m

CC (light rain) ⇒ Camber = 1 in 60

Straight line camber.

$\therefore y = \frac{W}{2N} = \frac{3.5}{2 \times 60} = \underline{\underline{29.16}}$ mm

2. Thin BT (heavy rain) ⇒ Camber = 1 in 40

Parabolic camber.

$\therefore y = \frac{W}{2N} = \frac{3.5}{2 \times 40} = \underline{\underline{43.75}}$ mm

4. Gradient = 6%

$R = 50$ m.

$GC = \frac{30+50}{50} = 1.6$

$= \frac{75}{50} = 1.5$

$\therefore$ Compensated gradient $= 6 - 1.5 = \underline{\underline{4.5\%}}$

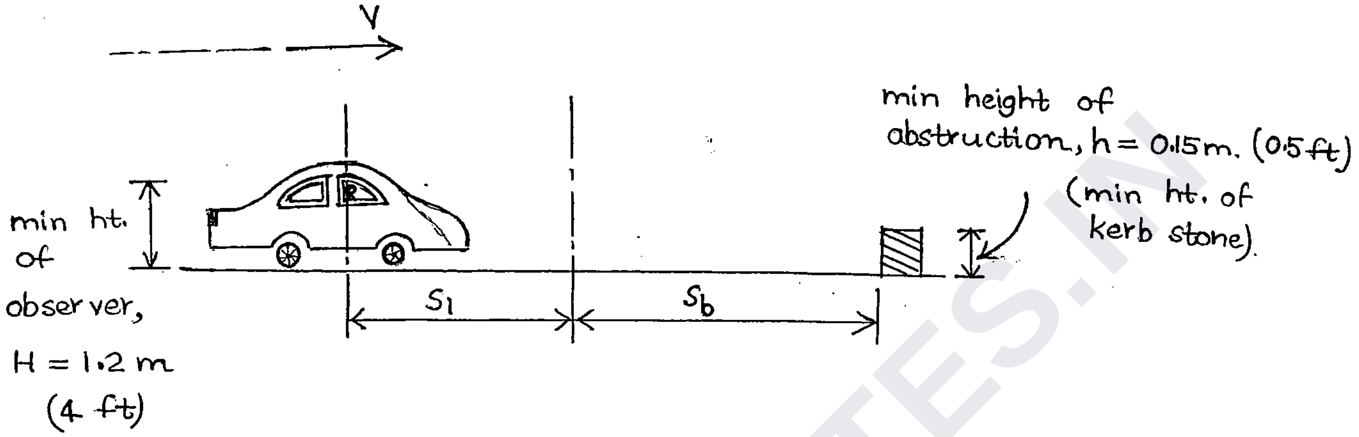
05. $y_{max} = 7.5$ cm.

$y = \frac{W}{2N}$.

$N = \frac{900}{2 \times 7.5} = 60$ ⇒ Camber = $\underline{\underline{\text{1 in 60}}}$

05. SIGHT DISTANCES

→ Stopping Sight Distance. (SSD)



V → design speed. (m/s).

S_l → lag distance.

S_b → braking distance.

$$SSD = S_l + S_b.$$

$$\boxed{SSD. = vt + \frac{v^2}{2gf}}$$; on level ground.

where t → reaction time (as per IRC min 2.5s)

t is based on PIEV theory

P : Perception (eyes)

I : Intellection (brain)

E : Emotion (brain).

V : Volition. (legs / hands)

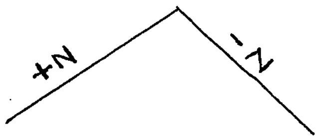
→ Factors affecting SSD.

(i) Braking efficiency. (η).

$$SSD = vt + \frac{v^2}{2g(f\eta)}$$

(ii) Gradient

- upward gradient → (+N)
- downward gradient → (−N)



$$SSD = vt + \frac{v^2}{2g(f \pm N)}$$; N → gradient as a ratio.

ie $N = 2\% = \frac{2}{100}$

(iii) Braking efficiency & Gradient.

$$\boxed{SSD = vt + \frac{v^2}{2g(\eta f \pm N)}}$$

4th nov, 21DAY

→ Safe SSD

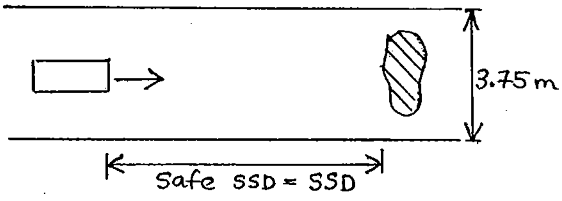
It depends on:

(i) No: of lanes

(ii) Direction of traffic (one way or two way)

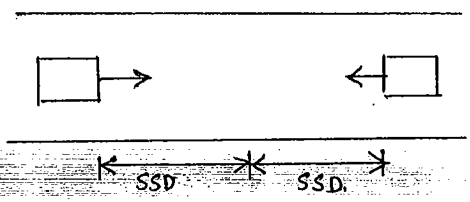
* Single Lane (one way)

$$\boxed{\text{Safe } SSD = SSD}$$



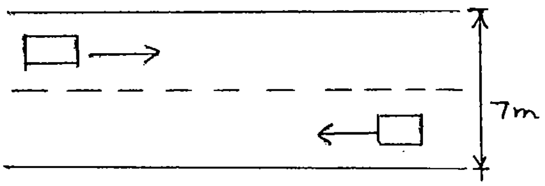
* Single Lane (two way).

$$\boxed{\text{Safe } SSD = 2SSD}$$



* Duel Lane (two way)

$$\boxed{\text{Safe } SSD = SSD.}$$



NOTE:

- Except in case of single lane two way roads, safe SSD = SSD.

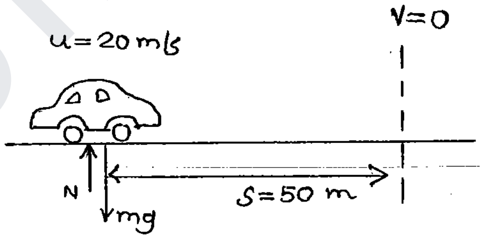
⊙ If the vehicle skids on the road by locking the wheels, linear motion equations should be used (SSD equation is not applicable).

$V = u + at$
$V^2 - u^2 = 2as$
$S = ut + \frac{1}{2}at^2$

P-19

08. $m = 1250$ kg , $v = 72$ kmph. $= 72 \times \frac{5}{18}$ m/s

$= 20$ m/s.



$$V^2 - u^2 = 2as$$

$$0 - 20^2 = 2a \times 50.$$

$$a = -4 \text{ m/s}^2 \text{ (retardation)}.$$

$$f = \frac{a}{g} = \frac{4}{g}$$

Skid resisting force = Frictional force.

$$= F = fN.$$

$$= \left(\frac{4}{g}\right) \times mg$$

$$= 4 \times 1250 = \underline{\underline{5000 \text{ N}}}$$

9. $a = 4.2$ m/s^2

$$f = \frac{a}{g} = \frac{4.2}{g} = \underline{\underline{0.43}}$$

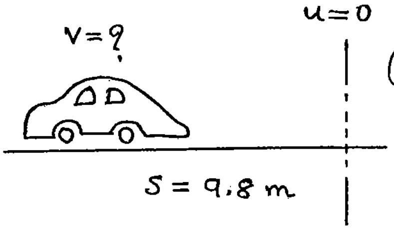
10. $t = 2s$, $S = 9.8$ m.

$$S = 0 + \frac{1}{2}at^2$$

$$9.8 = 0 + \frac{1}{2} \times a \times 2^2$$

$$a = 4.9 \ m/s^2$$

$$f = \frac{a}{g} = \frac{4.9}{9.81} = \underline{\underline{0.5}}$$



04. $V = 80 \text{ kmph} = 80 \times \frac{5}{18} = 22.22 \ m/s$

Assume $t = 2.5s$

$f = 0.35$

$$SSD = Vt + \frac{V^2}{2gf} = 22.22 \times 2.5 + \frac{22.2^2}{2g \times 0.35}$$

$$= \underline{\underline{127 \ m}}$$

05. $$\frac{V^2}{2g(f+N)} * 2 = \frac{V^2}{2g(f-N)}.$$

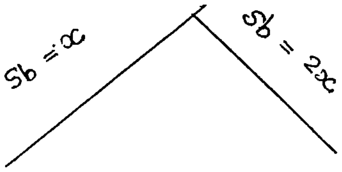
$$\frac{2}{0.4+N} = \frac{1}{0.4-N}$$

$$N = \frac{0.4}{3} = \underline{\underline{13.33\%}}$$

$$\frac{2}{0.4+n} = \frac{1}{0.5-n}.$$

$$0.8-2n = 0.4+n.$$

$$0.2 = 3n.$$



08. $V = 60 \text{ kmph} = 16.667 \ m/s$

$$\frac{S_1}{S_b} = \frac{6}{5}.$$

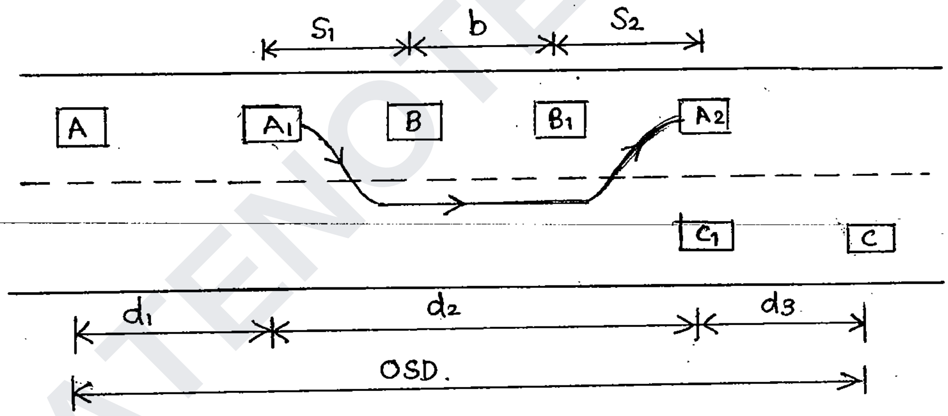
$$\frac{Vt}{\frac{V^2}{2g(f+N)}} = \frac{6}{5}.$$

$$\frac{2g(0.36+N) \times 2.5}{16.667} = \frac{6}{5} \Rightarrow N = \underline{\underline{4.78\%}}$$

th nov,
21DAY

06 OVERTAKING SIGHT DISTANCE

- For overtaking process, minimum two lanes are required.
- If all the vehicles are moving with design speed, there is no need of overtaking the vehicles.



$V_B \rightarrow$ speed of slow moving vehicle ($V_B = V - 16$ kmph)

$v \rightarrow$ design speed of road (kmph).

$t \rightarrow$ reaction time of average driver

$t = 2s$ (max. as per IRC)

During overtaking time, vehicle A moves from A_1 to A_2, vehicle B moves from B to B_1 and C from C to C_1.

$$\boxed{d_1 = V_B \cdot t}$$

$$d_2 = S_1 + b + S_2$$

$$\boxed{d_2 = S_1 + V_B T + S_2} \; ; \; T \rightarrow \text{overtaking time.}$$

↳②

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

$$d_2 = V_B T + \frac{1}{2} a T^2 \rightarrow ①$$

Equating ① & ②,

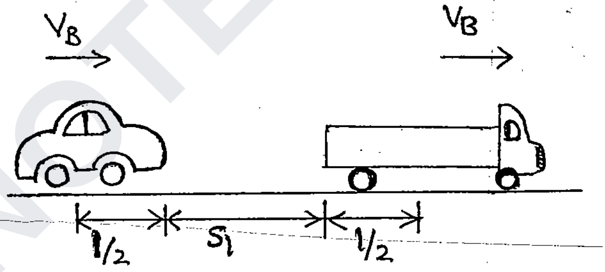
$$\boxed{T = \sqrt{\frac{2(S_1+S_2)}{a}}}$$

$$\boxed{d_3 = vT}$$

$$\boxed{OSD = d_1 + d_2 + d_3}$$

$S = S_1 = S_2 = 0.7\,V_B + l.$; $l \rightarrow$ length of vehicle.

Lag distance for an ideal driver while overtaking,



$S_1 = t\,V_B$

$= \textcircled{0.7}\,V_B.$

$\hookrightarrow$ reaction time of ideal driver.
(as per IRC).

$\Rightarrow \boxed{S = 0.7\,V_B + l}$ $(l = 6.1\text{ m}$ as per IRC).

→ Factors affecting OSB

(i) Braking Efficiency.

OSD is independent of braking efficiency.

(ii) Gradient.

No effect of gradient on OSD.

→ Safe OSD

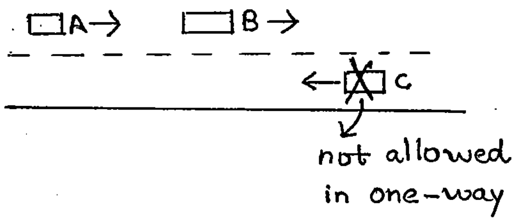
Depends on

(i) No: of lanes

(ii) Direction of traffic.

* Two lane (One way).

$$\text{Safe OSD} = d_1 + d_2$$



* Two lane (Two way).

$$\text{Safe OSD} = d_1 + d_2 + d_3$$

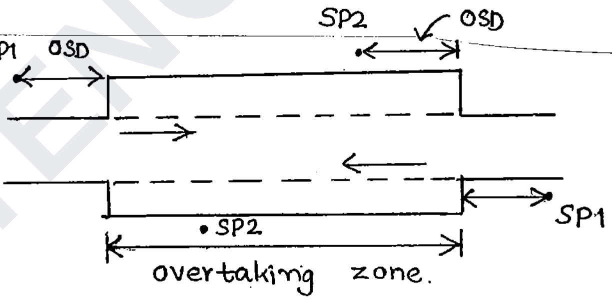
* 4 lane (Two way).

$$\text{Safe OSD} = d_1 + d_2 .$$

NOTE:

- Except in <u>2 lane - 2 way</u> road in all other cases, d_3 should not be considered in the calculation of OSD.

→ Overtaking Zone.



Min. length = 3. OSD

Desirable length = 5. OSD (as per IRC)

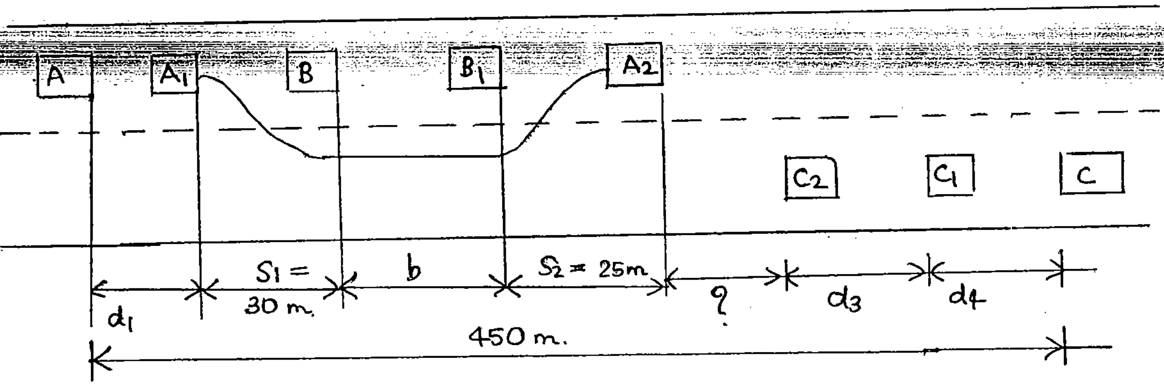
Overtaking zones are provided in single lane roads to facilitate overtaking.

Sign posts are provided at overtaking zones as shown.

SP1 → OT zone ahead. (Info sign)

SP2 → End of OT zone (mandatory)

th nov,
TUESDAY
- 22



Overtaking time ~~time~~, $T = \sqrt{\frac{2(S_1+S_2)}{a}}$

$= \sqrt{\frac{2(30+25)}{1.2}} = \underline{\underline{9.57s}}$

$d_1 = V_B t = 11.11 \times 2 = 22.22\ m$

$d_3 = V(T) = 22.22 \times 9.57 = 212.65\ m.$

$d_4 = v(t) = 22.22 \times 2 = 44.44\ m.$

$d_2 = S_1 + b_t + S_2 = 30 + V_B\ T + 25$

$= 30 + 11.11 \times 9.57 + 25 = 161.3227$

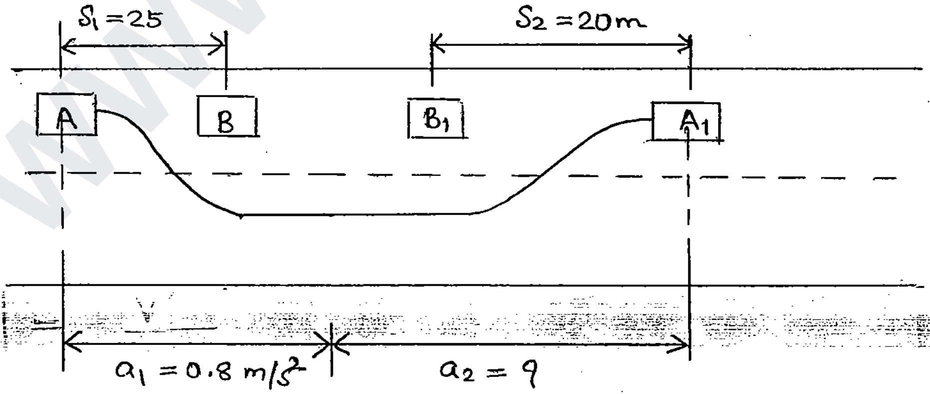
$d_1 + d_2 + d_3 + d_4 + x = 450$

Distance b/w A & c after completion of overtaking action

$= 450 - 22.22 - 212.65 - 44.44 - 161.3227$

$= \underline{\underline{9.3673}}$ (safe ; no collision).

5. $V_B = 100\ kmph = 100 \times \frac{5}{18} = 27.78\ m/s$



$t_1 = 5s$ $\quad$ $t_2 = 5s.$

$S_1 = 25m$ $\quad$ $S_2 = 20\ m.$

Overtaking time, $T = 10s.$

$BB_1 = b = V_B T = 27.7 \times 10 = 277\ m.$

$S = AA_1 = S_1 + b + S_2 = 25 + 277 + 20$

$= \underline{\underline{322.2\ m}}$

5 $V = u + at$ (Zone I).

$= 27.7 + 0.8 \times 5 = 31.7\ m/s.$

$S_1 = ut + \frac{1}{2}at^2 = 27.7 \times 5 + \frac{1}{2} \times 0.8 \times 5^2$

$= 148.5\ m.$

$S_2 = S - S_1 = 322.2 - 148.5 = 173.7\ m$

$S_2 = 31.7 \times 5 + \frac{1}{2} a_2 \times 5^2$

$\Rightarrow a_2 = \underline{\underline{1.2}}\ m/s^2$

---

07 $V = 22.22$, $V_B = 16.67$, $a = 0.7\ m/s^2$, $t = 2s.$, $l = 6\ m.$

Spacing b/w vehicles, $S = 0.7\ V_b + l = 17.67\ m$ (V_B in m/s)

Overtaking time, $T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 17.67}{0.7}} = \underline{\underline{10.05s}}$

Minimum overtaking sight distance on a two lane undivided highway $= d_1 + d_2 + d_3$

$= 16.67 \times 2 + (2 \times 17.67 + 16.67 \times 10.05) +$

22.22×10.05

$= \underline{\underline{459.45}}\ m$

08 Desirable length of overtaking zone $= 5 * OSD$

$= 5 * 459.45$

$= \underline{\underline{2352.75}}\ m$

09. $v = 100 \text{ km/hr} = 27.78 \text{ m/s}$

$V_B = 100 - 16 = 84 \text{ km/hr} = 23.33 \text{ m/s}$

Rate of acceleration, $a = 1.92 \text{ kmph/s}$

$= 0.53 \text{ m}^2/\text{s}^2$

$S = 0.2 V_B + l = 0.2 \times 84 + 6.1$ (V_B in kmph).

$= \underline{\underline{22.9}} \text{ m}$

Overtaking time, $T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 22.9}{0.53}} = \underline{\underline{13.105}} \text{ s}$

Safe OSD on a 4-lane divided highway $= d_1 + d_2$.

$= 23.33 * 2 +$

$2 \times 22.9 + 23.3 \times 13.1$

$= \underline{\underline{398.25}} \text{ m}$

01. $a = 0.53 \text{ m/s}^2$, $V = 100 \text{ kmph}$, $V_B = 84 \text{ kmph}$.

$\Rightarrow S = 0.2 \times 84 + 6.1 = 22.9$

$T = \sqrt{\frac{4S}{a}} = 13.1 \text{ s}$.

Safe OSD on a two lane two way $= d_1 + d_2 + d_3$

$= 398.25 + 27.78 * 13.1$

$= \underline{\underline{762.17}} \text{ m}$

02. $V = 80 \text{ kmph} = 22.22 \text{ m/s}$, $V_B = 13.88 \text{ m/s}$, $a = 2.5 \text{ kmph/s} = 0.694 \text{ m/s}^2$

$S = 16 \text{ m}$, $t = 2\text{s}$.

Safe OSD on 2 lane one way traffic $= d_1 + d_2$

$= 13.88 \times 2 + 2 \times 16 + 13.88 \sqrt{\frac{4 \times 16}{0.694}}$

$= \underline{\underline{193.008}} \text{ m}$

03. Safe OSD on 2 lane 2 way traffic $= 193.008 + 22.22 \sqrt{\frac{4 \times 16}{0.694}} = \underline{\underline{406.4}} \text{ m}$

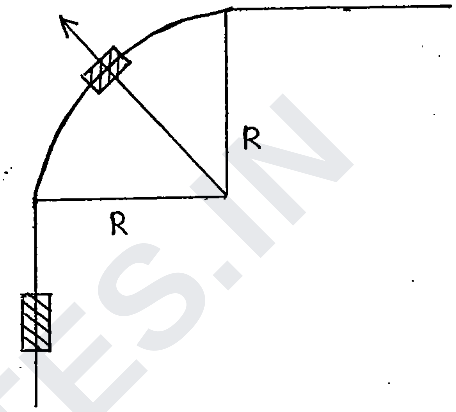
8th nov,
TUESDAY

07. HORIZONTAL CURVES

Horizontal Curves :

- Arc of a circle (R = const)
- Centrifugal force,

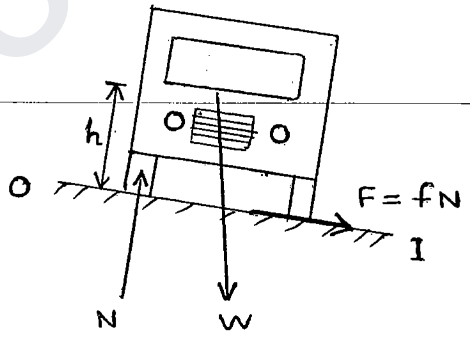
$$P = \frac{mv^2}{R} = \frac{w}{g}\left(\frac{v^2}{R}\right)$$



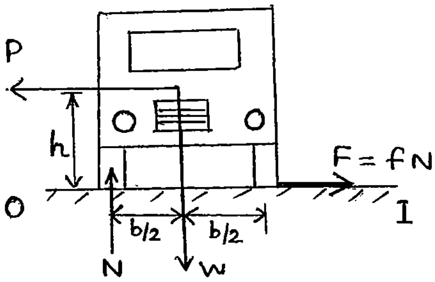
- Centrifugal ratio / Impact factor.

$$\boxed{\frac{P}{w} = \frac{v^2}{gR}}$$

* Overturning



- At the verge of overturning, the contact b/w inner tyre and road will be lost. ∴ normal reaction pass through outer wheels.



$$\Sigma M_{outer} = 0$$

$$P(h) = w\left(\frac{b}{2}\right).$$

$$\underbrace{\boxed{\frac{P}{w} = \frac{b}{2h}}} = \frac{v^2}{gR}$$

Centrifugal ratio.

resistance against overturning

- If $\frac{P}{w} > \frac{b}{2h}$ ⇒ Overturning occurs

$\frac{P}{w} \leqslant \frac{b}{2h}$ ⇒ no overturning

- Higher the b value, and lower the h value, more will be the resistance against overturning.

* Lateral Skid.

$$\Sigma F_x = 0$$

$$P = F = fN$$

$$P = fw$$

$$\boxed{\frac{P}{w} = f}$$

resistance against skid.

$f \rightarrow$ coeffecient of lateral friction (0.15)

- If $\frac{P}{w} > f \Rightarrow$ skid occurs

  $\frac{P}{w} \leqslant f \Rightarrow$ no lateral skid.

⊙ Case 1 : $P/w \leqslant f$ & $\frac{P}{w} \leqslant \frac{b}{2h}$

$\Rightarrow$ No skid and no overturning.

⊙ Case 2 : $\frac{P}{w} \leqslant f$ & $\frac{P}{w} > \frac{b}{2h}$

$\Rightarrow$ No skid and overturning occurs.

⊙ Case 3 : $\frac{P}{w} > f$ & $\frac{P}{w} \leqslant \frac{b}{2h}$

$\Rightarrow$ Skid occurs and no overturning.

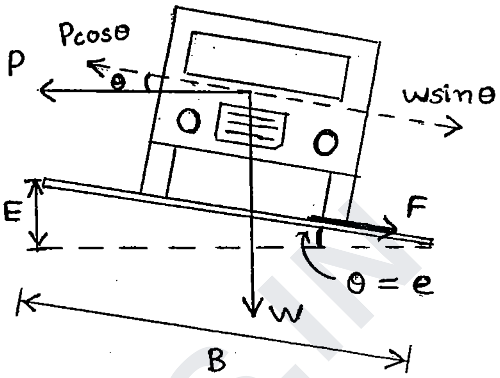
⊙ Case 4 : $\frac{P}{w} > f$ & $\frac{P}{w} > \frac{b}{2h}$.

a) $f > \frac{b}{2h}$. $\Rightarrow$ overturning occurs

b) $f < \frac{b}{2h}$ $\Rightarrow$ Skids first & then overturning occurs.

→ Super Elevation (or) Cant (or) Angle of Banking

$$\boxed{e + f = \frac{V^2}{gR}} = \frac{P}{W}$$



- For level ground without super elevation $(e = 0)$

$$f = \frac{V^2}{gR} = \frac{P}{W}$$

- $e = \tan\theta = \sin\theta = \frac{E}{B}$

$$\Rightarrow \boxed{E = eB}$$

where E → rise of outer edge wrt inner edge.

B → total width of road over the curve. (which includes extra widening over the curve)

$$B = \underset{\text{actual width}}{W} + \underset{\text{extra width on curved road.}}{W_e}$$

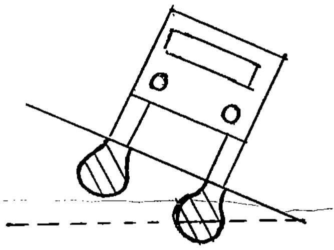
e → rate of super elevation. (1 in N or %)

* Equilibrium Super elevation (Balanced SE)

The super elevation required to balance a vehicle moving with design speed over a curve without considering friction b/w road and tyre. $(f = 0)$

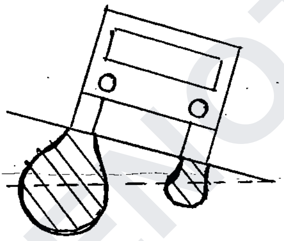
$$e_{EQ} = \frac{V^2}{gR}$$

- Equilibrium SE is very effective if all the vehicles are moving with design speed.
- But for mixed traffic in India design speed over curves is not possible in such a case the vehicle may skid or overturn inwards.
- However vehicle with design speed will have balanced condition (pressure on outer wheel = pressure on inner wheel with equilibrium SE)



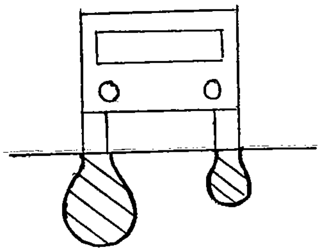
- e_{EQ}

$P_{outer} = P_{inner}$



- $e < e_{EQ}$

$P_{outer} > P_{inner}$



- Level road over curve

$P_{outer} > P_{inner}$.

→ Design Super Elevation.

- For mixed traffic
- use 75% design speed $(f = 0)$ {as per IRC}

$$e + \cancel{f}^{0} = \frac{(0.75\,V)^2}{gR}$$

$e_{design} \leq e_{max}$ (given by IRC)

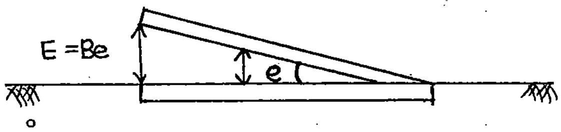
$e_{max} = 7\%$ (in plain & rolling terrains)
(in snow bound hilly terrain)

$= 10\%$ (on hill roads not bound by snow)

→ Attainment of Superelevation.

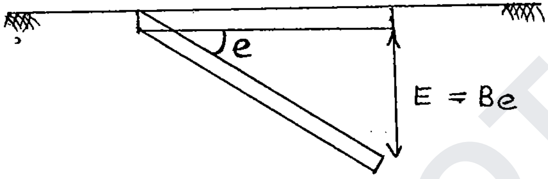
(i) Rotation with respect to inner edge

- common method.



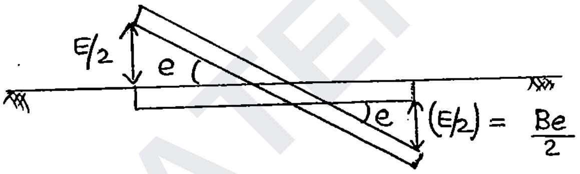
(ii) Rotation wrt Outer edge.

- not common.



(iii) Rotation wrt Centre line.

- common over bridges.



-28

01 $R = 600$ m, $B = 7$m, $V = 65 \times \frac{5}{18} = 18.06$ m/s (mixed traffic ⇒ 75%)

⇒ Rotated with respect to centre line

$$e = \frac{(0.75\,V)^2}{gR} = \frac{(0.75 \times 18.06)^2}{9.81 \times 600} = 0.0312$$

$$e_{design} = 3.1\ \%$$

NOTE:

In this problem, e_{max} is not given and the type of terrain through which road is passing is also not given.

∴ use calculated SE. directly as design super elevation.

$$\left.\begin{array}{l}\text{Rise of outer edge} \\ \text{wrt GL}\end{array}\right\} = \frac{E}{2} = \frac{eB}{2} = \frac{0.0312 \times 7}{2} = \underline{\underline{0.11}}\ m.$$

02. Rotated wrt inner edge.

$$\left.\begin{array}{l}\text{Rise of outer edge} \\ \text{wrt GL}\end{array}\right\} = eB = 0.0312 \times 7 = \underline{\underline{0.22}}\ m$$

03. $V = 65 \times \frac{5}{18} = 18.05\ m/s.$

Mixed traffic :

$$e_{max} = 7\% = 0.07$$

$$f = 0.15$$

$$e = \frac{(0.75 \times 18.05)^2}{9.81 \times 125} = 14.9\ \% > 7\ \%$$

But, $e_{design} \leq e_{max}$

$$\Rightarrow \underline{\underline{e_{design}}} = 7\ \%$$

NOTE :

⊙ If f is considered in the equation, full speed is required in the general equation.

$$e + f = \frac{V^2}{gR}$$

$$0.07 + 0.15 = \frac{V^2}{9.81 \times 125}$$

$$\left.\begin{array}{l}\text{Allowable speed} \\ \text{on road with friction}\end{array}\right\}, V = 16.42\ m/s = \underline{\underline{59.12}}\ kmph$$

04. $R = 1400$ m, $V = 65$ kmph $= 18.05$ m/s

~~$$e = \frac{(0.75\times 18.05)^2}{9.81\times 1400} = 1.3\,\%$$~~

For thin BT road (low rain), Camber $= 1$ in $\overset{50}{40}$

$= \underline{2.0}\%$

5. While vehicle is moving on outer edge, camber acts like negative superelevation of $(-2\,\%)$. But the vehicle is safe upto a negative SE of (-12.126%).

∴ Vehicle is safe even it is moving on outer edge.

4. SE required for the vehicle,

$$e + f = \frac{v^2}{gR}$$

$$e + 0.15 = \frac{18.05^2}{9.81\times 1400}$$

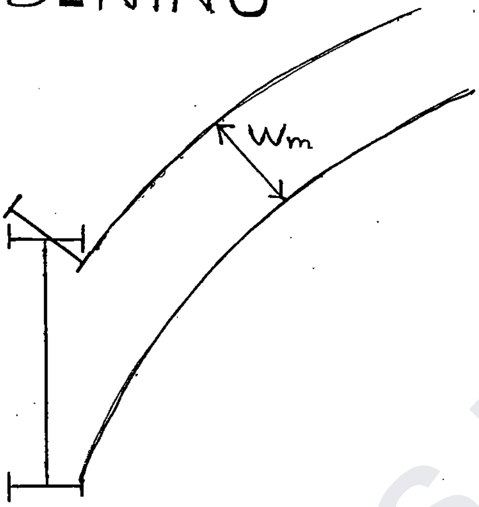
$$e = -\underline{12.6\,\%}$$

∴ No need of SE for vehicle on inner edge.

20th nov,
THURSDAY

08. EXTRA WIDENING

- on straight road



- on curve

* Extra widening = Mechanical widening + Psychological widening.

$$\boxed{W_e = W_m + W_{ps}.}$$

where Wm → Off tracking (or) Mechanical widening.

- For test vehicle on road,

$$W_m = \frac{l^2}{2R} \quad (\text{single lane}).$$

- For total road,

$$\boxed{W_m = \frac{nl^2}{2R}}$$

; n → no. of lanes
l → length of wheel base.
(6 m)

Wps → Psychological widening.

$$\boxed{W_{ps} = \frac{V}{9.5\sqrt{R}}}$$

; V → kmph.
R → m
Wps → m

01 $W_m = \frac{l^2}{2R} = \frac{6.5^2}{2 \times 125} = \underline{\underline{0.17\ m}}$

06. $B = 7.5\ m$. (2 lane road with raised kerb).

$l = 6.1\ m$

$R = 300\ m$

$V = 80$ kmph.

$$W_e = \frac{V}{9.5\sqrt{R}} + \frac{nl^2}{2R}$$

$$= \frac{80}{9.5\sqrt{300}} + \frac{2 \times 6.1^2}{2 \times 300} = \underline{\underline{0.61\ m}}$$

10. W_m of test vehicle $= 0.096 = \frac{l^2}{2R}$

$$0.096 = \frac{l^2}{2 \times R} \Rightarrow R = \underline{\underline{226.875\ m}}$$

$$W = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} = 2 \times 0.096 + \frac{80}{9.5\sqrt{226.8}}$$

$$= \underline{\underline{0.75\ m}}$$

07 $e = \frac{1}{15}$, $f = 0.15$, $V = 76$ kmph. $= 21.11\ m/s$

$$e + f = \frac{V^2}{gR} \Rightarrow \frac{1}{15} + 0.15 = \frac{21.11^2}{gR.}$$

$\therefore$ Radius of curve, $R = \underline{\underline{209.75}}\ m$

08. Extra widening given by $\frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} = \frac{2 \times 7^2}{2 \times 209.75} + \frac{76}{9.5\sqrt{209.75}}$

$$= 0.786\ m.$$

Total width of pavement $= W + W_e = 7 + 0.786 = \underline{\underline{7.786\ m}}$

09. $W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} = \frac{2 \times 8^2}{2 \times 300} + \frac{100}{9.5\sqrt{300}} = \underline{\underline{0.821\ m}}$

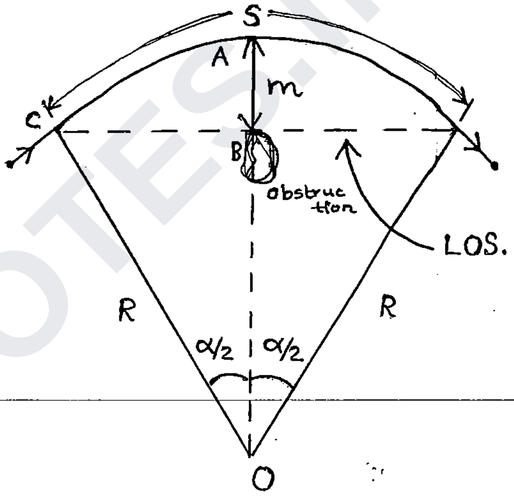
20th nov,
THURSDAY

09. SET BACK DISTANCE

The distance from centre line of entire road to nearest obstruction on inner side of the road to have proper sight distance over entire length of curve is called Set back distance.

* Single Lane Road.

Case 1 : $L \geq S$



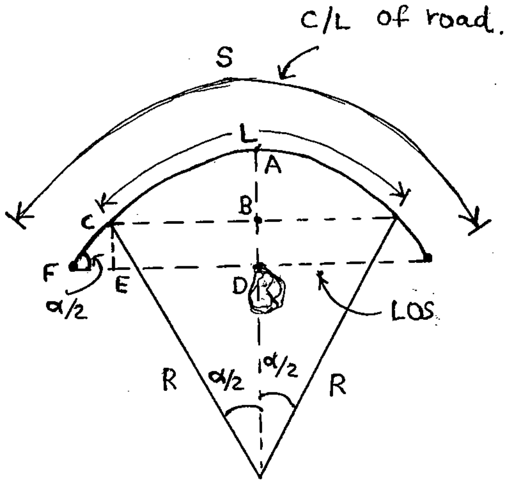
$$\boxed{m = R - R\cos(\alpha/2)}$$

$$m = R\left(1 - \cos\left(\frac{\alpha}{2}\right)\right)$$

$$\boxed{\alpha = \frac{S}{R} \text{ (rad).}}$$

$$\alpha = \frac{S}{R} \cdot \frac{180}{\pi} \text{ (degree).}$$

Case 2 : $L < S$



$$m = AD$$

$$= AB + BD$$

$$AB = R - R\cos\left(\frac{\alpha}{2}\right).$$

From ΔCEF,

$$\sin\frac{\alpha}{2} = \frac{CE}{\left(\frac{S-L}{2}\right)}$$

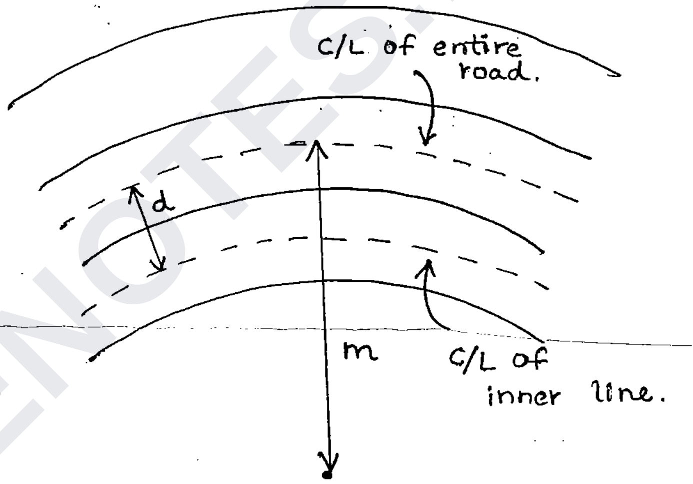
$$BD = CE = \left(\frac{S-L}{2}\right)\sin\left(\frac{\alpha}{2}\right)$$

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

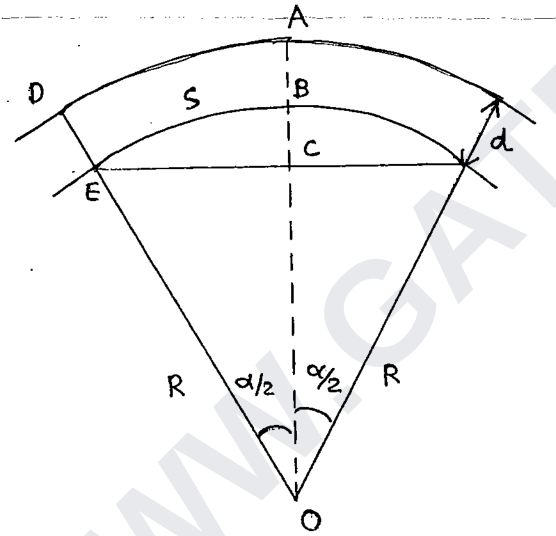
* Multi lane Road.

- For multi lane roads, vehicle travelling at the centre of inner lane, sight distance is critical over horizontal curves. However set back distance is always taken from centre line of entire road.
- Radius, R is also taken from centre line of entire road.

- The sight distance should be measured along centre line of inner lane.



Case 1 : $L \geq S$



$OD = R$

$OE = R - d.$

In ΔOEC,

$$\cos\left(\frac{\alpha}{2}\right) = \frac{OC}{OE}$$

$$\therefore OC = OE \cos\frac{\alpha}{2} = (R-d)\cos\left(\frac{\alpha}{2}\right).$$

$$\therefore m = OA - OC$$

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

$$S = (R-d)\alpha \qquad \boxed{\alpha = \frac{S}{(R-d)} \text{ (rad)}}$$

Case 2: **L < S**

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

$$L = (R-d)\alpha$$

$$\boxed{\alpha = \frac{L}{R-d}}$$

→ Approximate formulae (for Single Lane).

(i) $L \geqslant S$

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

(ii) $L < S$

$$m = \frac{L(2S-L)}{8R}.$$

P-33

02. $m = \dfrac{S^2}{8R}$

$$R = \frac{80^2}{8 \times 10} = \underline{\underline{80\ m}}$$

05. 2-lane, 2-way ($\Rightarrow$ SSD).

Safe stopping sight distance = SSD

$$= vt + \frac{v^2}{2gf}$$

$$= 80 \times \frac{5}{18} \times 2.5 + \frac{(80 \times 5/18)^2}{2g \times 0.355}$$

$$= \underline{\underline{126.48\ m}}$$

$d = \frac{7}{4} = 1.75\ m$.

Assume $L \geq S$ (if nothing given).

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

$$= 200 - (200-1.75)\cos\left(\frac{35.9}{2}\right)$$

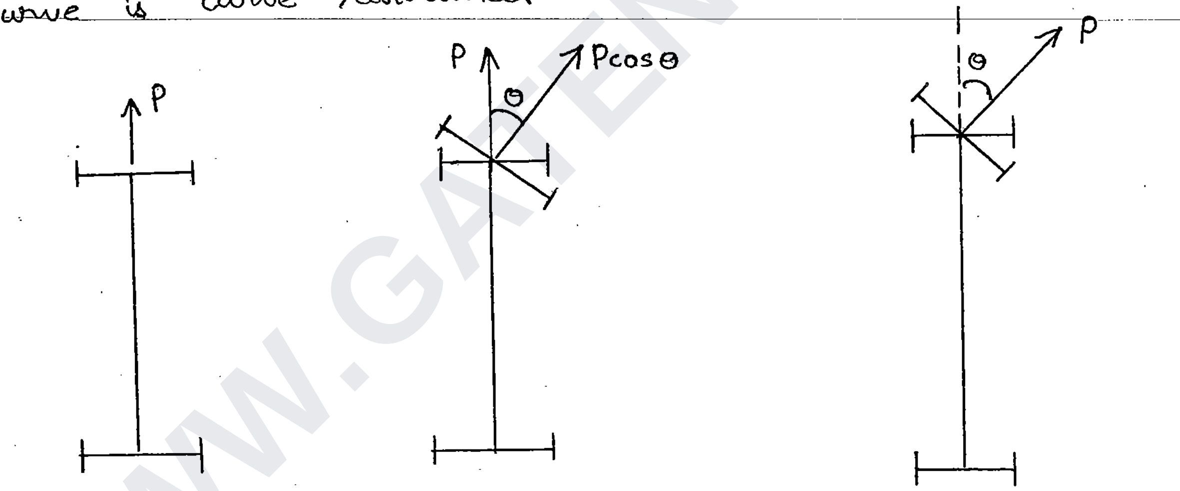
$= 11.4\ m$ (set back distance from C/L of two lane).

Set back distance from centre line of inner lane

$$= 11.4 - 1.75 = \underline{\underline{9.77\ m}}$$

CURVE RESISTANCE:

Loss of tractive force or engine power over a curve is curve resistance.



- Rear wheel driven.

- front wheel driven.

– Loss of power over curve = Curve resistance (CR).

$$= P - P\cos\theta$$

$$= P(1-\cos\theta)$$

If $\theta = 0$ (on straight road), $CR = 0$.

If $\theta = 90^\circ$, $CR = P$

– Loss of power over curve for a front wheel driven vehicle = 0

Level 1
P-33

1. $R = 600$ m, $S = 200$ m.

Assume $L \geqslant S$. ($\because$ nothing specified).

$$\alpha = \frac{180}{\pi} \times \frac{S}{R} = \frac{180}{\pi} \times \frac{200}{600} = 19.09^\circ$$

$$m = 600 - 600 \cos\left(\frac{19.09}{2}\right) = \underline{\underline{8.314\ m}}$$

2. $R = 450$ m, $SSD = S = 300$ m, $L = 200$ m.

$$S > L \Rightarrow \alpha = \frac{L}{R} * \frac{180}{\pi} = \frac{200}{450} \times \frac{180}{\pi} = \underline{\underline{25.46^\circ}}$$

$$m = R - R\cos\left(\frac{\alpha}{2}\right) + \left(\frac{S-L}{2}\right)\sin\frac{\alpha}{2} = 450 - 450\cos\frac{25.5}{2} + \left(\frac{300-200}{2}\right)\sin\frac{25.5}{2}$$

$$= \underline{\underline{22.08\,m}}$$

3. $OSD = 225$, $L = 175$ m, $R = 350$ m, Width of road $= 8$ m (2 lane road).

$$d = \frac{8}{4} = 2\text{ m}.$$

$$OSD > L \Rightarrow \alpha = \frac{L}{R-d} = \frac{175}{350-2} = 0.503\text{ rad} = \underline{\underline{28.81^\circ}}$$

Set back distance from C/L of road,

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

$$= 350 - 348\cos\left(\frac{28.8}{2}\right) + \left(\frac{225-175}{2}\right)\sin\left(\frac{28.8}{2}\right)$$

$$= \underline{19.162\text{ m}}$$

Clearance from inner edge of road $= 19.162 - \frac{8}{2} = \underline{\underline{15.162\,m}}$

4. $R = 360$ m, $L = 180$ m, $OSD = 250$ m.

$$L < OSD \Rightarrow \alpha = \frac{180}{\pi}\,\frac{L}{R} = \frac{180}{\pi} \times \frac{180}{360} = \underline{\underline{28.65^\circ}}$$

07. $V = 80$ kmph, $R = 900m$, $B = W = 7m$, $N = 150$

$$e = \frac{V^2}{225R} = \frac{80^2}{225 \times 900} = 0.032$$

$$C = \frac{80}{75+V} = \frac{80}{75+80} = \underline{\underline{0.516}}$$

08 Based on super elevation,

when rotated about c/L, $L_s = \frac{eBN}{2}$

$$= \frac{0.032 \times 7 \times 150}{2}$$

$$= \underline{\underline{16.6\ m}}$$

Based on comfort criteria,

$$L_s = \frac{V^3}{CR} = \frac{(0.278 \times 80)^3}{0.516 \times 900} = \underline{\underline{23.7\ m}}$$

Based on IRC empirical formula,

For plain terrain, $L_s = 2.7 \frac{V^2}{R}$

$$= 2.7 \times \frac{80^2}{900} = \underline{\underline{19.2\ m}}$$

$\therefore$ Min. length of transition curve, $L_s = \underline{\underline{23.7\ m}}$

04. $$L_s = \frac{V^3}{CR} = \frac{(0.278 \times 80)^3}{0.516 \times 400} = \underline{\underline{53.33\,m}}$$

05. V = 65 kmph., R = 200 m, W = 7.5 m, N = 150.

w = 7.5 m (2 lane road).

$$e = \frac{V^2}{225R} = \frac{65^2}{225 \times 200} = 0.09$$

$$W_e = W_m + W_{ps}$$

$$= \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} = \frac{2 \times 6.1^2}{2 \times 200} + \frac{65}{9.5\sqrt{200}}$$

$$= \underline{\underline{0.669}}$$

$$B = 7.5 + 0.669 \cancel{+} = \underline{\underline{8.17\,m}}$$

Based on superelevation,

$$L_s = \frac{E}{2} N = \frac{eB}{2} N = \frac{0.07 \times 8.17}{2} \times \overset{150}{\cancel{\ }}$$

$$= \underline{\underline{42.89}}\,m$$

Based on comfort criteria,

$$c = \frac{80}{75+V} = \frac{80}{75+65} = \underline{\underline{0.57}}$$

$$L_s = \frac{V^3}{CR} = \frac{(0.278 \times 65)^3}{0.57 \times 200} = \underline{\underline{51.79}}\,m$$

As per IRC empirical formula,

For rolling terrain, $L_s = \frac{2.7\,V^2}{R} = \frac{2.7 \times 65^2}{200}$

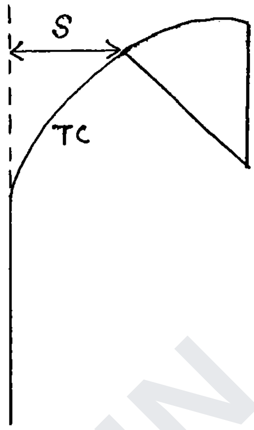
$$= \underline{\underline{57.03\,m}}$$

$\therefore$ Length of transition curve $= \underline{\underline{57.03\,m}}$

06. $$\text{Shift} = \frac{L_s^2}{24R} = \frac{57.03^2}{24 \times 200} = \underline{\underline{0.68\,m}}$$

→ Shift.

$$\boxed{S = \frac{l_s^2}{24R}}$$



-37.

01. (i) Super elevation

(rotation about inner edge).

Use design SE, (for mix traffic).

$$e_{des} = \frac{V^2}{225R} = \frac{60^2}{225 \times 200} = 0.08$$

$$e_{des} \lessgtr e_{max}.$$

$\therefore$ e = 0.07. (reduced to e_{max}).

$$l_s = e(w + we)N = 0.07(3.5 \times 2 + 0.2) \times 100$$

$$= \underline{\underline{50.4 \text{ m}}}$$

(ii) Comfort criteria

$$C = 0.6 \text{ m/s}^3$$

$$l_s = \frac{V^3}{CR} = \frac{16.667^3}{0.6 \times 200} = \underline{\underline{38.58 \text{ m}}}$$

(iii) Empirical formula.

$$l_s = \frac{2.7V^2}{R} = \frac{2.7 \times 60^2}{200} = 48.6 \text{ m} \quad \text{(plain terrain)}$$

02. Shift $= \frac{L_s^2}{24R} = \frac{50.4^2}{24 \times 200} \doteq \underline{\underline{0.53 \text{ m}}}$

03. R = 400 m, V = 80 kmph, B = 7 m.

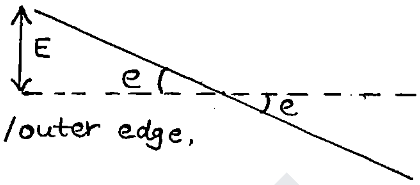
$$C = \frac{80}{75+V} = \frac{80}{75+80} = \underline{\underline{0.516}}$$

Length of transition curve, $l_s = EN$.

$$l_s = e(W + W_e)N.$$

$$\boxed{l_s = e(W + W_e)N}$$

↳ rotation wrt inner / outer edge.



$$\boxed{l_s = \frac{e(W + W_e)N}{2}}$$

↳ rotation wrt c/L

→ Comfort / Centrifugal force Criteria.

- Rate of introduction of centrifugal acceleration } $C = \frac{80}{75 + V}$; $V \rightarrow$ kmph
  $C \rightarrow m/s^3$

$0.5 < C < 0.8$ (as per IRC).

$$\boxed{l_s = \frac{v^3}{CR}}$$; $v = m/s$

→ Empirical formula (as per IRC).

$$\boxed{l_s = 2.7\frac{V^2}{R}}$$ (plain & rolling terrain)

$$\boxed{l_s = \frac{V^2}{R}}$$ (mountainous or steep terrain).

$V \rightarrow$ kmph

In practical design, consider max. of centrifugal, SE and IRC empirical formulae

$$m = R - R\cos\frac{\alpha}{2} + \frac{S-L}{2}\sin\frac{\alpha}{2}.$$

$$= 360 - 360\cos\frac{28.65}{2} + \frac{250-180}{2}\sin\frac{28.65}{2}.$$

$$= \underline{\underline{19.85\ m}}$$

05. SSD = 90 & OSD = 300 m. ; R = 400 m ; L = 200 m ; B = 12 m. ($\frac{4}{8}$ lane).

$$d = 6 - 1.5 = 4.5\ m.$$

(i) Set back for SSD.

$$S < L.$$

$$\alpha = \frac{S}{R-d} \times \frac{180}{\pi} = \frac{90}{400-4.5} \times \frac{180}{\pi} = \underline{\underline{13.04^0}}$$

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

$$= 400 - 395.5\cos\frac{13.04}{2}\ \cancel{+} = \underline{\underline{7.06\ m}}$$

(ii) Set back for OSD.

$$OSD > L.$$

$$\alpha = \frac{L}{R-d} \times \frac{180}{\pi} = \frac{200}{395.5} \times \frac{180}{\pi} = \underline{\underline{28.97^0}}$$

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

$$= 400 - 395.5\cos\left(\frac{28.97}{2}\right) + \left(\frac{300-200}{2}\right)\sin\frac{28.97}{2}.$$

$$= \underline{\underline{29.58\ m}}$$

evel 2

03. R = 360 m, L = 180 m, SSD = 80 m.

$$L > S \Rightarrow m = \frac{S^2}{8R} \quad \text{(approx. formulae)}$$

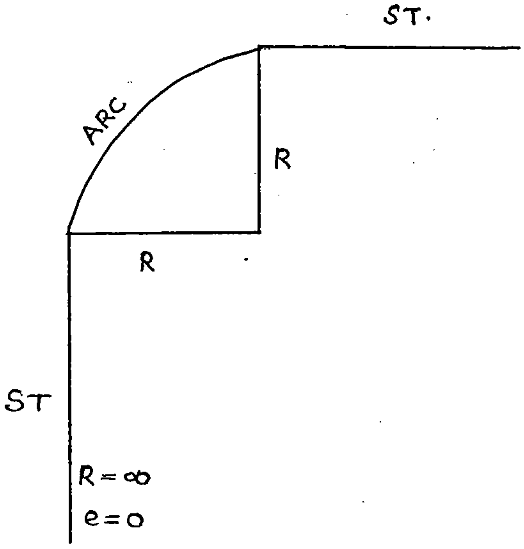
$$= \frac{80^2}{8 \times 360} = \underline{\underline{2.22\ m}}$$

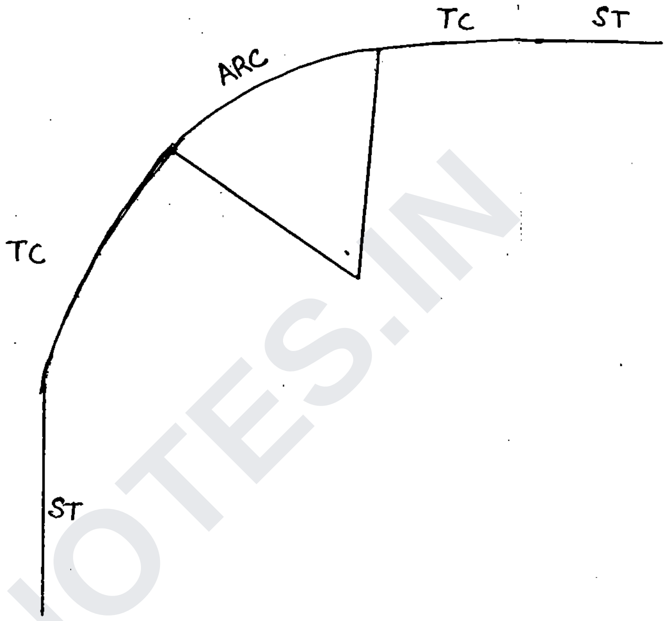
04. OSD = 250 m, L = 180 m $\Rightarrow \alpha = \frac{180}{360} \times \frac{180}{\pi} = 28.65^0$

$$m = 360 - 360\cos\frac{28.65}{2} + \frac{250-180}{2}\overset{\sin}{\cancel{\cos}}\frac{28.65}{2} = \underline{\underline{19.85\ m}}$$

21st nov,
FRIDAY

10. TRANSITION CURVES





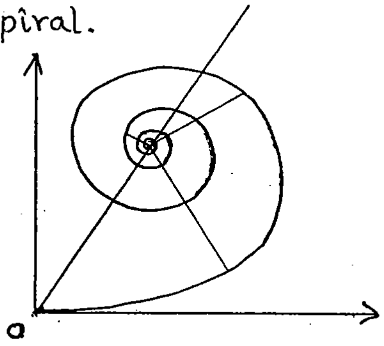
- Transition curve is introduced between a straight and a circular curve.

- As per IRC, transition curves are spiral.

- Design criteria is based on :

  (i) Super Elevation.

  (ii) Centrifugal force.

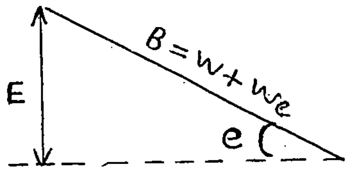


→ Super Elevation Criteria.

- Rate of introduction of SE : 1 in N.

  Plain / rolling : 1 in 150

  Hilly : 1 in 60



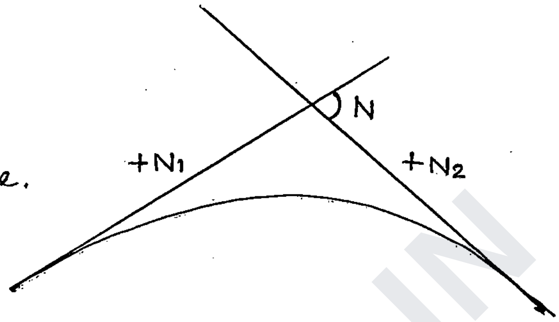
* $E = eB = e(w + w_e)$ {rotation about inner/outer edge}

$\uparrow$ rise of outer wrt inner edge

11 VERTICAL CURVES

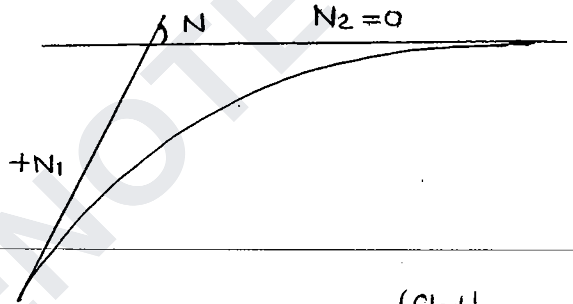
→ Summit Curve

Deflection or deviation angle, N = algebraic difference.

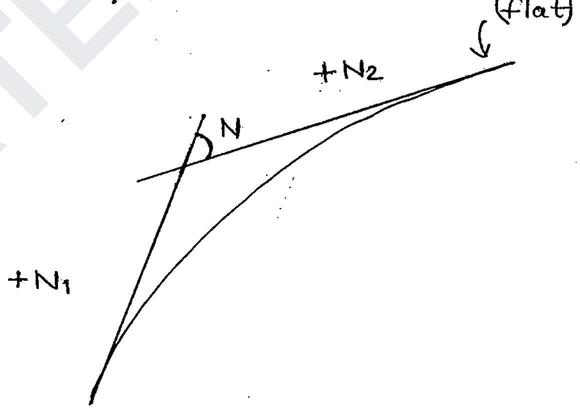


$$\boxed{N = (+N_1) - (-N_2)}$$

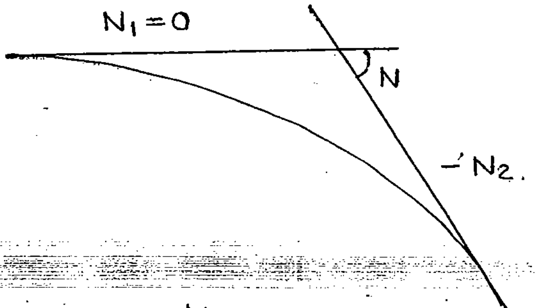
$$N = (+N_1) - (+0)$$



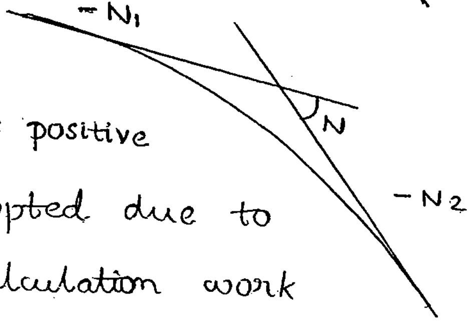
$$N = (+N_1) - (+N_2)$$



$$N = 0 - (-N_2)$$



$$N = (-N_1) - (-N_2)$$



- ⊙ For summit curve, N is always positive
- ⊙ Square Parabolic curves are adopted due to best riding qualities, simplicity of calculation work and uniform rate of change of grade.

→ Design of Summit Curve

* Length of Summit Curve for SSD.

Case 1: $L \geqslant SSD$.

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

when $H = 1.2\,m$ & $h = 0.15\,m$.

$$L = \frac{NS^2}{4.4}$$

Case 2: $L < SSD$.

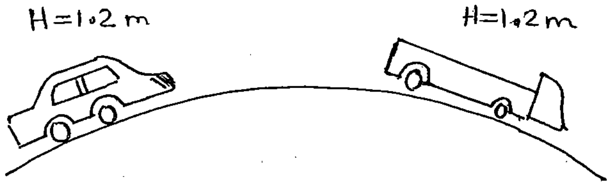
$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

$$L = 2S - \frac{4.4}{N}$$

* Length of Summit curve for OSD or ISD.

Case 1: $L \geqslant$ OSD or ISD.

$$L = \frac{NS^2}{8H} = \frac{NS^2}{9.6}$$



Case 2: $L \leqslant$ OSD or ISD.

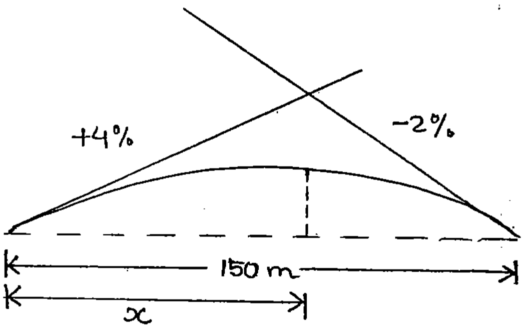
$$L = 2S - \frac{8H}{N} = 2S - \frac{9.6}{N}$$

- Maintenance and drainage are not a problem over summit curves.

- Min. radius of parabolic summit curve, $R = \frac{L}{N}$

P-41.

Q.2. $N = (+4) - (-2) = 6\%$



$6\% \longrightarrow 150$ m.

$4\% \longrightarrow x$ m.

$$x = \frac{4 \times 150}{6} = \underline{\underline{100\ m}}$$

03. $N = \frac{1}{50} - \left(\frac{-1}{100}\right) = \underline{\underline{3\%}}$

$1\% \longrightarrow 100$ m

$3\% \longrightarrow x$.

$\therefore\ x = \underline{\underline{300}}$ m

04. $N = \frac{1}{25} - \left(\frac{-1}{50}\right) = 6\%$

SSD = 180 m.

$V = 100$ km/hr. $= \underline{\underline{27.78}}$ m/s

Assume $L \geq S$,

$$L = \frac{NS^2}{4.4} = \frac{(6/100)\ 180^2}{4.4} = \underline{\underline{442\ m}}$$

$6\% \longrightarrow 442$ m.

$4\% \longrightarrow x$

$$x = \frac{442 \times 4}{6} = \underline{\underline{294.67\ m}}$$

01. $S = 120$ m, $H = 1.5$ m, $h = 0.15$ m, $N = 0.09$.

$$L = \frac{NS^2}{\left(\sqrt{2H} + \sqrt{2h}\right)^2} = \frac{0.09 \times 120^2}{\left(\sqrt{2 \times 1.5} + \sqrt{2 \times 0.15}\right)^2} = \underline{\underline{249.36\ m}}$$

06. $N = \frac{1}{100} + \frac{1}{120} = 0.018$

$OSD = 470$ m.

Assume $L \geqslant OSD$,

$$L = \frac{Ns^2}{9.6} = \frac{0.018 \times 470^2}{9.6} = \underline{\underline{422}} \text{ m}$$

But $L < OSD$ (assumption wrong).

Assume $L < OSD$.

$$L = 2S - \frac{9.6}{N} = 2 \times 470 - \frac{9.6}{0.018} = \underline{\underline{406.67}} \text{ m}$$

07. $SSD = 128$ m.

$N = 0.03 + 0.05 = 0.08$

Assume $L \geqslant SSD$,

$$L = \frac{Ns^2}{4.4} = \frac{0.08 \times 128^2}{4.4} = \underline{\underline{297.89}} \text{ m}$$

NS^2 [illegible] $= 0.075 \times 120^2$ [illegible] 192.47 m

If designed by this value, 29 hours will be subjected to traffic jam in a year (365*24 = 8760 hours).

→ Speed. Studies

1. Spot Speed (or) Instantaneous Speed.
   - Enoscope : outdated method used to measure spot speed.
   - Speed gun :
2. Running Speed.
   - average speed b/w two stations without stops.
3. Journey Speed
   - average speed with stops.

* Presentation of Spot Speed Data.

(i) Cumulative Speed Distribution Curve

– 98th percentile speed : 2% vehicles are above this speed and the remaining 98% vehicles are below this speed. Highway geometric design is based on this speed.

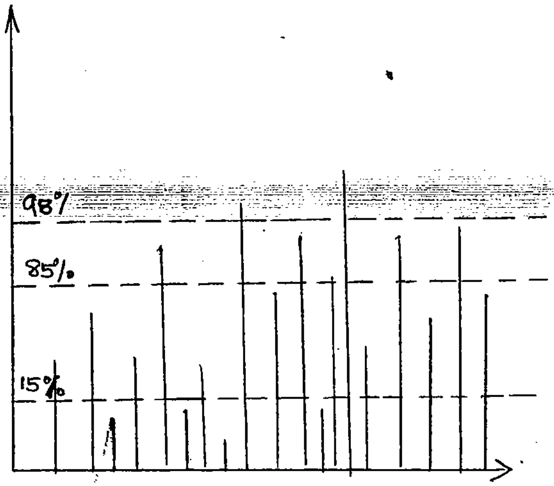
– 85th percentile speed : This is the safe speed on the road.

– 15th percentile speed : minimum speed on major highways.

P-83.

05.

Speed range	No:of veh/hr	% vehicles	Cumulative %
0-10	10	1	1.
10-20	40	4	5
20-30	50	5	10
30-40	50	5	15
40-50	150	15	30
50-60	250	25.	55.



Speed range	No. of veh/hr.	% vehicles	cumulative %
60-70	300	30	85
70-80	90	9	94
80-90	40	4	98
90-100	20.	2	100

Min speed = 30 – 40 (15%).

Design speed = $\overset{90}{80-\cancel{100}}$ (98%).

Safe speed = $\underline{60-70.}$ (85%).

* Spot Speeds can be divided into:

1. Time mean speed (V_t)

Average speed of all the vehicles passing a point on a highway over some specified time period. This is average of spot speeds.

2. Space mean speed (V_s)

Average speed of all the vehicles occupying a given section of a highway over some specified time. ~~period~~. This is the harmonic mean of spot speed.

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \frac{1}{V_3} + \dots$$

$$\boxed{V_s = nV.}$$

cal Capacity (Design Capacity)

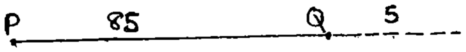
$$\boxed{V_t = V_s + \frac{\sigma^2}{V_s}} \; ; \; \sigma^2 \rightarrow \text{std deviation.}$$

- $V_t > V_s$ in general.
- If all vehicles travel with same speed, $\sigma = 0$ & $V_t = V_s$

P-83.

1. Lay over time (rest period) = 5 hour.

Journey time = 85 hours.



Total duration for round trip = 85 + 85 + 5 = 175 hours

No: of vehicles required $= \frac{175}{24} = 7.5$ vehicles $\simeq \underline{\underline{8 \text{ vehicles}}}$

02. V_t = avg or mean $= \frac{50+40+60+54+45}{5} = \underline{\underline{49.8}}$ kmph.

$V_s = V \times n$

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

$\therefore V_s = 9.765 \times 5 = \underline{\underline{48.82}}$ kmph

---

03. $V_t = \frac{2.75 + 7.5\times4 + 11.5\times0 + 15.5\times7}{1+4+0+7} = \underline{\underline{11.75}}$ mps

$V_s = nV.$

$$\frac{1}{V} = \frac{1}{2.5} + \frac{4}{7.5} + \frac{7}{15.5}$$

$V = 0.722$

$V_s = 12 \times 0.722 = \underline{\underline{8.66}}$ mps

04. Entry speed related time mean speed.

$V_t = \frac{80+75+62+90+70}{5} = \underline{\underline{75.4}}$ kmph

$V_1 = \frac{1000}{45}$, $V_2 = \frac{1000}{50}$, $\frac{V_3}{} = \frac{1000}{56}$, $V_4 = \frac{1000}{39}$

$V_5 = \frac{1000}{53}.$

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \frac{1}{V_3} + \frac{1}{V_4} + \frac{1}{V_5}$$

$$\frac{1}{v} = \frac{1}{\frac{1000}{45}} + \frac{1}{\frac{1000}{50}} + \frac{1}{\frac{1000}{56}} + \frac{1}{\frac{1000}{39}} + \frac{1}{\frac{1000}{53}}$$

$$v = 4.115 \text{ mps.}$$

$$V_s = nV = 4.115 \times 5 = 20.58 \text{ mps}$$

$$= \underline{74.07} \text{ kmph}$$

→ Traffic Density (k)

Number of vehicles occupying a unit length (1 km) of roadway at a given instant.

Unit: PCU/km

$$\boxed{\underset{(PCU/hr)}{q} = \underset{(km/hr)}{V} * \underset{(PCU/km)}{k}}$$

q → traffic volume. (dependent)

k → traffic density. (Independent).

V → speed. (Independent).

- ⊙ k is more independent than V.

→ Time Head Way

Time gap b/w two successive vehicles which are crossing a section on a road.

Unit: sec/veh or hour/vehicle.

$$\boxed{H_T = \frac{1}{q}\left(\frac{hr}{veh}\right) = \frac{3600}{q} \text{ sec/vehicle.}}$$

→ Distance Head way (Space Head way), S

Average distance b/w two successive vehicles or inverse of density.

Unit: m/vehicle.

$$\boxed{S = \frac{1}{K}} = \frac{1000}{K} \text{ m/veh.}$$

→ Traffic Capacity

Ability of roadway to accomodate traffic volume is the max. traffic volume or max. traffic flow.

$$C = q_{max} = K_{max} \cdot V.$$

$$= \frac{1000}{S_{min}} \cdot V$$

$$\boxed{C = \frac{1000\ V}{S_{min.}}}$$

design speed (kmph)

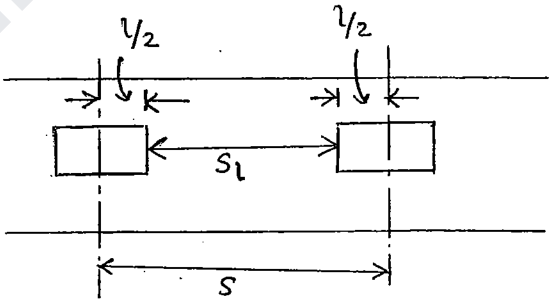
min. space headway (m)

(i) Basic Capacity (Theoretical or Ideal Capacity)

Maximum number of vehicles that pass a given point on a lane or road way during one hour under ideal road way and traffic conditions.

$$S = l + S_1.$$

$$\boxed{S = l + 0.7\ V}$$



where $V \rightarrow m/s$

Under ideal conditions, c/c distance b/w two successive vehicles is governed by length of vehicle and lag distance of ideal driver. As per IRC, $l = 6.1$ m & reaction time of ideal driver is 0.7 s.

For ideal vehicle, braking distance (S_b) = 0.

(ii) Practical Capacity (Design Capacity).

$$S = l + SSD.$$

$$\boxed{S = l + vt + \frac{v^2}{2gf}}$$

In the above case, for the calculation of SSD, gradients and braking efficiency are not considered.

06. $S = l + vt + \frac{v^2}{2gf}$

$= 5 + 0.278 \times 65 \times 2.5 + \frac{(0.278 \times 65)^2}{2g \times 0.4} = \underline{\underline{91.79}}$ m

Capacity $= \frac{1000\ V}{S} = \frac{1000 \times 65}{91.79} = \underline{\underline{708.09}}$ veh/hour/lane

07. $S = l + 0.7\,V = 5 + 0.7\,(0.278 \times 40)$

$= \underline{\underline{12.784}}$ m

Capacity $= \frac{1000\ V}{S} = \frac{1000 \times 40}{12.784} = \underline{\underline{3129}}$ veh/hr/lane

08. $S = 20 + 6 = 26$ m.

Capacity $= \frac{1000V}{S} = \frac{1000 \times 40}{26} = \underline{\underline{1538.2}}$ veh/hr

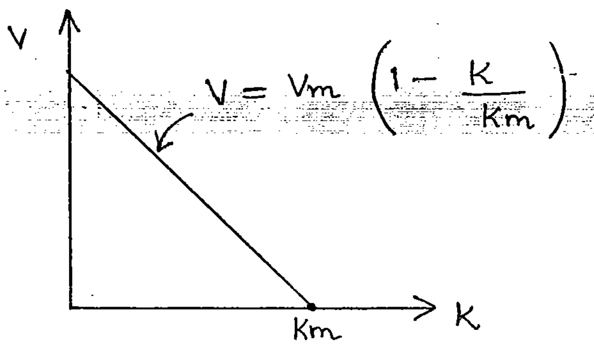
09. σ = std. deviation. = 8.8 kmph.

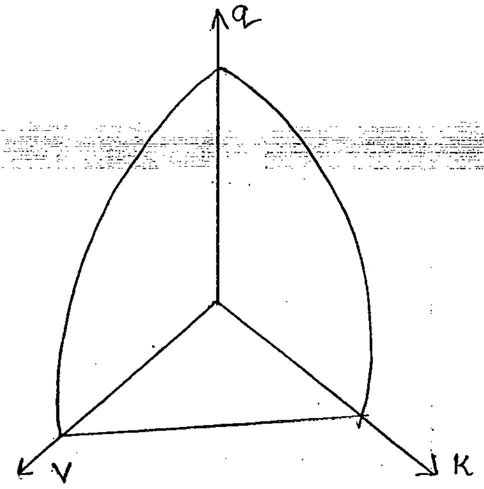
Mean = 33 kmph.

Co effecient of variation $= \frac{\sigma}{\bar{x}} = \frac{8.8}{33} = \underline{\underline{0.2666}}$

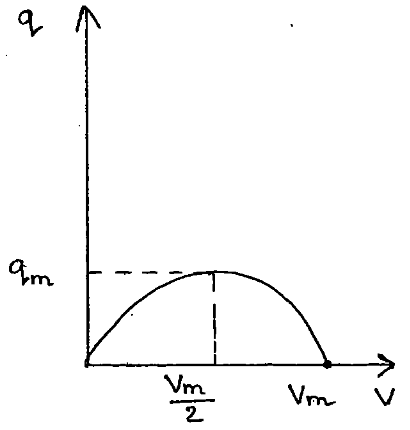
→ Traffic Stream Models

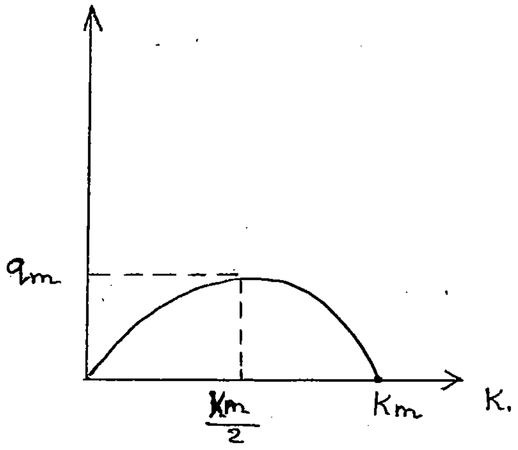
1. Greenshield's Model - Linear speed density model.





$\textcircled{V} = \frac{q}{\textcircled{K}} \Rightarrow V \propto \frac{1}{K}$





K_m → max. density (or) ~~zone~~ jam density

V_m → design speed (or) max speed ~~do~~ on road.

- Jam density is the density at which all vehicles are closely arranged on the road with min spacing b/w them which occurs during traffic jam or before red signal.

$$\boxed{C = q_m = \left(\frac{K_m}{2}\right)\left(\frac{V_m}{2}\right)}$$

$$\boxed{V = V_m\left(1 - \frac{K}{K_m}\right)}$$

10. $S = 7\,m.$

$K_{max} = \frac{1000}{S} = \frac{1000}{7} = 142.86$

$q_{max} = \frac{K_{max}}{2} \cdot \frac{V_{max}}{2} = \frac{142.86}{2} \cdot \frac{70}{2}$

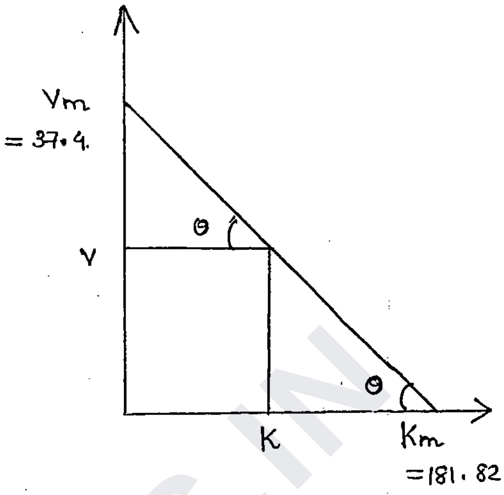
$= \underline{\underline{2500}}$ veh/hr/lane

11. $K_m = 100$, $V_m = 80$ kmph.

$q_m = \frac{V_m \cdot K_m}{4} = \frac{8000}{4} = 2000$ veh/hr @ 40 kmph.

13. $q_m = C = 1700$ veh/hr.

$$K_{max} = \frac{1000}{S} = \frac{1000}{5.5} = 181.82 \text{ veh/km}$$



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

$$1700 = \frac{181.8}{2}\left(\frac{V_m}{2}\right)$$

$$\underline{\underline{V_m = 37.4}} \text{ km/hr}$$

$$\frac{V}{K_m - K} = \frac{V_m}{K_m}$$

$$\frac{V}{181.82-K} = \frac{37.4}{181.82} = 0.206.$$

$$4.86\,V = 181.82 - K.$$

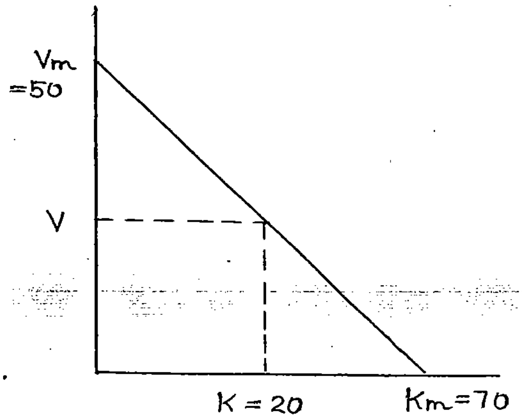
$$V = \frac{181.82-K}{4.86}.$$

But $q = VK$.

$$1000 = \left(\frac{181.82-K}{4.86}\right)K = 37.41\,K - 0.206\,K^2$$

$$K = 32.57 \text{ veh/km} \quad \& \quad \underline{\underline{149.2}} \text{ veh/km}$$

14. $$\frac{V}{70-20} = \frac{50}{70}$$



$$V = \underline{\underline{35.7}} \text{ kmph}$$

2. Greenberg's Logarithmic model.

$$\boxed{V = V_m \ln\left(\frac{K_m}{K}\right)}$$

$$\boxed{C = q_{max} = \frac{K_m V_m}{e}} \quad ; \quad e = 2.72$$

3. Underwood's Exponential model.

$$\boxed{V = V_m e^{-K/K_m}}$$

→ Origin & Destination Studies :

– method of collecting O & D. data :

(i) Road side interview method.

(ii) License plate method.

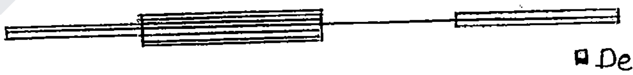
(iii) Post card survey.

(iv) Home interview.

– presentation of O & D data :

(i) O & D tables.

(ii) Desire lines – straight lines connecting origin points with destinations, summarized into different area groups.



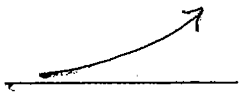
▪ Desire line

Width of a desire line is drawn proportional to number of trips in both directions.

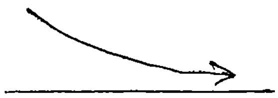
(iii) Piecharts

(iv) Contour lines

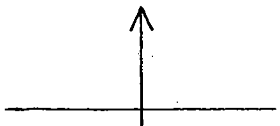
→ Traffic flow Characteristics



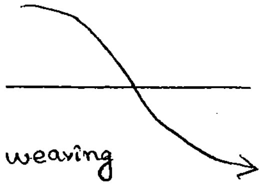
▪ diverging



▪ merging



▪ crossing



▪ weaving

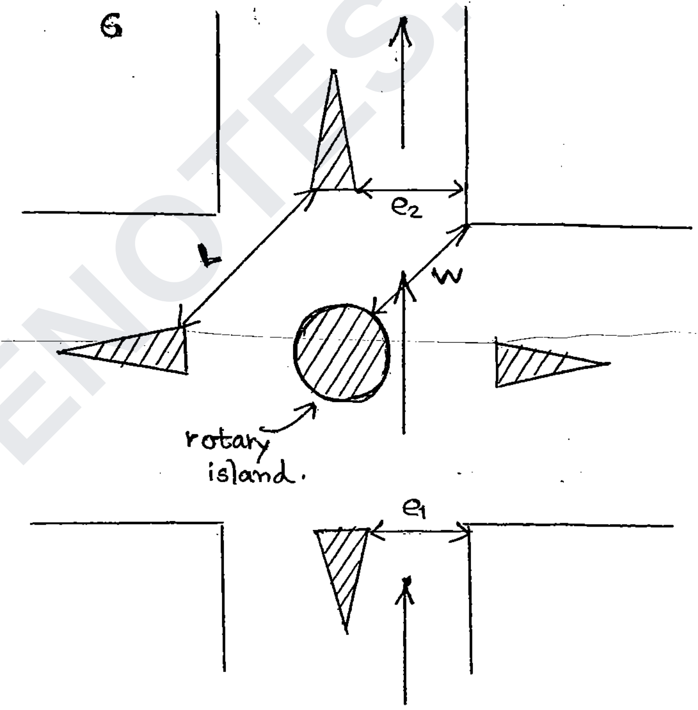
→ Point of Conflict

— Accident prone zone.

— No. of points of conflicts on two lane roads meeting at right angles:

Type of Traffic	No. of conflicting points
Both the roads 2-way	24
One road one-way	11
Both the roads 1-way.	6

L → weaving length.



→ Width of rotary road way

$$W = \left[\frac{e_1 + e_2}{2}\right] + 3.5$$

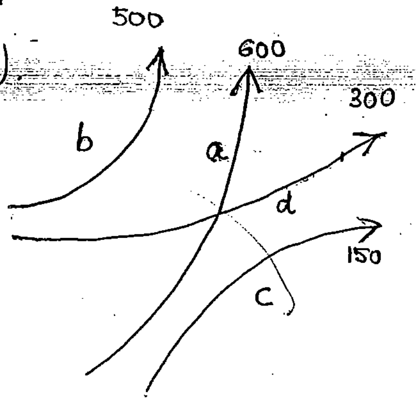
e_1 → avg width at entry

e_2 → avg. width at exit.

* Practical capacity of rotary road way.

$$\boxed{Q_p = \frac{280w\,(1+e/w)\,(1-P/3)}{(1+w/L)}}$$

w → width of rotary road (6 to 18 m).



$$e = \frac{e_1 + e_2}{2}$$

$$P = \frac{b+d}{a+b+c+d}$$; proportion of weaving traffic

$$= \frac{\text{black}}{\text{black+ red}}$$

16. $e = 8.4 m$

$w = 14 m$

$L = 35 m$

$b+c = 1000$ pcu/hr

$a+b+c+d = 2000$ pcu/hr.

$$P = \frac{b+c}{a+b+c+d} = \underline{\underline{0.5}}$$

$$Q_p = \frac{280 w(1+e/w)(1-P/3)}{(1+w/L)}$$

$$= \frac{280 \times 14 (1+8.4/14)(1-0.5/3)}{(1+14/35)} = \underline{\underline{3733.33}} \text{ pcu/hr}$$

17. $e = 5.5$, $w = 6 m$, $L = 20m$, $P = 0.5$

$$Q_p = \frac{280 \times 6(1+5.5/6)(1-0.5/3)}{(1+6/20)} = \underline{\underline{2064}} \text{ pcu/hr}$$

18. Weaving traffic :

$V_{13} = 450$

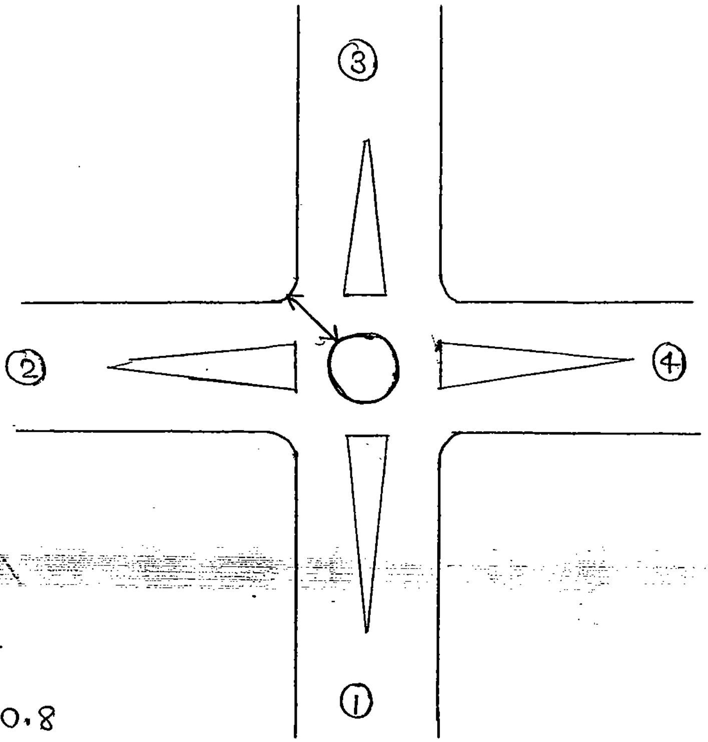
$\boxed{V_{14} = 412}$

$V_{21} = 310$

$V_{24} = 1090$

$\boxed{V_{23} = 200}$

$V_{43} = 600$



$$p = \frac{\text{weaving traffic}}{\text{total traffic}}$$

$$= \frac{450+310+1090+600}{450+412+310+1090+200+600} = \underline{\underline{0.8}}$$

→ Parking

(i) On street (or) kerb parking

(ii) Off street parking

→ Highway lighting

– As per IRC, minimum illumination required on important roads is 30 lux and main roads 15 lux

$$* \text{ Spacing of lamps} = \frac{\text{lamp lumen} * \text{coefficient of utilisation} * \text{maintenance factor}}{\text{Avg. lux on road} * \text{width of road.}}$$

th nov,
ONDAY

→ Traffic Signals

Cycle : The time lapsed from the beginning of getting red to a particular side to the beginning of next red to the same side is called a cycle.

Cycle time : (R→G→A)

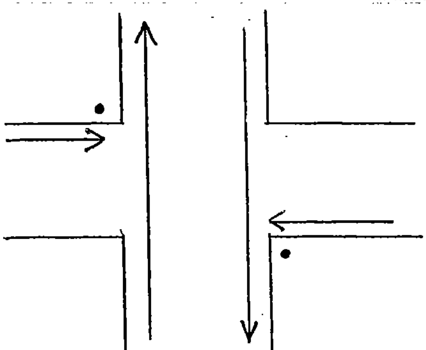
– Given by Webster. as :

$$\boxed{C_o = \frac{1.5L + 5}{1 - Y}}$$

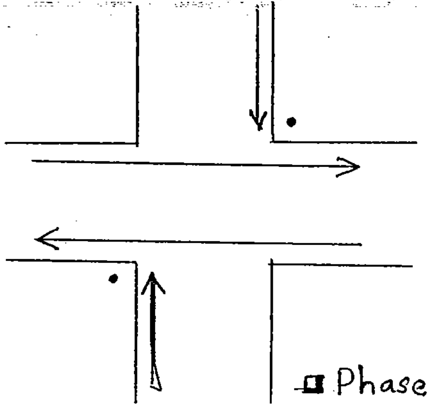
where L → lost time per cycle (= 2n + R)

n → no: of phases.

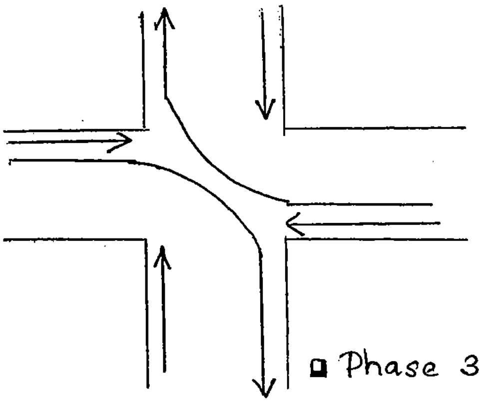
R → all red time.



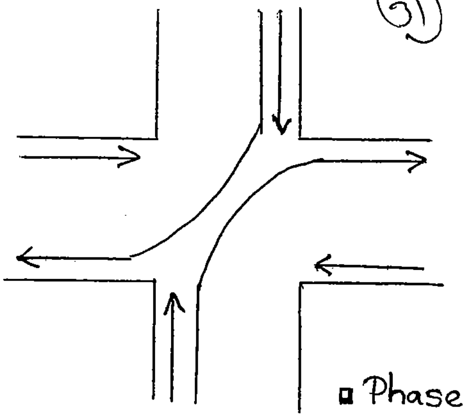
Phase 1



Phase 2.



Phase 3



Phase 4.

$$Y = y_1 + y_2 + y_3 + \dots$$

$$= \frac{q_1}{S_1} + \frac{q_2}{S_2} + \dots$$

$q_i \rightarrow$ normal flow (volume) ; veh/hr

$S_i \rightarrow$ saturated flow ($q_{max} = C =$ capacity)

* Effective Green Time

$$Y \longrightarrow C_o - L$$

$$y_1 \longrightarrow G_1 = ?$$

$$\boxed{G_1 = \frac{y_1}{Y}(C_o - L)}$$

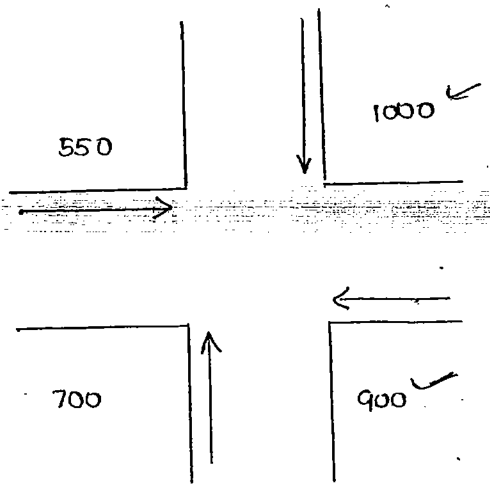
Similarly $G_2 = \frac{y_2}{Y}(C_o - L)$.

20. $Y = \frac{1000}{2500} + \frac{900}{3000} = 0.4 + 0.3$

$$= \underline{\underline{0.7}}$$

$$C_o = \frac{1.5L + 5}{1 - Y} = \frac{1.5 \times 12 + 5}{1 - 0.7}$$

$$= \underline{\underline{76.67\,s}}$$



2 $$G_{NS} = \frac{y_{NS}}{y}(C_0 - L) = \frac{0.4}{0.7}(77-12).$$

$$= \underline{\underline{37.14\ s}}$$

$$G_{EW} = \frac{0.3}{0.7}(77-12) = \underline{\underline{27.86}}\ s$$

21. $$C_0 = \frac{1.5L+5}{1-y} = \frac{1.5 \times 10 + 5}{1-0.5} = \underline{\underline{40s}}$$

* Effective green time, $$G = \underset{\text{green light on}}{G_{act}} + \underset{\text{amber light on}}{A} - \underset{\text{lost. time}}{L}$$

→ Lane Capacity

$C_0 \longrightarrow S$ (when no signals).

$G \longrightarrow q.$

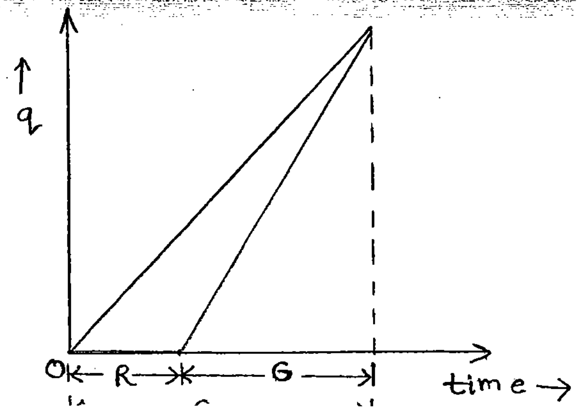
* Lane capacity with signals,

$$\boxed{q = q_{max} = S\left(\frac{G}{C_0}\right)}$$

where S → max flow with no signals.

$\frac{G}{C_0}$ → green ratio (<1)

→ Webster's delay model:



$$\text{Average delay} = \frac{0+R}{2}.$$

$$\boxed{\text{Delay}_{avg} = \frac{R}{2}}$$

* Webster's Emperical eqn :

$$\boxed{\text{Average delay} = \frac{\frac{C_o}{2}\left(1 - \frac{G}{C_o}\right)^2}{1 - \frac{q}{S}}}$$

G → effective green time ($G_{act} + A - L$).

C_o → cycle time

q → normal flow (volume).

S → saturation or max. flow. (volume).

22. $q = 1000$ veh/hr $C_o = 90s$

$S = 2800$ veh/hr $\frac{G}{C_o} = 0.55$.

$$\text{Average delay} = \frac{\frac{90}{2}\left(1 - 0.55\right)^2}{1 - \frac{1000}{2800}} = \underline{\underline{14.175\,s}}$$

$$\text{Critical capacity of lane, } q_{max} = S\left(\frac{G}{C_o}\right).$$

$$= 2800 \times 0.55 = \underline{\underline{1540}} \text{ veh/hour}$$

24. $C_o = 60$

$G_{act} = 27\ s$.

$A = 4s$

$L = 2+1 = 3s$

Effective green time, $G = 27 + 4 - 3 = \underline{\underline{28s}}$

Saturated time head way = 2.4 sec/vehicle.

$$\text{Saturated flow, } S = \frac{3600}{2.4} = 1500 \text{ veh/hr.}$$

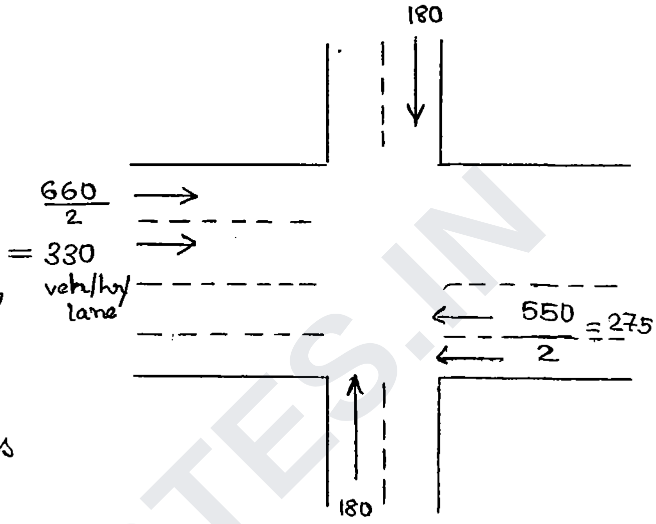
Capacity of lane (with signals), $q = S\left(\frac{G}{C_o}\right)$.

$$= 1500 \times \frac{28}{60} = \underline{\underline{700 \text{ veh/hr}}}$$

23. 330 veh/hr/lane increased to 440 veh/hr/lane in E-W direction.

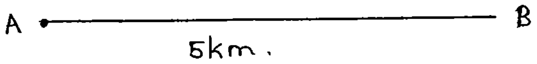
$\therefore$ Green time increases in E-W

No change in green time in N-S direction as flow remains the same.



Q. A student is riding a bicycle in one-way street. He take 40 min to reach home. Student stopped for 15 min during the ride. Meanwhile 45 vehicles overtaken the student. During the ride, 60 vehicles overtook the student. Determine average speed of vehicle stream on road. Length of ride is 5 km.

40 min includes 15 min delay.



Time of travel = 40 − 15 = 25 min.

$$V_s = \frac{5 \text{ km}}{25 \text{ min}} = 12 \text{ kmph.}$$

Assume traffic density, k to be constant

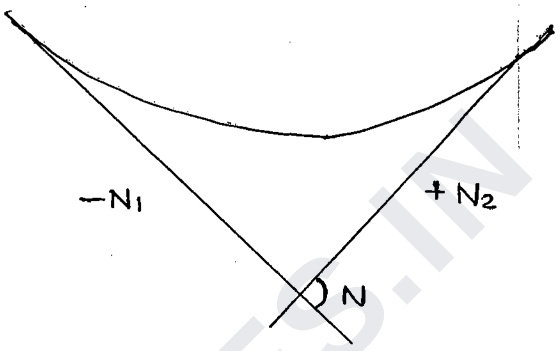
During stop,

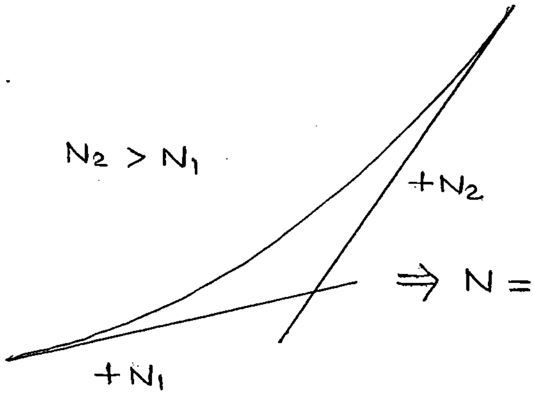
$$q = kV.$$

$$\frac{45}{15} \frac{\text{veh}}{\text{min}} = kV. \quad ; V \rightarrow \text{velocity of stream}$$

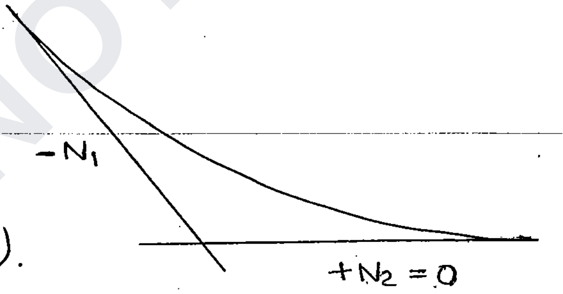
12. VALLEY CURVES

$N = -N_1 - (+N_2)$.



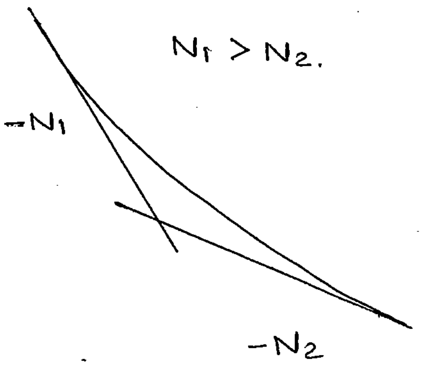


$\Rightarrow N = N_1 - N_2$

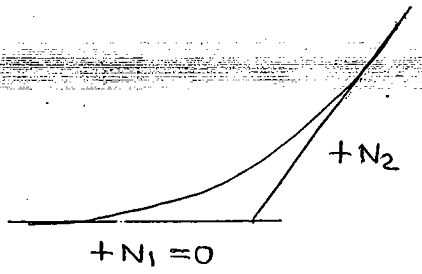


- IRC recommends 3° parabola or cubic parabola (transition curve).

Type of Curve	IRC recommended form.
(i) Horizontal curve →	ARC of circle
(ii) Horizontal transition →	spiral.
(iii) Summit. →	2° / square parabola or parabola.
(iv) Valley curve. →	3°/ Cubic parabola.



→ Design Criteria



* from headlight sight distance.

Case 1: $L \geq S$ = HSD.

$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha}$$

where $h_1 \rightarrow$ height of headlight $(= 0.75\ m)$.

$\alpha \rightarrow$ head light beam angle $(= 1°$ as per IRC$)$ (upwards).

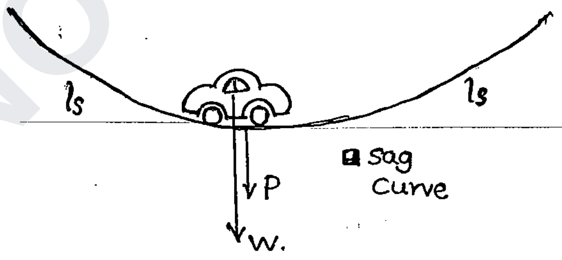
$$L = \frac{Ns^2}{(1.5 + 0.035\,s)}.$$

Case 2: $L < SSD$

$$L = 2s - \frac{2h_1 + 2s\tan\alpha}{N}.$$

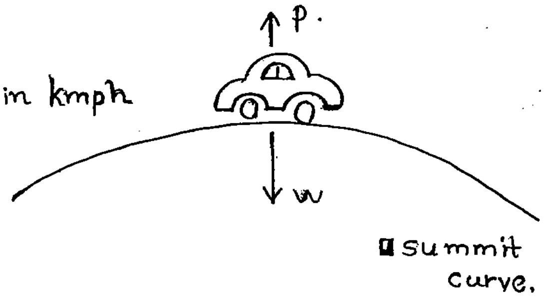
* from comfort condition.

C = rate of change of centrifugal acceleration. $(0.61\ m/s^3)$



- $L = 2\,l_s = 2\left(\frac{NV^3}{C}\right)^{1/2}$

$$\boxed{L = 0.38\,(NV^3)^{1/2}}\ ;\ V \text{ in kmph}$$



- Minimum radius of valley curve for cubic parabola,

$$R = \frac{L_s}{N} = \frac{L}{2N}.$$

$\rightarrow$ Impact factor

Ratio of max. centrifugal force to the weight of vehicle (expressed as %).

$$I = \frac{P}{W} = \frac{1.6\,NV^2}{L}\ \% \qquad (\leqslant 17\%)\ ;\ V \text{ in kmph}.$$

01 $N_1 = \frac{1}{25}$, $N_2 = \frac{1}{20}$, $V = 100$ kmph , $C = 0.6$ m/s^3, SSD = 180 m.

$$N = \frac{-1}{25} - \frac{1}{20} = -0.09$$

Assume L > SSD,

$$L = \frac{Ns^2}{1.5+0.035} = \frac{0.09 \times 180^2}{1.5+0.035 \times 180} = 373.85 \text{ m}$$

By Comfort criteria,

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

$$= 114 \text{ m}$$

$$\therefore \; L = 373.85 \text{ m}$$

02. Impact factor $= 1.6 \frac{NV^2}{L} = \frac{1.6 \times 0.09 \times 100^2}{373.85} = 3.85\%$

---

03. $0.09 \longrightarrow 373.85$

$0.04 \longrightarrow x$

$$x = \frac{373.85 \times 0.04}{0.09} = 166.16 \text{ m}$$

04. $N_1 = \frac{-1}{20}$, $N_2 = \frac{1}{40}$, $V = 80$ kmph, $C = 0.6$ m/s^3 , $S = 120$ m.

$$N = \frac{-1}{20} - \frac{1}{40} = -0.075.$$

Assume L > SSD,

$$L = \frac{Ns^2}{1.5+0.035S} = \frac{0.075 \times 120^2}{1.5+0.035 \times 120} = 189.47 \text{ m}$$

05. Impact factor $= 1.6 \frac{NV^2}{L} = \frac{1.6 \times 0.075 \times 80^2}{189.47} = 4.05\ \%$

23rd nov
SUNDAY

16. TRAFFIC ENGINEERING

→ Traffic Volume :

No: of vehicles crossing a section of road in unit time.

Unit : vehicle/hour per lane (or) vehicle/day per lane.

- Volume can be obtained as a uniform value, when expressed in terms of 'Passenger Car Unit' (PCU) per hour or day.
- PCU number is assigned based on disturbance caused.

* Method of Volume Counting

(i) Manual method.

Eg: In a busy hour, the following vehicles are observed at a cross section of a road. Calculate traffic flow.

Cars — 200
Buses — 80
2 wheeler — 500
HDV — 8.

$$\text{Traffic volume} = 200*1 + 80*3 + 500*0.5 + 8*4.$$
$$= 720 \text{ pcu/hour}$$ or
720 vehicle / hour.

MSROADS is the software used to calculate traffic flow based on videographs taken.

- Barchart is the method most suitable for representing traffic data.

- 30th Highest Hourly Volume (Design volume)

The hourly volume that will be exceeded only 29 times in a year and all other hourly volumes of the year will be less than this volume.

During motion,

$$q = k\, v_R .$$

$$\frac{60}{25} = k\,(v - v_S) = k\,(v-12)$$

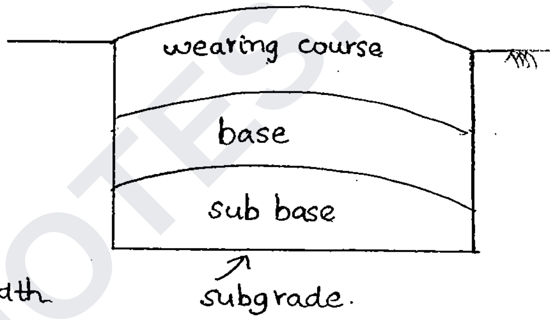
$$\frac{3}{v} = \frac{2.4}{v-12}$$

$$\Rightarrow \quad v = \underline{\underline{60}}\ \text{kmph}$$

13. HIGHWAY MATERIALS & TESTING

→ Flexible Pavement

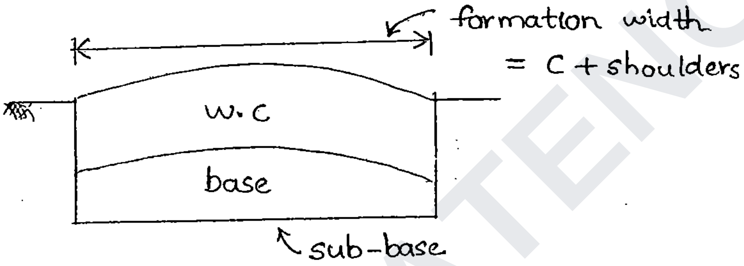
Eg: WBM, Gravel, Earth, B.T.



→ Rigid Pavement

Eg: Cement Concrete.

Reinforced Cement Concrete.



→ Properties of Subgrade required:

1. C B R - California Bearing Ratio

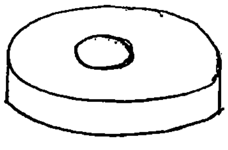
↑ CBR ⇒ ↑ strength of subgrade.

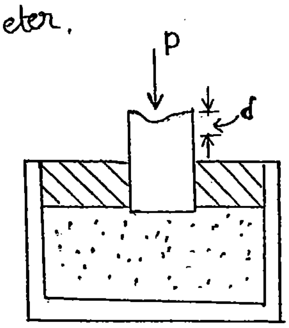
2. Modulus of Subgrade Reaction (K):

↑ K : ↑ stiffness ⇒ ↓ settlement.

→ California Bearing Ratio test:

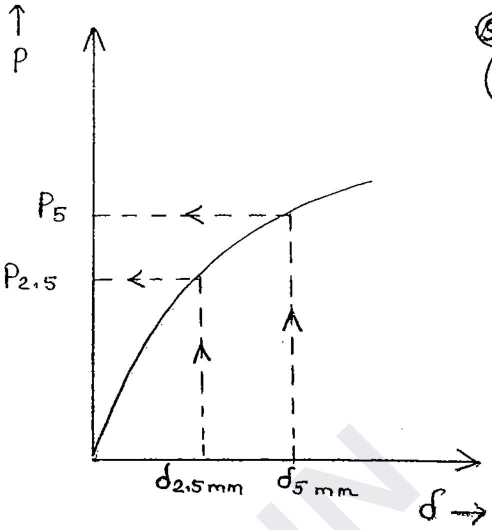
- CBR is the primary design parameter.
- counterweight is provided to avoid soil heaving





- $$\boxed{CBR_{2.5} = \frac{P_{2.5}}{\text{std. } P_{2.5}} * 100}$$

$$\boxed{CBR_5 = \frac{P_5}{\text{std. } P_5} * 100}$$



- Std. $P_{2.5}$ = 1370 kg

  Std P_5 = 2055 kg

  $CBR_{2.5} > CBR_5$

- As per IRC, if $CBR_{5} > CBR_{2.5}$, repeat the test. If the same results are obtained again, use the higher of the two.
- CBR gives the relative strength of soil wrt crushed aggregate of California.

  CBR = 15% ⇒ strength of subgrade is 15% of strength of crushed aggregate of California.

→ Plate Load or Bearing Test.

- This test gives.
  - (i) K of soil (stiffness of subgrade soil).
  - (ii) Young's modulus, E.
- Standard plate size = 75 cm dia

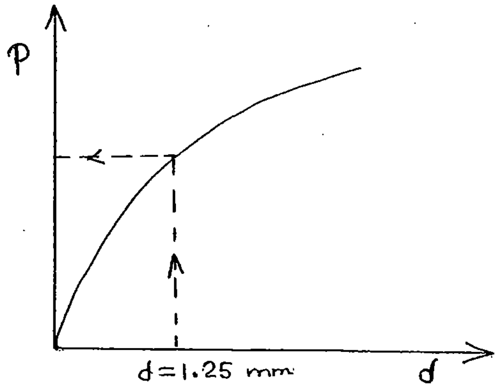
  Commonly used = 30 cm φ

- Pressure on soil, $p = \frac{\text{Load.}}{\text{plan area of plate}}$

* Method 1 : fix δ = 1.25 mm

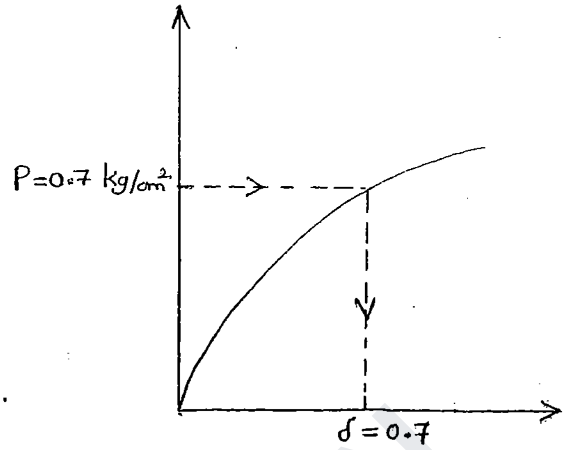
$$K = \frac{\text{Pressure}}{\text{Unit Deflection.}} \left(\frac{kg}{cm^3} \text{ or } N/mm^3 \right)$$

$$K = \frac{P_{1.25 mm}}{1.25 mm}$$



* Method 2 : fix $p = 0.7$ kg/cm^2

$$K = \frac{0.7}{\delta_{0.7}}$$



As per IRC, fixing independent parameter ($= \delta$) is recommended.

* E of soil

– E of soil by plate load test given by Boussinesq

(i) For rigid plate. (MS).

$$\boxed{E_s = \frac{1.18\,pa}{\delta}}$$

where a → radius of plate.

p → pressure on soil.

δ → settlement.

(ii) For flexible plate (rubber plate).

$$\boxed{E_s = \frac{1.5\,pa}{\delta}}$$

Test with rubber plate is a replica of rubber tyre on road.

std. plate

* K of soil $= (K)_{75\,cm\,\phi} = \frac{(K)_{30\,cm\,\phi}}{2}$

03. $K_{75\,cm} = \frac{K_{30\,cm}}{2} = \frac{200}{2} = 100$ N/cm^3

05 $E = \frac{1.18\,pa}{\delta} = \frac{1.18 \times 0.8 \times 75/2}{0.25} = 141.6$ kN/cm^2

12. $CBR_{2.5} = \frac{60.5}{1370} \times 100 = \underline{\underline{4.4\%}}$

$CBR_5 = \frac{80.5}{2055} \times 100 = \underline{\underline{3.92}} \%$

$CBR_{2.5} > CBR_5 \Rightarrow CBR = CBR_{2.5} = \underline{\underline{4.4\ \%}}$

→ Tests on Road Aggregate.

1. Toughness

- resistance against impact.
- aggregate impact value is percentage fine passing 2.36 mm sieve to total aggregate weight.
- aggregate impact testing machine.

2. Soundness

- resistance to weathering action.
- solution of sodium sulphate or magnesium sulphate used.

3. Shape test

- angular shape is preferred.

(i) Flakiness index.

Thickness $< 0.6 \times$ (avg size). ⇒ flaky

(ii) Elongation index.

Length $> 3 \times 0.6 \times$ (avg size) ⇒ elongated.

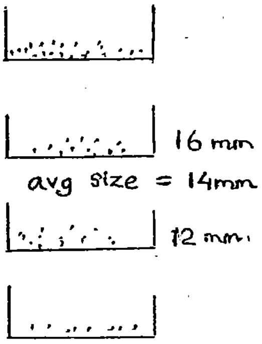
On a given sample, flakiness test is conducted and over non-flaky aggregates, elongation test is conducted.

Thickness $< 0.6 \times 14 = 8.4$ mm.

Length $> 3 \times 0.6 \times 14 = 25.2$ mm.

Range of particle size :

8.4 mm — 25.2 mm



Eg: Sample aggregate = 500 g.

Flaky material = 150 g

Elongated material = 100 g

$$\text{Flakiness index} = \frac{\text{Flaky material}}{\text{Total weight}} * 100 = \frac{150}{500} \times 100 = \underline{\underline{30\%}}$$

$$\text{Elongation index} = \frac{\text{Elongated material}}{\text{Non flaky}} * 100$$

$$= \frac{100}{500-150} * 100 = \underline{\underline{28.57\%}}$$

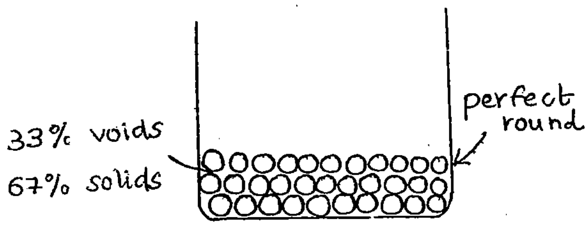
4. Strength.
   - resistance against gradual load.
   - aggregate crushing test

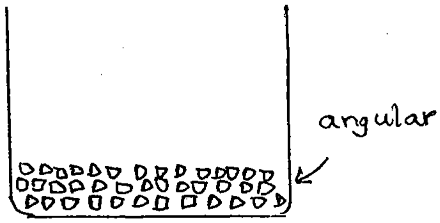
5. Hardness
   - resistance to abrasion.
   - standard abrasion test are :
     a) Los Angel's test. – resistance to impact & abrasion.
     b). Deval abrasion test.
     c). Dorry abrasion test.

6. Specific gravity
   - preferably b/w 2.6 & 2.9

7. Water absorption ≤ 0.6%

8. Angularity number
   - voids in excess of rounded gravel for which voids ratio is 33%





- Angularity number = 67 − % solid volume.

$$= 67 - 100 \frac{W}{C.G} \quad \text{(whole number)}.$$

- ↑ angularity number ⇒ ↑ angular aggregates
  ↑ coarser aggregates

→ Bitumen.

- Fractional distillation of petroleum.

Gasolene → Petroleum → Diesel → Kerosene → ... Bitumen.

- Destructive distillation of wood or coal gives tar. (in the absence of oxygen). Tar is always obtained as a liquid. State of bitumen depends on temperature.

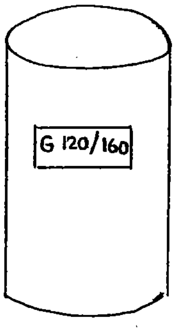
→ Tests on Bitumen

1. Penetration test.
   - determines hardness or softness of bitumen.
   - Penetrometer ~~test~~ apparatus. is used.
   - Penetration value: penetration in $\frac{1}{10}$ mm units for 5s.
   - Grade of bitumen is decided based on penetration value.

Penetration value =

$$\frac{120}{10} \text{ mm to } \frac{160}{10} \text{ mm}$$

$$= 12 \underline{\underline{\text{to}}}\ 16 \text{ mm}$$



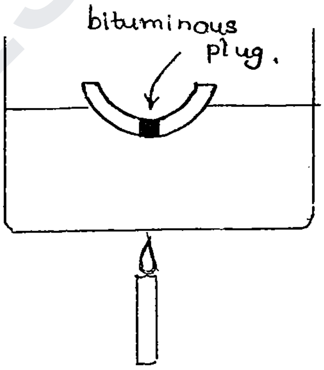
2. Ductility Test
   - elongation at failure is calculated.

3. Viscosity test

- resistance to flow
- viscosity is a general term for consistency.
- Orifice type of Viscometer is used for bitumen in liquid form.
- time in seconds for 50 mL bitumen to flow standard orifice at standard temperatures.

4. Float test.

- used for bitumen in solid form.



5. Specific gravity

- Pure bitumen : 0.97 - 1.02

Tar : 1.10 - 1.25

6. Softening Point test.

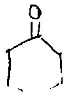
- Ring & Ball test.
- Higher the softening point, lower will be temperature susceptibility. and is preferred in warmer climates.

7. Flash & Fire point test.

- 'Pensky - Martens' closed cup or open cup apparatus
- Flash point : 175°c

8. Solubility Test

- Bitumen soluble in Benzene, carbon disulphide & carbon tetrachloride
- Tar soluble in Toluene.



9. Spot test

- Naphtha solution used.

→ Cut back Bitumen.

- bitumen with reduced viscosity due to additives.

* Types of Cutbacks :

(i) Rapid Curing (RC)

- naphtha or gasoline are fluxed with bitumen.

(ii) Medium Curing (MC)

- fluxed with kerosene or light diesel oil.

(iii) Slow Curing (SC)

- high boiling point gas oil.

RC0, RC1, RC2, RC3, RC4, RC5.
MC0, MC1, ... MC5.
SC0, SC1, SC2 . . . . SC5.

↑ no. $\Rightarrow$ ↑ viscosity $\Rightarrow$ ↓ fluidity

RC5 more viscous than RC1.
MC5 more viscous than MC2.
MC2, SC2, RC2 have same viscosity.

} viscosity depends only on the <u>number</u>.

→ Bitumen Emulsion.

- Bituminous particles suspended in water with the help of some emulsifier.
- can be used in wet weather, even when its raining.
- emulsion is used for strengthening of soil.

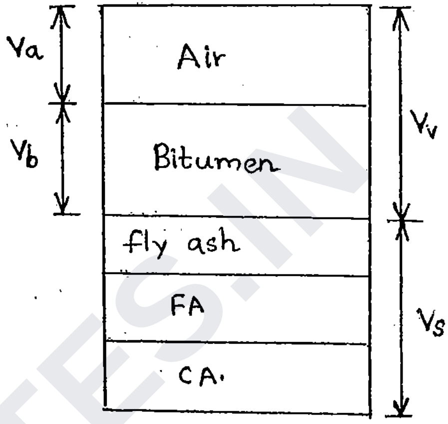
→ Road Tar (RT).

- RT-1, RT-2, RT-3, RT-4, RT-5. (increasing order of viscosity)
- Normal Indian climatic conditions → RT-2

→ ~~Marshall Stability Test.~~

→ Ingredients of Bituminous Concrete.

- Bitumen : Binder.
- Coarse aggregate : Strength.
- Fine aggregate : Void filler.
- Fly ash : void filler.



* Percentage Air Voids

$$- \boxed{V_a = \frac{G_t - G_m}{G_t} * 100}$$

where $G_t \rightarrow$ theoretical specific gravity. (without air voids).

$$- G_t = \frac{100}{\frac{W_{CA}}{G_{CA}} + \frac{W_{FA}}{G_{FA}} + \frac{W_{fly}}{G_{fly}} + \frac{W_{bit}}{G_{bit}}}$$

$W_{CA} \rightarrow$ % wt of coarse aggregate (CA).

$G_{CA} \rightarrow$ specific gravity of CA.

Measured (or) bulk density, $\gamma_m = \frac{\text{wt. of bit. sample}}{\text{Vol. of bit. sample.}}$

$G_m \rightarrow$ bulk or measured sp. gravity.

$$- G_m = \frac{\gamma_m}{\gamma_w}$$

* Percentage volume of bitumen

$$\boxed{V_b = G_m \left(\frac{W_b}{G_b}\right)}$$

* Percentage voids in mineral aggregate.

$$VMA = \underbrace{V_a + V_b}_{\text{obtained as above.}} \quad (\text{in } \%)$$

* Percentage voids filled with bitumen.

$$VFB = \frac{V_b}{V_v} * 100 = \frac{V_b}{VMA} * 100.$$

55.

Q. 06. $G_m = 2.325$

$G_t = 2.41.$

$G_b = \frac{\gamma_b}{\gamma_w} = \frac{1.03}{1} = 1.03$

$W_b = 4.5\,\%$

$$V_a = \frac{G_t - G_m}{G_t} * 100 = \frac{2.41 - 2.325}{2.41} \times 100$$

$$= \underline{\underline{3.527\,\%}}$$

$$V_b = G_m\left(\frac{W_b}{G_b}\right) = 2.325\left(\frac{4.5}{1.03}\right) = 10.16\%$$

$$VMA = V_a + V_b = 3.527 + 10.16 = \underline{\underline{13.685\%}}$$

$$VFB = \frac{V_b}{VMA} * 100 = \frac{10.16}{13.685} * 100 = \underline{\underline{74.243}}\ \%$$

08. $\gamma_m = \frac{1100}{475} = 2.31\ g/c.$

$G_m = \frac{\gamma_m}{\gamma_w} = \underline{\underline{2.31}}$

Specimen	A1	A2	A3	A4	Bitumen.
wt (g)	825	1200	325	150	100.
% wt	31.73	46.15	12.5	5.77	3.85
sp.gr.	2.63	2.51	2.46	2.43	1.05

$$G_t = \frac{100.}{\frac{31.73}{2.63} + \frac{46.15}{2.51} + \frac{12.5}{2.46} + \frac{5.77}{2.43} + \frac{3.85}{1.05}}$$

$$= \underline{\underline{2.405}}$$

a) % air voids, $V_a = \frac{G_t - G_m}{G_t} \times 100$

$$= \frac{2.405 - 2.31}{2.405} \times 100 = \underline{\underline{3.95\%}}$$

b) % bitumen by volume, $V_b = G_m \left(\frac{W_b}{G_b}\right).$

$$= 2.31 \times \frac{3.85}{1.05} = \underline{\underline{8.47\%}}$$

c). % voids in mineral aggregates, VMA $= V_a + V_b.$

$$= 3.95 + 8.47 = \underline{\underline{12.42\%}}$$

$\frac{2.486 - G_m}{2.486} = 7$

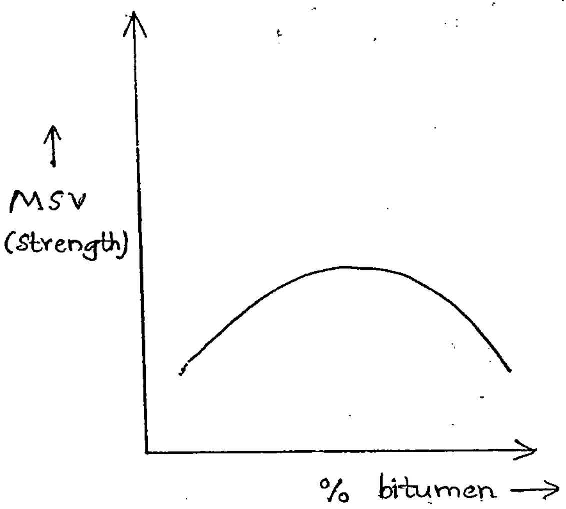
2.31

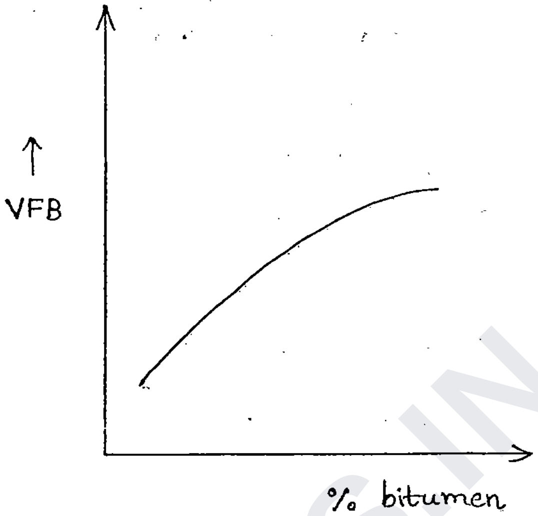
→ Marshall Stability Test.

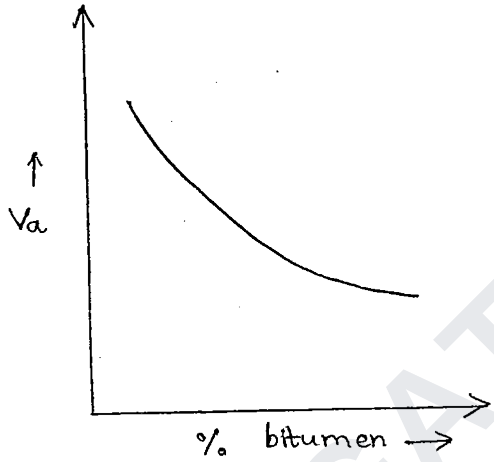
- Applicable to hot mix-paving mixture design using penetration grade bitumen and containing aggregates with maximum size of 2.5 cm.
- 10 cm ϕ & 6.3 cm height specimen.
- Load at failure known as 'Marshall Stability Value' (in kg) and deformation at failure known as 'Marshall flow value' (1 unit = $\frac{1}{4}$ mm), are noted.
- ↑ MSV ⇒ ↑ strength

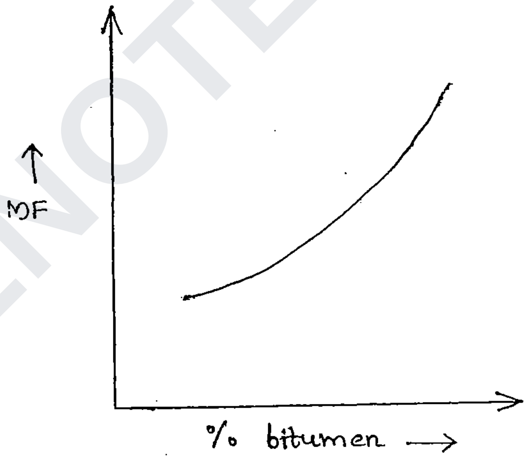
  ↑ MFV ⇒ ↑ deformation

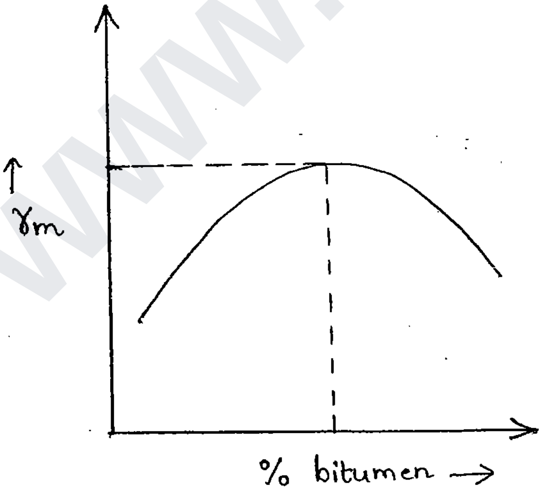
  ↓ stiffness.


↑
MSV
(Strength)
% bitumen →


↑
VFB
% bitumen


↑
Va
% bitumen →


↑
MF
% bitumen →


↑
γm
% bitumen →

25th nov,
UESDAY

14. PAVEMENT DESIGN

Flexible Pavement	Rigid Pavement.
(i) Series of layers	(i) one cource portland concrete slab.
(ii) Pavement design influenced by subgrade strength.	(ii) Flexcural strength of concrete is major factor for design.
(iii) Load distribution through component layers	(iii) distributes load over a wide area because of its rigidity and high elastic modulus.
Eg: BT, WBM, Gravel, Earth.	Eg: RCC, CC

→ Design Factors :

(i) Design Life :

Flexible pavements – 10 to 20 years

Rigid pavements – 20 to 30 years

(ii) Anticipated Traffic :

$$\boxed{A = P(1+r)^n}$$

Eg: Present traffic, P = 2520 commercial vehicles /day.

Rate of growth, r = 7.5%.

n = 2 years.

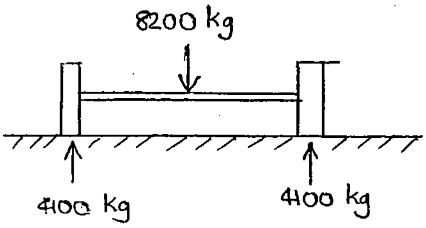
Anticipated traffic (or) Expected traffic

$$= 2520\left(1 + \frac{7.5}{100}\right)^2 = \underline{\underline{2912.2}}\ \text{cv/day}$$

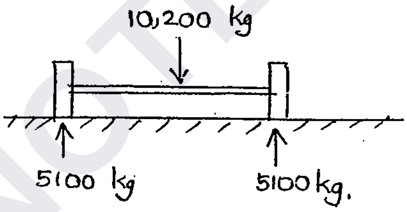
- ⊙ Commercial Vehicles – laden weight > 3t

(iii) Design Wheel Load.

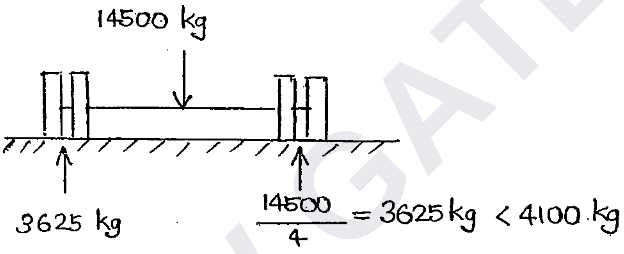
Type of Load.	Flexible Pavement.	Rigid Pavement.
Max. legal axle load.	8200 kg	10200 kg.
Max equivalent single wheel load. (ESWL)	4100 kg	5100 kg



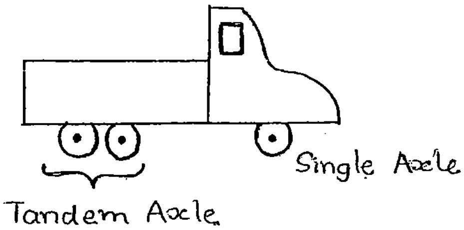
▪ flexible pavements



▪ rigid pavements.



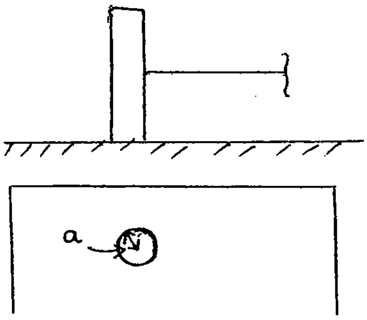
▪ Dual wheel Single axle load.



– Design of pavement is based on 98th percentile of axle load.

* Contact Pressure

$$\text{Contact pressure} = \frac{\text{Load on wheel.}}{\text{Contact area (or) area of imprint}}$$



– Contact area is assumed to be circle, though it is actually elliptical

– Radius of contact area = a

$a = 15$ cm (if not given)

* Rigidity factor

$$\text{Rigidity factor} = \frac{\text{Contact Pressure}}{\text{Tyre Pressure}}.$$

If tyre pressure = 7 kg/cm², then rigidity factor = 1

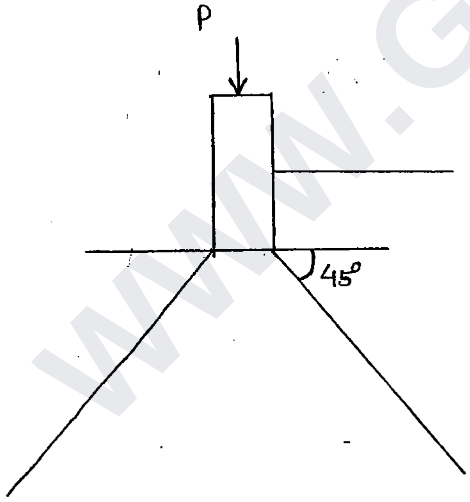
If tyre pressure < 7 kg/cm², then rigidity factor > 1

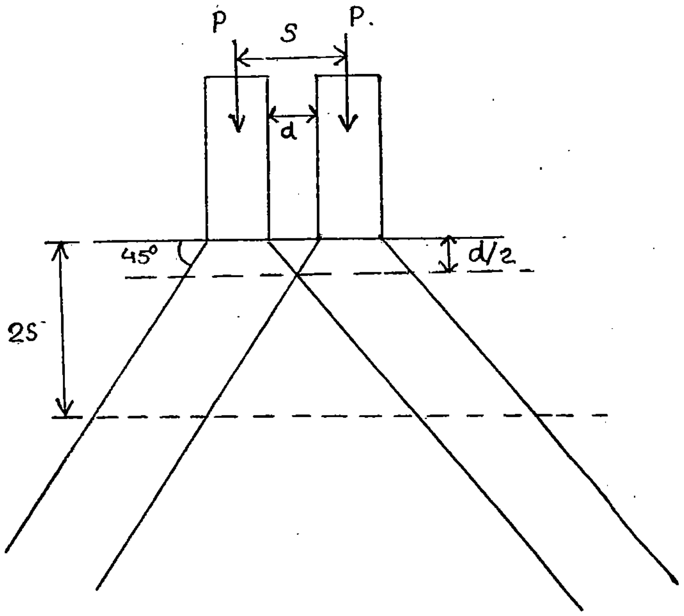
If tyre pressure > 7 kg/cm², then rigidity factor < 1

$$7\ \text{kg/cm}^2 = 0.7\ \text{MPa} = 28\ \text{pound/sq.in (psi)}$$

- On an average, tyre pressure is maintained at 30-35 psi
- IRC recommends 0.8 MPa (8 kg/cm²).
- N_2 is used for inflation :
  (i) less expansion (almost similar to ideal gas).
  (ii) high compression ratio.

→ Equivalent Single Wheel Load :





- For single wheel single axle load :

ESWL = P.

- For dual wheel single axle load :

ESWL = P (upto a depth d/2)

ESWL = 2P . (depth > 2S)

ESWL = P to 2P ($\frac{d}{2}$ < depth < 2S),

↳ based on logarithmic interpolation.

Eg: In a dual wheel assembly of an ~~wheetaxle~~, the load on each tyre is 4000 kg. The c/c distance b/w the tyre is 50 cm, the clear distance b/w tyre is 25 cm. Determine ESWL at a depth of :

(i) 10 cm (ii) 120 cm (iii) 70 cm from road surface.

(i) $Z_1 = 10\,cm \; (< \frac{25}{2})$.

ESWL = P = 4000 kg.

(ii) $Z_2 = 120\,cm \; (> 2 \times 50)$.

ESWL = 2P = 8000 kg.

(iii). $Z_3 = 70\,cm \; (12.5 < 70 < 100)$.

ESWL = P to 2P.

$\log 10 \longrightarrow \log 4000$

$\log 70 \longrightarrow \log ESWL.$

$\log 100 \longrightarrow \log 8000$

$\log\left(\frac{d}{2}\right) \rightarrow \log P$

$\log(2S) \rightarrow \log 2P.$

$$\ln ESWL = \ln 4000 + \left(\frac{\ln 8000 - \ln 4000}{\ln 100 - \ln 10}\right) * (\ln 70 - \ln 10)$$

$$= 8.88$$

$\Rightarrow$ ESWL = $\underline{\underline{7185.55}}$ kg

→ Equivalency factor, EF

$$\boxed{EF = \left[\frac{\text{Actual wheel load.}}{\text{Std. wheel load.}}\right]^4}$$

Eg: Actual wheel load = 3800 kg

Std. wheel load = 4100 kg

$$EF = \left(\frac{3800}{4100}\right)^4 = \underline{\underline{0.74}}$$

Damage caused by actual wheel load is 74% of that caused by std. wheel load.

If actual axle load = 9000 kg.

Std axle load = 8200 kg

$$EF = \left(\frac{9000}{8200}\right)^4 = \underline{\underline{1.45}}$$

Q. The no. of wheel loads moving on a road with different load range is given below. Determine total number of vehicles in terms of standard wheel load.

Load range	No:of veh./day.	Equivalency factor
4100 kg	300	1.
5200 kg	100	2.59
3800 kg	50	0.74.

Total no. of vehicles in terms of standard vehicle

$$= 300 \times 1 + 2.59 \times 100 + 0.74 \times 50$$

$$= \underline{\underline{595 \text{ veh/ day}}}$$

→ Modified CBR method:

$$\left.\begin{array}{l}\text{Cumulative}\\ \text{Standard}\\ \text{Axles}\end{array}\right\}, \quad \underset{(msa)}{N} = \frac{365\left((1+r)^{n}-1\right) A D F}{r}$$

where A → initial traffic at the time of end of construction in terms of cv/day.

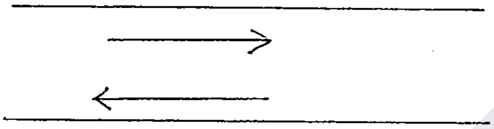
n → design life in years.

D → lane distribution factor.

F → vehicle damage factor.

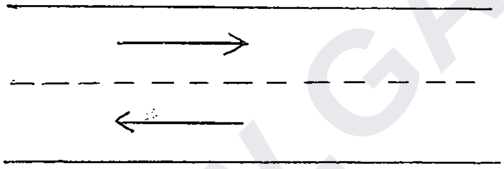
$A = P(1+r)^{x}$; x → construction period.

* LDF (D) for various types of roads.



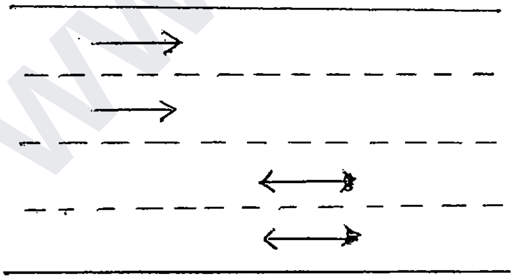
D = 1

▫ single lane



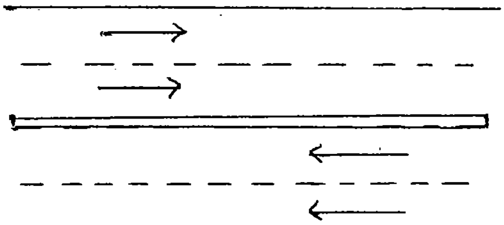
D = 0.75

▫ two lane single carriage way



D = 0.4

▫ four lane single carriage way



D = 0.75

▫ Dual 2 lane Carriageway

→ Repetition of Loads

$$P_1 N_1 = P_2 N_2$$

Eg: $P_1 = 4100$ kg, $N_1 = 6$ million, $P_2 = 3800$ kg, $N_2 = ?$

$$4100 \times 6 = 3800 \times N_2$$

$$N_2 = \underline{\underline{6.47}} \text{ million}$$

P-64.

02. $n = 15$ years; $r = 7.5\%$; $P = 1000$ cv/day; $x = 5$ years.
VDF, $F = 2.5$; LDF, $D = 1$. (If not given).

$$A = P(1+r)^x = 1000(1+0.075)^5$$
$$= 1435.63 \text{ cv/day.}$$

$$N = \frac{365((1+r)^n - 1) ADF}{r} = \frac{365((1+0.075)^{15} - 1) \times 1435.63 \times 1 \times 2.5}{0.075}$$
$$= 34.2 \times 10^6 \text{ c.s.a} = \underline{\underline{34.2}} \text{ msa}$$

04. $A = 2500(1+0.08)^1 = 2700$ cv/day

$$N = \frac{365(1.08^{10} - 1) \times 2700 \times 0.75 \times 3.5}{0.08} = \underline{\underline{37.475}} \text{ msa}$$

05. $N = N_1 + N_2$

LDF is considered.

$$N_1 = \frac{365((1+0.075)^{10} - 1) 2000 \times 5}{0.075} = \underline{\underline{51.64}} \text{ msa}$$

$$N_2 = \frac{365((1+0.075)^{10} - 1) \times 200 \times 6}{0.075} = \underline{\underline{6.196}} \text{ msa}$$

$N = \underline{57.83}$ msa

Q. A traffic survey on a road gives 5000 cv/day. The axle load distribution on the road is given below. Design period of road is 15 years. Growth rate 7.5%. Vehicle damage factor should be calculated from the above data. Load safety factor is 1.3. Determine cumulative standard axles (in msa).

Axle load (ton)	Frequency (in %)	EF
18	10	23.2
14	20	8.5
10	35	2.212
8	15	0.905
6	20	0.287

Standard axle load (as per IRC) = 8.2 t (for flexible pavement).

Weighted average of EF = vehicle damage factor

$$= \frac{0.1\times23.2 + 0.2\times8.5 + 0.35\times2.212 + 0.15\times0.905 + 0.2\times0.287}{1}$$

$$= \underline{\underline{5}}$$

$$N = \frac{365\left(\left(1+0.075\right)^{15}-1\right)5000\times1\times5}{0.075} = \underline{238.33} \text{ msa}$$

Taking load safety factor in account,

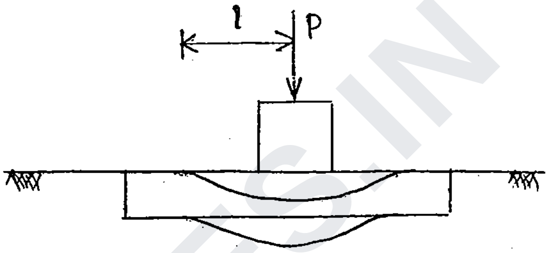
N = 238.33 * load safety factor.

$= 238.33 * 1.3 = \underline{\underline{309.83}}$ msa

25th nov,
TUESDAY

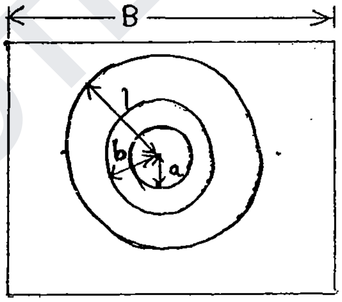
15. RIGID PAVEMENTS

- Load carrying capacity due to :
  (i) rigidity
  (ii) modulus of elasticity of slab ; slab action.



* Radius of Relative Stiffness, l

Radius of a circular zone in which the rigid pavement is deflecting due to wheel load at its centre.



$$\boxed{l = \left[\frac{Eh^3}{12K\,(1-\mu^2)}\right]^{1/4}}$$

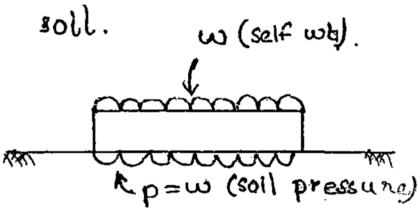
where E → modulus of elasticity of concrete (= 5000 $\sqrt{f_{ck}}$)
μ → poisson's ratio of concrete (= 0.15)
h → slab thickness.
K → modulus of subgrade reaction.

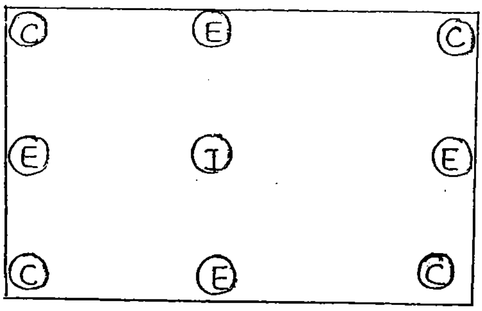
* Radius of Resisting Section, b

Radial zone in which soil below the pavement is deflecting

→ Critical Load positions

- The stresses due to self wt are ignored as pavement panel is fully supported over soil.
- The LL on pavement is moving wheel load.





- Safest loading position is interior.
- Most critical is loading at corner; causing tension at top.
- Loading at interior and exterior causes tension on bottom.

* Westergaard's Equation for wheel loads:

Tensile Stress @ slab top }
$$\sigma_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

* Modified Westergaard formula.
(Teller & Sutherland)

Corner loading:

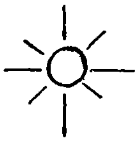
$$\sigma_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$$

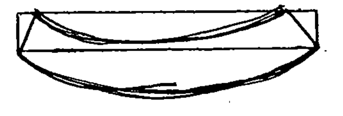
→ Secondary Stresses

1. Temperature Stresses

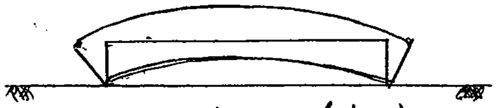
(i) Warping Stress

- daily variation of temperature.
- Bradbury





▪ warping up (night).



▪ warping down (day).

- A pavement freely warping, no stress develops. Over a warped ~~stress~~ surface, if wheel load is placed, stresses develop.
- Nature of warping stress is same as wheel load stress

Interior } Tension @ bottom.
Edge }

Corner → tension @ top.

* Warping stress at edge:

$$\boxed{\sigma_{w(e)} = \frac{C_x E \alpha t}{2} \text{ or } \frac{C_y E \alpha t}{2}}$$ (whichever is higher)

where t → temperature gradient across the pavement.
α → coeffecient of thermal expansion.

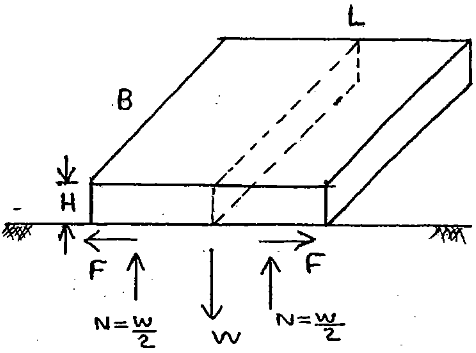
* Warping stress at corner:

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

(ii) Frictional Stresses:

In winter, temperature decreases tension develops.

In summer, temperature increases, compression develops.



Tension developed in winter due to drop in temperature causes the slab to develop crack in the middle.

$$F = fN$$
$$= f\left(\frac{W}{2}\right)$$
$$= f\left(\frac{\gamma_c \times B \times L \times h}{2}\right)$$

Frictional force = resisting force.

$$F = \sigma_f\,(B \times h).$$

$$f\left(\frac{\gamma_c \times B \times L \times h}{2}\right) = \sigma_f\,(B \times h).$$

$$\boxed{\sigma_f = \frac{f \gamma_c L}{2}}$$

- For safety, σ_f should not be more than modulus of rupture of concrete $(f_{cr} = 0.7\sqrt{f_{ck}})$

$$\sigma_f \leq 0.7\sqrt{f_{ck}}$$

- To reduce tensile stress due to friction, it is better to construct pavement in water. If its compulsory to construct pavement in summer, better time is night time.

→ Critical Combination of Stresses.

1. Summer mid day : the critical stress is for edge region

$$\boxed{\sigma_{critical} = \sigma_e + \sigma_{w(e)} - \sigma_f}$$

compression +ve -ve
tension +ve

2. Winter midday : critical stress is for edge region.

$$\boxed{\sigma_{critical} = \sigma_e + \sigma_{w(e)} + \sigma_f.}$$

3. Winter midnight : critical stress is for corner region.

$$\boxed{\sigma_{critical} = \sigma_c + \sigma_{w(c)}.}$$

NOTE :

- The stress due to friction at corner is always zero.
- Max stress due to friction develops at the edge region. of middle of length.

03. Summer mid day :

$$\sigma_{critical} = 210 + 90 - 10 = 290 \text{ N/mm}^2$$

04. $\sigma_e = 30 \text{ kg/cm}^2$ $\quad \sigma_{w(c)} = \overset{7}{9} \text{ kg/cm}^2.$ $\quad \sigma_{f(w)} = 4 \text{ kg/cm}^2$

$\sigma_c = 32 \text{ kg/cm}^2$ $\quad \underset{(summer)}{\sigma_{w(e)}} = 8 \text{ kg/cm}^2$ $\quad \sigma_{f(s)} = 5 \text{ kg/cm}^2.$

$\underset{(winter)}{\sigma_{w(e)}} = 6 \text{ kg/cm}^2.$

Summer (mid day) :

$$\sigma_R = \sigma_e + (\sigma_w)_e - \sigma_f$$

$$= 30 + 8 - 5 = \underline{\underline{33 \text{ kg/cm}^2}}$$

Winter (mid day) :

$$\sigma_R = \sigma_e + \sigma_{we} + \sigma_f.$$

$$= 30 + 6 + 4 = \underline{\underline{40 \ kg/cm^2}}$$

Winter (mid-night) :

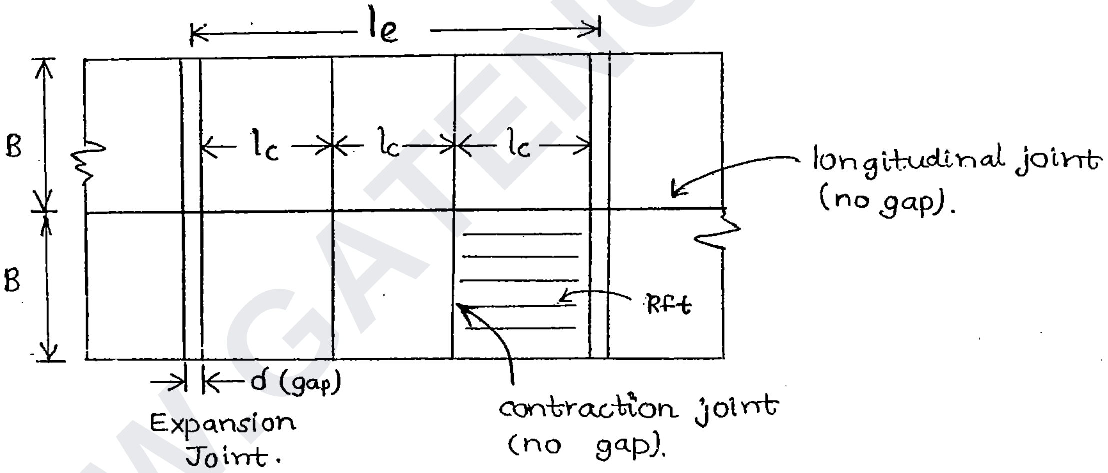
$$\sigma_R = \sigma_c + (\sigma_w)_c$$

$$= 32 + 7 = \underline{\underline{39 \ kg/cm^2}}$$

$\therefore$ Most critical stress value = max of above three

$$= \underline{\underline{40 \ kg/cm^2}}$$

→ Joints in Rigid Pavements.



1. Expansion joint

- to allow expansion of pavement due to rise in temp.
- mastic pad is provided in b/w joints which can compress by 50%

* Spacing of expansion joint :

$$\frac{\delta}{2} = (le)(\alpha \ t) \Rightarrow \boxed{Le = \frac{\delta/2}{\alpha t}}$$

where t : increase in temp from const. temp.

δ : actual gap at joint.

P-72

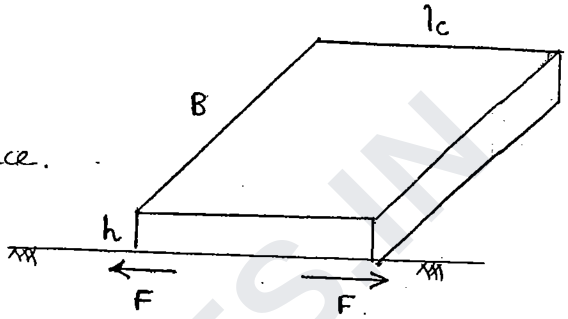
01 $$\text{Spacing, } L_e = \frac{\delta/2}{\alpha t} = \frac{2.5/2}{10\times10^{-6}(45-10)} = 3571.4 \text{ cm}$$
$$= \underline{\underline{35.7 \text{ m}}}$$

2. Contraction Joints.

⊙ for PCC Slab.

Frictional force = Resisting force.

$$f\left(\frac{\gamma_c B l_c h}{2}\right) = \sigma_f \, (B \times h).$$



$$\boxed{l_c = \frac{2\sigma_f}{\gamma_c f}}$$

σ_f is tensile strength of concrete (or) modulus of rupture.
$= (0.7\sqrt{f_{ck}})$

⊙ for RCC

Frictional force = resisting force

$$f\left(\frac{\gamma_c . B . l_c h}{2}\right) = \sigma_s . A_s$$

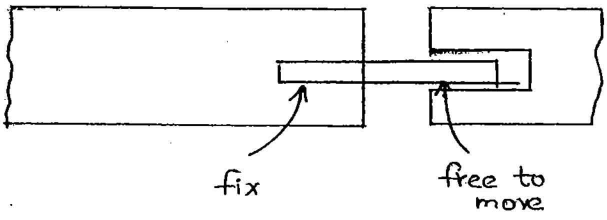
$$\boxed{l_c = \frac{2\sigma_s A_s}{B h f \gamma_c}}$$

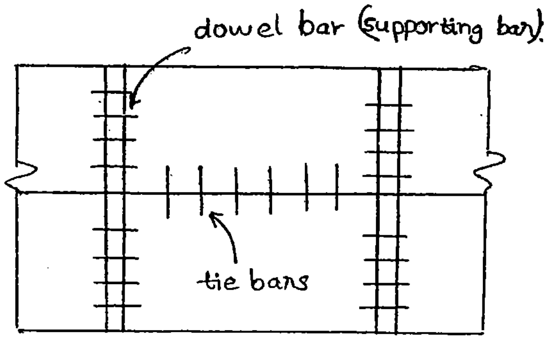
where σ_s → allowable tensile strength of steel (given in prob.).

3. Longitudinal Joints

– provided if pavement width is more than 4.5m

→ Dowel Bars





* Specifications:

(i) Dowel bars MS; round bars of short length (coated with zinc or lead based paints or epoxy coated).

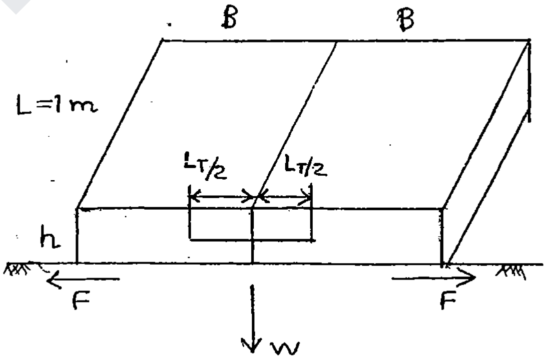
(ii). Max. load transferred through dowel bars is 40% max. axle load.

(iii) not provided for slab thickness < 150 mm

(iv) bearing stress in concrete is responsible for performance of joints for dowel bars

→ Tie bars

- used across longitudinal joints.
- ensures two adjacent slabs to remain firmly together
- not designed as load transfer devices.
- bars are designed to withstand tensile stress induced due to friction at bottom.



* Diameter & Spacing

Frictional force = Resisting force.

$$f\left(\frac{\gamma_c \times 1m \times 2B \times h}{2}\right) = A_s \cdot \sigma_s$$

Area of tie bars, $A_s = \dfrac{f\,\gamma_c\,Bh}{\sigma_s}$

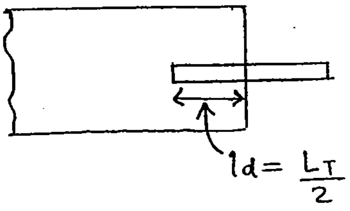
Assume dia of tie bar as ϕ

$$a_s = \frac{\pi}{4}\phi^2$$

- $\boxed{\text{Spacing of tie bars} = \dfrac{1000\,a_s}{A_s}}$

- Length of tie bar :

$$\boxed{l_d = \frac{L_T}{2} = \frac{\phi\,\sigma_s}{4\,\tau_{bd}}}$$



⇒ $L_T = ?$

NOTE:

- ⊙ In RCC pavements, duty of steel is to resist tension developed due to friction (secondary stress due to temp.)
- ⊙ Wheel load stresses should be completely resisted by concrete alone. ∴ min. strength of concrete in rigid pavement is M35 grade

P-72

04. $h = 18\text{ cm}$ $\quad f = 1.5$

$2B = 7.2\text{ m}$ $\quad \sigma_b = 24.6\text{ kg/cm}^2$

$\sigma_s = 1700\text{ kg/cm}^2$ $\quad$ Diameter of bar, $\phi = 10\text{ mm}$

$\gamma_c = 2400\text{ kg/m}^3$

$$\text{Area of tie bars} = \frac{f\gamma_c Bh}{\sigma_s} = \frac{1.5 \times 2400 \times 3.6 \times 0.18}{1700/10^{-4}}$$

$$= 137.22\text{ mm}^2$$

$$\text{Spacing} = \frac{1000\, a_s}{A_s} = \frac{1000 \times \pi/4 \times 10^2}{137.22} = \underline{\underline{572}}\text{ mm}$$

05. $$\text{Min. length of tie bar} = \frac{2\phi\sigma_s}{4\tau_{bd}} = \frac{0.1 \times 1700}{24.6} = \underline{\underline{34.5}}\text{ cm}$$

08. Slab thickness, $h = 20\text{ cm}$

$f = 1.2$

$L_c = 4\text{m}$

$b = 3\text{ m}$

$\gamma_c = 2400\text{ kg/m}^3$

$$\text{Spacing, } L_c = \frac{2\sigma_c}{\gamma_c f}$$

$$\sigma_c = \frac{4 \times 2400 \times 1.2}{2 \times} = 5760\text{ kg/m}^2 = \underline{\underline{0.5760}}\text{ kg/cm}^2$$

02. $h = 20\text{cm}$, $K = 8 \text{ kg/cm}^3$, $\mu = 0.15$, $E = 3 \times 10^5 \text{ kg/cm}^2$, $\alpha = 10 \times 10^{-6}$

$C_x = 0.92$, $C_y = 0.72$, $t = 16.2°c$, $a = 15$ cm.

Radius of relative stiffness, $l = \left(\dfrac{Eh^3}{12K(1-\mu^2)}\right)^{1/4}$.

$$= \left[\frac{3 \times 10^5 \times 20^3}{12 \times 8 (1-0.15)^2}\right]^{1/4} = \underline{\underline{71.14 \text{ cm}}}$$

$C_x > C_y$.

$\therefore$ Warping stress at edge, $\sigma_{w(e)} = \dfrac{C_x E\alpha t}{2} = \dfrac{0.92 \times 3 \times 10^5 \times 10 \times 10^{-6} \times 16.2}{2}$

$$= \underline{\underline{22.356}} \text{ kg/cm}^2$$

03. Warping stress at corner $= \dfrac{E\alpha t}{3(1-\alpha)} \sqrt{\dfrac{a}{l}}$

$$= \frac{3 \times 10^5 \times 10 \times 10^{-6} \times 16.2}{3(1-0.15)} \sqrt{\frac{15}{71.14}}$$

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

06. $h = 20$ cm, $b = 3.75$m, $f = 1.5$, $\sigma_c = 0.8 \text{ kg/cm}^2$, $\sigma_s = 1200 \text{ kg/cm}^2$

10mm ϕ bars at a spacing of 300 mm.

For PCC slab,

$$\text{Spacing } L_c = \frac{2\sigma_c}{\gamma_c f} = \frac{2 \times 0.8 \times 10^4}{2400 \times 1.5} = 4.4 \text{ m c/c.}$$

07 & $\quad 300 = \dfrac{3750 \times \frac{\pi}{4} \times 10^2}{A_s} \Rightarrow A_s = 981.75 \text{ mm}^2$

For RCC,

$$\text{Spacing } L_c = \frac{2 \times 1200 \times 981.75 \times 10^{-2}}{3.75 \times 0.2 \times 2400 \times 1.5} = \underline{\underline{8.73}} \text{ m c/c}$$

~~05~~

07. $W_b = 5\%$

$G_t = 2.442$ ~~g/cc~~

$G_m = 2.345$

$G_b = 1.02.$

$$V_b = G_m\left(\frac{W_b}{G_b}\right) = 2.345\left(\frac{5}{1.02}\right) = 11.49\ \%$$

$$V_a = \frac{G_t - G_m}{G_t} * 100 = \frac{2.442 - 2.345}{2.442} * 100 = 3.97\%$$

$$VFB = \frac{V_b}{VMA} = \frac{11.49}{11.49+3.97} * 100 = \underline{\underline{74.3\%}}$$

09. $$G_t = \frac{100}{\frac{60}{2.72} + \frac{35}{2.66} + \frac{5}{1}} = 2.486$$

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

$$\frac{7}{100} = \frac{2.486 - G_m}{2.486} \Rightarrow G_m = \underline{\underline{2.312}}$$

$$\gamma_m = G_m\, \gamma_w = \underline{\underline{2.312}}\ g/cc$$

10. Specific weight of bituminous concrete $$= \frac{100}{\frac{\cancel{300}\ 50}{300} + \frac{30}{500} + \frac{10}{65} + \frac{10}{125}}$$

$$= \underline{\underline{217.15}}\ kg/m^3$$

11. $$G_t = \frac{100}{\frac{55}{2.62} + \frac{34.6}{2.72} + \frac{4.8}{2.7} + \frac{5.6}{1.02}} = \underline{\underline{2.44}}$$

P-65.

05. $r = 5\%$, $n = 10$ years , VDF = 2.4 , A = 2723 veh/day.

$$N = \frac{365\left((1+r)^n - 1\right) ADF}{r} = \frac{365\ (1.05^{10} - 1)\, 2723 \times 2.4 \times 1}{0.05}$$

$$= \underline{\underline{30}}\ \text{msa}$$

From the table given,

for 30 msa, total thickness = $\underline{\underline{670}}$ mm

07.

Wheel load, kg	% in total traffic volume	EF
2268	25	1
2722	12	2.07
3175	9	3.84
3629	6	6.55
4082	4	10.49
4536	2	16
4990	1	23.43

Standard axle load = 2268 kg.

Vehicle damage factor, VDF = weighted average of EF.

$$= \frac{0.25 \times 1 + 0.12 \times 2.07 + 0.09 \times 3.84 + 0.06 \times 6.55 + 0.04 \times 10.49 + 0.02 \times 16 + 0.01 \times 23.43}{0.59}$$

$$= \underline{\underline{3.75}}$$

Dual 4-lane carriage way ⇒ LDF = 0.4.

No: of vehicles per day per lane $= \frac{1860}{4} = 465$ veh/day/lane.

Cumulative standard axles per lane of road $= \frac{365\left(\left(1 + \frac{7.5}{100}\right)^{10} - 1\right) ADF}{0.075}$

$$= \underline{\underline{11.02}}\ \text{msa}$$