Highway Engineering

Published By:

Physics Wallah

ISBN: 978-93-94342-39-2

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HIGHWAY ENGINEERING

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1 HIGHWAY ENGINEERING

1.1. Geometrical Design

"Design of visible dimensions"

Geometric design components depend on:

1. Type of Road:

(a) Non-Urban Roads : (IRC 73 – Design of rural highways)

(i)	Expressway	:	Permits only high speed vehicles
(ii)	NH	:	Join various states
(iii)	SH	:	Join various districts
(iv)	MDR	:	Connects district's serving areas of production.
(v)	ODR	:	Rural areas to market places
(vi)	Village Roads	:	Connects villages to a road of higher category.

(b) Urban Roads

- Expressway
- Arterial roads
- Sub Arterial roads
- Collector streets
- Local streets

2. Type of Vehicle:

- Width of vehicles governs **width of pavement.**
- Length of wheel base governs bearing path [IRC : Design vehicles]

Ex. : Width of vehicle **:** 2.5 m
Height of vehicle **:** 3.8 to 4.75 m (Double Decker bus)

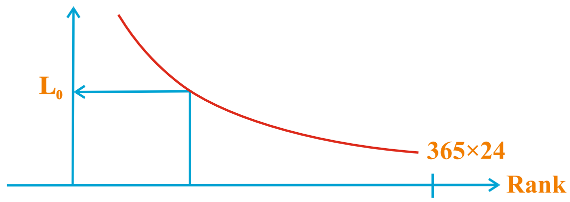
3. Terrain Classification:

- If cross slope of ground is large, then it is very "costly" to provide large radius of curvature (at turns to counteract centrifugal force); hence speed is restricted instead."

	Cross Slope	
Plain	< 10%	
Rolling	10 - 25%	
Maintenance	25 -60%	Hilly
Steep	> 60%	Hilly

4. Traffic capacity:

- Ability to accommodate "maximum traffic volume at a particular level of service" (vehicles per unit time)
- Generally, design capacity is taken as **"30^{th} highest hourly volume".**
- This comes out as ~ 8-10% of AADT (numerically only) for Indian condition.



- 30^{th} HHV is exceeded 29 out of 365×24 times.

5. Design speed:

- Theoretically, 98^{th} percentile speed.
- However, IRC has recommended values based on terrain (for design).

	Plain Terrain		Rolling	
	Ruling	**Min**	**Ruling**	**Min**
EW	120	100	100	80
NH/SH	100	80	80	65

- Normally **Ruling speed** should be adopted as design speed, however if not possible (from cost p.o.v.), then minimum speed can be adopted.

6. Friction:

- $\mu_{longitudinal} = 0.35 - 0.4$
  $\mu_{lateral} = 0.15$
- In actual 0.8 but not used in calculations.
- Lack of friction causes **skidding** (Long movement > πd) or **slipping.**
  New tyres → more friction than old on wet pavement.
  Old tyres → more friction than old only dry pavement.

1.2. Unevenness Index

- Cumulative unwanted vertical undulation on road.
- Measured using **BUMP INTEGRATOR.**
  - < 1500 mm/km : Good surface
  - < 2500 mm/km : Satisfactory for speed upto 100 km/hr.
  - > 3500 mm/km : Unsatisfactory for speed upto 50 km/hr.

1.3. Cross Sectional Elements

1. Carriage Way:

- Part of pavement **"designed to carry vehicle".**

	Carrying Width
Single Lane	3.75 m
Two Lanes without kerb	7m
Two Lanes with kerb	7.5m
Intermediate carriageway	5.5 m
Multi Lane	3.5 m/lane
Multi Lane × Bridge	3.5 m/lane + 0.5 m/carriage way

2. Shoulder:

- To accommodate stopped vehicles.
- Provide **lateral confinement to layer**
- Should be strong enough to bear weight of a fully loaded truck even in wet condition.

Desirable Length = 4.6 m
Minimum width = 2.5m for 2 Lane Highway

Formation Width = Width of pavement + Shoulder
(Roadway width) (Carriage way)
↓
Doesn't include shoulder

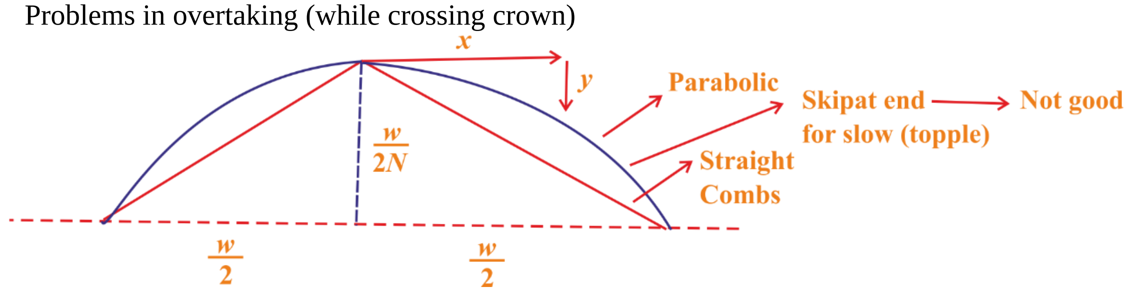
↓ 12m (Formation Width)
↓ For both single/dual Lane NH

3. Kerb :

- Mountable Kerb
- Barrier Kerb etc.

4. Combs (Crossfall/Cross slope) :

- To drain off water (prevent any harm to surface, layer & subgrade).
- But **too steep slope is also undesirable** because
  - ♦ Height of vehicles → more thrust near edge of pavement →unequal wear
  - ♦ Toppling of highly laden bullock etc.
  - ♦ Problems in overtaking (while crossing crown)



For cc → straight
For BT → Parabolic

$$y = kx^2 \Rightarrow \boxed{y = \frac{2}{wN}x^2}$$

- ♦ Parabolic combs suitable for **fast moving vehicle**, but since steep at ends, mixed cross slope is given (Straight + Parabolic)

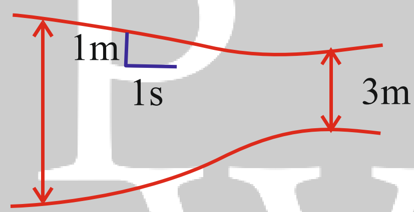
Type of road surfaces	Heavy Rain (> 100 cm)	Low Rain (< 100 cm)
cc– or high type bituminous	2%	1.7%
Thin Bituminous	2.5%	2%
WBM/Gravel	3%	2.5%
Earthern roads	4%	3%

Note:
1. Slope of **shoulder** should be atleast **0.5%** more than combs **Min. of 3%**
2. **Rigid Pavement** : Generally straight
   Flexible Pavement : Generally parabolic

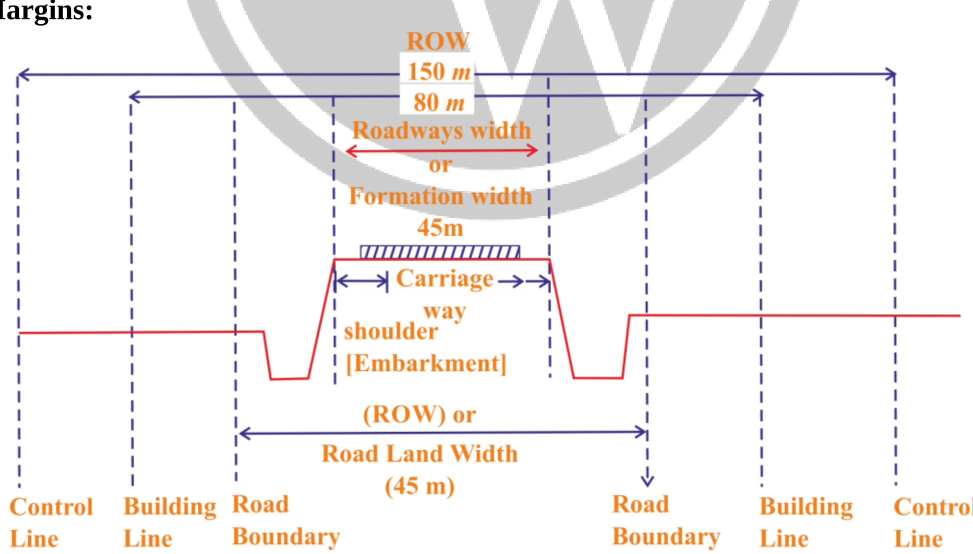
5. Median :

- To prevent **head on collision.**
- **Desirable Width = 5m** ; may be reduced to **3m** for rural highways & **1.2m** for urban areas.

  On bridge : 1.2m – 1.5m
- If there is transition in median width or carriageway width, then it should be **1 in 20 to 1 in 15** i.e. gradient transition.



- **Guard rails :** provided when embankment **(height > 3m)**.
- **Road Margins:**



- **ROW:** Width of land acquired, **considering future development** (entire 150 m is acquired)
- **Building Line :** No building activity permitted.
- **Control Line :** Building activity controlled.

  The values given are for NH and SH.

1.4. Sight Distances :

From every point on highway, length of view should be such that vehicle could be stopped or overtaking can be safely performed.

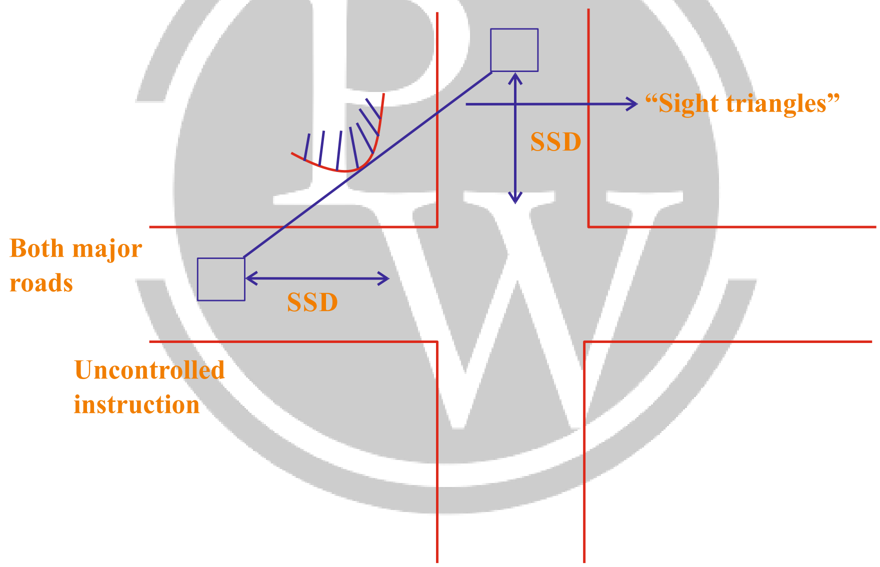
For straight road, LOS is ∞; no issue; hence this concept is relevant on curves.

1. **SSD** : Absolute minimum sight distance/Non-passing sight distance.
2. **OSD** : Passing sight distance.
3. **ISD** : Provided when OSD can't be provided.

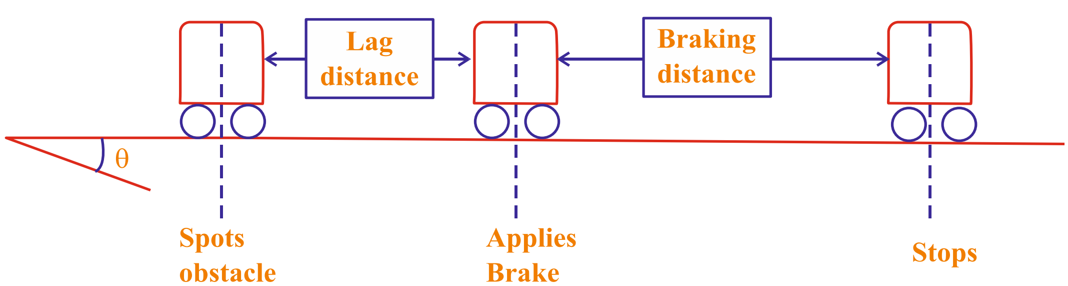
   ISD = 2.SSD

   SSD < ISD < OSD

4. **Headlight Sight Distance (HSD) :**
   - Visibility under headlight @ night.
   - Minimum value of HSD should be SSD.
   - Critical at up gradient and descending street at curve.
5. **Sight distance at intersections:**



1. **SSD:**
   - IRC incorporates **50% brake efficiency** in the f_e itself (between actual ~ 0.7 taken ~ 0.35) .
   - Longitudinal friction coefficient used



   - Lag Distance = vt_R → (2.5 sec.)

- For ascending slope.
- Acceleration = – g (μ cos θ + sin θ)
- Braking distance (l) = $\dfrac{v^2}{2g(\mu\cos\theta+\sin\theta)}$

  [Horizontal projection = l cos θ × l]

  ∴ $$\boxed{\text{SSD} = vt_R + \frac{v^2}{2g(\mu \pm \tan\theta)}}$$

- **For calculation:**

  (i) t_R = $\boxed{2.5 \text{ sec.}}$ (for SSD calculation)

  (ii) μ :

≤ 30 kmph	60 kmph	≥ 80 kmph
0.4	0.36	0.35

  For subjective, take judiciously.

- **IRC Recommendations:**

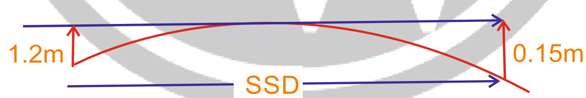
  (i) **On single lane, 2 way traffic,**

  ♦ provided SSD = $SSD_1 + SSD_2$

  (ii) **On undivided highway with 2-way traffic**

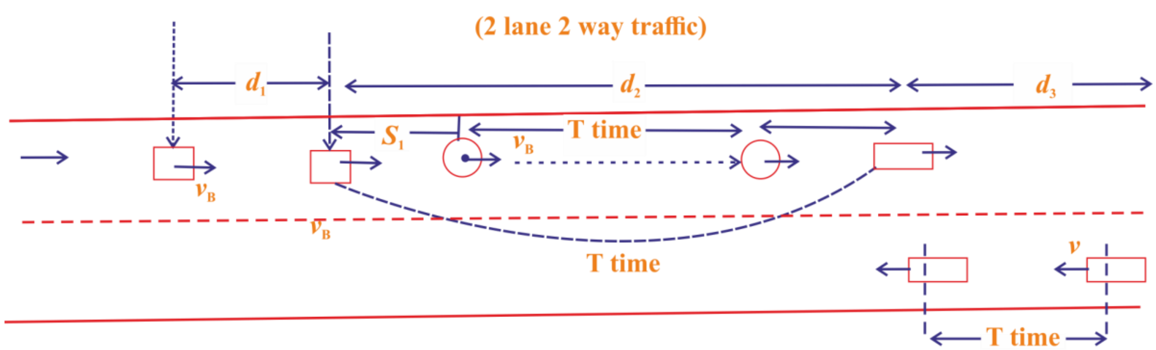
  ♦ Effect of gradient not considered while calculating SSD (because sufficient degree of freedom to driver). However, **for divided highway :** considered.

  (iii) **SSD on vertical curve;** length along c/L straight driver with eye level 1.2 m can see obstruction 0.15m above the road surface.



  If SSD can't be provided, then proper signboard with **"speed restriction".**

2. OSD:



- $\boxed{d_1 = v_B t_R}$

- $\boxed{d_2 = v_B T + B_1 + B_2} = v_B T + \frac{1}{2}\, aT^2$

  $\Rightarrow \boxed{T = \sqrt{\frac{2(S_1 + S_2)}{a}} = \sqrt{\frac{4S}{a}}}$

- $\boxed{d_3 = vT}$

  Where v = Design speed of road

  v_B = Speed of slow vehicle

  For calculation:

  (i) $\boxed{t_R = 2 \text{ sec.}}$

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

  $0.7v_S$ ↓ 0.7 sec. of $r \times n$ time, while following forward vehicle

  l ↓ 6 m (if not given)

  (ii) $\boxed{v_B = v - 16 \text{ kmph}}$

  For conventional :

  (iv)

v_3	*a*
60 kmph	1 m/s^2
80 kmph	0.72 m/s^2
100 kmph	0.53 m/s^2

Sometimes
For oversafe case approximation is taken for s, S = SSD + l

- **IRC Recommendations for OSD :**

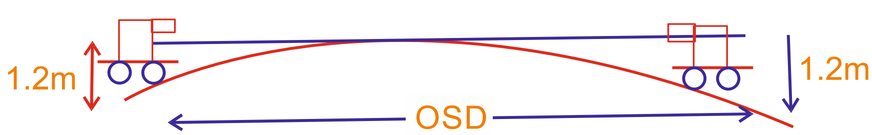
  (i) **For one way traffic ; divided highway**

  OSD = $d_1 + d_2$

  (ii) **On undivided highway with 4 or more lanes**

  No need to provide OSD. (SSD is sufficient).

  (iii) **On vertical curve;** 1.2 m device eye level and 1.2 m top of object.



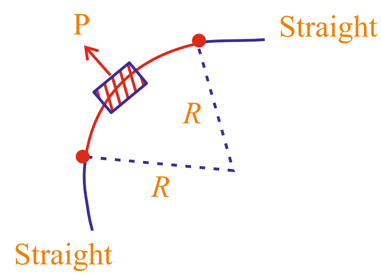
Note : Calculation Effect of gradient is not considered in OSD.

Overtaking Zone :

- Minimum Width = 3 × OSD

- Desirable Width = 5 × OSD

1.5. Horizontal Curve & Alignment



- Circular curve recommended by IRC.

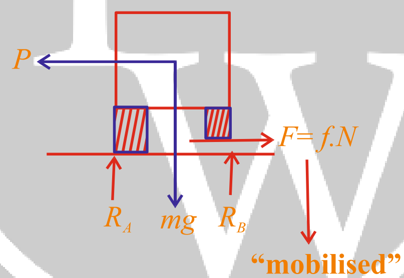
  $P = \dfrac{mv^2}{R}$ = Centrifugal force

  $\boxed{\dfrac{P}{W} = \dfrac{v^2}{Rg} = \text{Impact Factor/Centrifugal Ratio}}$

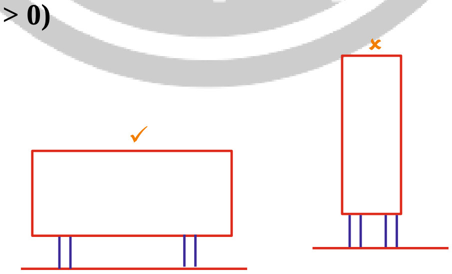
  ∴ If **high speed** on sharp curve ($R \downarrow$), impact very high.

- **Vehicle moving on horizontal curve:**

  $\boxed{\sum F_y = 0 \Rightarrow [R_A + R_B = N = W]}$



(i) **For no overturning: (R_A > 0)**



$\sum M_A = 0 \Rightarrow \boxed{\dfrac{P}{W} = \dfrac{v^2}{Rg} \leq \dfrac{b}{2h}}$

When just overturn, R_B = 0 & equilibrium satisfied.

(ii) **For no skidding : (R_A > 0)**

$f = f_b$ (Full mobilised)

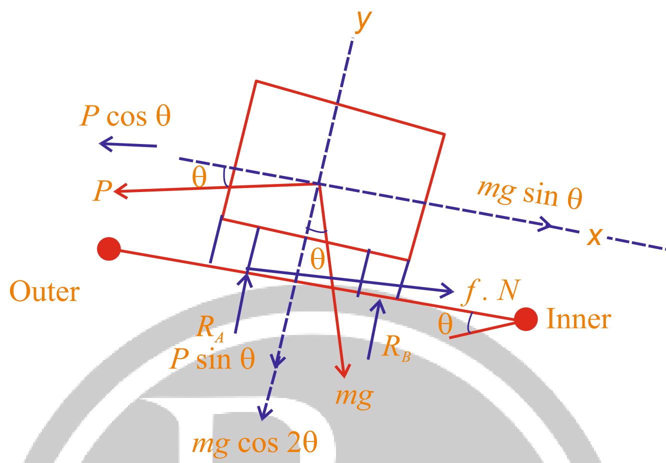
$\sum f_x = 0 \Rightarrow f_x(N) = P \Rightarrow \boxed{\dfrac{v^2}{Rg} = \dfrac{P}{W} \leq f_s}$

(h + ht) of CG of vehicle ; b = width of wheel base

To avoid both overturning and skidding

$$I < \begin{cases} \dfrac{b}{2h} \\ f_{max} \end{cases}$$

- **Vehicle moving on Banked Road:**



$N = (R_A + R_B) = mg \cos\theta + P \sin\theta$

(i) For no overturning: (Critical : R_B = 0 & equilibrium)

$\sum M_A = 0 \; ; \; (P\cos\theta - w\sin\theta)\,h = (P\cos\theta + P\sin\theta)\,.\,\dfrac{b}{2}$

$$\Rightarrow \boxed{\frac{v^2}{Rg} \le \frac{e + \frac{b}{2h}}{1 - e.\frac{b}{2h}}} \quad \text{when } e = \tan\theta$$

(ii) For no skidding : ($f = f_s$)

$$\sum f_x = 0 \; ; \; \boxed{\frac{v^2}{Rg} \le \frac{e + f_s}{1 - ef_s}}$$

Practically:

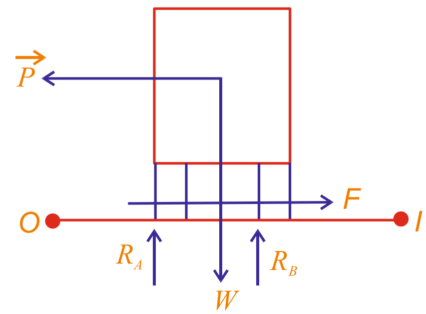
"Skidding occur first" (governing),

$$\frac{b}{2h} \approx \frac{2.5}{2(3)} = 0.4$$

$f_s = 0.15$ (Low)

Reaction of inner & outer wheel:

Horizontal:

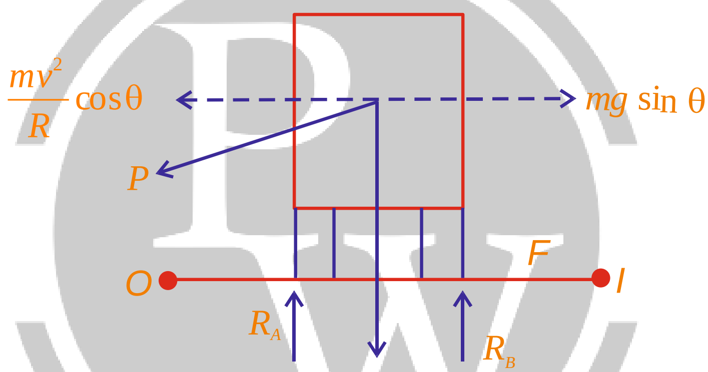


$$\sum M_{CG} = 0 \Rightarrow R_A \cdot \frac{b}{2} = R_B \cdot \frac{b}{2} + F.h \Rightarrow R_A = R_B + \frac{F}{\frac{b}{2h}}$$

$\Rightarrow R_A > R_B$

F always acts inward, if no superelevation. Direction in which friction will act, at that direction, pressure will be less.

Superelevation:



"FAST VEHICLE" i.e. $\frac{mv^2}{R}\cos\theta > mg \sin\theta \Rightarrow \boxed{v^2 = Rg\tan\theta}$

Ex. Design Vehicle

- F acts inwards.
- $R_A > R_B$

"SLOW VEHICLE" i.e. $\boxed{\text{i.e. } \frac{v^2}{Rg} < \tan\theta}$

Ex. Stopped vehicles

- F acts outwards.
- $R_A < R_B$

Conclusion: On horizontal curve, pressure on outer wheel is greater than inner wheel as long as friction is mobilised inward.

Superelevation Cases:

Recommended for preliminary:

$$\underset{\text{actual}}{e} + \underset{\text{mobilised}}{f} = \frac{v^2}{Rg} = \frac{v^2}{127R}$$

actual | mobilised | max. upto 0.15

(i) Equilibrium Super elevation:

- No need of f to be mobilised ($f = 0$)

$$e_{EQ} = \frac{v^2}{Rg} = \frac{v^2}{127R}$$

- **Pressure on inner wheel = Pressure on outer wheel**
- Hence, we provide design superelevation on road as given by IRC.

(ii) e_{DGN} : Based on IRC

- "For mixed traffic conditions"

$$e_{DGN} = \frac{(0.75v)^2}{Rg} = \frac{v^2}{225R} \ngtr e_{max.}$$

- If $e_{calculated} > e_{max.}$; provide $e_{max.}$ & check f;

$$e_{max.} + f = \frac{v^2}{Rg} = \frac{v^2}{127R} \text{ ; where } f \text{ should be } \leq 0.15$$

- **Restrict speed:**

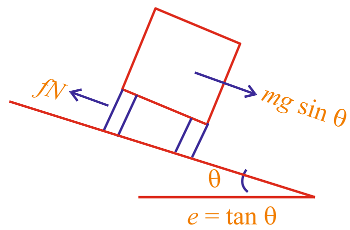
$$e_{max.} + f_s = \frac{v^2}{Rg} = \frac{v^2}{127R}$$

"For Maximum allowable speed."

- $e_{max.}$: Given to consider slow moving & stopped vehicle inward skid.

Plain/Rolling	7%
Hilly (Mount/Steep)	10%
Hilly with Snow bound	7%
Urban (Built-up)	4%

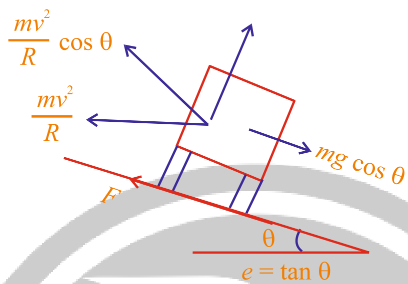
(iii) Stopped which on horizontal curve



$\boxed{e < f_s} \approx 0.15$

For no inward skid, free anyways.

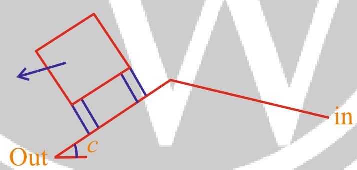
♦ Slow vehicle



$$\left[\frac{mv^2}{R}\cos\theta + f_s\left(mg\cos\theta + \frac{mv^2}{R}\sin\theta\right) \geq mg\sin\theta\right]$$

Note:

- ➢ Minimum superelevation is required from drainage point of view. Hence, combs is provided (minimum).
- ➢ When camber is only given on road, we have to check for stability of vehicle on outer edges.



C acts as ⊖ ve superelevation.

$\boxed{-c + f = \frac{v^2}{Rg}}$; Check if f_s adequate.

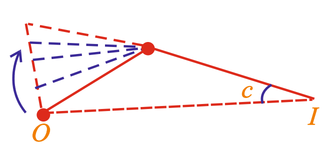
Note:

- ➢ f = mobilised friction coefficient.
- ➢ f_s = Friction coefficient available (max.) = 0.15

Attaining Superelevation:

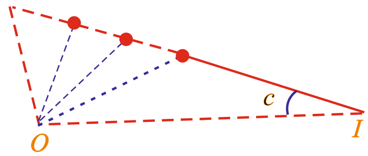
Step 1 : Elimination of crown

Rotation about c/L



Drainage problem (backward slope downward)

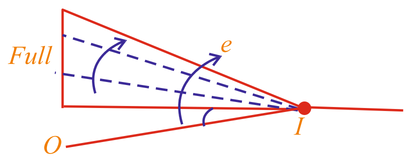
Shifting of crown



– ve superelevation too high on outer lane.

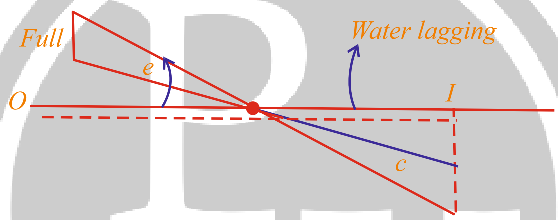
Step 2 : Rotation of pavement to achieve full elevation

Rotation about inner edge



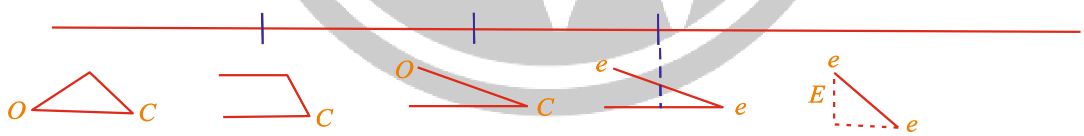
- C/L profile of road : changes (shifted up)
- Most common

Rotation about C/L



- Balanced earthwork
- But can be used only on **"embarkments & bridges"** b/c
- C/L of profile doesn't change.

C/s along Transition Curve :



- At beginning of TC, one leg is made horizontal & by end of TC, full superelevation is achieved.
- If no TC provided, then $\frac{2}{3}$ rd of elevation achieved on straight road & $\frac{1}{3}$ rd on circular curve.

> **Note:**
>
> In problem, read carefully if rotated about inner edge or C/L and if raise of outer edge w.r.t. inner edge asked or w.r.t. centre.
>
> f_s = Friction coefficient available (max.) = 0.15

- Ruling minimum radius & Absolute minimum radius of curve:

$$R_{\text{ruling minimum}} = \frac{v^2_{\text{ruling}}}{(e+f)_{\text{max.}}}$$

$$R_{\text{abs min.}} = \frac{v^2_{abs\,min.}}{(e+f)_{max.}}$$

- Radius beyond which no superelevation needed (IRC)

$$\underset{\text{Camber}(c)}{\not{e}} + \not{f} = \frac{(0.75v)^2}{Rg} \Rightarrow \frac{v^2}{225c}$$

- **Extra Widening on horizontal curve**
  - **Off tracking of a vehicle =** $\frac{l^2}{2R}$

    where l = length of wheel base= 6 m (Usually)
  - Psychological widening is required because generally driver has tendency to drive **"close to outer edge".**

$$\boxed{W_e = n\left(\frac{l^2}{2R}\right) + \frac{V_{kmph}}{9.5\sqrt{R}}}$$

n ↓ No. of lanes (Each lane → 3.5m)

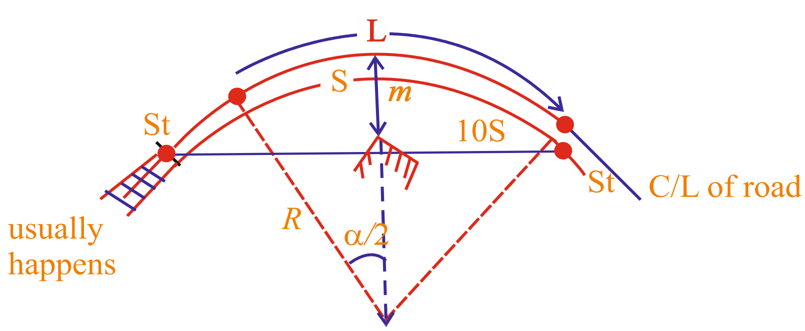
IRC :

1. For single lane, Psychological widening is not required.
2. If R > 300 m, then extra widening is not generally done.
3. W_e is provided along TC gradually; [if no TC, then $\frac{2}{3}$ on straight road, $\frac{1}{3}$ rd on curve].
4. On sharp curves, on 'hills' W_e is provided on inner side. In general, equally provided on both sides.
   (i) On sharp curves (R < 50 cm) also
   (ii) Rear wheel travels shorter path (radius) during off tracking.

1.6. Setback Distance (m)

The clear distance from **"C/L of entire road to inner side obstruction",** so that required sight distance is available.

Single Lane Road:



(i) When $L > S$ (usually happens)

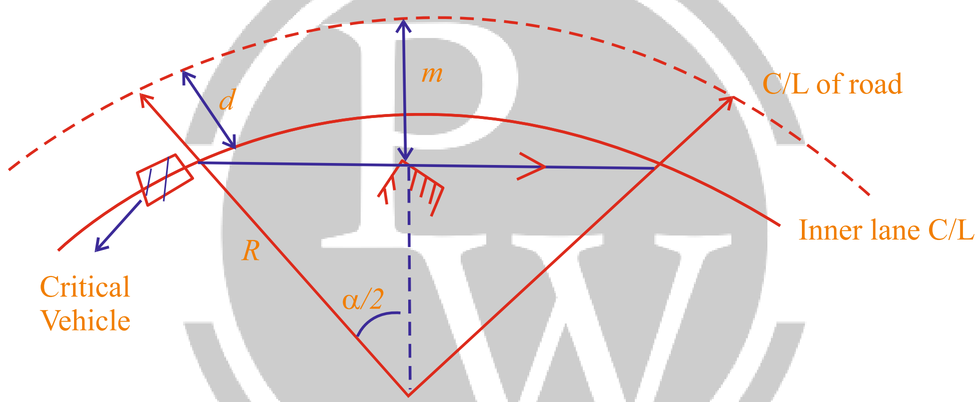
$$m = R - R\cos\left(\frac{\alpha}{2}\right)$$
$$\text{where } \alpha = \frac{S}{R}$$

(ii) When $L < S$

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

1.7. Multi-Lane Road

Critical which is moving on inner lane, though m is defined as distance from C/L only.
Let d = distance between C/L of road & inner Lane C/L



(i) When $L > S$

$$m = R - (R-d)\cos\frac{\alpha}{2}$$
$$\text{where} \frac{\alpha}{2} = \frac{S}{2(R-d)}$$

(ii) When $L < S$

After approximately L = L' (Length of curve along)

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

Approx formulae for ESE prelims

Single Lane Only: $m = R\left(1-\cos\frac{\alpha}{2}\right);\ \frac{\alpha}{2} = \frac{S}{2R}$

$$\cos\frac{\alpha}{2} \approx 1 - \frac{\left(\frac{\alpha}{2}\right)^2}{2} \Rightarrow \boxed{m = \frac{S^2}{8R} \quad (\text{When } L > S)}$$

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

$$\frac{\alpha}{2} = \frac{L}{2R} \Rightarrow m = R\left(\frac{L^2}{8R^2}\right) + \frac{L-S}{2}.\frac{L}{2R}$$

$$\Rightarrow \quad m = R\left(\frac{L^2}{8R^2}\right) + \frac{L-S}{2}.\frac{L}{2R}$$

$$\boxed{m = \frac{L(2S-L)}{8R} \quad \text{when } L < S}$$

Note: (i) *m* is from C/L of road, sometimes **setback from inner lane** may be asked, then $m' = m - d$

(ii) if not given, assume $L > R$ case) .

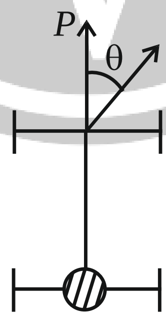
1.8. Curve Resistance

Curve Resistance

- Loss of pulling power on horizontal curve.

Rear wheel driven vehicle

- Loss of power = $\boxed{CR = P - P\cos\theta}$



$\boxed{CR = 0 \text{ for front wheel driven vehicles.}}$

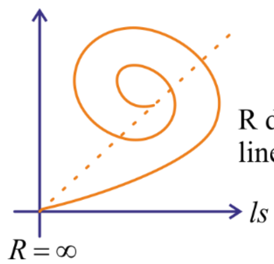
1.9. Transition Curves

- To introduce centrifugal force gradually.
- Introduce superelevation gradually.
- Introduce extra widening gradually.
- Aesthetics

1.9.1. Types

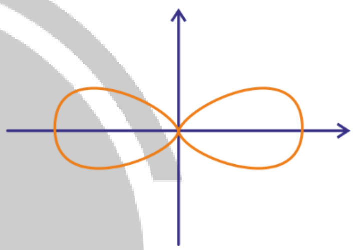
1. Spiral

- $\left(l \propto \frac{1}{R}\right)$ i.e. $P \propto l \rightarrow \left(\frac{mv^2}{R}\right)$
- *IRC* recommended (ideal)



2. Bernouli Lemiscate

- Autogenuour curve (follows path of freely moving are)
- Ok for low speed roads (city where large deflection)
- Suitable if deflection angle < 60°



3. Cubic (Froude's transition curve)

Parabola (will be used in valley curves)

Length of Transition curve is max of the following:

1. $\left(\frac{v^3}{CR}\right) where \boxed{\frac{80}{75+V}}$ $\boxed{0.5 \le C \le 0.8}$

2. eN (W + We) → rotated about inner edge

   $eN\frac{(W+We)}{2}$ → rotated about C/L

   e is e_{DGN} if not given

3. $2.7\frac{V^2}{R}$ → Plain / Rolling

   $\frac{V^2}{R}$ → Hilly (Mount /step)

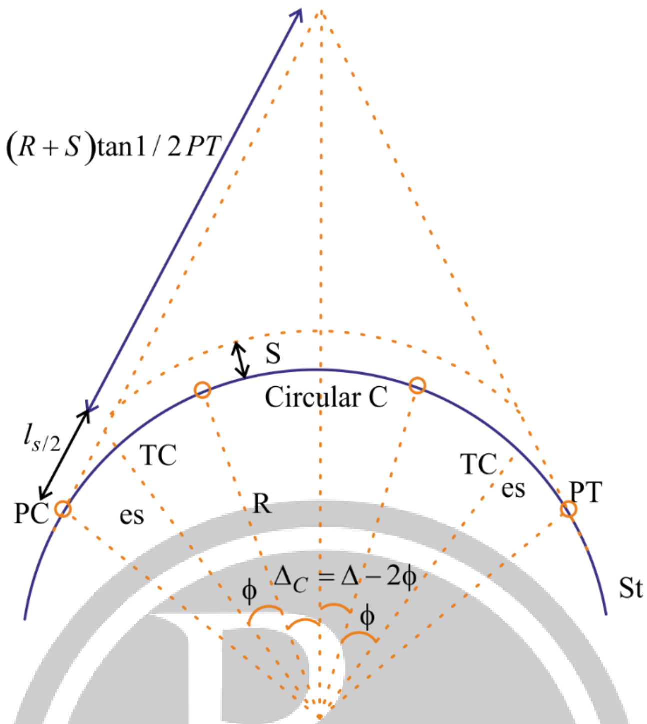
Note : 1 in N is rate of introduction of super elevation

1 in 150 : Plain / Rolling

1 in 60 : Mount / Step

Note : Long gradient of outer edge is the rate of intruder of super elevation

1.10. Setting of Transition Curve



- [Shift of circular curve due to introduction of TC = $\frac{ls^2}{24R}$]
- [Spiral angle, $\phi = \frac{ls/2}{R}$]
- $\left[\frac{\text{Length of tangent}}{(\text{PC to PT})} = \frac{ls}{2} + (R+S)\tan\frac{\Delta}{2}\right]$
- Length of circular curve = $R.\Delta_C = R(\Delta - 2\phi)$

Total length of curve = LC + 2*ls*

1.11. Grade Compensation

When a horizontal curve on a road which already has maxm permissible gradient, gradient has to be reduced to compensate for loss of tractive effort due to the curve.

$$GC =_{\min} \begin{cases} \frac{30+R}{R}\% \\ \frac{75}{R}\% \end{cases}$$

- Compensated grade = Actual grad – GC (not less than 4%)
- for gradients less than 4% ; no GC reqd.

1.11.1. Vertical Alignment

Long steep gradient is not desirable especially if proportion of heavy vehicles is high.

Types of gradient:

1. **Ruling gradient (Design gradient) :**
    - "max gradient allowed on regular roads"
    - at this gradient, "Vehicle is able to maintain constant speed at its maximum pulling power over entire length."
2. **Limiting gradient :**
    - Can be provided for SHORT STRETCHES when can't go for ruling gradient (mostly cost concerns); in ruling and hilly terrain mostly.
3. **Exceptional gradient :**
    - allowed under unavoidable circumstance.
    - not more that 100m or 60 m in 1 km at a stretch followed by 100m of flats gradient.
    - ghat roads / Hilly roads
    - Exceptional grad on hairpin bends is 2.%.

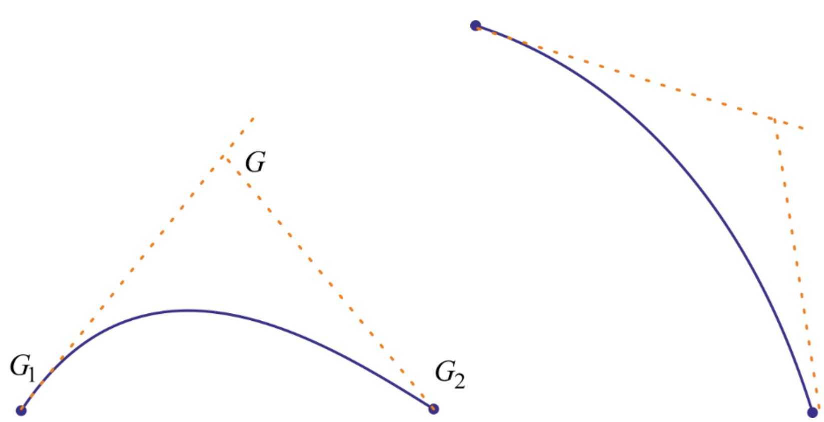
	Ruling	Limiting	Exceptional
Plain / Rolling	3.3%	5%	6.7%
Hilly	5%	6%	7%
Elevation upto 3000 m	6%	7%	8%

4. **Minimum gradient :**
    - from drainage consideration only
    - 0.2 % : concrete train
    - 0.5 % : open earthen train.
5. **Floating gradient :**
    - Grad at which no tractive effort is reqd. to maintain constant speed of vehicle.
    - Thumb rule for gradient & camber :

   This is for smooth traffic flow & drainage.
6. **Critical length of grade :**

   Length of (ascending) grade over which TRUCK can move w/o reducing its speed more than 25 kmph.

Summit Curve

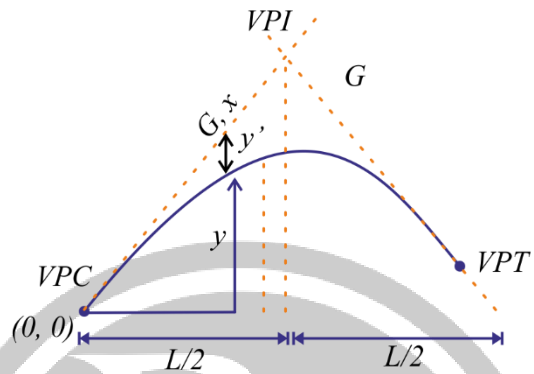


Design criteria:

- All sight distance (SSD, ISD, OSD ec. As reqd) (sight distance is a problem on summit curves)
- Certifugal force not apb. b/c ahh W decrease
- Drainage not a problem.

From sight distance criteria, CIRCULAR should be ideal b/c equal sight dist from all points:

But IRC → Square Partabola $\left(\frac{d}{dx}\left(\frac{dy}{dx}\right)=C\right)$



Eqn:

$$y = G_1x - \frac{(G_1 - G_2)x^2}{2L}$$

$$y' = \frac{(G_1 - G_2)x^2}{2L}$$

- Location of highest point on summit curve :

For ymax $y_{max} : \frac{dy}{dx} = 0 \Rightarrow \boxed{x = \frac{G_1 L}{G}}$

- Can also be viewed as :

$$\left.\begin{matrix}(G_1 - G_2)\,\text{grade change is}\, L \\ \text{then}\, G_1\, \text{grade change in}\, \frac{G_1}{G}L\end{matrix}\right\}$$ → since rate of grade change is constt.

- Radius of curvature :

$$\text{Curvature} = \frac{1}{R} = \frac{d^2y/dx^2}{\left[1+(dy/dx)^2\right]^{3/2}}$$

$$(\text{curvature})_{max} = \frac{1}{R_{min}} = \frac{d^2y}{dx^2} = \frac{G}{L}$$

$\therefore$ min Radius of curvature = $\left(\frac{L}{G}\right)$

1.11.2. Length of Curve

If S = SSD :

$$L \geq S$$

$$L = \frac{GS^2}{2\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$$

$$\frac{h_1 = 1.2m}{h_1 = 0.15m} \text{ (ht. of drives eye)} \Longrightarrow L = \frac{GS^2}{4.4}$$

If S = OSD / ISD :

$$L \geq S$$

$$L = \frac{GS^2}{2\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$$

$$h_1 = 1.2m$$

$$\boxed{\begin{matrix} h_1 = 1.2m \\ h_2 = 1.2m \end{matrix}} \Rightarrow L = \frac{GS^2}{9.6}$$

When $L < SD$

(i) For SSD $\quad L_S = 2S - \frac{4.4}{N}$

(ii) For OSD $\quad LS = 2S - \frac{9.6}{N}$

IRC: If length corner out to be –ve means there is no sight distance restriction; simply provide minm length.

Speed	Nominal length of curve
80 kmph	50 m
100 kmph	60 m

Valley Curve

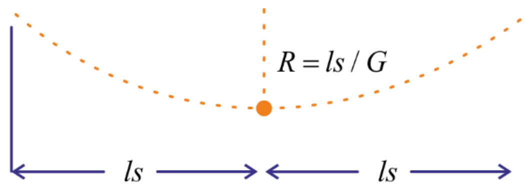
$$\boxed{G = G_1 - G_2 = -ve}$$

Design :

- No restriction of sight distance during day.
- At night visibility is only under headlight "hence designed for HSD = SSD"
- (HSD is not taken as ISD or OSD because other vehicle's headlight also there)
- **Comfort :** Certifugal force increases effective wt. & causes discomfort.
- Drainage considerations
- Aesthetics considerations
- Length of valley curve :

(i) Centrifugal criteria

CUBIC PARABOLA (vertical transition curve)



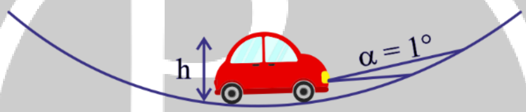
$$ls = \frac{v^2}{CR} \text{ where } R = \frac{ls}{G}$$

$$L = ls \implies \therefore \boxed{L = 2\sqrt{\frac{Gv^3}{C}}}$$

IRC : C = 0.6 m/s^3 $\implies$ $\boxed{L = 0.38\sqrt{GV^3}}$

(ii) HSD Criteria :

for small deviation angles : square parabola is sufficient : considering this



For L > S ;

$$\boxed{L = \frac{GS^2}{2\left(h + S(\tan\alpha)\right)}}$$

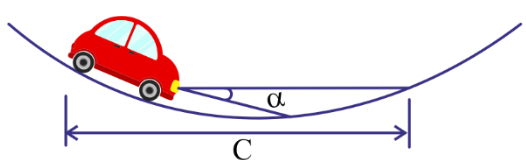
ICR : h = 0.75 m (ht. of headlight)

$\alpha = 1° \implies \tan 1° = 0.017$

$\therefore$ $$\boxed{L = \frac{GS^2}{1.5 + 0.035S}}$$

L < S : $$\boxed{L = 2S - \frac{2\left(h + S(\tan\alpha)\right)}{G}}$$

Here critical position is beginning of curve in both sag & valley curve, while calculating S (SSD) 'we should not consider gradient effect.



Location of lowest pt :

(i) if Square Parabola:

$$x = \frac{G_1 \bullet L}{G}$$

(ii) if 3° parabola :

$$\boxed{x = L\sqrt{\frac{G_1}{2G}}}$$

Generally ; valley curve is designed as cubic parabola however IRC command square parabola

Impact factor :

$$\frac{P}{W} = \frac{v^2}{Rg} = \frac{v^2}{\left(\frac{L}{2G}\right)g}$$

For ESE : Impact factor $= 1.6\,\frac{GV^2}{L}\,\% \not> 17\%$ (IRC)

❑❑❑

2 TRAFFIC ENGINEERING

2.1. Introduction

Basic objective is to achieve free & rapid flow with least no. of accidents

I. Traffic characteristic:

(1) Factors affecting road user characteristics

- Physical – Psychological
- Mental – Environmental

P : Perception (eye)

I : Intellection (Brain) As per IRC $r \times n$ time = 2.5s for SSD and $t = 2s$ for OSD

E : Emotion

V = Volition (leg / hand)

(2) Vehicular characteristics :

- Static vehicular characteristics - Dimensions, Weight Dynamic vehicular characteristics - speed, acceleration and braking charcteristics

(3) Braking characteristics :

Braking test → Find (Mg) → skid resistance

$$\left[\eta_B = \frac{M}{M_{\text{known}}}\right]$$

II. Traffic studies:

Traffic survey is conducted. Various studies conducted are:

(1) Traffic volume study :

quantity of traffic flow (vehicle per hour crossing a given section)

Complete traffic volume study include:

(a) Classified volume study : no. of diff. types of vehicles are counted.

(b) Directional study : distribution in different lanes counted.

(c) Turning movement study at intersections

(d) Pedestrain volume study

Presentation of Traffic volume study data:

(i) AADT:
- avg. daily volume for 365 days at a location.
- it include seasonal variation

(ii) ADT:
- avg. for some period of time
- > 7 days faken to incorporate daily variation (like Saturday, Sunday)

(iii) Trend chart:
- tend over period of years
- usefull for future expansion, design & regulation
- Also variation charts showing hously, daily & seasonal variation one also prepared.

(iv) Traffic flow map along the route:
- thickness of line represents traffic volume : can be an any scale (ex : google maps)

(v) 30th highest hourly volume:
- taken as "design hour volume"
- congestion only during 29 hour in a year.
- 8 – 10% of AADT for India

Estimation of traffic volume using EXPANSION Factors:

$$24\text{-hr volume} = (1 \text{ hr volume}) \times HEF$$
$$\text{Weekly volume} = (24 \text{ hr volume}) \times DEF$$
$$AADT = ADT \times MEF$$

ADT of that month (usually taken as $\frac{\text{weekly volume}}{7}$)

2. Traffic Speed study:

(a) SPOT speed :
- Instantaneous speed
- Needed in
  - Curves (horizontal & vertical) design
  - Accident analysis
  - Traffic signal design
  - Measuring device-Radar speed gun

(b) Average Speed :

Time mean speed (v_t)	Space mean speed (v_s)
AM of spot speeds of vehicle crossing a section	HM of spot speeds of vehicles
$v_t = \frac{\sum v_i}{n}$	$v_s = \frac{n}{\sum\left(\frac{1}{v_i}\right)}$

Note : (i) $v_t > v_s$, also $v_t = v_s + \frac{\sigma^2}{v^2}$

(ii) SMS gives more weightage to slow moving vehicles : v_{SMS} is used in flow density relations.

(iii) Reciprocal of SMS give avg. travel time of all vehicles /km

(c) Running Speed :

- excludes stops delays : "used to assess the adequacy of existing road network.

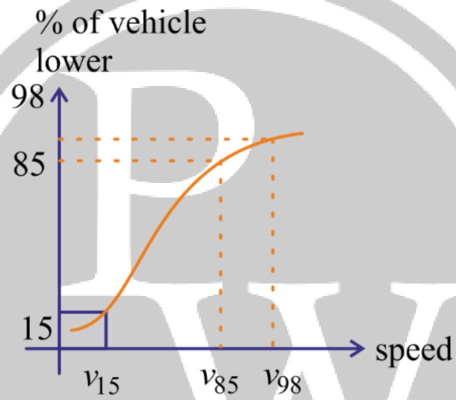
(d) Journey speed : "used to analyse traffic flow condition".

- Various types of speed studies one :

(i) Spot speed study : represented in the form of

(a) Average speed of vehicles : –SMS and TMS

(b) Cumulative speed distribution diag :

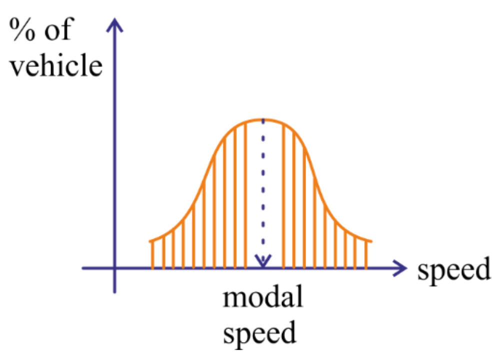


v_{85} → upper safe speed limit

v_{15} → lower speed limit (to avoid congestion)

v_{98} → design speed (for geometric design)

(c) Frequency distribution diagram :



(ii) Speed & Delay Studies :

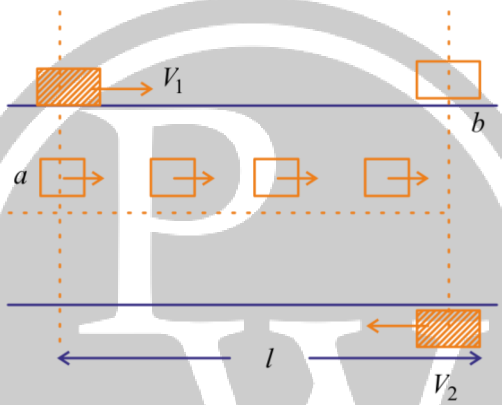
These study help in determining flow characteristics (ex. DENSITY). Location of congestion travel timer over stretch of road etc.

Methods:

- Floating car method
- License plate method (Vehicle no.)
- Interview technique
- Photographic technique
- Elevated observation method

Floating Car Method:

- Suitable for 2 lane traffic
- 4 observers are used :
- Observer 1 : records total journey time and amount of delay
- Observer 2 : Location and cause of delay
- Observer 3 : Number of vehicle overtaking and overtaken by that vehicle (along stream)
- Observer 4 : Number of vehicle in opposite direction



Along the traffic : Relative flow wrt that vehicle $=\dfrac{n_0-n_p}{t_1}k(v-v_1)$

Against the traffic : Relative flow wrt that vehicle $=\dfrac{m_0}{t_2}=k(v+v_2)$

Find $(q=kv),k,v$

For prelims simplified result : $\dfrac{(n_0-n_p)+m_0}{t_1+t_2}=q$

For k : subtract (i) and (ii)

For v : devide (i) and (ii)

Note :

- v obtained here will be journey speed b/c includes stope and delays (b/c last vehicle will also go same delay)
- To obtain running speed $=\dfrac{\ell}{\frac{\ell}{v}-(\text{delay})}$

- **Question :** A student riding bicycle on 5 k one way taken 40 min to reach home, he stopped for 15 minute in which 45 vehicle overtook him. During the ride 60 vehicle overtook him. Find traffic speed on road.

- **Solution:** During 25 min: $q_{vec} = \frac{60}{\left(25/60\right)} = k\left(v - \frac{5}{25/60}\right)$

  During 15 min $q_{vec} = \frac{45}{15/60} = k(v)$

  Solving, v = 60 kmph

(iii) Origin & Destination study:

- Determines the origin and destination of number of vehicles in a particular zone.
- These gives info about directions of travel selection of routes etc.
- Used in planning mass rapid transit systems.
  - Road side interview method : (given good details)
  - License plate method: A large number of observers, speed vs study area and large work
  - Return post card method
  - Tag on car method
  - Home interview method
  - Work spot interview

O & D data is presented as:

(a) Desire lines : Width denotes number of trips in both direction

(b) Pie charts : Diameter denotes number of tripes

(c) Contour lines

(iv) Traffic Capacity Study:

PCU equivalent passengers cars "more the congestion, higher the PCU"

$$\text{PCU} \;\&\; \frac{\text{Bulk of vehicle } (W \times L)}{\text{Speed of vehicle}}$$

- Car, tempo, auto, pickup van → 1
- Motorcycle, cycle, scooter → 0.5
- Cycle, Rickshaw → 1.5 or 2
- Bus, Truck → 3
- Horse, driven vehicle → 4
- Small bullock driven → 6
- Big bullock driven → 8

Traffic Density

- Number of vehicle occupying unit length of road at a given time.
- Time headway $= \frac{1}{q}$
- Space headway $= \frac{1}{k}$
- Space headway = Time headway × v
- Space headway (s) is generally taken between rear to rear.

Traffic Capacity

Maximum number of vph that can cross a section on road with a given level of service.

(a) Basic capacity / theoretical capacity / Ideal capacity:

- ➢ Maximum vph under the most ideal roadway condition.
- ➢ Two identical (geometrically) road will have same basic capacity.

$$q = \left(\frac{1}{s}\right)v \text{ where } s = 0.7v + \ell$$

(b) Possible capacity:

- ➢ Capacity under prevailing roadway condition can lie between O (high congestion) to basic capacity.

(c) Practical capacity/Design capacity:

- ➢ Capacity w/o density being too high to cause delay and restriction to drivers

$$\text{(ACC to ACE)} \quad q = \left(\frac{1}{s}\right)v \text{ space SSD + } \ell \left(vt_r + \frac{v^2}{2gf}\right)$$

Hence practical cap. is less than ideal capacity.

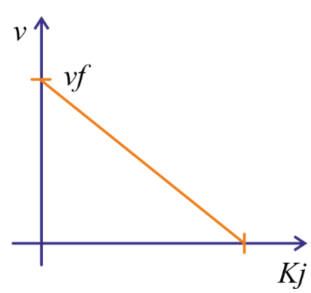
- ➢ (Capacities can also be founded as $\frac{1}{\text{min avg } t_n}$

Macroscopic Traffic Stream Models:

- All calculation are done for single lane, then converted as required
- (Note : when doing $\frac{1000}{S}$ we directly get k for one lone only)

Green Shield:

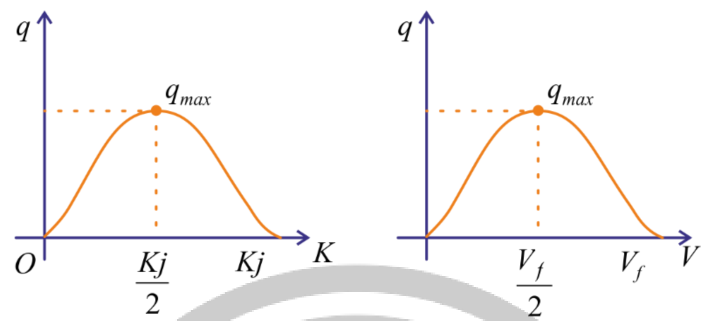
- Linear speed density relation



$$v = v_f\left(1 - \frac{k}{k_j}\right)$$

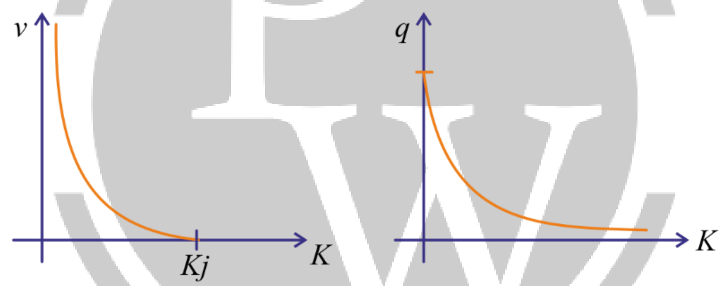
$\therefore q = kv = kv_f\left(1 - \frac{k}{kj}\right)$: Parabola

For maximum, $\frac{dr}{dk} = 0$ or $\frac{dq}{dv} = 0 \Rightarrow q_{\max} = \left(\frac{k_j}{2}\right)\left(\frac{v_f}{2}\right)$



Green berg (Logorithmic):

$$v = v_\phi \ln\left(\frac{k_j}{k}\right)$$

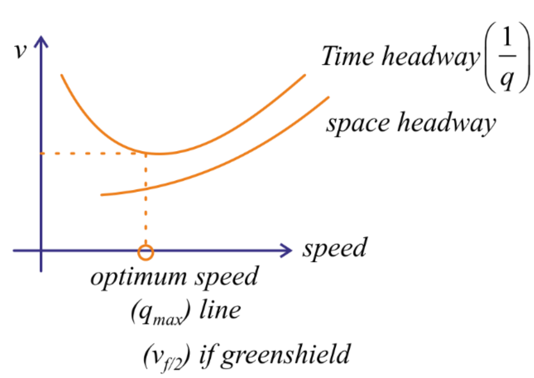


Suitable for congested flows (Not for low k)

$$q_{\max} = \left(\frac{k_j}{e}\right).v_\phi$$

Underwood Exponential

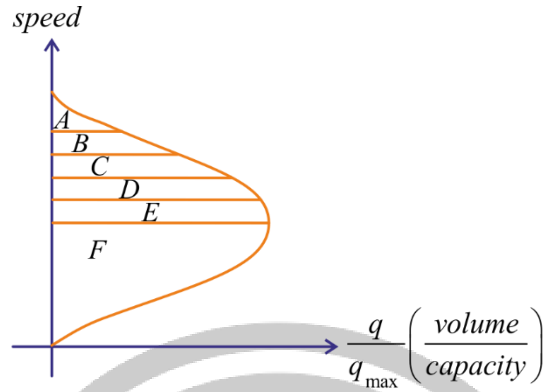
$$v = v_{\phi.e} - k/k_j$$



Suitable for low density flows.

Level of service : (Not in GATE)

- Capacity is quantitative measure which LOS is quantitative measure of flow.
- defined on the basis of measure of effectiveness (MOE); 3 parameters are generally considered.
  - (a) Speed and travel time
  - (b) Density
  - (c) Delay



Los A: Free flow, no delay (~ 90% v_f)

Los B: Masonable free flow, no delay (~ 70% v_f)

Los C: Stable flow, minimal delay (~ 50% v_f)

Los D: Limit of stable flow (Unitability approached), minimal delay (~ 40% v_f)

Los E: At capacity level, unstable flow

Los F: Breakdown, long queele congestion,

(v) Parking study:

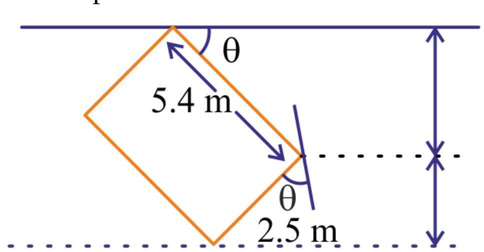
- Off street parking
- On street / kerb parking

(a) Parallel parking

- Least number of vehicle per unit length of road
- Parking is difficult
- But least accident with main traffic

(b) Angle parking : 30°, 45°, 60°, 90°

- In 90° → maximum number of vehicle in unit length
- accident with main traffic
- width requirement high
- 45° Parking – most optimum



(vi) Accident studier:

Various records maintained in this study are:

(a) Location file : Points of high accidents noted

(b) Spot map : Accidents spots are pointed on map

(c) Condition diagram : Diagram prepared at scale sowing all physical condition @ time of accident

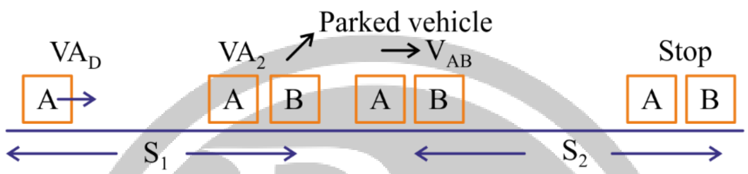
(d) Collision diagram : Path of vehicle and crash type, severity, speed involved

To determine speed of vehicles assumptions:

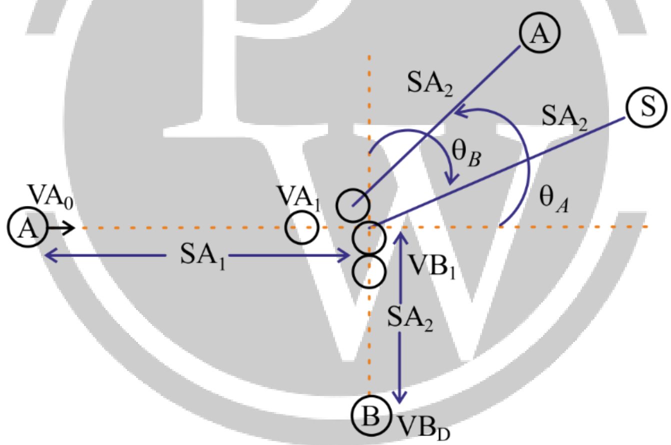
(i) If skid marks → 100% skidding (brake efficiency) assumed no skid molar → means no break (free collision)

(ii) When vehicle on same path → plastic collision assumed.

Case (i) :



Case (ii) :



X-axis : $m_A, v_{A_1}, +0 = m_A v_{A_2} \cos\theta_A + m_B v_{B_2} \sin\theta_B$

Y-axis : $m_B v_{B_1} = m_B v_{B_2} \cos\theta_B + m_A v_{A_2} \sin\theta_A$

$$\begin{bmatrix} v_{A_1} = v_{A_0}^2 - 2gfS_{A_1} \\ v_{B_1} = v_{B_0}^2 - 2gfS_{A_2} \end{bmatrix} \quad \begin{bmatrix} v_{A_2} = \sqrt{2gfS_{A_2}} \\ v_{B_2} = \sqrt{2gfS_{B_2}} \end{bmatrix}$$

2.2. Poisson Distribution Module

$$p(n,t) = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \quad \lambda = \text{flow rate (vph)}$$

Arrival of *n* vehicle is *t* time

(i) Problem of 'O' vehicle in time t

$$P(t_h > t) = e^{-\lambda t}$$

*Distribution of time headway is exponential

(ii) $P(t_1 < t_n < t_2) = e^{-\lambda t_1} - e^{-\lambda t_2}$

2.2.1. Traffic Control and Regulation

Traffic instruction : Area where 2 or more roads join or cross ; change in direction of movement may occur leading to various conflicts.

(a) Crossing conflict : (MAJOR Conflict)

(1) Through – Through

(2) Right – Through

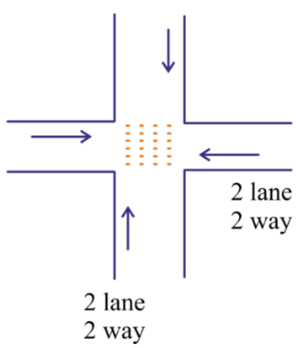
(3) Right – Right

(b) Merging conflict : (MINOR conflict)

(c) Diverging conflicts (Very minor)

Number of lanes		Number of vehicles conflicts		
Road A	**Road B**	**Both 2 way**	**1 way & 2 way**	**Both 1 way**
2	2	24	11	6
2	4	32	17	10
4	4	44	25	18

(i)

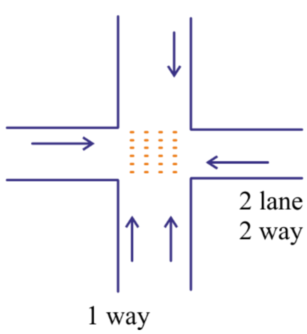


Major : Through through = 4, Right through = 8, Right right = 4 } 16

Minor : Merging = 8} = 24

Pedestrian confliction = 8.

(ii)



Major : Through through = 4, Right through = 2, Right right = 1 } 7

Minor : Merging = 4} $\frac{4}{11}$

Pedestrian = 8

2.2.2. Intersection Control

To reduce conflicts

(1) Passive control :

Traffic rules sign & markings only

Ex : GIVE WAY ∇ (for minor road) or priority intersection.

(2) Semi control / Partial control

- Drives are gently guided
- channelisation and rotary

(3) Active control

- Traffic signals
- Grade separated intersection

Grade Separated Intersection:

1. Overpass
2. Underpass
3. Interchanges

Interchange ramps:

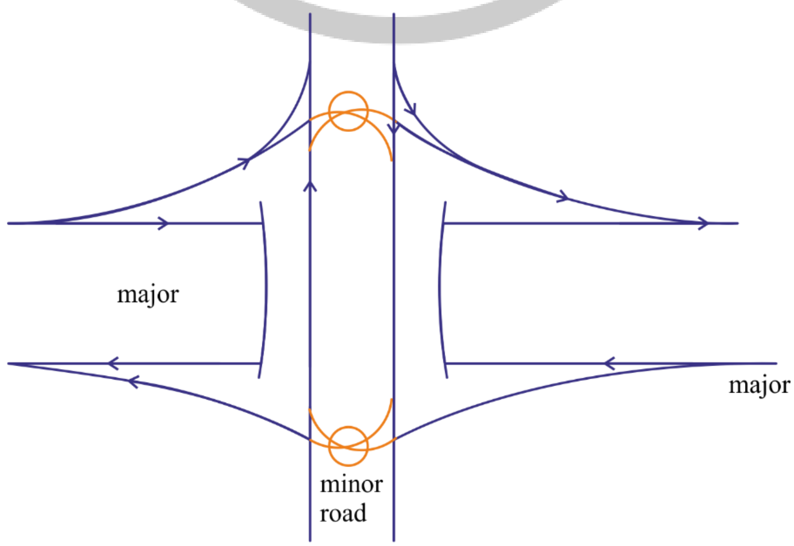
- DIRECT RAMP right diverse right merge
- Semi direct left divers right merge
- Indirect method left diverging or left merge

(a) Trumpet Interchange :

- used for 3 legged intersection (Y or T)

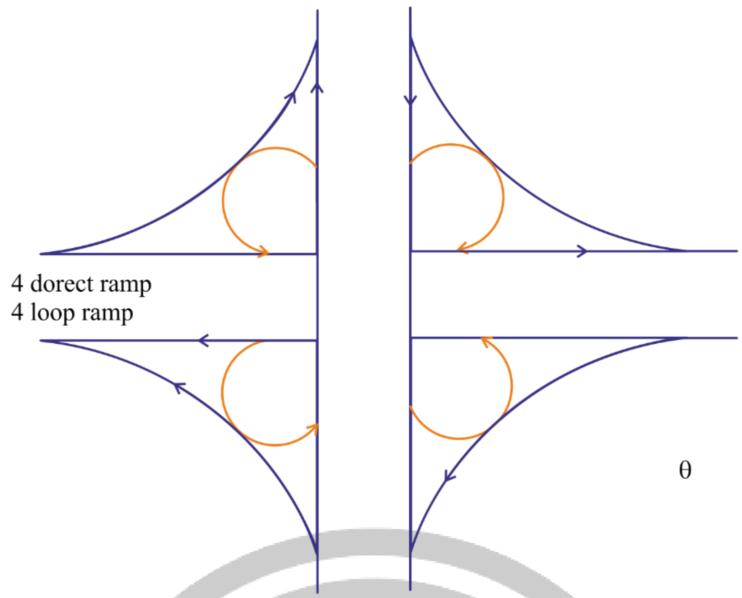
(b) Diamond interchange

- Simplest of 4- legged; less space road
- Used when one major and one minor road
- All merging are not left merging
- All crossing conflicts are not eliminated between at grade terminals on minor road.



(c) Closer leaf (Full)

➢ 4 legged when major road crosses another major road.



- All crossing conflicts one eliminated
- All mergings are left merging

➢ Partial clover leaf when one major and one minor road (ie at grade crossing can be hosted on minor road) (4 direct ramp, 2 loop ramp)

(d) Rotary interchange :

When multiple roads (> 2) intersect

(e) Directional interchange:

➢ Most efficient, most expensive

At grade intersection :

All roads meet at about same level categorised as:

- Unchannelised, , channelised and rotary
- Traffic islands :
- Divisional Islands : Median; separate opp. Traffic and prevents head on collision.
- Channelising island: Traffic is guided gently
- Pedestrian refuge island: For crossing multilane highways; after 2-3 lanes
- Pedestrian loading island : Near bus stop.

Rotary: Converts all crossing (major) conflicts into weaving manoeuvre.

- No need for vehicle to stop thought right turning traffic has to travel little extra.
- All traffic proceeds at a slower but uniform speed.

@ a rotary:

➢ Merging
➢ Diverging
➢ Weaving (merging then diverging)

Advantages	Disadvantage

Crossing conflicts converted into weaving	Large area required
Self governing	Not suitable for pedestrians
Vehicles need not stop	Speed of vehicle has to be reduced.

Guidelines

(1) Suitable when traffic from all approacher are equal.

(2) Upper limit ; 3000 vehicle from all approacher

Lower limit : 500 vehicle from all approacher

(3) Highly suitable when right turning traffic is large (> 30%) (over traffic signal)

Design Elements :

- Design speed : (Slow down at rotary)

  30 kmph : URBAN

  40 kmph : RURAL

- Radial

  At entry : → Due to curvature, drivers are forced to slow down.

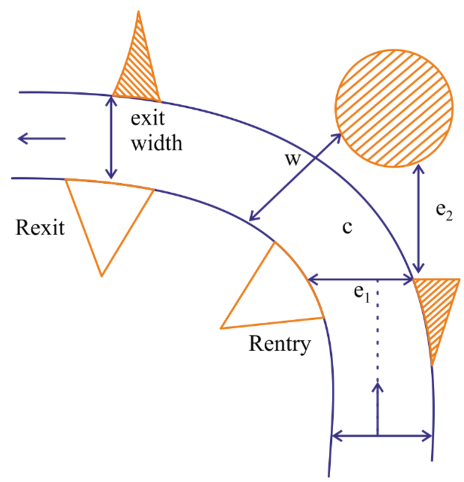
  Entry $R = \frac{v^2}{gf} = \frac{v^2}{127f}$; $f = 0.41$ to 0.47

  Hence; for $\begin{bmatrix} \text{Urban} & R \approx 20m \\ \text{Rural} & R \approx 25m \end{bmatrix}$

- $R_{exit} = (1.5 - 2) R_{entry}$
- $R_{central}$ island $= 1.33 R_{entry}$

Width

Entry width (e_1) should be lower than approach carriageway width.



(i) Ex : For 7m (2 lane) approach

e_1 = 7m (urban)

e_1 = 6.5m (rural)

(ii) For 14m approach

e_1 = 10m (urban)

e_1 = 8m (rural)

e_1 = entry width

e_2 = width of non weaving selection

Should be equal to widest single entry s < w

i.e., generally $e_1 \approx e_2$ (if not given)

W = width of weaving section

$$w = \frac{e_1 + e_2}{2} + 3.5\ m$$

L = weaving length :

- How smoothly vehicle can merge and diverge
- L = 4w or greater

$$\text{Design } \left\{0.12 \le \frac{W}{L} \le 0.4\right\}$$

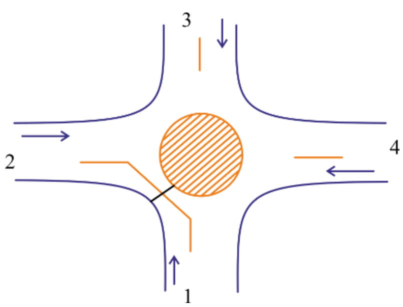
Note: Weaving angle should be as small as possible but not smaller than 15°; use $R_{\text{central island}}$ required will be very large.

- Capacity of rotary :
- Determined from all waving section & taken min.

$$Q_P = \frac{280\, w \left(1 + {e}/{w}\right)\left(1 - {P}/{3}\right)}{\left(1 + {w}/{L}\right)} \text{ pcu/hr}$$

- P = weaving ratio = $\dfrac{\text{Weaving traffic}}{\text{Total traffic}}$ at a section.

Calculation of P :



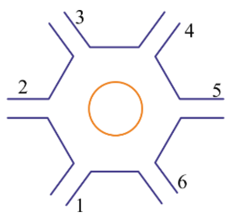
At section 1-2

TT = 12, 13, 14, 32, 42, 43

WT = 13, 14, 32, 42

$$P = \frac{WT}{TT}$$

5 legged :



At section 1-2

TT = 12, 13, 14, 15, 16, 32, 42, 43; 52, 53, 54, 62, 63, 64, 65, 66

WT = 13, 14, 15, 16, 32, 42, 52, 62

Trick : Between 1 & 2

For WT : 1 to all, all to 2 except 12

For TT : 1 to all, 2 to none, 3 to 2 onwards, 4 to 2

Traffic Signals:

Types of traffic signals

(i) Fixed time / Pre timed signal :

- Signal cycle is fixed independent of traffic volume

(ii) Semi actuated :

- Signal time is affected when vehicle are detected on some (not all approach)

Ex.: When major road crosses a minor road

(iii) Fully actuated :

- Signal time is controlled by traffic volume or all approach.
- Used when high variation throughout day

Types of Co-ordination of Traffic Signal System :

(i) Simultaneous System :

- ➢ All signal show same indication at same time (i.e., cycle time also same)

(ii) Alternate system :

- ➢ Alternate signals show "Opposite indication" at same time
- ➢ More satisfactory → This both are operated by signal controller.

(iii) Simple progressive system :

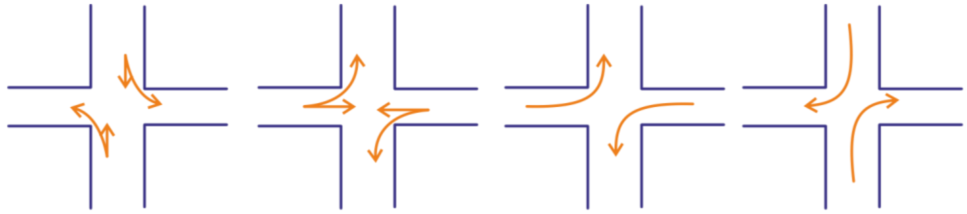
- ➢ a "time schedule" is made to permit a continuous operation of vehicles along the main road at reasonable speed.
- ➢ The phases and intervals at each signal may be different but each signal behaves as fixed time signal.

Flexible Progressive :

- Possible to automatically vary the cycle length division, time schedule etc

Traffic phase ;

- To clear a 4 legged intersection w/o conflict, we require 4 phase signal



But 2 phase is designed, keeping in mind that right turning traffic is not very high.

Definition :

(1) Interval :

Represents change from one stage to another

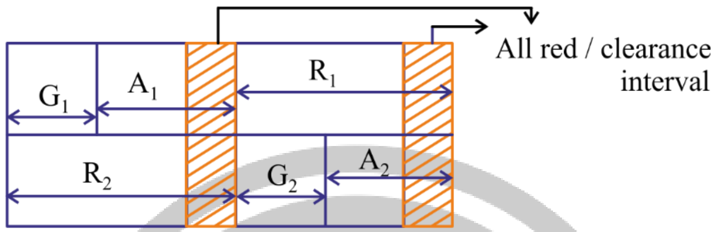
(a) Change interval (Amber time)

(b) Clearance interval (All red time)

Included after each yellow interval

When all signal faces shown red

Optional and not provided for small intersection



(Note : G + A + R = C_0) for each phase : ALWAYS TRUE

> **Note :**
> - Change interval (Amber) is used for warning of incoming red.
> - Clearance interval (All red) for clearing intersection

(2) Initial Amber (Red Ambers) :

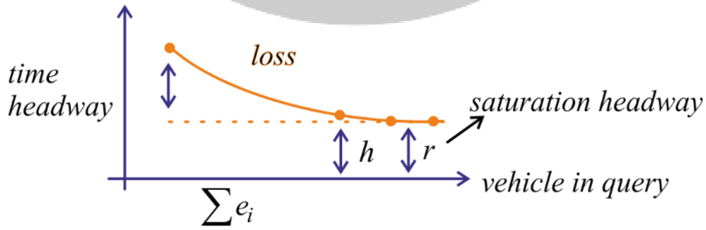
Sometimes provided before start of green for indicating get set part of red only

(3) Loss time :

Time that is not effectively serving any movement of traffic

(a) Startup loss time:

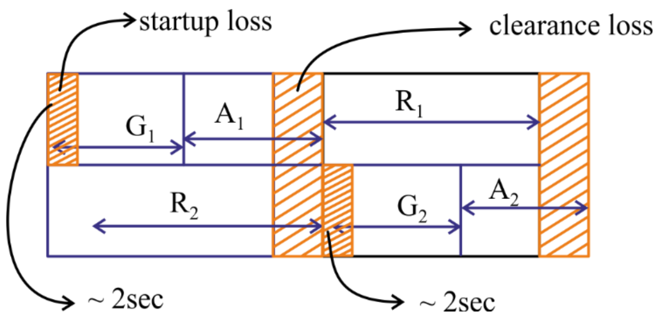
Due to $r \times n$ time of driver when signal changes from red to green.



(b) Clearance Loss:

(i) When signal changes from green to yellow, some part is not utilised

(ii) All red time



Hence, $t_L = t_{SL} + t_{CL}$

(4) Effective green time (g)

$g_1 = G_1 + A_1 - t_{L_1}$ total loss time in phase 1 (clearance + startup)

- Capacity of a lane :

Capacity of lane : $\left(\frac{g_L}{C_O}\right) \times S_i$ Saturation capacity $= \frac{3600}{t_h}$ of the lane

Note:

(i) Generally, saturation headway = 2.5 sec

(ii) Time need to clear N vehicle $N \times t_h + t_{SL}$ sartup loss time

- Ctritical lane volume : q_i

During each phase there will be one lane where traffic is most intense

Note : Theorotically : $C_0 = \frac{L}{1-Y}$

$$Y = \sum y_i = \left(\frac{q_1}{s_1} + \frac{q_1}{s_2}\right)$$

If Y > 1 then traffic lanes to be split i.e., number of lanes need to be increased

- Green splitting :

$g_i = \frac{y_i}{Y}(C_0 - L)$ total lost time

Where $y_i = q_i \rightarrow$ critical lane volume of its phase

$s_i \rightarrow$ saturated flow of lane

$Y = \Sigma y_i$

and $g_i = G_i + A_i - T_{L_i} \Rightarrow$ calculate Gi

- Pedestrian crossing requirement :

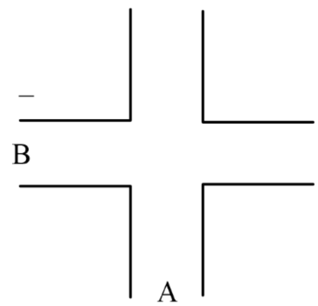
$$G_{P_I} = 7\sec + \frac{W_1}{1.2\ m/s}$$

And $G_{P_I} = R_I$

If no pedestrian signal, then miss 5 sec time

Methods of traffic signal design :

(a) Trial cycle method :



n_A, n_B 15 min traffic count per lane of roads A and B during peak hour

Assume C_0

$x_A = \frac{n_A}{15\times 60}\times C_0$ (per lane vehicle is C_0 time)

$x_B = \frac{n_B}{15\times 60}\times C_0$ (per lane vehicle is C_0 time)

Hence, $G_A = x_A \times t_h \qquad G_B = x_B \times t_h$

Calculate, $C_0^1 = G_A + A_A + G_B + A_B$ compare

Single step : $C = \frac{n_A}{15\times 60} C \times t_h + A_A + \frac{n_B}{15\times 60} C \times t_h + A_h$

(b) Approximate method :

green time is first calculated based on pedestrian observe time then checked for vehicle

$$G_{P_I} = 7 + \frac{w_I}{1.2}$$

$$G_{P_{II}} = 7 + \frac{w_{II}}{1.2}$$

$$G_1 + A_1 = G_{P_I} \Rightarrow G_I =$$

$$G_2 + A_2 \pm G_{P_{II}} \Rightarrow G_2$$

Check : For Vehicle

$$\because \frac{G_{I\ Vehicle}}{G_{II\ Vehicle}} = \frac{q_1}{q_2} \rightarrow \text{(Critical lane volume)}$$

Assume $G_{I\ Vehicle}$ and calculate $G_{II\ Vehicle}$ if $G_{II\ Vehicle}$ comes greater than G_{II} then acceptable.

(c) WEBSTER Method

Used for pretimed signals

Principles : Least total delay.

$$C_0 = \frac{1.5L + 5}{1 - Y}$$

L = total lost time = nt_{SL} + All red

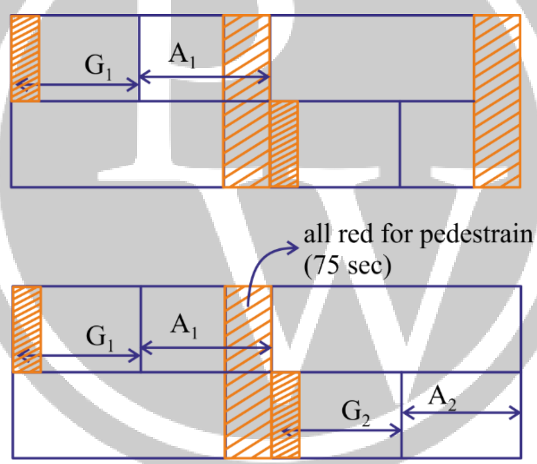
$$Y = y_1 + y_2 + ... \left(y_1 = \frac{q_1}{s_1} \right)$$

Now, effective green time $g_i = \frac{y_i}{Y}(C_0 - L)$

Y should not be greater than 1.

Note : If s_i is not given then solution flow for carriageway can be taken as 525 per m width for width > 5.5m During design (to find G_1, G_2 etc.)

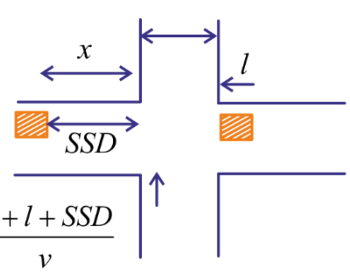
2.3. Types of all Red



(i) For vehicle diagram $g_1 = G_1 + A_1 - (t_{S_i} + all\ red)$

(ii) For pedestrian $g_1 = G_1 + A_1 - t_{sL}$

Fixing Amber time :



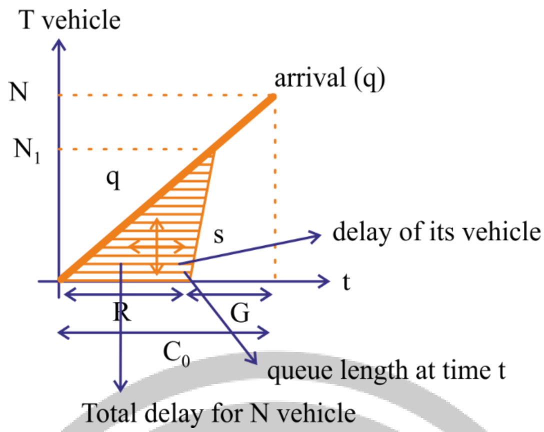
$$t = \frac{w + l + SSD}{v}$$

$$t = \frac{w + \ell + SSD}{v}$$

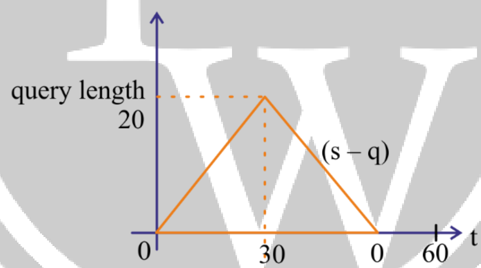
2.4. Delay Analyser

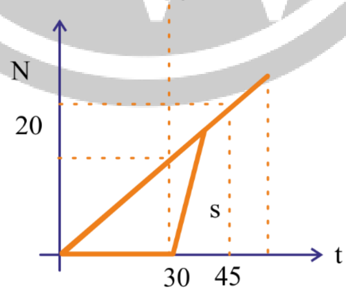
Assumption

- Arrival is determinant (uniform)
- System is unsaturated.



- Average delay $= \frac{TD}{N}$
- Average delay $= \frac{C_0\left(1-g/C_0\right)^2}{2\left(1-q/s\right)}$





Peak Hourly Factor :

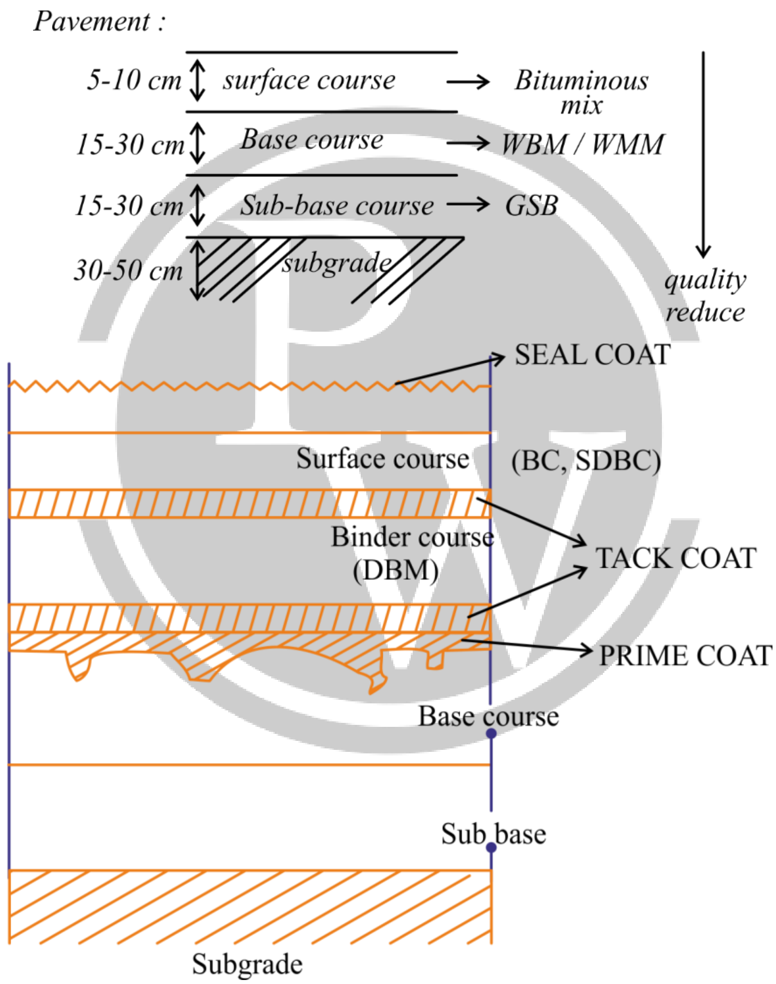
Traffic fluctuation within peak hour, $PHF = \frac{\text{flow during peak hour}}{4(q_{15})}$

range of PHF_{15} $\left(\frac{1}{4} \text{ to } 1\right)$

Generally saturation flow rate = $4q_{15}$

3 PAVEMENT DESIGN : (BC, SDBC, HMA, PC)

3.1. Flexible Pavement



- **Tack coat:** binds 2 layers together

  Thicker than prime coat

  AQUEOUS EMUSION

- **Prime coat:** Least vision; plugs voids of base course & prepare surface for application of TACK

  CUTBACK BITUMEN

  Bitumen emulsifier in petrol, kerosene, diesel

- **Seal coat:** high viscosity

  Impermeability and skid resistance etc.

  Load distribution to lower layers through grain to grain transfer

  Any deformation in bottom layers is visible on top layers top.

  Natural soil compacted to "97% of modified proctor density"

  Subject : Base and base provide drainage apart from structural support.

  In flexible parameter stage construction is possible (make WBM for now; when traffic ↑ then put above layer)
- Base and subjection base provide drainage apart from structural support and also frost action prevention, intrusion of water

Modes of failure of flexible pavement:

(1) FATIGUE $\rightarrow$ alligator cracks

(2) Rutting

(3) Thermal cracking (not considered)

3.2. Rigid Pavement

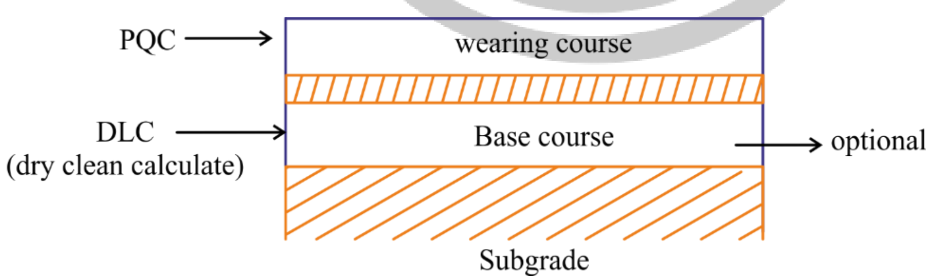
- Flexural action of CC slab (WC)
- Function of base / sub base is to prevent "mud pumping" & help in drainage

Failure:

(1) Fatigue cracking $\rightarrow$ IRC consider only this

(2) Mud pumping No rutting b/c deformation in bottom layers is not

(3) Thermal cracking



- 125 μ PVC sheet or
- 3-4 cm BC_2

to reduce friction and allow slipping during (temperature changes)

1. Design life :

$$\begin{aligned} &\text{EW} \quad ; \quad 20\,yrs \\ &\text{NH, SH} \quad ; \quad 15\,yrs \\ &\text{others} \quad ; \quad 10-15\,yrs \end{aligned}$$

Rigid (IRC : 58-2015)

High volume : 30 years

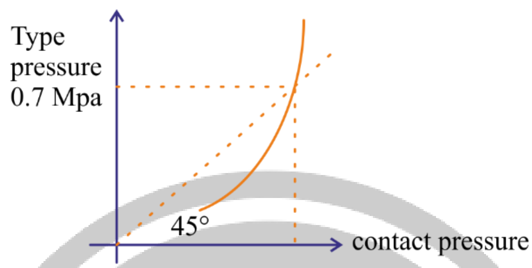
Low volume : 20 years

2. Design traffic :

CV are counted for 24 × 7 (7 days to includes weekday) and average taken

CV : Laden wt > 35 (30 kw)

3. Type process and contact pressure :



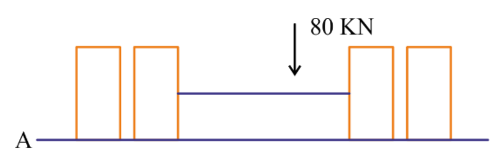
When T.P. < 0.7 MPa — T.P. > 0.7 MPa

Type under compression — Type under Tension

$$\text{Rigidity factor} = \frac{C.P.}{T.P.}$$

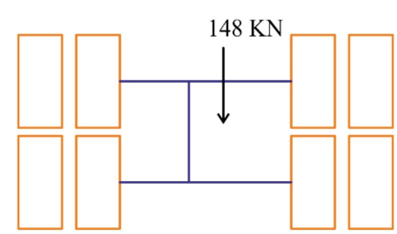
R.F > 1	R.F < 1
T.P < 0.7 MPa	T.P. > 0.7 MPa
More wear & tear	Less full consumption
More full consumption	Less wear & tear
More damage to road	Type under reason

IRC no comment 0.8 MPa type pressure :



4. Design Axle loads:

- Single when single axle load : 65 KN
- Dual where single axle load : 80 KN (standard axle)
- Dual wheel tandem axle : 148 KN
- Dual wheel tridem axle : 224 KN
- Fixed vehicle Approach :
- Here design is governed by no. of repetition of standard axle (80 KN)
- Fi (equivalent axle Load factor for ith axle) = $\left(\frac{axle\ load}{80\,KN}\right)^4$



∴ Total no. of repetition of std. axle = $\sum f_i n_i$

- VDF : → no. of std. axles / no. of vehicles
- 1 avg CV on road = no. of std. axles
- If std. axle not given then use 80 KN
- However, if asked to covert. In equivalent single axle single wheel then $\left(\frac{P}{65}\right)^4$: Equivalent dual wheel tandom axle : $\left(\frac{P}{148}\right)^4$.

Note:
- Front axles are mostly single with single axle
- Riar axles may be single with dual wheel, tandem, tridem etc.
- Fixed traffic approach will be discussed late

5. Sample size for axle load survey :

Total CV / d	Min % to survey
< 3000	20%
3000 – 6000	15%
> 6000	10%

6. Traffic Forecast

$$N = \frac{365A\left((1+r)^n - 1\right)}{r} \,.\, (VDF) \,.\, (LDF)\; CSa$$

N = cumulative no. of standard axles throughout the design life of road.

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

- Calculated at the end of construction.
- Last count traffic : (x→ yrs upto completion)
- n → design life
- r → growth rate → 5% (IRC 37 – 2018)

LDF:

$$\text{SINGLE}\begin{bmatrix}\text{Single lane} \to 1\\ \text{Dual lane} \to 0.5\\ \text{Intermediate lane} \to 0.75\\ \text{Four lane} \to 0.4\end{bmatrix}\text{of traffic in both direction}$$

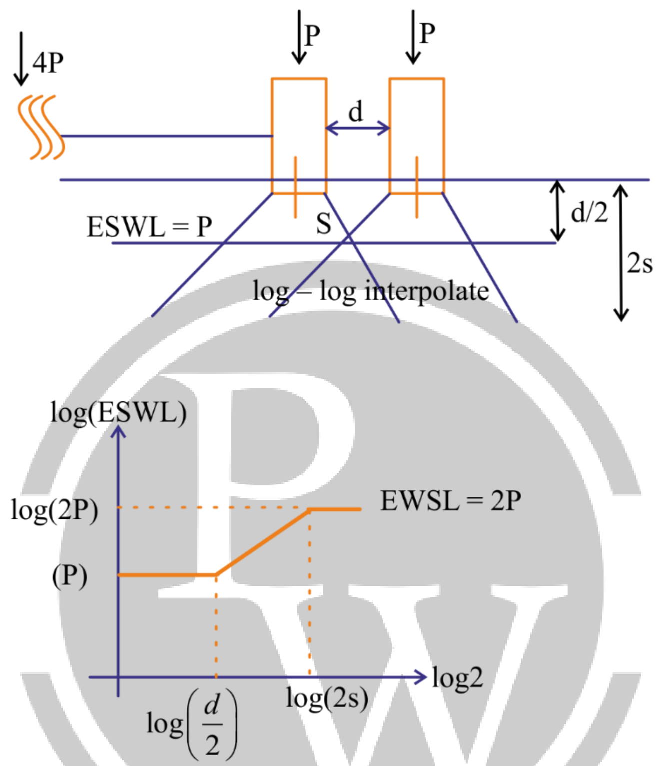
$$\begin{matrix}\text{Carriage}\\ \text{way}\end{matrix}\begin{bmatrix}\text{2 lane dual carriageway} \to 0.75\\ \text{3 lane dual carriageway} \to 0.6\\ \text{4 lane dual carriageway} \to 0.45\end{bmatrix}\text{of one direction}$$

7. EWSL (equivalent single wheel load)

Fixed traffic approach

- Instead of repetition : heaviest which is considered.
- Pavement is designed for single wheel load (multiple wheels at a loon one converted to ESWL).
- Used for AIRPORT PAVEMENT design, not highway design (b/c multiple repetition of small wheel load can also cause damage). In our case we will take equivalency in term of stress (though can be strain deflection etc)

ESWL for dual wheel assembly.



3.3. Design of Flexible Pavement

Design of Flexible Pavements

Empirical

- GI method
- Mcleod method
- CBR method
- Stabilometer
- California resistance value method

Semi Empirical

- Triaxial method

Theoratical

- Burmister
- Layer theory
- Boussinesq single layer theory

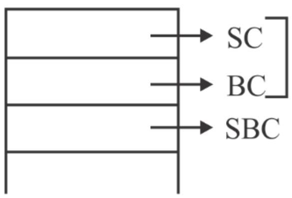
GI Method

$$GI = 0.2a + 0.005ac + 0.01bd$$

$a = p - 35$, $b = p - 15$ ⊁ 40 → Expressed as whole number (0 - 40 to 0 - 20)

$c = \omega_l - 40$, $d = I_P - 10$ ⊁ 20

(a)



SC, BC → t depends on GI and Anticipated traffic

SBC → t depends on GI only

Light	Med	Heavy
<50	50 - 300	> 300

(b) GI lies between **0 to 20**

GI increase Þ poorer the soil

GI	Class
0 – 1	Good
2 – 4	Fair
5 – 9	Poor
10 – 20	Very poor

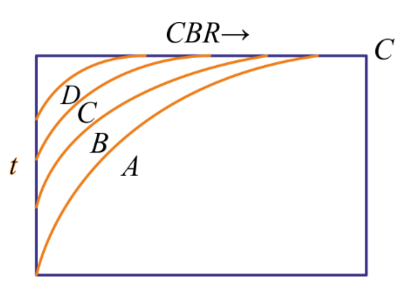
(c) Materials used in different layers not considered.

3.3.1. CBR Method

Board on *CBR of a layer thickness of pavement required above that layer calculated.

$$t_{(cm)} = \sqrt{\frac{1.75P}{CBR(\%)} - \frac{A}{\pi}}$$

This equation holds three tier CBR < 12%.



Class	CV/d
A	0 – 15
B	15 – 45
C	45 – 150
D	150 – 450
E	450 – 1500
F	1500 – 4500
G	> 4500

- Consider only anticipated traffic and not number of std. axle.
- Same curve abot 4500 cv/d.

IRC 37 – 2012
- Modified CBR method
- Consider CBR with CSA is design life

3.3.2. IRC Design Criteria

1. Fatigue cracking in bituminous layer
2. Rutting due to subgrade deformation

Rutting

$$N_R = 4.166 \times 10^{-8}\left[\frac{1}{6v}\right]^{4.5337} \quad ; (80\% \text{ reliability})$$

G_Y = Vertical comp. strain or top of subgrade

N_R = Number of CSa to cause 20 mm depth of rest

Fatigue

$$N_f = 1.6 \times C \times 10^{-4}\left[\frac{1}{\varepsilon_t}\right]3.89\left[\frac{1}{M_{Rm}}\right]^{0.854}$$

$$C = f\left(\frac{V_{ol}}{V_a + V_{oC}}\right)$$

- Board on 20% crack area
- E_t = horizontal tensile strain at bottom of bottom bit layer

  V_{bC} = Percentage of volume of bitumen is bottom bit layer

  V_o = Percentage of void in bottom bit layer

To increase fatigue life, V_{OL} increase (i.e. make bottom most bitumen layer *richer* in it).

Note: M_{Rm} = Moilent modules (of bottom bit layer)

Dynamic elastic modulus used for graduler mat.

(a) California Resistance Value Method

Based on

(a) Stabilometer R value

(b) Cohesionmeter C value

Greater the R & C, better is soil.

EWL (Equivalent wheel load constant)

No. of axle	EWL constant
2	330
3	1070
9	2460

$$EWL = \Sigma(AADT) \times EWL \text{ constant}$$

Important Points: t_1 thickness of material with C value equation C_1 is equivalent to t_2 thickness of material having C value C_2 when,

$$\frac{t_1}{t_2} = \left(\frac{C_2}{C_1}\right)^{1/S} \qquad t \propto \frac{1}{C^{1/S}}$$

For C_{eq} of various layers $\quad [t_1 C_1^{1/S} + t_2 C_2^{1/S} + \ldots = t_{\text{total}} . C_{eq}^{1/S}]$

3.3.3. Triaxial Method

Thickness of pavement for material having modulus E_P over subgrade of modulus E_S;

$$\underset{(cm)}{t} = \left(\sqrt{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2}\right) \times \left(\frac{E_S}{E_P}\right)^{1/3}$$

$E_S \rightarrow \text{kg/cm}^2$
$P \rightarrow \text{kg}$
Δ = 0.25 cm (if not given)

$X \rightarrow$ traffic coefficient : F(AADT)

$Y \rightarrow$ rainfall coefficient (depends on rainfall), Δ = design deflection here, equivalently,

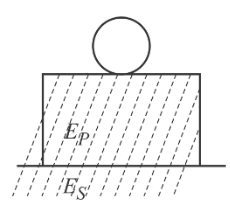
$$\frac{t_1}{t_2} = \left(\frac{E_2}{E_1}\right)^{1/3}$$

3.3.4. Burmister Method:

(Elastic layer theory)

2 layer elastic theory

Load on pavement ⟶ Flexible *plate analogy*.



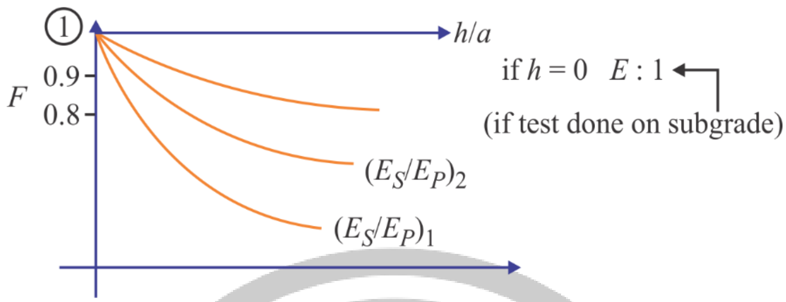
$$\Delta = \frac{1.5pa}{E_S} . F \qquad \text{For Wheel load test/Flexible plate method}$$

$$\left(\frac{\text{Wheel load}}{\pi a^2}\right) = p = \text{contact pressure due to wheel load}$$

a = radius of contact area (15 cm)

Δ = design deflection = 0.25 cm (if not given)

$$F \rightarrow \text{deflection factor} = f\left(\frac{r}{a}, \frac{E_S}{E_P}\right)$$



- Δ select, a known, p known find F
- From curve find h.
- To find E_S and E_P; plate bearing test is done (Rigid plate load test).

$$\boxed{\Delta = \frac{1.18\,pa}{E_S}.F}$$

- Once on subgrade ($F = p$); find E_S.
- On pavement, find E_P.

***a* = radius of plate**

Note:
Assumption:
- Homogeneous, isotropic, semi-infinite
- $v = 0.5$ used (for both subgrade and pavement)
- $E_P > E_S$ (necessary)

3.3.4. Macleod method

$$\boxed{P_1 n_1 = P_2 n_2}$$

Wheel load P_1 which causes failure due to n_1 repetition equivalent to P_2 for n_2 repetition.

3.4. Design of Rigid Pavement

Can be thought of resting on *viscous or spring foundation*. *(Winkler foundation)*.

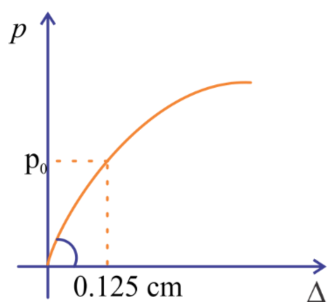
Modulus of subgrade *r×n*:

$$\text{Spring constant; } \frac{\text{kg/cm}^2}{\text{cm}} = \frac{\text{kg}}{\text{cm}^3}$$

K is calculated corresponding to deflection of 0.125 cm. For 75 cm plate (dia).

$$K = \frac{p\,(\text{kg/cm}^2)}{0.125\,\text{cm}}\text{; from plate load test}$$

Note:



$$\Delta = 1.18\frac{pa}{E_S}$$

$$K\,.\,a = \frac{E_S}{1.18} = \text{constant}$$

Hence, K depends on radius of plate also.

$$K_{15\,\text{cm}} \times \frac{75}{2} = K_{30\,\text{cm}} \times \frac{30}{2}$$

$\Rightarrow$ $$\boxed{K_{25} = 0.4\,K_{30}}$$

For all design

- K_{75} cm is standard value of modulus of subgrade.
- if 30 cm plate used, then adopt

$$\boxed{K_{75\,\text{cm}} = 0.5\,K_{30\,\text{cm}}} \rightarrow \text{IRC suggested}$$

3.4.1. Radius of Relative Stiffness

- Relative stiffness of slab wrt subgrade.
- Radis in which slab is deflecting.

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

IRC:

$$V = 0.15$$

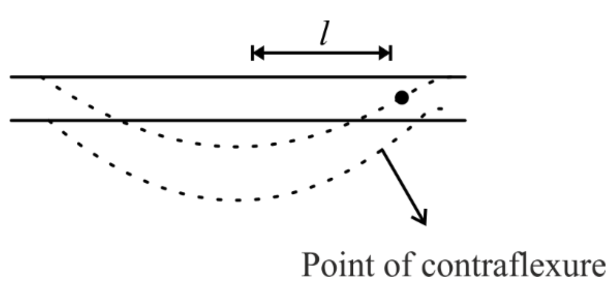
$$E = 5000\sqrt{Fck} = 3 \times 10^5\ \text{kg/cm}^2$$

Equivalent radius of resisting section (b):

- Radius of plate "effective in resisting the *BM*".

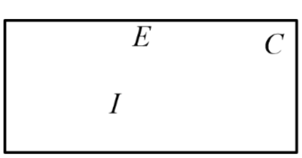
$$b = \sqrt{1.6a^2 + h^2} - 0.675h;\ \text{if } a < 1.724\text{h}$$

$$b = a \qquad \text{if } a \geq 1.724\ \text{h}$$



Stresses:

1. Westergaard stresses due to loading:



(assumed winker foundation)

Due to wheel loading

$$\sigma_I = \frac{0.316P}{h^2}\left(4\log\frac{l}{b} + 1.069\right)$$

$$\sigma_E = \frac{0.572P}{h^2}\left(4\log\frac{l}{b} + 0.359\right)$$

$$\boxed{\sigma_C = \frac{3P}{h^2}\left(1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right)}$$

IRC 58: Modified westergaard

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

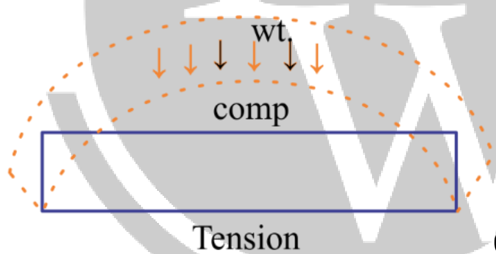
Temperature Stresses

Due to variation in temp; resistance is provided by weight of slab AND friction between slab and ground.

(a) Daily variation:

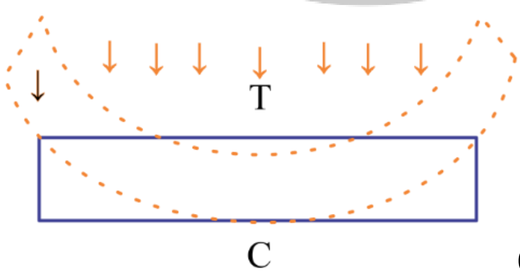
- Causes temp gradient across slab
- Warping stress

Mid day ($T_{top} > T_{bott}$)



(Bottom up crack)

Mid day ($T_{top} < T_{bott}$)



(Top down crack)

Note: (Obj)

(i) at mid night, temp grade is low and linear.
At mid day, temp grade is large and non linear.

(ii) In general:
Warping stress: $\boxed{\text{interior} > \text{edge} > \text{centre}}$

Equation of warping stress (Bradbury):

$$\sigma_I = \frac{E\alpha\Delta T}{2}\left(\frac{C_X + vC_Y}{1 - V^2}\right)$$

$$\sigma_E = \max\left(\frac{E\alpha\Delta T}{2}C_x, \frac{E\alpha\Delta T}{2}C_y\right)$$

$$\sigma_C = \frac{E\alpha\Delta T}{3(1-V)}\sqrt{\frac{a}{l}}$$

C_x, C_y depend on $\left(\frac{l_x}{l}, \frac{l_y}{l}\right)$; length and width

* [lx = distance between contraction joints]

$$v = 0.15;\ E = 5000\sqrt{Fck} = 3 \times 10^5 \text{ kg/cm}^2$$

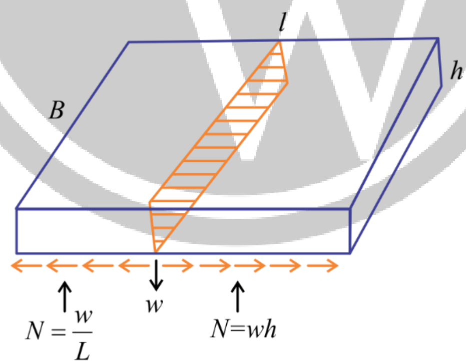
$$\alpha = 0.15 \text{ m}$$

(b) Frictional Stresses:

- Due to seasonal variation of temp from construction temp.
- Don't consider temp grade across the slab.

SUMMER $\rightarrow$ (Expansion) $\rightarrow$ Compressive stress
WINTER $\rightarrow$ Tensile stress

Winter:



$$f\left(Y_C \cdot \frac{Blh}{2}\right) = \sigma_f$$

$$\sigma_f = \frac{f V_C L}{2}$$

σ_f = internal stress

f = 1.5 (friction coefficient between slab and soil)

Y_C = 2400 kg/m^3

l = distance between contraction joints

(Frictional stresses are maximum at mid of longer edge)

Critical Combinations of Stresses

- For wheel load = $\sigma_C > \sigma_E > \sigma_I$
- For kmp stress = $\sigma_I > \sigma_E > \sigma_C$

Note: Warping stresses in summer are generally higher than in winter.

Combination:

1. Summer mid day (Edge)

$$(\sigma_{\text{load}})_E + (\sigma_w)_E - (\sigma_f)_E$$

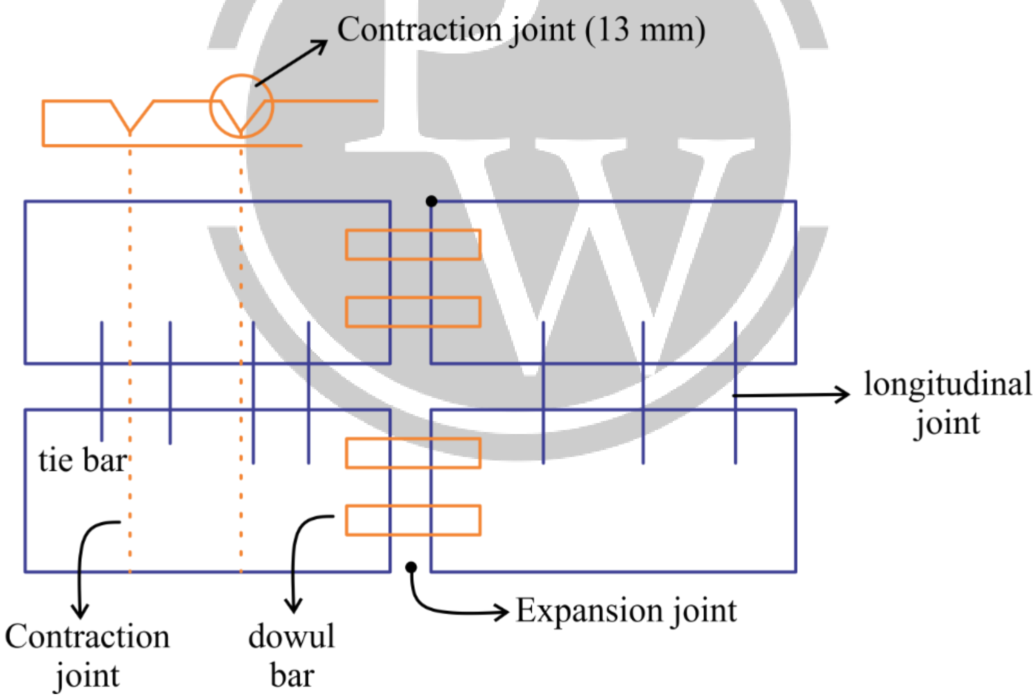
2. Winter mid day (Edge)

$$(\sigma_{\text{load}})_E + (\sigma_w)_E + (\sigma_f)_E$$

3. Mid night (comes)

$$(\sigma_{\text{load}})_C + (\sigma_w)_C + (\sigma_f)_C$$

Joints in rigid pavement:

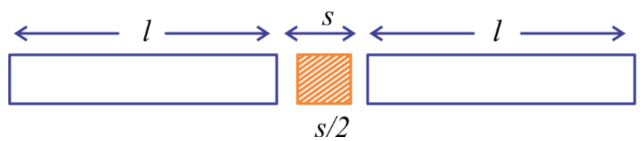


3.5. Transverse Joint

Expansion (Dowel)
Contraction (RIF are optional, however dowel bar should be provided if expd > 450)
Construction joint: Generally tied to match with contraction / expansion it.

- **Longitudinal Joints:** *TIE BARS*

- **Expansion Joint**



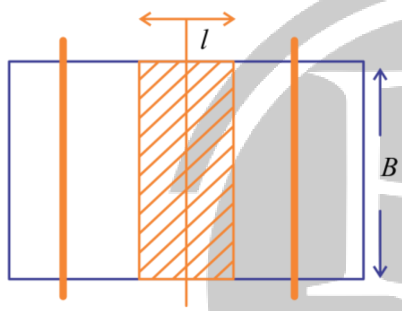
$\boxed{L\alpha\Delta T = 50\% \text{ of } \delta}$ {Files compressed by 50%}

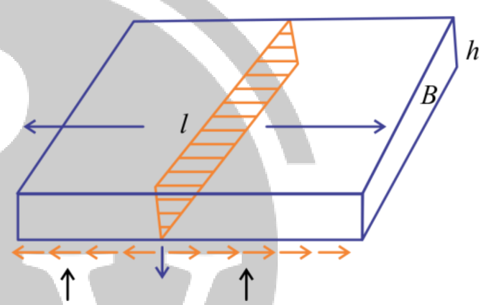
3.6. Contraction Joint

- To control cracking due to shrinkage (predetermined location)
- In contraction joint it is assumed that load is transferred through *aggregate interlock* hence *r/f is optional* from load point of view.

Spacing of Contraction Joint:

1. When r/f not provided:





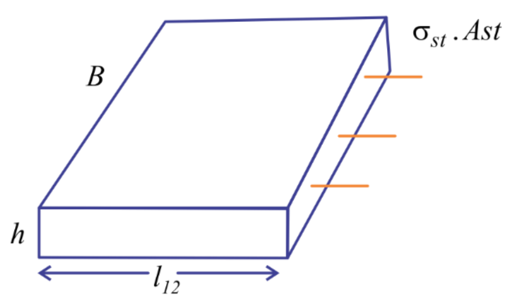
Spacing contration joint

$$\boxed{\begin{gathered} f \cdot y\left(\frac{Bhl}{2}\right) = \sigma(Bh) \\ l = \frac{2\sigma_t}{fy} \end{gathered}}$$

σ_t = permissible tensile stress in concrete (0.8 kg/cm^2)

$\boxed{f = 1.5}$; Y_C = 2400 kg/m^3

2. When r/f is provided:

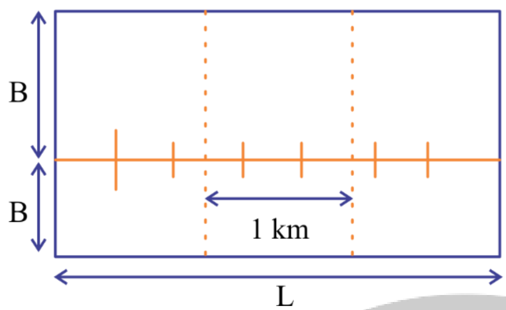


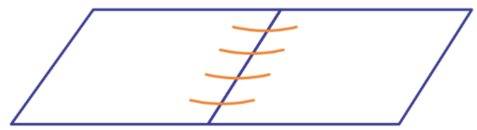
$$\boxed{\sigma_{\text{St. Ast}} = f(V_C)\left(\frac{Bh \,.\, L}{2}\right)}$$

Note: When r/f is not provided, max spacing between contraction joints is 4.5.

3.7. Longitudinal Joints

- Reduce working stress function as "contraction joints" and lane demarcation.
- **Tie bars** are bonded to concrete and generally *deformed bars* are used (10 – 16 mm).
- Tie bars are not designed as load transfer device; load transferred through aggregate interlocking.
- They are designed to withstand tensile stresses generated due to frictional forces.





$$f \cdot Y_C (B.1.h) = \sigma_{st} \cdot Ast$$

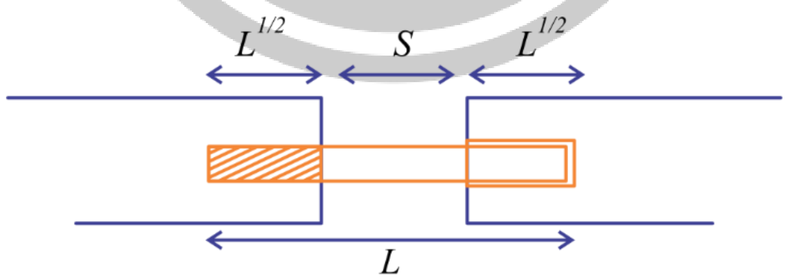
$\therefore$ $$\text{Spacing} = \frac{1000 \text{ mm}}{\left(\dfrac{Ast}{\pi/4.12}\right)}$$

Development length:

$$L_d = \frac{\sigma_{St}\phi}{4\tau_{bd}}$$

$$\text{Length of tie bar} = 2L_d$$

Design of Dowel bars:



'L' = embedded length ; L = L' + S

'L' = embedded length; $L = L' + \delta$

- Load transfer devices between slabs.
- Dowel bars are "mild steel bar"
  - Shearing
  - Bending
  - Bearing

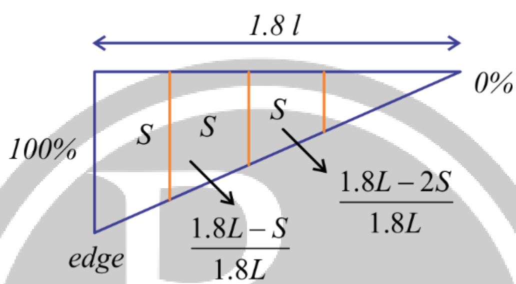
Bradbury Analysis

Load transferred by single dowel if 100% effective:

$$\begin{bmatrix} P_\delta = \pi / 4\sigma^2 \sigma_S \\ P_b = \left(\dfrac{-\phi^3}{1}\right)\sigma_b \\ P_{br} = \left(\dfrac{\sigma}{11}\right)\sigma_{br} \end{bmatrix}$$

- Load transfer capacity of dowel bar is assumed to be *40% of wheel load.
- Hence, no of fully effective dowel bars required.

$$\boxed{\text{Load capacity factor } = \left\{\frac{0.4P}{P_s} . \frac{0.4P}{P_o} , \frac{0.4P}{P_{br}}\right\}}$$



- Dist upto which some effectiveness = 1.8 l. (New code → l)

$$\boxed{\text{Load capacity} = \left(1 + \frac{1.8L - S}{1.8L} + ...\right) \geq LCF}$$

Note:

1. Flexible pavement → aggregate particle interlock (C-ϕ)

   → Subgrade strength influences a lot.

   Rigid pavement → distributes load over a wide area of subgrade between its rigidity and high modulus of elasticity.

2. CBR test should be conducted on *4 days soaked sample;* (remoulded)
3. CBR method consider the quality of soil subgrade (CBR value) only and traffic volume; not the quality of materials.
4. Sometimes in traffic survey:

   80 kN → 25%

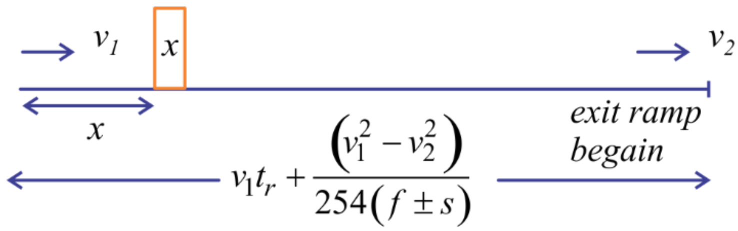
   65 kN → 10%

   108 kN → 80%

   224 kN → 10%

Mean remaining 25% are non commercial vehicles and in using 365 A$[(1 + r)^n – 1]$

Signboard Placing



- if a driver can see 1″ letter from 2 m then he can see 6″ letter from 12 m.
- if 6/6 driver can see from 12 m then 6/9 driver can see from $\frac{6}{9} \times 12 = 8$ m.
- $\left(\frac{dV}{dt} = a = \alpha - \beta V\right) = \frac{dV}{\alpha - \beta V} = dt \Rightarrow a = a(t)$
- [Put relevant BCs] $\leftarrow \left| \begin{array}{l} \frac{dX}{dt} = \int a \, . \, dt \\ X = \int a . \, dt \end{array} \right.$

4 HIGHWAY MATERIALS

4.1. Introduction

Test carried out on subgrade material:

- **Shear tests:** on small sample in lab.
- **Bearing tests:** carried out in-situ with a load bearing area.
- **Penetration tests: "small scale bearing tests" can be done in lab or field.**

CBR Test:

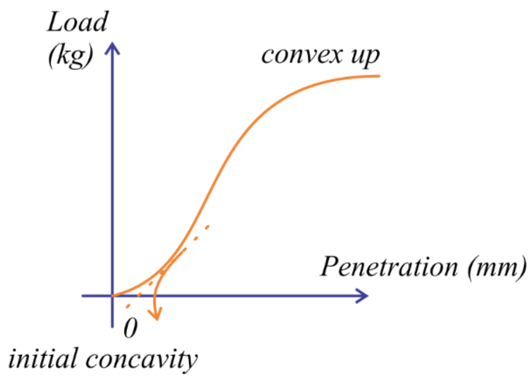
- For classifying and evaluating sub-grade and base course materials* for flexible pavements*.
- **Empirical test:** not true representation of resilient modulus.
- Generally CBR decreases with increase in penetration.

Hence, $CBR_5 < CBR_{2-3mm}$, but if we get greater value of CBR_5 then adopt if after confirmation.

- Standard plunger → 50 mm (1.25 mm/min)

Load values of Standard Crushed Stone:

- 2.5 mm → 1370 kg (70 kg/cm^2)
- 5 mm → 2055 kg (195 kg/cm^2)
- $\left[CBR = \frac{\text{load carried by specimen}}{\text{Load carried by std. stones}} \right]$



CBR		
Clay	2 – 5	Poor subgrade
Silt	5 – 8	
Sand	8 – 20	Fair/good subgrade
Gravel	20 – 100	

As per IRC

CBR test to be conducted on 4 days soaked

- 20 – 30 $\rightarrow$ Excellent subgrade
- 30 – 60 $\rightarrow$ good sub base
- 60 – 80 $\rightarrow$ good base
- 80 – 100 $\rightarrow$ Best base

The CBR values are generally co-related with modulus of subgrade $r \times n$ (only co-relate, not found)

Plate Bearing Test

- To find support capability of sub-grades, basis, and win complete pavement.
- Applicable for design of both flexible and rigid.
- Rigid plates are used to apply load.
- Standard plate = 75 cm dia.

Connection/Allowance

1. **For worst subgrade moisture condition:**

$$\boxed{K_{\text{soaked}} = K_{\text{unsoaked}} \cdot \frac{P_{\text{soaked}}}{P_{\text{unsoked}}}}$$

K = Modulus of subgrade $r \times n$

P = pressure required to cause 0.125 cm settlement in respective condition.

$$\boxed{K = \frac{P}{\Delta}} \rightarrow 0.125\,\text{cm}$$

Theoretically; P-A curve should be straight line and its slope should give K. (nut not true)

2. **Consider for small size of plate:**

$$\boxed{K_1 a_1 = K_2 a_2}\,*$$

Hence, if 30 cm plate used;

$$\boxed{K_{75} = 0.4 K_{30}} \quad \text{(IRC has taken 0.5)}$$

If Δ is not known, it can be found theoretically;

$$\boxed{\Delta = \frac{1.18\,pa}{E_S}}$$

$a \rightarrow$ radius of plate (not diameter)

$E \rightarrow$ modulus of elasticity of soil

- Hence plate bearing test can be used to find both (K) and (E_S).
- boussinesq equation for flexible plate;

$$\boxed{\Delta = \frac{1.5\,pa}{E_S}}$$

- Wheel is treated as flexible plate.

  a – radius of flexible plate (wheel load distribution)

4.2. Aggregator

Desirable Properties

1. Strength
2. Hardness
3. Toughness
4. Shape of aggregate

   Flaky and elongated aggregate have less strength hence undesirable.

5. **Affinity with water:** Aggregates should have less affinity with water compared to bitmen, else stripping .
6. **Durability:** Also free from dust etc.

Crushing Test

- Gradual load
- 10 mm to 12.5 mm particles
- 3 layers @ 25 temping
- Passed through 2.36 mm sieve.

$$\boxed{ACV \ngtr 30\%} \rightarrow \text{ working course}$$
$$\boxed{\ngtr 45\%} \rightarrow \text{ Base course}$$

Abrasion Test:

- Los Angeles Abrasion test
- dewal test
- Dory test

$$\boxed{\text{Abrasion value} \ngtr 40\% \text{ WBM}}$$

- hardness
- 48 mm dis stac charges; 30-33 rpm
- Sieved through $\boxed{1.75 \text{ mm sieve}}$

Impact Test:

- 14 kg hammer; 15 blows

$$\boxed{\begin{array}{l} AIV \not> 30\% \\ \quad\;\; \not> 40\% \end{array}} \begin{array}{l} \rightarrow \text{ wearing course} \\ \rightarrow \text{ WBM} \end{array}$$

- $$\boxed{\text{Coefficient of harden} = 20 - \frac{100 \text{ of wt/g}}{3}}$$

Soundness Test

- Conducting accelerated weathering test cycle.
- Alternate wetting in $\boxed{Na_2SO_4}$ or $\boxed{MgSO_4}$ and then loss in wt. is detrmined.

$$\boxed{\text{Loss in wt} \not> \begin{array}{l} 12\% \text{ if } Na_2SO_4 \text{ in used} \\ 18\% \text{ if } SO_4 \text{ is used} \end{array}}$$

Shape Test:

Flakiness

Least dimension < 0.6 (mean dimension)

Elongated

Greatest dimension > 1.8 (mean dimension).

Note: After carrying out flakiness test, flaky particles are removed and then test done on remaining sample 100 gm sample

20 gm → flaky.

> 15 gm elongated

$$\text{FI} = \frac{20}{100} = 20\%, \; EI = \frac{15}{80} = 18.75\%$$

$$\boxed{\text{Combined flatiness index and elongated index } = FI + EI}$$

$$\boxed{\text{Combined FI \& EI} \not> 35\%}$$

Angularity No.

Represents $\boxed{\text{design of packing}}$

$$\boxed{\text{Angularity no.} = 67\% - \% \text{ solid volume}}$$

- For most rounded compacted aggregate, 33% voids i.e. $A_N = 0$.
- Higher the A_N, more angular aggregate and more the voids.
- Range of AN (generally): 0 – 11
- Angular aggregate are preferred for bituminous concrete because strength is important (for CC → rounded)

4.3. Specific Gravity

4.3.1. Apparent Specific Gravity

- Volume of aggregate excluding the water present in voids (adsorbed water) is taken Bulk specific gravity.
- Board on total volume of aggregate including water permeable voids.

Between Adhesion Test:

- Adhesion problem does not occur when no water, occur when aggregate is $\boxed{\text{COLD \& WET}}$
- Hence either dry aggregate or increase mixing temperature.
- Also, water causes stripping of bonds (mostly when Bitumen is permeable to water).
- "Static immersion test" $\rightarrow$ to determine adhesion of bitumen with aggregate in presence of water.

$$\boxed{\text{Maximum stripping value} \ngtr 5\%}$$

4.4. Bitumen

- Soluble in CS_2, insoluble in water.
- $G_S \rightarrow 1$ (G_S of far is greater)
- *Thermoplastic*

4.4.1. Testing of Bitumen

- **Viscosity**
  - ➢ Sliding plate viscometer ; $\left\{F = \eta\left(\frac{V}{d}\right)A\right\}$
  - ➢ Viscosity of liquid bitumen (low viscous) is measured using $\boxed{\text{efflux / orifice higher viscometer}}$.
- **Ductility:**
  - ➢ Generally minimum of 50 cm is specified though may be low for **waxy bitumen**.
  - ➢ **Penetration:** (not valid for tar because too soft)*
  - ➢ Measures of hardness or consistency.
  - ➢ Unit = $\frac{1}{10}$ mm **Ex:** [80/100 mean 8 – 10 mm penetration]
  - ➢ 100 gm needle, 5 sec.
  - ➢ Hot climate $\Rightarrow$ low penetration (30/40)

Softening Point (~ 50°C)

↓ Ring & Ball test

- Temperature at which bitumen attains a particular degree of softness. (Passes from solid to liquid consistency).
- For avoiding bleeding; bitumen should have softening point 5 – 10°C above attempt temperature.

Flash & Fire Point

Flash point: Temperature at which test flame causes vapor to momentarily catch fine (flame).

Fire Point: Ignite and burn for atleast 5 sec.

- Normally, it is safe to heat bitumen 50°C below flash point.

Spot test: For detecting over heated or cracked bitumen.

- NAPTHA solution is used.

Specific gravity:

- Measured by pycnometer
- Bitumen $\rightarrow$ 1 (0.97 – 1.02)

  Tar $\rightarrow$ 1.1 – 1.25

Solubility

Solubility in Trichloroethylene is measure of its pavity (99% desired).

Float Test

- Used to measure consistency of very viscous bitumen (where penetration or viscosity test can't be used)
- Time (sec) for small plug to become fluid when heated in floating saucer.

Loss of heating	Water content
Heated to 163°C	$\ngtr$ 0.2% by weight
$\ngtr$ 1% loss in weight	If more causes foaming of bitumen when heated

4.4.2. Cutback Bitumen

Viscosity of bitumen is reduced by a volatile dilutant.

(i) Rapid curing

naphtha or gasoline

(ii) Medium curing

kerosene or light diesel oil

(iii) Slow curing

Blending bit with high BP gas oil

RC-3 is more thick than RC-1 i.e. less solvent.

Emulsion

- 2 phase system of 2 immiscible liquids
- Generally bitumen + water

Uses

Cutback	Emulsion
Surface dressing in cold weather.	Surface dressing in cold and wet weather (raining)
Premix in cold weather	Maintenance and patch repair work
Primary	Premix in wet weather
	Priming

Emulsion is used for sand stabiles in deserts.

4.5. TAR

- Not petroleum product, destructive distillation of coal/wood.
- Bit soluble in CS_2 and CCl_4 while tar is soluble only in TOLUENE.
- Bitumen is more resistant to water than far (and also temperature etc.)
- Free C content is more in ter.
    - RT-1: lowest viscosity : used in surface party.
    - RT-5: highest viscosity : used in grouting;
    - RT-3: pointing

Mix Design

Constituents

- CA → strength Ex: granite
- FA → Fills voids and stiffens binder
- Filler → Fills voids, stiffness binder
- Binder → Causes particle adhesion and impermeability.

4.5.1. Types of Mix

(i) Well graded mix:

- dense mix
- good comprehensive strength, some tensile

(ii) Gap graded mix

- some CA missing
- good fatigue and tensile strength

(iii) Open graded mix

- FA & fills missing
- porous, high speed

(iv) Unbounded:

- Binder is absent
- good interlocking, but no tensile strength.

4.5.2. Requirements of mix

1. **Stability:** Resistance of mix to deformation under traffic load.
2. **Higher of failure**
   - **Shoving:** transverse rigid-deformation (at areas st. high account)
   - **Grooving:** longitudinal ridging due to channels of traffic
3. **Durability**
   - Pot holes
   - stripping

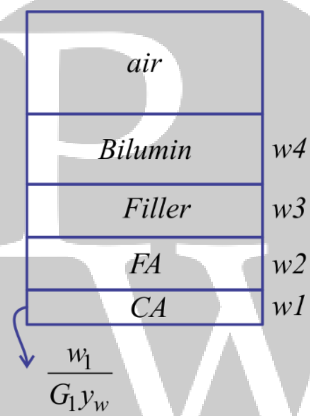
   Can be increased by high Binds content.

Marshall mix Design

- helps in deciding optimum bitumen content.

(a) Stability test: Max load (kg) carried by specimen before failure @60°C.

(b) Flow test: Deformation in units of 0.25 mm between no load and max load used in stability test.



1. **Theoretical specific gravity:** excluding air void

$$G_t = \frac{\text{wt of mix}}{V_1 + V_2 + V_3 + V_4}$$

2. **Bulk specific gravity**

$$= \frac{\text{wt. of mix}}{\text{total volume of mix}}$$

3. **% air voids:**

$$\frac{V_{\text{air}}}{V_{\text{total}}}$$

4. **% volume of Bitumen**

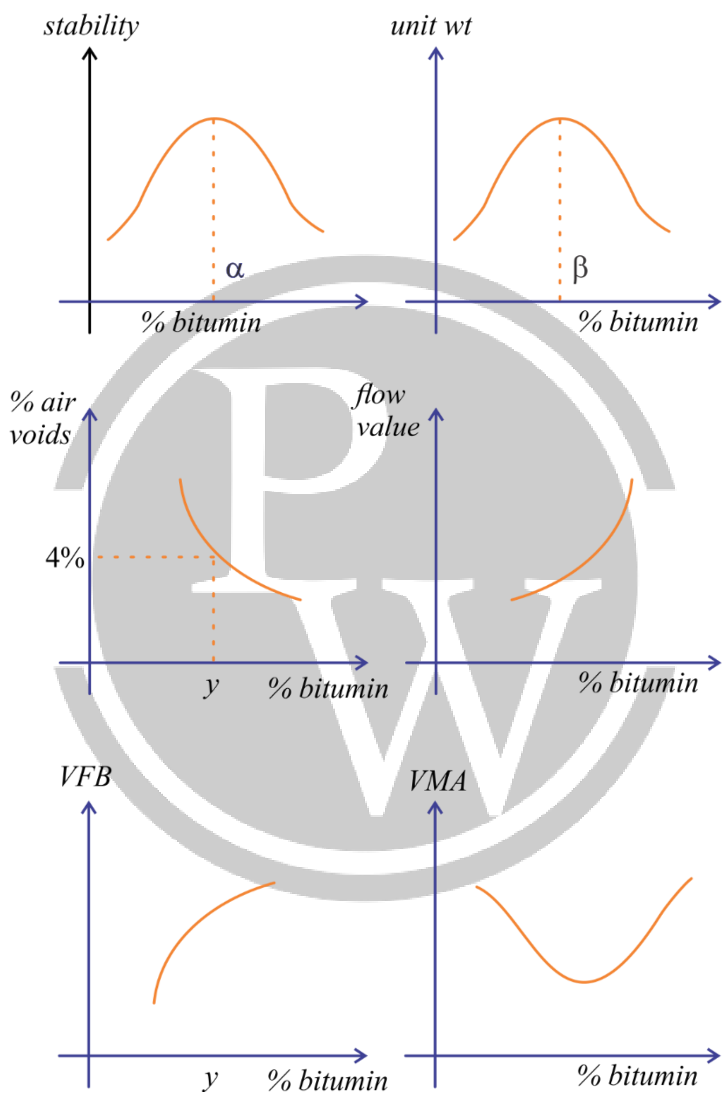
$$\frac{V_{\text{bitumen}}}{V_{\text{total}}}$$

5. Voids in Mineral aggregates

$$\frac{V_{\text{void}}}{V_{\text{total}}}$$

6. Voids filled with bitumen

$$\frac{V_{\text{bitumen}}}{V_{\text{voids}}}$$



4.5.3. Plots

Marshall Mix Specification

(a) Stability → 340 kg min

(b) Flow → 8 to 16 (2 – 4 mm)

(c) % air voids → 3.5 %

(d) VFB → 75 – 85%

4.6. EXTRA: ASPHALT PAVEMENT FAILURES

Asphalt Pavement failures

1. **Spalling:** Loss of small chunke of pavement between 2 cracker.
2. **Bleeding:** Margin of binder (bitumen) from mix to road surface.

   Causes:

   - Excessive binder in mix
   - Low air voids
   - Low viscous bitumen binder
   - Too heavy tack coat
   - Remedy → Apply "hot sand" and roll it during hot weather.
3. **Slippage cracking:** Slipping, when poor bond between surface and underlying layer; especially on steeper grade and intersection.
4. **Ravelling:**
   - Progressive disintegration of surface due to dislodgment of aggregator in mix.
   - Lack of sufficient cohesion.
   - Inadequate binder
   - Lack of finer
   - Ageing of asphalt
5. **Scaling:** Wearing course separate due to intrusion of moisture.